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Integrating Nature-based solutions – Constructed wetlands in sustainable sanitation and water management in Mediterranean countries

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Abstract

Water and sanitation issues are one of the main global problems that raised worldwide concerns and need to be tackled properly to protect human health and the environment. Water demand is increasing worldwide due to population growth, urbanization, migration, and other drivers.

Considering sanitation, globally around 3.6 billion people don't have safely managed services, including 1.9 billion people with basic services, 580 million with limited services, 616 million using unimproved facilities, and 494 million are practicing open defecation. Although many efforts for improvements have been made over the recent decades, the unsafe management of wastewater and excreta continues to present a major risk to both public health and the environment.

Many challenges are decelerating solving the sanitation problem globally, such as the cost problem for both implementation and operational costs, therefore, there is growing interest in low-cost and sustainable treatment solutions. The traditional conventional wastewater treatment systems are known for their high treatment efficiencies and high construction and operation maintenance costs. This has put the sustainability of conventional systems under question, especially for small communities.

There are increasing evidences in integrating Constructed wetlands (CWs) as a Nature-based Solution (NBS) in the water and wastewater sectors. CWs – NBS serve many functions which can be observed from different disciplinary perspectives. However, the application of CWs – NBS in some Mediterranean contexts is still limited due to many concerns about their sustainability and community acceptance. Hence, the sustainability of CWs – NBS must be investigated.

This research focused on Jordan and Italy as two case studies from the Mediterranean context. Jordan is ranked as the second poorest country in terms of daily water availability per person. Around 65% of Jordanians are covered with wastewater services and the treated wastewater covers almost 14% of the Jordanian water budget, the remaining Jordanians are living in remote rural and semi-urban areas in small communities. The objective of the government is to provide wastewater services to these small communities to increase the amount of collected and treated wastewater. However, serving them with centralized conventional engineering facilities is not feasible due to the high cost.

On the other hand, solutions such as CWs – NBS are more feasible economically and environmentally friendly with less maintenance. The same situation applied for the Italian context, where 30% of Italian people are currently living in the rural area, and 30% of the Italian people are not connected to wastewater treatment plants. The Italian government considered decentralization solutions and CWs – NBS to serve similar communities.

This research aimed to investigate and to determine the potential for integrating CWs – NBS in the water and environmental sector, and to analysis their sustainability as a wastewater treatment solution. In addition to assessing their resilience to climate change and analyzing the potential of connecting CWs – NBS with the circular economy.

The research included primary and secondary data analysis in its methodology from desk study, literature analysis, field data collections, site visits, disseminating questionnaires at different levels (stakeholder and community) using semi–structured interviews, implementation, operating, and monitoring a pilot scale CWs – NBS.

The Contingent Valuation (CV) method was used as an analysis tool to utilize and monetize the co – benefits of CWs – NBS. The Multi – Criteria Analysis (MCA) was used as a tool to compare and evaluate the sustainability of CWs – NBS with alternatives. The collected data among this research was analyzed using SPSS and MATLAB software. The main results were illustrated within seven chapters in this research.

The current practices and treatment performance were analyzed by referring to the local disposal and reuse standards. The collected data illustrated the low operation costs and the simplicity for operating CWs, and this provided the feasibility of CWs for small communities. The disseminated questionnaires helped in understanding the stakeholders' perspectives, communities' perspectives about CWs, and identified the gaps between those perspectives, thus identifying the interventions which stakeholders need to consider when applying CWs projects. The questionnaires have utilized CV method to indicate communities' willingness to Accept (WTA) and communities' willingness to pay (WTP) for having and benefiting from CWs. The measured WTP can be integrated with the circular economy approach leading to fulfill the financial criteria consequently the sustainability criteria. To illustrate the sustainability of CWs as a treatment technology, two case studies have been selected and MCA tool has been utilized as a sustainability assessment tool to evaluate the sustainability of CWs among other alternatives. Although MCA tool wasn't applied before within the environmental sector, it showed a huge potential to be included in the decision-making process and fulfilled the stakeholders' satisfaction. After engaging stakeholders for evaluating, selecting, and validating indicators and treatment alternatives, the MCA resulted in ranking CWs treatment solution as the best option among other alternatives as a decentralized solution at town level, while for the second case study at a small-scale level - mosque, CW with another alternative were ranked as the best option.

Finally, to simulate the output of this research, a pilot scale CW was implemented to treat greywater water generated from that mosque. The plant was operated, monitored, and evaluated according to local reuse standards. The treated greywater was used for irrigation and increasing the green area, which used to be irrigated with fresh water. The CW saves almost 70% of water consumption comparing to last year - almost 86% saving in water bill.

As a conclusion, there are promising perspectives for integrating CWs – NBS within the water and environmental sectors in Jordan and Italy. CWs provides a promising solution as decentralized sanitation solutions, can support the upgrading of centralized solutions, and can be also applied at household level to treat and reuse greywater. With a proper management, CWs – NBS can fulfill the sustainability criteria and have a potential be linked with the circular economy approach.

Sommario

Le questioni relative all'acqua e all'igiene sono uno dei principali problemi globali che hanno sollevato le preoccupazioni a livello mondiale e che devono essere affrontati adeguatamente per proteggere la salute umana e l'ambiente. La domanda di acqua è in aumento in tutto il mondo a causa della crescita della popolazione, dell'urbanizzazione, delle migrazioni e altri driver.

Considerando i servizi igienico sanitari, globalmente circa 3,6 miliardi di persone non hanno servizi gestiti in sicurezza, tra cui 1,9 miliardi di persone possiedono servizi di base, 580 milioni dispongono di servizi limitati, 616 milioni utilizzano strutture inadeguate e 494 milioni praticano la defecazione all’aperto. Nonostante gli sforzi compiuti e i miglioramenti degli ultimi decenni, la gestione non sicura delle acque reflue e degli escrementi continua a rappresentare un grave rischio sia per la salute pubblica che per l'ambiente.

Molte sfide stanno rallentando la risoluzione del problema dei servizi igienico-sanitari a livello globale, ad esempio il problema dei costi relativi all'implementazione e alla gestione operativa, pertanto, c'è un crescente interesse per soluzioni di trattamento sostenibili e a basso costo. Gli attuali sistemi di trattamento convenzionali diffusi sono ben noti per le loro elevate efficienze, ma anche per i loro alti costi di costruzione e mantenimento, pertanto la sostenibilità dei sistemi convenzionali è messa in discussione soprattutto per le piccole comunità.

Ci sono prove crescenti nell'integrazione della fitodepurazione, come soluzione basata sulla natura (NBS), nei settori dell'acqua e delle acque reflue. La fitodepurazione, come sistema di depurazione naturale, serve per molte funzioni che possono essere osservate da diverse prospettive disciplinari. Tuttavia, l'applicazione della fitodepurazione in alcuni contesti mediterranei è ancora limitata a causa delle molte preoccupazioni circa la sua sostenibilità e l’accettazione da parte della comunità. Quindi, la sostenibilità della fitodepurazione deve essere esaminata.

Questa ricerca si è concentrata sulla Giordania e sull'Italia come due casi studio del contesto mediterraneo. La Giordania è stata classificata come il secondo paese più povero per la sua disponibilità di acqua giornaliera per persona. Circa il 65% della popolazione giordana è coperta da servizi di trattamento delle acque reflue, il trattamento di queste acque reflue copre quasi il 14% del bilancio idrico della nazione, la restante popolazione, il 35%, vive in aree rurali e aree semi urbane in piccole comunità. L’obbiettivo del governo è quello di servire queste piccole comunità con servizi per le acque reflue che aumenteranno le acque reflue raccolte e trattate. Tuttavia, servirli con strutture convenzionali centralizzate non è fattibile per gli alti costi.

Perciò, soluzioni decentralizzate o semi centralizzate come la fitodepurazione sono le più adeguate a queste situazioni per gli aspetti economici e sostenibili. La medesima situazione vale per il contesto italiano, dove attualmente il 30% degli italiani vive in aree rurali e il 30% della popolazione non è collegato agli impianti di trattamento delle acque reflue. Il governo italiano ha preso in considerazione soluzioni decentralizzate per servire queste comunità.

Questa ricerca ha lo scopo di indagare e determinare il potenziale per l'integrazione della fitodepurazione nel settore idrico e ambientale e di analizzare la sua sostenibilità come soluzione di trattamento. Inoltre la ricerca continua con la valutazione della sua resilienza al cambiamento climatico e l'analisi del potenziale di collegamento tra la fitodepurazione e l'economia circolare.

La ricerca include l'analisi di dati primaria e secondaria nella sua metodologia dall'analisi a tavolino e della letteratura, raccolta di dati sul campo, dalle visite in loco, diffusione di questionari a diversi livelli (stakeholder e comunità), interviste semi-strutturate, all'implementazione, funzionamento e monitoraggio della fitodepurazione su scala pilota.

Il metodo del Contingent Valuation (Valutazione Contingente) è stato utilizzato per monetizzare i co-benefici della fitodepurazione. L'analisi multi criteriale (MCA) è stata utilizzata come strumento per confrontare e valutare la sostenibilità della fitodepurazione con diverse alternative. I dati raccolti in questa ricerca sono stati analizzati utilizzando i software SPSS e MATLAB. I risultati principali di questa ricerca sono stati illustrati in sette capitoli.

Le pratiche attuali e le prestazioni di trattamento sono state analizzate con riferimento agli standard locali di scarico e di riutilizzo. I dati raccolti hanno illustrato i bassi costi operativi e la semplicità di funzionamento della fitodepurazione e questo ha fornito la sua fattibilità per le piccole comunità. I questionari diffusi hanno aiutato a comprendere le prospettive degli stakeholder, quelle delle comunità sulla fitodepurazione e hanno identificato i divari tra queste prospettive, identificando così gli interventi che gli stakeholder devono considerare quando applicano i progetti basati sulla fitodepurazione. I questionari hanno utilizzato il metodo del Contingent Valuation per indicare la volontà delle comunità di accettare (WTA) e la volontà delle comunità di pagare (WTP) per avere e beneficiare della fitodepurazione. Il WTP misurato può essere integrato con l'approccio dell'economia circolare che porta a soddisfare i criteri finanziari, e quindi di conseguenza i criteri di sostenibilità. Per illustrare la sostenibilità della fitodepurazione come tecnologia di trattamento, sono stati selezionati due casi studio. Il metodo MCA è stato utilizzato come strumento per valutare la sostenibilità della fitodepurazione confrontando la tecnologia con varie alternative. Sebbene lo strumento MCA non sia stato applicato prima nel settore ambientale, ha mostrato un enorme potenziale da includere nel processo decisionale e ha soddisfatto le parti interessate. Dopo aver coinvolto le parti interessate per valutare, selezionare e convalidare indicatori e alternative di trattamento, il metodo MCA ha portato a classificare la fitodepurazione come la migliore opzione tra le varie alternative per il trattamento decentralizzato di acque reflue nel caso studio di una città, in grande scala. Mentre per il secondo caso, in piccola scala, di una moschea, la fitodepurazione e un'altra alternativa sostenibile sono state classificate come migliori alternative per il trattamento di acque reflue.

Infine, per simulare i risultati di questa ricerca, è stato implementato un impianto pilota in cui la fitodepurazione è il trattamento principale per trattare le acque grigie generate dalla moschea. L'impianto è gestito, monitorato e valutato secondo gli standard locali di riutilizzo. Le acque grigie trattate vengono utilizzate per l'irrigazione e l'aumento dell'area verde, che prima veniva irrigata con acqua dolce potabile. L'utilizzo della fitodepurazione fa risparmiare quasi il 70% del consumo di acqua rispetto allo scorso anno e il risparmio in bolletta relativa al consumo d'acqua è circa del 86%.

In conclusione, ci sono prospettive promettenti per l'integrazione della fitodepurazione nei settori idrico e ambientali in Giordania e in Italia. La fitodepurazione fornisce una soluzione promettente come soluzione di trattamento decentralizzata, può supportare il miglioramento di soluzioni centralizzate e può essere applicato anche a livello domestico per trattare e riutilizzare le acque grigie. Con una gestione adeguata, la fitodepurazione può soddisfare i criteri di sostenibilità e ha il potenziale per essere collegato all'approccio dell'economia circolare.

Table of Contents

Abbreviations

AHP	Analytical Hierarchy Process
ALLOWS	Assessment of Local Lowest-Cost Wastewater Solutions
ASP	Activated Sludge process
BOD	Biological Oxygen Demand
BoQ	Bill of Quantities
CAN	Climate action Now
Capex	Construction Costs
CBA	Cost benefits analysis
CFU	Colony forming unit
CI	Consistency index
CM	Cubic meter
COD	Chemical oxygen demand
CR	Consistency ratio
CS	Cross-sectional area
CSL	Cross-sectional organic loading rate
CSO	Combined sewer overflow
CV	Contingent Valuation
CW	Constructed Wetland
DOS	Department of Statistics
DWWM	Decentralized wastewater management
E. coli	Escherichia coli
ECAM	Energy Performance and Carbon Emissions Assessment and Monitoring
FAO	Food and Agriculture Organization (FAO) is a specialized agency of the United Nations
FCW	French Constructed Wetland
FOG	Fat, Oil, and Grease
FRB	French Reed Beds
FTW	Floating treatment wetland
FWS	Free water surface
GHG	Greenhouse gases
GW	Greywater
HF	Horizontal flow
HH	Household
HLR	Hydraulic loading rate
HRT	Hydraulic retention time
IR	Random index
ISTAT	Istituto nazionale di statistica (National institution for Statistics - Italy)
IUCN	International Union for the Conservation of Nature
IWA	International Water Association
JD	Jordanian Dinar
JMP	Joint Monitoring Programme for Water Supply, Sanitation and Hygiene
JS	Jordanian standards

JSMO	Jordan Standards and Metrology Organization
L/W	Length/Width
LCA	Life cycle assessment
M.L	Mass loading rates
MAVT	Multi-Attribute Value Theory
MCA	Multi criteria analysis
MCM	Million cubic meters
MDG	Millennium Development Goals
MPN	Most Probable Number
MWI	Ministry of water and irrigation
NBS	Nature Based Solution
NGO	Non-governmental organizations
NICE	National Implementation Committee for Effective Integrated Wastewater Management
NRW	Non-revenue water
NTU	Nephelometric Turbidity unit
O&M	Operation and maintenance
OM	Organic matter
Opex	Operation costs
PE	Population Equivalent
pH	Potential hydrogen
Ramsar	Convention on Wetlands of International Importance Especially as Waterfowl Habitat
RCM	Replacement Cost Methodology
RSDSP	Read Dead Sea Project
SDG	Sustainable Development Goals
SDRB	Sludge Drying Reed Beds
SF	Subsurface flow
SP	Stabilization Pond
SPSS	Social statistical packaging system
SS	Suspended solid
TC	Total carbon
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solid
UFZ	Helmholtz Centre for Environmental Research
UNICEF	United Nations International Children's Emergency Fund
USAID	U.S. Agency for International Development
USD	US dollar
UWWTD	Urban Wastewater Treatment Directive
VF	Vertical flow
WASH	Water, sanitation, and hygiene
WHO	World Health Organization
WSM	Weighted Sum Model
WTA	Willingness to accept
WTP	Willingness to pay
WWAP	World Water Assessment Program
WWTP	Wastewater treatment plant

List of Figures

List of Tables

Chapter 1: Introduction

1.1 Global Sanitation sector and water resource management

Globally, 3.6 billion people lacked safely managed services, including 1.9 billion people with basic services, 580 million with limited services, 616 million using unimproved facilities, and 494 million are practicing open defecation. (WHO/UNICEF JMP, 2021). Although the efforts made and the improvements over the recent decades, the unsafe management of wastewater and excreta continues to present a major risk to both public health and the environment (C. A. Arias et al., 2021). Around 80% of wastewater is discharged to the environment untreated (WWAP, 2018).

Climate change impacts to the global water cycle are well-known, water availability becomes more variable and unpredictable, leading to increase the challenging in providing sustainable access to adequate quality water for human health. Many countries are suffering from water scarcity, and they are relying on reusing the treated wastewater, mainly these countries are developing countries who already suffer from lack of proper sanitation systems, that double the problem to these countries, the need of sustainable sanitation systems to protect human's health and the environment as well as to provide a source of water to be used in agriculture and other purposes (WHO/UNICEF JMP, 2021).

The recent Covid19 pandemic has raised the challenges on the water, sanitation, and hygiene (WASH) sector because the basic measures to defeat the virus including handwashing, self-isolating and lockdowns and all of this require a sustainable access to acceptable amounts of acceptable quality water. And that also increased the amount of generated wastewater which it needs to be treated safely. In the other hand detecting Covid19 in the untreated wastewater raised the emergency level of having sustainable sanitation systems to protect humanity from the pandemic (la Rosa et al., 2020). As a result, strengthening water security is very important for preventing and combatting future pandemics (Cooper, 2020). Small communities in the developing countries are the most vulnerable communities to Covid19, the global efforts in providing sustainable sanitation systems have been directed to these communities before Covid19 time and now the pressure and the efforts have been raised to find sanitation solutions (Islam et al., 2021).

Many challenges are decelerating solving the sanitation problem globally, such as the cost problem for both implementation and operational costs, therefore, there is growing interest in low-cost and sustainable treatment solutions. The current widespread conventional treatment systems are well known with their high treatment efficiencies but also well know with their high costs, both construction and operation-maintenances cost, they are also known with the huge energy consumption, and that have put the sustainability of conventional systems under questioning especially for small communities (A. Stefanakis et al., 2014).

Constructed wetlands (CWs) and Nature based solutions (NBS) in the last years have been proved their valuable role in solving the sanitation problems as an appropriate system for different contexts both as main technology or combined with the conventional technologies and at several scales; centralized and decentralized (C. A. Arias et al., 2021). In addition to the cost-effective CWs can provide several environmental and socio-economic benefits. For better understanding and more elaboration, the following section describes a general comparison between conventional and NBS treatment system.

1.2 Conventional vs Nature based solutions Treatment System

1.2.1 Conventional treatment systems

Conventional wastewater treatment can be defined as a combination of physical, chemical, and biological processes and operations to remove solids, organic matter and, sometimes, nutrients from wastewater. General terms used to describe different degrees of treatment, in order of increasing treatment level, are preliminary, primary, secondary, and tertiary and/or advanced wastewater treatment. In some countries, disinfection to remove pathogens sometimes follows the last treatment step (FAO, 1992).

Conventional systems have proved quite effectiveness in wastewater treatment for several decades, but they come along with various undesired effects and prerequisites. Their treatment process relies on the building of extensive collection systems and transport systems to collect wastewater and treat it in a centralized plant. This fact causes negative impacts to both the environment and economy. Conventional treatment plants usually have industrial looking, unattractive facilities, located away from residential areas. Their equipment includes large mechanical parts (water pumps, air pumps, etc.) and extensive use of reinforced concrete. As a result, they require huge energy amounts for their operation, and that leads to high CO_2 emissions, conventional systems are well none with producing odors and noise. In addition, the initial construction cost is usually high, as also the necessary costs for a proper operation, including salaries for the essential specialized staff. Since the mechanical parts, damages and breakdowns are quit common phenomena, and that increase the cost for maintenance (labor and spare parts). Moreover, a daily by-product of the operation of conventional biological treatment plants, such as sludge, which needs to be handled and managed properly and that will increase significantly the total operational costs. Finally, they also have a relatively limited lifetime (usually up to 20-30 years), while they cannot easily manage sudden flow increases or they need additional units to handle that such as huge equalizer tanks. As a summary, conventional treatment facilities possess a negative environmental impact, although their main function is to improve the environmental situations (A. Stefanakis et al., 2014). In low-income regions, implementation of a conventional centralized system is often economically infeasible due to the previous mentioned reasons, especially the financial issues and lack of technical capacities to manage and operate them. (Abidi et al., 2009; A. Stefanakis et al., 2014).

The fact that the conventional treatment plants consume huge amount of energy and generate different types of greenhouse emissions (GHG) has led (Fighir et al., 2019) to study and assess wastewater treatment plants from environmental and energy point of views, the study illustrated that although wastewater treatment plants are essential infrastructures in any urban context, they are considered as a potential source of GHG emissions. The authors have used the (Energy Performance and Carbon Emissions Assessment and Monitoring (ECAM) tool software) to evaluate the sustainability of four Italian and Romanian WWTPs in terms of energy efficiency and GHG emissions. The study shows that the largest contributions in terms of GHG emissions were in all cases caused by energy consumption and methane produced during wastewater treatment and the energy consumption can be improved by biogas recovery (Fighir et al., 2019).

The main negative impacts sources including sludge disposal, electricity and chemical consumption, are direct GHG emissions. The main gases emitted from WWTP during the treatment processes are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), while carbon dioxide is also emitted from the production of energy necessary for the plant operation. By enhancing the energy efficiency of WWTPs or finding alternatives with less energy consumption, the carbon dioxide release may be reduced, leading to a decrease in treatment costs and environmental impacts (Fighir et al., 2019). The production of nitrous oxide is associated with biological nitrogen removal from wastewater as it is an intermediate product of the nitrification and denitrification processes (J. Wu et al., 2009). Around 72% of methane emissions are produced in the sludge treatment where anaerobic digestion occurs (Campos et al., 2016). The remaining emissions are generated from biological treatment as methane dissolved in wastewater (J. Wu et al., 2009).

According to WWAP report 2018, water and wastewater utilities are reportedly responsible for between 3 and 7% of GHG emissions, but these estimations do not include emissions associated with discharging untreated sewage. Indeed, untreated wastewater is an important source of GHGs. Given that, in developing countries, 80–90% of the wastewater is neither collected nor treated, the emissions related to the water supply and sanitation sector – and its potential to contribute significantly to climate change mitigation – should not be neglected (WWAP, 2018).

Despite the existence of many successful cases where WWTP generates electricity through the treatment process such as As Samra WWTP in Jordan, where the conventional plant treats more than 34000 cubic meter per day and the plant covers 80 % energy through hydro energy and biogas production, only 20% is drawn from the national grid. And that saved 300,000 tons of CO_2 per year. But still GHG emissions generated from the treatment process itself (Al-Ghazawi & Abdulla, 2008; Salahat et al., 2017).

On the other hand, (Al-Ghazawi & Abdulla, 2008) have assessed the consequences of climate change on the performance of a WWTP located in central Irbid in northern Jordan. Their results showed that the BOD removal will increase in summer season by about 6 mg/l for periods 2050-2065 and 2080-2099 so the removal efficiency will be enhanced from 98% to 99%. For winter season it is expected that the BOD removal will be reduced up to 8 mg/l and that reduced the removal efficiency from 93% to 89%. On the other hand, the results indicated an improvement in COD removal up 4 mg/l in the summer season while in the winter it is expected to be decreased up to 6 mg/l and that reduced the COD removal efficiency from 89% to 88%. The removal of TSS was slightly affected by the climate change. Considering the fact of the uncertainty of the climate change impacts, the reduction of the WWTP performance is raising an issue especially for countries where treated wastewater is one of the main water resources in their water budget (Abdulla & Farahat, 2020; Al-Ghazawi & Abdulla, 2008).

1.2.2 Nature based solutions – Constructed Wetlands

Over the last decades, the water purification capacity of Nature based solutions (NBS) was gradually more and more recognized. It is today identified that NBS are able to eliminate and transform various pollutants (organics, nutrients, trace elements, etc.) through a series of natural, biological, and physical processes, thus improving water quality. This overall realization of the wide range of ecological and economic benefits of NBS stimulated the interest regarding the possibility to exploit these wetland capacities for a series of specific technological applications.

NBS can be applied separated as a green infrastructure or combined with grey infrastructure for wastewater treatment system and can be used to treat different wastewater types including municipal, agricultural, and industrial wastewater, leachates, and stormwater. Applying NBS in wastewater treatment aims to develop engineered systems that mimic and take advantage of functioning ecosystems with minimal dependence on mechanical elements. NBS use plants, soil, porous media, bacteria, and other natural elements and processes to remove pollutants in wastewater including suspended solids, organics, nitrogen, phosphorus, and pathogens (Kadlec & Wallace, 2009). NBS also have the capacity to remove emerging contaminants such as steroid hormones and biocides (Yu et al., 2021), personal care products (Al-Wahaibi et al., 2021; A. Stefanakis et al., 2014) or pesticides (Vymazal, 2010). Different types of NBS can be combined to achieve the desired treatment efficiency. Using NBS for wastewater treatment can contribute towards healthier environments by improving water quality and enhancing the natural environment and surrounding habitats.

Constructed wetlands (CWs) are natural treatment technologies that efficiently treat many different types of polluted water. CWs are engineered systems designed to optimize processes found in natural environments and are therefore considered environmentally friendly and sustainable options for wastewater treatment. Compared to other wastewater treatment technologies, CWs have low operation and maintenance (O&M) requirements and are robust in that performance is less susceptible to input variations. CWs can effectively treat raw, primary, secondary, or tertiary treated sewage and many types of agricultural and industrial wastewater (Dotro et al., 2017). Today the ability of CWs to eliminate and transform various pollutants (organics, nutrients, trace elements, etc.) through a series of natural, biological, and physical processes have been identified, thus improving water quality. This overall realization of the wide range of ecological and economic benefits of CWs – NBS stimulated the interest regarding the possibility to exploit these wetland capacities for a series of specific technological applications (Dotro et al., 2017). This observation led to the investigation of human-made wetland systems, aiming at exploiting the purifying functions of wetlands (C. A. Arias et al., 2021).

Beside their treatment capacities, NBS and CWS can promote physical and mental health, clean air, clean water, and help enhance human health. Furthermore, NBS can provide aesthetic appeal and restorative properties, drawing people together and strengthening community ties. Economic benefits include lower water treatment costs, reduced flood damage costs, healthier fisheries, better recreational opportunities, and increased tourism and economic development. To account for such benefits when considering NBS options, there needs to be a holistic cost–benefit analysis (Chen et al., 2014; ElZein et al., 2016; WWAP, 2018)

Investing in CWs – NBS can help wastewater sectors to lower their operational costs, access new revenue streams, increase customer engagement, and provide public environmental goods and services (Oral et al., 2020). Operation and maintenance costs, as well as initial investments, are often lower than conventional systems, depending on land costs, technologies used and availability of resources (ElZein et al., 2016; Vymazal, 2010). Chapter two of the thesis covers a detailed and comprehensive literature review about CWs – NBS.

Several studies and authors have studied and summarized the comparison between conventional and CWs – NBs treatment systems, and Table 1.1 below summarizes the main differences between the two systems from several perspectives (Chen et al., 2014; A. Stefanakis et al., 2014; H. Wu et al., 2013).

Table 1. 1 Conventional treatment vs CWs systems

	Conventional Treatment System	CWs
Performance	Continuous effluent of high quality	Satisfying, small fluctuations with temperature variations
Facility/Plants	Many and large mechanical parts	No mechanical parts (maybe pumps)
Energy consumptions	High energy consumption	Low energy demand
Usage of raw material	Use of nonrenewable sources during construction (concrete, steel, etc.) and operation (electrical power, chemicals)	Almost exclusive use of renewable sources (solar, wind, etc.)—"ecological" systems
Capital and operational costs	Higher construction costs and higher operation costs	Lower construction cost (especially if there is available land and local materials), almost zero operational costs
Operation	Operation demand for continuous monitoring Useful lifetime up to 30 years	Only periodical check, prolonged lifetime (>30 years)
Required staff	Specialized staff required	No specialized staff needed
Maintenance	Maintenance for mechanical equipment! high maintenance cost, regular damages	Small mechanical parts! low maintenance cost
Area footprint	Low demands	High demand (e.g., 3-10 m^2/p.e.)
Odor	Open air tanks, odor production	Possible only in free water surface systems
Insects	Usually, no significant problems	Possible only in free water surface systems
Flow variation	High/shock inflow rate usually results in reduced performance	Robust to high flow variations
Robustness	Robustness Toxic pollutants may lead to system breakdown	Robust to some toxic constituents
By products (sludge)	Large volumes of by-products which demand daily handling and management	Zero production
Appearance	Unattractive	Aesthetically accepted, green view

1.2.3 NBS and the Sustainable Development Goals

The United Nations (UN), with many local governments, and international organizations have launched programs to deal with the negative impact on human health and on the environment caused by the lack of access to adequate sanitation. In the 1990s, 192 UN member states and at least 23 international organizations agreed to the Millennium Development Goals (MDGs) at the World Summits. MDG 6 was planned to halve the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015. In 2015, the 2030 Agenda for Sustainable Development Goals (SDGs) was approved by world leaders at the UN, which calls on countries to begin new efforts to achieve 17 SDGs over the coming 15 years, including SDG 6 which aims "to ensure the availability and sustainable management of water and sanitation for all" and includes targets for universal access to safe drinking water (6.1), sanitation and hygiene (6.2) for all (United Nation, 2015).

NBS are increasingly seen as innovative solutions to manage water-related risks, contributing to the 2030 Agenda for Sustainable Development as they provide numerous benefits including human health and livelihoods, food and energy security, sustainable economic growth, and ecosystem rehabilitation (Gomez Martin et al., 2020). Multiple services provided by NBS can support the achievement of different SDG targets, for instance by reducing GHG and environmental toxins, maintaining a stable groundwater level and even cooling the planet (Seifollahi-Aghmiuni et al., 2019).

NBS for wastewater treatment is directly linked to SDG 6 on Clean Water and Sanitation. At the same time, the benefits delivered by NBS can vary across spatial and temporal scales as well as among societal groups, meaning that the contribution of NBS to various SDGs will be in a context specific (Gomez Martin et al., 2020). For example, wetlands alone can affect ecosystem processes that are related to several SDGs including 1 (No Poverty), 2 (Zero Hunger), 6 (Clean Water and Sanitation), 12 (Responsible Production and Consumption), 13 (Climate Action) and their specific targets (Seifollahi-Aghmiuni et al., 2019). Depending on the location and application of the NBS, there could also be contributions to SDG 3 (Good Health and Well-being), SDG 7 (Affordable and Clean Energy), 11 (Sustainable Cities and Communities), 14 (Life Below Water) and 15 (Life on Land) (Seifollahi-Aghmiuni et al., 2019).

1.3 Research problem and objectives

The previous challenges decelerate the progress of solving the sanitation and water scarcity problems in many countries like Jordan where – in 2017 65% of Jordanian people are covered with wastewater services and the treated wastewater is covering almost 14% of water consumption in purposes other than drinking according to the Jordanian standards (MWI, 2017). About 35% of the Jordanian people are living in rural area and semi urban area in small communities and scattered area (MWI, 2016b, 2017). These small areas can't be served with centralized conventional facilities due to the previous challenges such as the huge costs. One the other hand decentralization or semi centralized concepts can be the appropriate solutions for similar cases. The centralized treatment plants are well known with their huge energy consumptions, and with their byproducts – sludge, which needs to be treated and managed safely. Therefore, a more sustainable solution, easy to operate and requires limited operation and maintenance costs is needed to be evaluated and proposed to the Jordanian in order to serve the scattered communities and can be also integrated with centralized plants to enhance their performance. The same situation applied for the Italian context, where 30% of Italian people are currently living in the rural area, and 30% of the Italian people are not connected to wastewater treatment plants. The Italian government considered decentralization solutions in their policy and standards in order to serve similar communities and in 1999 the Italian governments has added CWs in their standards (ISTAT, 2021; Masi, 2000). At centralized level and considering the fact that Italy has a combined sewer system, centralized treatment plants usually face wastewater overflow during winter seasons, and that has been worsened by the climate change impacts. Therefore, the Italian government has allocated resources to study, evaluate and apply NBS within the wastewater sector (Masi, 2000). However, applying and integrating NBS in general and CWs in specific are still challenging and underdeveloped, with underestimation of the performance of CWs – NBS and their co – benefits. Therefore, this research focuses on the Jordanian and Italian wastewater sectors as two examples from Mediterranean countries in order to assess the potential of integrating CWs – NBS as a sustainable solution and a step towards enhancing the sanitation conditions and water resources management in the countries.

Under the title of Integrating CWs - NBS with the sustainable sanitation and water management, leading to the circular economy, case studies in Mediterranean countries, this research aims to achieve the following main and specific objective

The objective of this research is to **recognize best practices** of CWs - NBS in sanitation and water management in Mediterranean countries and to **identify current limitations** of applying CWs - NBS as well as the potential of integrating circular economy approaches in Jordan and in Italy.

<u>This research will cover mainly:</u>

- Firstly: A comprehensive review and investigation about CWs – NBS and their sustainability as a sanitation solution and their role in water management.
- Secondly: Integrating NBS in the circular economy; through three approaches; assessing the potential of reusing harvested reeds, assessing the economical values of reusing the treated wastewater, monetizing the co – benefits and measuring peoples' willingness to pay for having CWs.
- Thirdly: Comparing and evaluating CWs – NBS among other treatment technology using sustainability assessment.
- Fourthly: Designing, implementing, monitoring, and evaluating a pilot scale CWs to treat greywater in a selected case study.

1.4 Thesis Structure:

Chapter 1: Introduction about the global sanitation, challenges in the global sanitation sector, objective, scope, and approach of the research. It highlighted the growing demand for sustainable sanitation solutions, that can be used at different levels especially decentralizations level, eco-friendly systems that can resist and reduce climate change impacts, easy and affordable to operate and implement. NBS serves many functions which can be observed from different disciplinary perspectives, it can be used in wastewater treatment and that can contribute to sustainability of water supply and sanitation systems with socio-economic benefits to people. The research objective is to analyze the integration of NBS – CWs in sanitation sector and water management and understand the opportunities and constraints that influence the adoption of NBS – CWs in wastewater treatment in the selected case studies.

Chapter 2: (published paper) A comprehensive review and description about NBS, and their environmental and socio-economic benefits to people, the role of NBS in treating municipal, application of constructed wetlands as a main wastewater treatment technology, the sustainability of NBS - CWs as a treatment technology, integrating NBS- CWs in circular economy under the financial sustainability. NBS – CWs reliance to climate change under the technical sustainability, and challenges and disadvantages of NBS – CWs.

Chapter 3: Study areas – case studies in Mediterranean region, Jordan and Italy; the chapter presents a background in the Jordanian and Italian water and sanitation sectors where the research was carried out focusing on the application of NBS – CWs in the two countries.

Chapter 4: The chapter covers a deep analysis and data collections to understand the stakeholder and communities' perspectives about NBS – CWs in the selected case studies thought extended questionnaires. The chapter analyzed the communities' willingness to accept (WTA) and willingness to pay (WTP) for having NBS – CWs and benefiting the co – benefits. A regression models were developed to affect Communities' WTA and WTP. This analysis will help to explain the fundamental driving forces for integrating NBS – CWs in the water and sanitation sector in the studied countries.

Chapter 5: A deep study for integrating and evaluating NBS – CWs in two case studies in Jordan, town level and governmental facility level. Multi – criteria analysis (MCA) tool has been used as a sustainability assessment tool to compare and evaluate different treatment technologies including NBS - CWs for the selected case studies.

Chapter 6: This technical chapter includes the design and implementation of NBS – CW to treat and reuse greywater generated from a mosque in Jordan. From the previous chapter NBS – CW has been selected as a treatment technology at the governmental facility level (mosque). The chapter covers the detailed design, implementation, and monitoring quality of the treated greywater according to the local reuse standards.

Figure 1.1 below summarizes the main structure of the thesis and illustrates the links and connections between the objectives and the chapters.

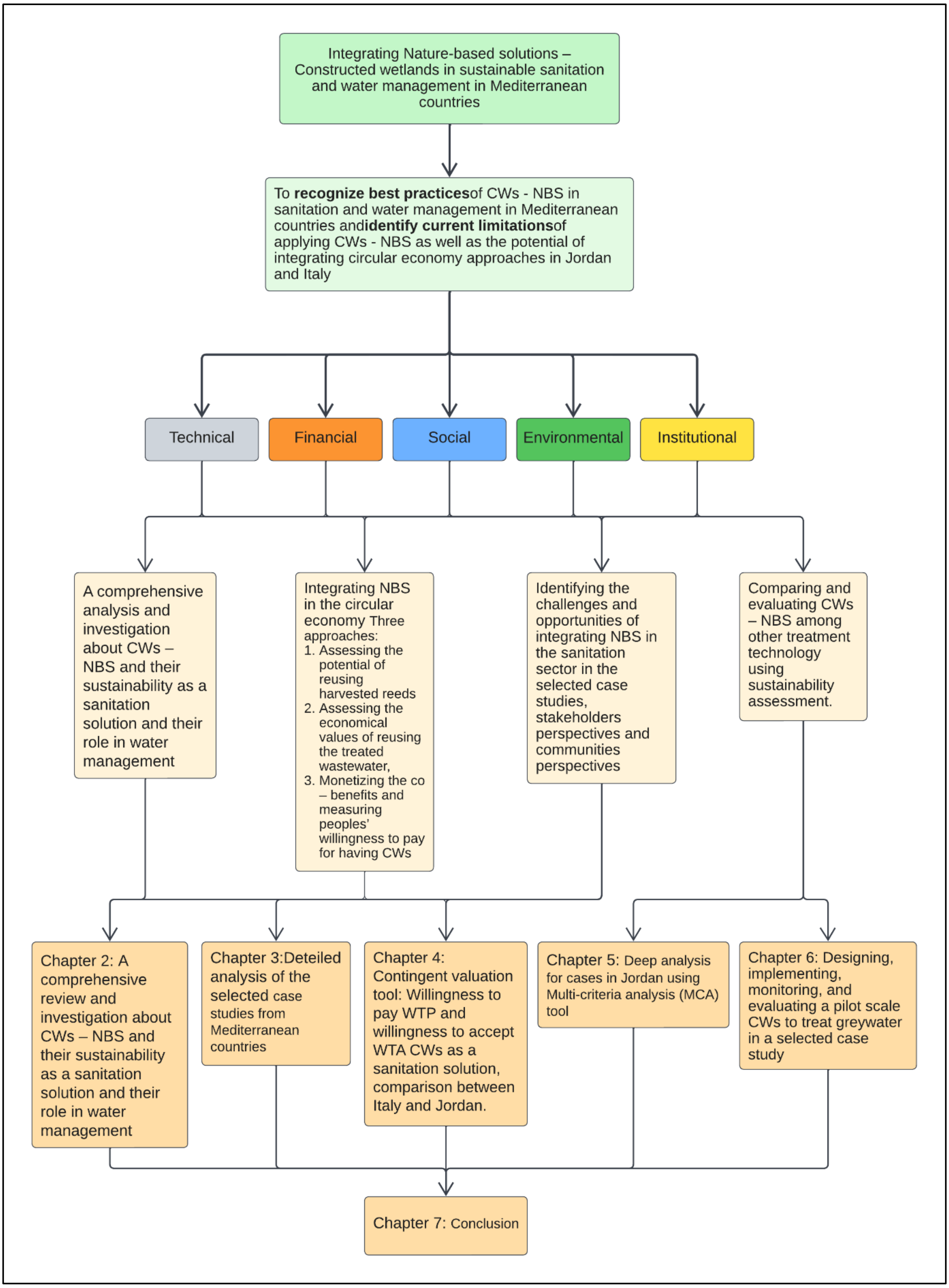

Figure 1. 1 Thesis structure

Chapter 2: CWs as a Solution for Sustainable Sanitation: A Comprehensive Review on Integrating Climate Change Resilience and Circular Economy (Published Paper)[1]

This Chapter describes Nature based solution (NBS) and its application in sanitation sector, the paper focus on constructed wetlands (CWs) as a treatment technology including definition of CWs, types of CWs, and treatment mechanisms with several case studies. The chapter analyzes the sustainability of CWs as a sanitation solution (technical, financial, environmental sustainability) with a focus on integrating climate change resilience and circular economy approach with the technical and financial sustainability, finally the chapter ends with limitations and challenges for applying CWs in sanitation and the co-benefits of applying CWs – NBS.

2.1 Nature–Based Solution (NBS) – Constructed Wetlands CWs, Definition, Classification.

2.2.1 Definition of NBS, CWs Types, and the usage in sanitation system

According to The United Nations World Water Development Report 2018, NBS are inspired and supported by nature and use, or mimic, natural processes to contribute to the improved management of water (WWAP, 2018). The defining feature of a NBS is, therefore, not whether an ecosystem used is 'natural' but whether natural processes are being managed to achieve a water-related objective. An NBS can involve saving or restoring natural ecosystems and/or the enhancement or creation of natural processes in modified or artificial ecosystems. They can be applied at different levels: micro-(e.g., a dry toilet) or macro- (e.g., landscape) scales (C. A. Arias et al., 2021; A. Stefanakis et al., 2014; WWAP, 2018).

NBS as defined by the International Union for the Conservation of Nature (IUCN) are "actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and

[1] This literature review chapter has been published as a review paper at Water Journal with the following details: Masoud, A.M.N; Alfarra, A.; Sorlini, S. Constructed Wetlands as a Solution for Sustainable Sanitation: A Comprehensive Review on Integrating Climate Change Resilience and Circular Economy. Water 2022, 14, 3232. https:// doi.org/10.3390/w14203232

biodiversity benefits" ("Nature-Based Solutions to Address Global Societal Challenges," 2016). While Stefanakis et al., have stated that Nature-based solutions (NBS) are actions inspired by, supported by, or copied from nature, that deploy various natural features and processes, are resource efficient and adapted to systems in diverse spatial areas, facing social, environmental, and economic challenges (A. Stefanakis et al., 2014).

The applications of NBS in treating wastewater is treatment wetlands or constructed wetlands (CW). CWs are natural treatment technologies that efficiently treat many different types of wastewater or polluted water (domestic wastewater, agricultural wastewater, coal drainage wastewater, petroleum refinery wastewater, compost and landfill leachates, fish-pond discharges, industrial wastewater from pulp and paper mills, textile mills, seafood processing), CWs can effectively treat raw wastewater to different level of treatments it can be used as a primary, secondary, or tertiary treatment (C. A. Arias et al., 2021; Dotro et al., 2017).
CWs are engineered systems designed to optimize and copy processes found in natural environments and are therefore considered sustainable, environmentally friendly options for wastewater treatment. CWs have low operation and maintenance (O&M) requirements and are robust in that performance is less vulnerable to input variations (Dotro et al., 2017).

2.2.2 Treatment mechanism within CWs

Treatment mechanism within CWs includes physical, chemical, and biological processes. The treatment process occurs within the combination of water, substrate, plants, plants debris and microorganisms (Hadidi, 2021). In conventional wastewater treatment systems, the treatment processes consist of a series of separated unit operations each of them designed for a specific purpose, multiple removal process can occur in one or two reactors, while the treatment process in CWs varies between being simple and complicated process which makes CWs not fully understood in terms of their treatment process, Table 2.1 below summarize the main treatment mechanisms in CWs as summarized from different references (Hadidi, 2021; Kadlec & Wallace, 2009; Moreira & Dias, 2020; Vymazal, 2010; Vymazal & Krö Pfelová, 2009).

Pollutant removals in CWs occur in the substrate materials and in the plant rhizosphere (Vymazal et al., 2006). CWs can efficiently remove the following components from wastewaters: suspended solids, organic matter, and excess nutrients, as well as natural remains of pathogens (Vymazal et al., 2006). The major pollutants and pathogens present in the wastewater are suspended solid, organic content, pathogens, Nitrogen and phosphorus, the removal mechanism for each is mentioned in Table 1 (Dotro et al., 2017).

The vegetation cover in CWs play important roles in treating wastewater, their roots and rhizomes provide a proper site for microbial biofilms leading to increase the biological activity per unit area compared to open water systems such as lagoons. They distribute the flow, limiting hydraulic short-load, and release small amounts of oxygen and organic carbon compounds into the rooting, which can be used for the aerobic and anoxic microbial processes (Dotro et al., 2017; Parde et al., 2021). CWs have the ability to support a diverse consortium of microbes; obligate aerobic, facultative, and obligate anaerobic microorganisms can be found due to large redox gradients, a factor contributing to the robust performance of CWs (Dotro et al., 2017).

In the substrate materials the filtration and sedimentation occur, sedimentation of the suspended particles present in the wastewater leads to the removal of pollutants, and higher retention times leads to achieve higher sedimentation percentage (Parde et al., 2021). Sedimentation process not only reduce the organic matter but also remove the coliform bacteria (Dotro et al., 2015; Parde et al., 2021). The retained particulates accumulate within the substrates and undergo hydrolysis, generating an additional load of dissolved organic compounds that can be degraded within the treatment bed (Dotro et al., 2017). Within the substrate materials adsorption process occurs which is an important process for the removal of phosphorus and heavy metals (Saeed et al., 2012; Stanković, 2017).

Nitrogen removal is one of the most challenges process within CWs (Dotro et al., 2017), Nitrogen presents in many forms and various processes convert it from one form to another within the nitrogen cycle. Nitrogen enters most primary and secondary CWs as organic N and ammonium (NH4-N). The removal process starts with Ammonification, it is the conversion of organic N to NH4-N (Dotro et al., 2017; Kadlec & Wallace, 2009). Ammonification occurs rapidly in an aerobic condition and occurs slowly in an anaerobic condition (Somarakis et al., 2019a) (Reddy & Patrick, 1984). After ammonification, next step for the transformation of nitrogen is nitrification. Nitrification is a two-stage process. Nitrification process converts ammonium to nitrate and nitrate to nitrite) (Reddy & Patrick, 1984).

In most CWs theoretically all pathways of the nitrogen cycle are active in CWs, including ammonification, nitrification, denitrification, plant and microbial uptake, nitrogen fixation, nitrate reduction, anaerobic ammonia oxidation, adsorption, desorption, burial, and leaching (Dotro et al., 2017; Vymazal, 2010). It is widely accepted that microbially-induced transformations of nitrogen common to other wastewater treatment systems dominate in CWs, with sorption and plant uptake also present to a limited extent. The contribution of each pathway is affected by the treatment wetland type, applied loading rate, hydraulic retention time, temperature, plant type and the properties of the substrate materials (Akratos & Tsihrintzis, 2007; Dotro et al., 2017).

Regarding heavy metals compared to the conventional treatment methods of removing heavy metals, such as chemical precipitation, ion exchange, adsorption, and membrane filtration CWs have proved their ability to remove heavy metals through several successful applications of treating industrial wastewater. CWs effectively remove heavy metals from wastewater through a combination of physical, chemical, and biological processes. Physical, flocculation, sedimentation, and filtration are the main removal processes able to remove heavy metals from wastewater, the physical process is carried out through the interactions between wastewater containing substrates and plant root systems. Biologically, plants can absorb heavy metals via their root systems, transferring and storing them in other plant tissues in a process called phytoaccumulation; thus, CWs allow the permanent removal of heavy metals by harvesting plant shoots. Furthermore, the microbiological activities of some microorganisms in CWs can remove heavy metals through their metabolism and biosorption. Chemically, several chemical processes to remove heavy metals can occur within CWs such as chemical adsorption, ion exchange, and oxidation

Table 2. 1 CWs Treatment Mechanisms

Main removing mechanisms for pollutant and pathogen in CWs.	
Parameter	Main removal mechanisms
Suspended solids (SS)	Sedimentation, filtration
Organic matter (OM)	Sedimentation and filtration for the removal of particulate organic matter, biological degradation (aerobic and/or anaerobic) for the removal of dissolved organic matter
Nitrogen (N)	Ammonification and subsequent nitrification and denitrification, plant uptake and export through biomass harvesting
Phosphorus (P)	Adsorption-precipitation reactions driven by filter media properties, plant uptake and export through biomass harvesting
Pathogens	Sedimentation, filtration, natural die-off, predation (carried out by protozoa and metazoa)
Heavy metals	Sedimentation, filtration, adsorption, ion exchange, precipitation, and biological degradation through plants and microbiological metabolism

2.2.3 Classification of CWs

Treatment wetlands can be divided into two main categories: surface flow and subsurface flow systems. Despite there are many wetland classifications in the literatures, but the simplest classification is i) **Subsurface flow** (SF) treatment wetlands which are subdivided into Horizontal Flow (HF) and Vertical Flow (VF) wetlands depending on the direction of water flow. And ii) **Free Water Surface** (FWS) wetlands (also known as surface flow wetlands) which are densely vegetated units in which the water flows above the media bed, but in subsurface flow wetlands, the water level is kept below the surface of a porous medium such as sand, gravel, soil, biochar or other material. (Dotro et al., 2017; A. Stefanakis et al., 2014). **SF** (**HF** and **VF**) wetlands are generally used for secondary treatment of wastewater. **VF** wetlands for treating screened raw wastewater have also been introduced and successfully applied, while **FWS** wetlands are generally used for tertiary wastewater treatment (Dotro et al., 2017).

A combination of various wetlands, known as hybrid CWs, was also introduced for the treatment of wastewater, generally this design consisted of two stages of several parallel CWs such as VF–HF CWs, HF–VF CWs, HF-FWS CWs and FWS-HF CWs (Kadlec & Wallace, 2009; Vymazal, 2013). In recent years, more innovations and wide application took place to enhance the performance of CWs, such as aerated CWs, baffled flow CWs, step feeding CWs and circular flow corridor CWs. (S. Wu et al., 2014). A simple diagram for various types of CWs is shown in Figures 2.1 to 2.4 (Dotro et al., 2017). CWs can be used to as a treatment technology at different levels treat different types of wastewater; raw domestic wastewater, Primary treated wastewater, secondary treated wastewater, tertiary treated wastewater, combined sewer overflow (CSO) discharge wastewater, and greywater (Dotro et al., 2017).

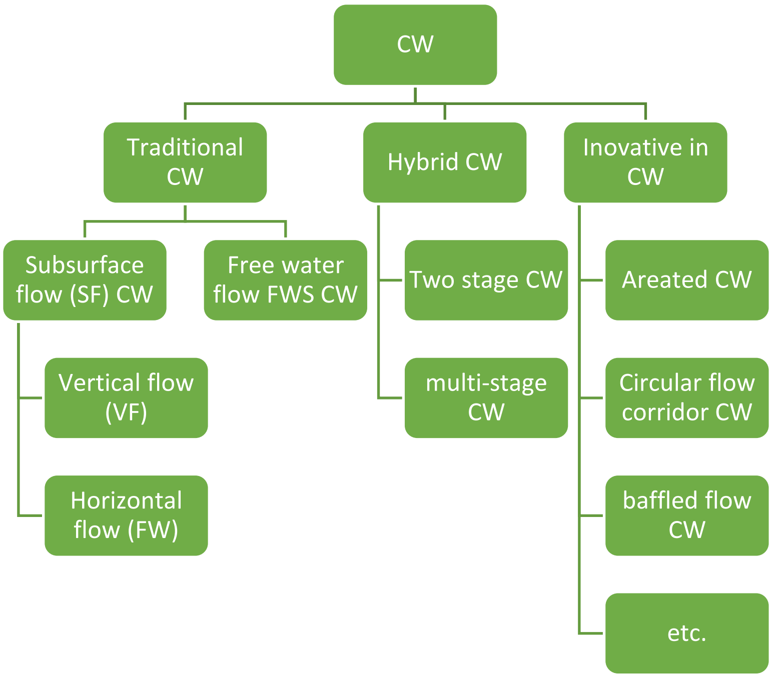

Figure 2. 1 Classification of CWs for wastewater treatment.

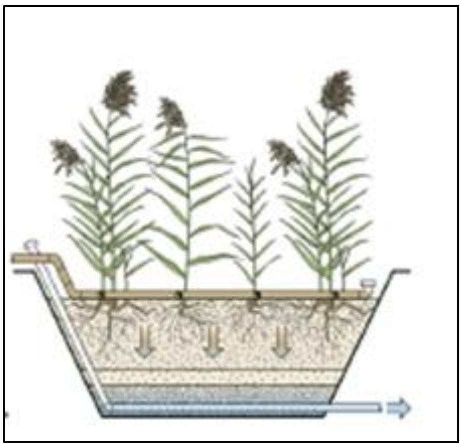

Figure 2. 2 SF VF CW

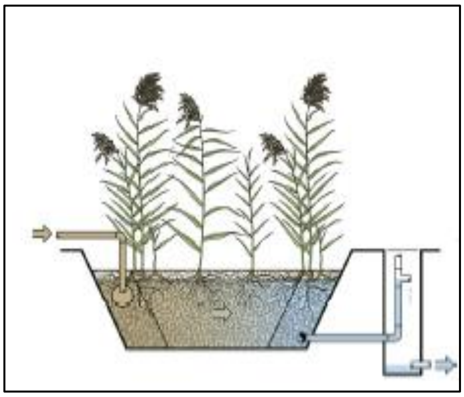

Figure 2. 3 SF HF CW

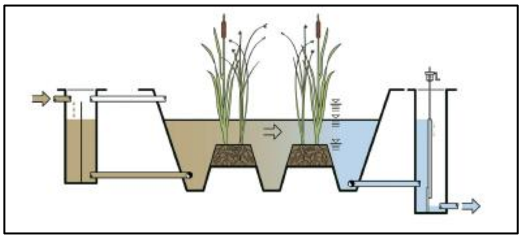

Figure 2. 4 FWS CW

Another classification can be made based on the growth characteristics of the vegetation. Thus, one can distinguish (A. Stefanakis et al., 2014):

- Floating treatment wetlands (FTWs) (Floating Islands),
- Emergent macrophyte wetlands, and
- Submerged macrophyte wetlands.

Usually, CW systems are planted with rooted emergent macrophyte species.

2.2 CWs as a safe technology

The main goal of having a sanitation system is to protect human health by reducing the risk of exposure to pathogens and hazardous substances at all points of the sanitation system and to improve the hygiene level, nutrition, and livelihood. CWs as a sanitation solution have three intervention to human health, i) Several studies and literatures have proofed the efficiency of CWs in treating wastewater to the acceptable level according to national and international standards especially as a decentralized solution for scattered communities where they are usually have unimproved/improved onsite sanitation solution (C. A. Arias et al., 2021), ii) CWs as an affordable and easy to operate sanitation solution provides a source of treated wastewater to be used in the community level leading to reduce the pressure on the available water resources which is needed for human uses such as hand washing and other hygienic purposes (Masi et al., 2018; A. Stefanakis et al., 2014; A. I. Stefanakis, 2019), iii) natural areas and CWs can promote physical and mental health, clean air and clean water, and help enhance human health. Furthermore, NBS can provide aesthetic appeal and restorative properties, drawing people together and strengthening community ties, many people find beauty or aesthetic value in various aspects of ecosystems, as reflected in the support for parks, “scenic drives”, and through the selection of their residence. CWs used for wastewater treatment could be the biophysical characteristics or qualities of species or ecosystems (settings/landscapes/cultural spaces) which people appreciate because of their non-utilitarian qualities. (C. A. Arias et al., 2021; ElZein et al., 2016; A. Stefanakis et al., 2014; WWAP, 2018). The previous proved facts have encouraged to investigate of the sustainability of CWs as a safe treatment technology.

2.3 CWs and Sustainability

As the main objective of a sanitation system is to protect and promote human health through providing a clean environment and breaking the cycle of disease. From that fact it is highly important to implement a sustainable sanitation solution to achieve that objective in the long term, and in order to be sustainable, a sanitation system has to be not only economically viable, socially acceptable, and technically and institutionally appropriate, it should also protect the environment and the natural resources (Hashemi, 2020).

Many literatures studied and determined the sustainability criteria and identified different sustainability indices in sanitation sector. According to (Andersson et al., 2016) a sanitation system can be considered sustainable if it is economically viable, socially acceptable, technically, and institutionally appropriate, and protect the environment and natural resources. This definition has been illustrated with many authors such as (Bao et al., 2013; Lennartsson et al., 2009).

A sustainable sanitation system protects and promotes human health, does not contribute to environmental degradation or depletion of the resources, is technically and institutionally appropriate, economically viable and socially acceptable (Kvarnström et al., 2004). Considering the main objective of the sanitation system is to protect the human health, many authors focus on the technically, financial, and social sustainability in sanitation such as (Hashemi, 2020), he has considered technical, social and economic aspects in evaluating the sustainability of sanitation systems. While Han focused on the technical aspects in evaluation and comparing the sustainability of sanitations systems (Han & Hashemi, 2017) other studies compared different sanitation systems based on economic aspects and social approaches toward achieving sustainable sanitation (Sadhan Kumar Ghosh, 2017; Ssemugabo et al., 2020).

According to Hashemi Sustainable sanitation recognizes to be sustainable; it must be socially acceptable and economically viable. In this way, sustainable sanitation is a loop- based approach that differs from the current linear concepts of wastewater management, and that doesn’t only recognize technology, but also social, environmental, and economic aspects. Sustainable sanitation is an approach that considers sanitation holistically. It recognizes that human wastes and wastewater are valuable resources. This view comes from considering wastewater as a source of significant amount of nutrients and also water that can be recycled and reused (Han & Hashemi, 2017). When improving or designing a new sanitation system, the following sustainability criteria should be considered: i) Health and hygiene, ii) environment and natural resources, iii) technology and operation, iv) financial and economic issues, and v) sociocultural and institutional aspects (Han & Hashemi, 2017; Sadhan Kumar Ghosh, 2017).

Roland & Arene, (2008) have illustrated that the main concept of sustainability is more of a direction than a state to reach. Nevertheless, it is critical that sanitation systems are evaluated carefully with regard to all dimensions of sustainability (Roland & Arne, 2008). To succeed as sustainable sanitation, a sanitation system has to be economically viable, socially acceptable, technically and institutionally appropriate, and protect the environment and natural resources. Based on the mentioned before in this study a deep focus on the technical, social, finical, and environmental sustainability criteria will be considered to evaluate the sustainability of CWs in as a sanitation technology.

2.3.1 Is CWs technically sustainable?

The technical sustainability is one of the important criteria within the sustainability criteria, as the treatment system should be technical appropriate and perform according to the treatment efficiency required. CWs can treat varies types of wastewater and can be used at different stages of treatment as described before. CWs provide a solution for different contexts, it can be used as a centralized, semi centralized and decentralized solutions (A. Stefanakis et al., 2014). The fact that CWs is easy to operate and maintain can compensate the lack of technical staff and local available expertise particularly for the small and medium communities also in low and developing countries (Mannino et al., 2008; Sonneveld et al., 2018)
Technically, constructed wetlands have proved their capacities in treating several types of wastewater, as a main system or combined technology with conventional systems, for instance (Masi et al., 2017) have analyzed French constructed wetland to treat domestic wastewater in Moldova and he illustrated that the removing efficiency was 86% for both the COD and BOD. Another example from Austria where (Langergraber et al., 2018) have studied a vertical flow small wastewater treatment plant in Austria that serves 40 population equivalents, and the removing efficiency is 98% for both COD and BOD (Langergraber et al., 2018).

In Sicily (Italy) a Horizontal flow constructed wetlands HFCW have been used as tertiary treatment after a trickling filter. After five years of study, it was concluded that HFCW can be used as a tertiary treatment and having a removal efficiency of TSS, BOD, COD, TN, TP, TC and E. Coli were 98.21%, 85%, 63%, 71%, 42%, 31%, 98.57% and 98.21% respectively. It also very effective for the removal of salmonella and helminth (Cirelli et al., 2007).

In Nepal, wastewater treated with CWs achieved removal percentage 90.9% for TSS, 90% BOD, 48.3% COD, 15.3% TN (Parde et al. 2021). (Yoon et al., 2001) observed that, In South Korea wastewater treated with CWs has removal percentage 90% for TSS, 93.04% BOD, 41.17% TP and 19.6% TN. While (Liu et al., 2009) found that, In China wastewater treated with Phragmites australis, Typha latifolia and Canna indica plants has removal percentage 62.06% for TP, 81.7% BOD, 73.3% COD and 44.3% TN. (Verhoeven & Meuleman, 1999) found that in Netherland wastewater treated with Phragmites australis plants has removal percentage 99% for TSS, 95% BOD, 80% COD, 35% TN and 25% TP. Other examples for different applications or CWs are mentioned in the Table 2.2 below.

It is worth to mention although the absences of clear guidelines to design CWs, several studies and design concepts have approved their reliability to be used to design CWs to treat several types of wastewater (Dotro et al., 2017; Kadlec & Wallace, 2009). Many authors have illustrated that the easiness and flexibility of design and the possibility of using local materials have made CWs sustainable solutions for different contexts, the high resistance of phragmites also played avital role in the technical sustainably (Dotro et al., 2017; Oral et al., 2020). As a technology it was proved that it has very limited requirements for operation, the technology doesn’t require skilled labors or experts to operate, (Al-Wahaibi et al., 2021; Dotro et al., 2017; A. Stefanakis et al., 2014; A. I. Stefanakis, 2019) mentioned that it is only required to monitor the feeding system and to harvest the reed periodically.

Table 2. 2 Worldwide examples of CWs

			Treatment efficiency removal (%)				
#	**Case**	**Application**	**COD**	**BOD**	**TSS**	**TN**	**references**
1	VF CW FOR POLLUTION CONTROL IN PINGSHAN RIVER WATERSHED, SHENZHEN, CHINA – COMBINED SEWER	Tertiary treatment	40.00	40.00	80.00		(C. A. Arias et al., 2021)
2	TWO-STAGE VF CW AT THE BÄRENKOGELHAUS, AUSTRIA - DOMESTIC WASTEWATER	Secondary treatment	98.03	99.46	97.35	70.60	(Langergraber et al., 2018)
3	VF CW FOR MATANY HOSPITAL, UGANDA - DOMESTIC WASTEWATER	Secondary treatment	92.00	99.31	99.87		(Elike Müllegger et al., 2012)
4	French VF CW IN ORHEI MUNICIPALITY, MOLDOVA – DOMESTIC WASTEWATER	Primary and secondary treatment using French reed beds	85.59	85.85	96.05		(Masi et al., 2017)
5	CHALLEX TREATMENT WETLAND: FRENCH CWs FOR DOMESTIC WASTEWATER AND STORMWATER	Primary and secondary treatment beds (FRBs) and VFTWs	96.24	96.21	98.92	91.25	(C. A. Arias et al., 2021; L. Arias et al., 2014)
6	TAUPINIÈRE TREATMENT WETLAND: UNSATURATED/SATURATED FRENCH CWs FOR DOMESTIC WASTEWATER IN A TROPICAL AREA	Primary and secondary treatment	95.69	96.68	98.11	68.48	(Molle et al., 2015)
7	HS FLOW SYSTEM FOR GORGONA PENITENTIARY, ITALY - DOMESTIC WASTEWATER	Secondary treatment	68.44	71.58	29.47	31.25	(Vymazal, 2018)
8	HS CW IN KARBINCI, REPUBLIC OF NORTH MACEDONIA - DOMESTIC WASTEWATER	Secondary treatment	84.25	88.96			(C. A. Arias et al., 2021)
9	HF CW IN CHELMNÁ, CZECH REPUBLIC - DOMESTIC WASTEWATER	Secondary treatment	80.00	93.26	91.72		(Vymazal, 1996)
10	FWS CW IN ARCATA, CALIFORNIA, USA - DOMESTIC WASTEWATER	Secondary and tertiary treatment		91.28	93.81		(C. A. Arias et al., 2021; Gearheart, 1992)
11	FWS CW TERTIARY TREATMENT IN JESI, ITALY – DOMESTIC WASTEWATER	Tertiary treatment	13.16	16.67	76.32	27.06	(C. A. Arias et al., 2021; Masi, 2008)
12	full-scale experimental VF CW with effluent recirculation in OMAN – INDUSTRIAL WASTEWATER	Primary and secondary treatment	98.15	98.81			(Al-Wahaibi et al., 2021)

Is CW resilient to climate change?

The technical sustainability can be extended to include the technology resilience to climate change impacts. In the recent years the needs to have a technology and system that can perform efficiently under the climate changes impacts has been increased, several studies compared and studies the performance of different sanitation technology under climate change impacts. NBS in general and CWs in specific has a wide range of application to minimizes the impact of the climate change (WWAP, 2018), for instance the application of CWs in flood risk reduction plays a vital role in protecting the valuable infrastructure, NBS and CWs have contributed to reduction and mitigating the flood risks through storing water and regulating and managing the land (WWAP, 2018). An increasing interest to apply and use CWs to support the conventional wastewater treatment plants during heavy rain and flash floods, especially in case of combined sewer overflow (CSO) (Oral et al., 2020). For example, In Gorla Maggiore where they implemented a vertical flow and free water surface flow to manage the excess runoff and floods and to protect the combined sewer system, the CWs have succeed in reducing the peak flow by 53% and 86% for five CSO mean peaks and for a CSO event with a return period of 10 years, respectively (Rizzo et al., 2020).

CW helped several WWTPs in treating and managing first flush rain events, especially in industrial areas where the COD concentration increased up to 80% within the first flush (Barco et al., 2008).

In the urban context where CW can retain the rainwater aiming to increase the capacity of the city the "sponge city" where it can store and retain water through CWs at roofs, parking areas and public parks, in all cases the application of CWs can protect the economic value of the city and such as the infrastructure (Masi et al., 2018; Qi et al., 2020).

Several studies have monitored the performance of CWs in treating wastewater under the variation of climate change, for instance (López et al., 2019; Mander et al., 2015; Salimi et al., 2021) have studied the impact of climate change to CWs and he found that the performance might be affected with the water level within the CWs that affect varies between enhancing the aerobic decomposition and the anaerobic decomposition depending of the water level within the CWs, the temperature impacts have also analyzed and it showed an enhancement in the photosynthesis process and will enhance the degradation of the wastewater but to a certain limit.

Lopez et al., (2019) have illustrated in their study that the performance of CWs can be regulated from the design phase and during operation of CWs in order to maintain the removal efficiency under different climate conditions, They have illustrated that CW play a vital role in solving problems associated to climate change impacts such i) the increase of pathogens concentration in wastewater due to the rise of global temperature; (ii) higher precipitation that can lead to increase of pathogens due to runoff and first flush problem (López et al., 2019).
The previous facts and cases have illustrated that CWs have achieved to be a sustainable sanitation from the technical point of view.

2.3.2 Is CWs socially acceptable?

Stefanakis (2019) showed in his publication that the benefits of using CW include a series of ecosystem services, such as cooling, biodiversity restoration, and landscaping. From social point of view CW are providing sustainable solutions to the problems that modern cities and peri-urban areas face an increasing growth rate and intensity, the green multi-purpose option for water management and wastewater treatment, beside the effectively proven applications around the world and multiple environmental and economic advantages, these systems can function as water treatment plants, habitat creation sites, urban wildlife refuges, recreational or educational facilities, landscape engineering and ecological art areas (A. I. Stefanakis, 2019).

The social aspect of CWs as treatment systems is increasingly improved. The green, aesthetical appearance of CWs compared to the conventional treatment plants makes them more acceptable by the society. Many enterprises in industries, municipal-private companies, etc. choose the CWs for the treatment of wastewater produced in their premises to enhance their green profile and incorporate the CWs installation to their corporate social responsibility plan (A. I. Stefanakis, 2015).

(Zitácuaro-contreras et al., 2021) in their study have analyzed the social potential of using plants used in CWs and he classified the potential into decorative, artisan, medicinal, and food. Therefore, plant species can be used as raw material in the elaboration of handicrafts, flower arrangements, and the cultivation of seedlings which can be marketed locally, they illustrated a huge potential of enhancing the social sustainability as he provided several benefits and opportunities to use the cultivated plant species with possibilities of generating incomes, in their case study they also mentioned that 90.5% have an decorative use, and the rest can be used in artisanal activities; they both have the potential to be commercialized and used in social and cultural local events.

2.3.3 Is CWs financially sustainable?

The limited operational costs and construction costs comparing to the conventional systems and the fact that the energy consumption for CWs is far less than that of conventional systems, have created a very important role in considering CWs as sustainable sanitation solutions especially as a decentralized solution for scattered communities. A series of studies and literatures indicate that CWs have shown advantage in economic value (construction and operation costs) in comparison with conventional wastewater treatment plants (WWTP) (Gajewska et al., 2020; H. Wu et al., 2015; S. Wu et al., 2014; Zhang et al., 2012). Similarly, energy consumption for CWs is far less than that of conventional WWTP. (Gajewska et al., 2020; Skrzypiecbcef & Gajewskaad, 2017).

Parde et al. (2021) illustrated that CWs is a cheaper treatment process to treat wastewater with low operation and maintenance cost, for example the operational cost equal to 1%–2% of plant construction cost (Parde et al., 2021). (Eriks Tilgalis & Linda Grinberga, 2011) have studied the costs difference between CWs and activated sludge treatment system and they showed that the activated sludge constructions costs are 30% more than the construction costs of CWs, while the maintenance costs for activated sludge are almost equal to their construction costs, the maintainers costs for CWs are almost negligible. This fact has been illustrated through many examples and studies like the horizontal flow treatment wetland in CHELMNÁ, Czech Republic where the operational cost is 1500 USD yearly and the capital cost was 23000 USD as illustrated by (C. A. Arias et al., 2021; Vymazal, 1996).

Langergraber et al. (2018) have calculated the operational cost for two stage CW in Austria and he found that the operation cost equal to 3.8% of the total construction cost (Langergraber et al., 2018) . While the French CW in Moldova which treat the domestic wastewater for more than twenty thousand population equivalents, the construction cost was 3.4 million euros while the operation cost is 85000 euros per year (around 2.5% of the total construction costs) as calculated by (Masi et al., 2017). While (L. Arias et al., 2014) have analyzed a case of French CW in Challex and they found that the construction cost was 1.850 million euros while the annual operational cost is 15000 euros (around 1% of the total implementation costs). Another examples from Italy where the operation cost for Gorgona CW is 0.5% of the construction costs, and in Jesi CW the operation cost is 6.7% of the construction costs (C. A. Arias et al., 2021).

Other papers have studied the financial and environmental analysis of CWs for industrial wastewater; (Dimuro et al., 2014; Mannino et al., 2008) have used the Replacement Cost Methodology (RCM) for financial analysis and (LCA) for environmental assessment, the result indicated that the total net present value savings calculated for implementing CW instead of the sequencing batch reactors is $282 million over the project's lifetime. The LCA demonstrates that the lower energy and material inputs to the CW resulted in lower potential impacts for fossil fuel use, acidification, smog formation, and ozone depletion leading to lower potential impacts for global warming.

However, land requirements for CWs may be the most limiting factor for their application, especially in some regions, where the costs of lands are expensive due to limited land availability and resources are scarce and population density is high. This fact is critical for the financial sustainability of CWs. The problem can be solved with innovative ideas such as artificial aeration CWs but that options will increase the lifecycle cost of CWs (H. Wu et al., 2015; S. Wu et al., 2014).

Is CWs in line with a circular economy approach?

The financial sustainability of CWs can be integrated with the circular economy approach several recent studies has been analyzed and studied CWs in the circular economy and compare it to the linear economy approach, for example (Masi et al., 2018) have studied the role of CWs in the circular economy and resource recovery paradigm, in their study they illustrated the CWs intervention in the circular economy such as water reuse, nutrient recovery, energy and biomass production and ecosystem services. As an example of nutrients recovery, French CW or French Reed Beds (FRBs) with its particular design shows a promising and appropriate, FRB contains a first stage where the raw wastewater is fed and most of the total suspended solid TSS and organic content create an organic top layer, rich in macronutrients, which will be dehydrated and decomposed over time, this humified biomass is removed from the beds and can be reused as soil conditioner and fertilizer (Paing et al., 2015). The FRB has a second stage that improves the removal efficiency of TSS, and organic content and it also completes the nitrification, which achieved in the first stage, and obtains some denitrification. It is therefore a solution to divert part or all the effluent from the first stage when nutrients are needed for fertilizing of crops instead of completing the nitrogen cycle inside the treatment plant itself (Masi et al., 2018). Sludge Drying Reed Beds (SDRBs) are also another example which present similar process and the same final product as the FRBs. SDRBs are getting stabilized sludge load produced by activated sludge plants. SDRBs have been proved as the cheapest solution to process excess sludge from activated sludge plants, with potential to reuse the dewatered sludge as soil conditioner in agriculture (Nielsen & Bruun, 2015).

Among energy production the harvested reeds of CWs can be used in energy generation, reed biomass can be used as an energy source in three ways, combustion, biogas production and biofuel production. All stems and leaves can be used regardless of length or diameter (Köbbing et al., 2013).

The generated biomass reed has an economical value in agriculture. Reed has been used for centuries for grazing by animals and harvested as a fodder plant. Reed is still widely and commonly used as a fodder plant for water buffalo, cows, sheep, cattle, goats and donkeys; for instance, in Scandinavia, the Netherlands and China (Köbbing et al., 2013; Niels Thevs, 2007; Parde et al., 2021). Its high content of nitrogen, potassium (10.9 g /kg) and manganese (2.65 g /kg) make it a good fodder plant for ruminants (Baran et al., 2002). The nutritional value of 13.31 kg of reed is equivalent to that of one kilogram of oats (Köbbing et al., 2013). Although it has a lower nutritional value than other fodder plants, it is still cheap and appropriate source. As a summary, integrating CWs with the circular economy paradigm will illustrate the financial and economic sustainability of this system

2.3.4 Is CWs environmentally sustainable?

CWs are multifunctional, providing many benefits to the environment (D'Amato et al., 2017). Several co-benefits beyond wastewater treatment make CWs consider as sustainable sanitation systems from environmental point of view, these co – benefits should be evaluated when selecting CWs as a treatment technology (WWAP, 2018). CWs play an important role in restoring biodiversity, many researchers studied how CWs help in restoring biodiversity, they concluded that CWs can enable cities to conserve, restore and thrive with nature. CWs are increasingly integrated in urban development practices. They have the potential to effectively address biodiversity challenges through conserving nature, restoring nature, and mobilizing people's (Balzan et al., 2020; Collier & Bourke, 2020; Linjun Xie, 2020). CWs and NBS in general help in the process of pollination mainly provided by insects but also by some birds and bats. The pollination is essential for the development of fruits, vegetables, and seeds (Bailey, 2012). As the CWs enhanced the biodiversity it plays a main role in pollination.

CWs can regulate and the humidity and localized temperatures during hot weather conditions, by ventilation and transpiration process as illustrated by (Baker et al., 2021). CWs play an important role in climate change adaption, i) CWs consume less energy than the conventional treatment system and hence less emissions generation (Eriks Tilgalis & Linda Grinberga, 2011), ii) CWs is important for carbon sequestration, during the treatment (physical or biological processes) such as photosynthesis, carbon is being removed from the atmosphere and depositing it in a reservoir or carbon sinks (such as oceans, forests, or soils). (Coll et al., 2021). Several studies used different tools to evaluate the environmental impacts of CWs and to compare the environmental impacts with other treatment technologies, (Flores et al., 2019) have used LCA tool to compare the long term environmental impacts of using CWs to treat winery wastewater comparing to other scenarios including activated sludge treatment system, the study showed that the CWs were the most environmentally friendly options; the potential environmental impacts of CWs 1–10 times lower compared to activated sludge scenarios. CWs showed to be an environmentally friendly technology with low energy consumption. (de Feo & Ferrara, 2017) also used LCA to evaluate between two on-site small-scale wastewater treatment systems (activated sludge and CW), they considered three sensitive parameters with three values resulted in 27 combinations, were evaluated with three different impact assessment methods (IPCC 2007 100 years, Ecological Footprint and ReCiPe 2008 H). CW was the best environmental choice in 93% of the scenarios.

The growing reeds play an important role in carbon sequestration through absorbing atmospheric carbon in their structure. The estimated rate at which the reeds do this is 3.3 kg/m2/year with an accuracy of ±15% (Dixon et al., 2003).

The treated water in general is a valuable water resource that can be used for purposes (usually other than domestic) such as agriculture and irrigation, groundwater replenishment, industrial processes, and environmental restoration. Water reuse can provide alternatives to existing water supplies and be used to enhance water security, sustainability, and resilience (C. A. Arias et al., 2021; Sonneveld et al., 2018; van Hullebusch et al., 2021).

2.4 Challenges and disadvantages

Although the advantages and the co-benefits of CWs as a sustainable treatment technology, CWs as every treatment process has its limitations, these limitations and disadvantages create challenges for applying CWs in sanitation summarized in Table 2.3 (but not limited to).

Table 2. 3 Disadvantages and challenges for applying CWs

Disadvantage/challenge	Description	Reference
CWs required more area than the conventional systems	HFCW required 5–10 m^2/PE, VFCW required 1–3 m^2/PE, French CW required 2.0–2.5 m^2/PE). Limited land available for sanitation system or the land costs can be unaffordable especially in the urban areas, which make CW as unsustainable sanitation solution for some contexts	(BOGUNIEWICZ-ZABŁOCKA & CAPODAGLIO, 2017; Dotro et al., 2017; Tsihrintzis, 2017).
The accuracy of designs	The performance of CWs' is highly affected with the local conditions where the plant located, this challenge increased with lack of standard guidelines on design and sizing for recently developed types of CWs'. In addition, a unique operation and maintenance guidelines are required for each specific CW.	(C. A. Arias et al., 2021).
The need for a preliminary treatment	a preliminary treatment is needed before CWs which required more costs and more materials consumption. And CWs' required more retention time comparing to the conventional systems, thus we need more CW beds and more land area.	(Lotfy & Rashed El-Khiaria, 2002; Masi et al., 2018; A. Stefanakis et al., 2014).
Biomass production	Although the vegetation covers used in CWs have an economic value, it can produce higher biomass since regular harvesting is required to enhance the removal efficiency of the system. Leading to increase the maintenance cost of CWs	(Köbbing et al., 2013).
Varieties of pollutants removals	Every species has different removal rates for pollutants and only a few species can be planted in the site that is why removal of all pollutants are not possible	(C. A. Arias et al., 2021; Skrzypiecbcef & Gajewskaad, 2017)
Longer HRT	The treatment process in CWs takes time as compared to other mechanical treatment processes. CWs efficiency is varied on seasonal basis. In the summer season, the removal efficiency of many species is better when compared to the winter season.	(Chintakovid et al., 2008)
Efficiency and insects	In FWS CW, removal of some pollutants is not efficient for the aquatic phytoremediation like heavy metals. In the free water surface, mosquito breeding is also a problem if not operated well.	(Alayu & Leta, 2021; Masi et al., 2017).
Required proper operation	Although the operation of CWs doesn't require skilled staff, but a proper operation and maintenance are needed to avoid clogging problems and to meet the disposal or reuse final standards for the effluents.	(A. Stefanakis et al., 2014).

2.5 Co-benefits of using NBS

CW are multifunctional, providing many benefits to the environment and society (Droste et al., 2017). The following shows a summary of different co-benefits when NBS are used for wastewater treatment:

1. Biodiversity (fauna): Variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. All animals (kingdom Animalia), Fungi (Fungi), and any of the various groups of bacteria (United Nation, 1992).

2. Biodiversity (flora): Variability among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. Any organism in the kingdom Plantae (United Nation, 1992).

3. Pollination: Animal pollination is an ecosystem service mainly provided by insects but also by some birds and bats. The pollination is essential for the development of fruits, vegetables and seeds (Millennium Ecosystem Assessment, 2005).

4. Carbon sequestration: The process of removing carbon from the atmosphere and depositing it in a reservoir or carbon sinks (such as oceans, forests, or soils) through physical or biological processes, such as photosynthesis (Somarakis et al., 2019b; United Nation, 2021).
5. Temperature regulation: he regulation of humidity and localized temperatures during hot weather conditions, including through ventilation and transpiration (Baker et al., 2021; Haines-Young & Potschin-Young, 2018).

6. Flood mitigation: The regulation of water flows by virtue of the chemical and physical properties or characteristics of ecosystems that assists people in managing and using hydrological systems, and mitigates or prevents potential damage to human use, health

or safety (e.g., mitigation of damage as a result of reduced in magnitude and frequency of flood/storm events) (Haines-Young & Potschin-Young, 2018).

7. Biomass production: The collection of above-ground plant material through regular harvesting and removal. Biomass harvesting can – in some cases – increase the removal of nitrogen and phosphorus. The harvested biomass material may subsequently be utilized for other economically productive purposes (Andersson et al., 2016).

8. Storm peak mitigation: During storm periods, the volume of the rain might sometimes exceed the capacity of the drainage systems, leading to shock overflows; characteristics of most NBS will prevent this from happening, through infiltration, retention and detention. For example, the permeability and porosity of the ground where NBS are installed facilitate infiltration during the peak event, and vegetation increases friction along the rain flow path to prolong the runoff process and reduce the peak flow (Y. Huang et al., 2020; A. I. Stefanakis, 2019).
9. Food source: Food from wild plants and animals. This includes parts of the standing biomass of a non-cultivated plant species that can be harvested and used for the production of food; and non-domesticated, wild animal species and their outputs that can be used as raw material for the production of food (Haines-Young & Potschin-Young, 2018).

10. Biosolids: Biosolids are treated wastewater sludge that are rich with organic nutrients material produced as a byproduct from wastewater treatment facilities. When treated and processed, these residuals can be reused and applied as fertilizer to improve and maintain soli productivity (Somarakis et al., 2019b; A. I. Stefanakis, 2019).

11. Recreation: People often choose where to spend their leisure time based in part on the characteristics of the natural or cultivated landscapes in a particular area. In the context of NBS being used for wastewater, depending on the level of treatment and the technology and design applied to a site, people may use the environment for sport and recreation (Haines-Young & Potschin-Young, 2018; Millennium Ecosystem Assessment, 2005).
12. Aesthetic value: Many people find beauty or aesthetic value in various aspects of ecosystems, as reflected in the support for parks, “scenic drives”, and through the

selection of their residence. For NBS used for wastewater treatment, this could be the biophysical characteristics or qualities of species or ecosystems (settings/landscapes/cultural spaces) which people appreciate because of their non-utilitarian qualities (Haines-Young & Potschin-Young, 2018; Millennium Ecosystem Assessment, 2005).

13. Water reuse: Water reuse is the use of treated wastewater for purposes (usually other than domestic) such as agriculture and irrigation, potable water supplies, groundwater replenishment, industrial processes, and environmental restoration. Water reuse can provide alternatives to existing water supplies and be used to enhance water security, sustainability, and resilience (Somarakis et al., 2019b).

2.6 Summary and conclusion

Conclusion this review based study illustrates that the sustainability criteria of CWs as a sanitation technology has been fulfilled in many cases and projects, CWs can be adopted for the treatment of different types of wastewater with higher removal of BOD, COD, NH4, NO3 TN, TP, etc. CWs have removal efficiencies 80%–91% BOD, 60%–85% COD and 80%–95% TSS. CWs can be considered as resilient technology to climate change impacts if operated appropriately, climate change might affect the degradation process and the total emissions but limited impacts to the overall efficiency. Economically the review has illustrated that CWs require low energy and low operation and maintenance cost, CWs require only 1%–2% of capital cost for its operation and maintenance which is very low as compared to other treatment technologies, the application of CWs can be liked with the circular economy approach thought different interventions such as the energy productions and nutrients recovery. The review has summarized the benefits of applying CWs to the environments rather than protecting the environments from discharged wastewater, CWs play important role in biodiversity restoration and carbon sequestration, this treatment technology also providing a green and aesthetic area with clean air which is important for human health. CWs can be applied at different levels, centralized, semi centralized and decentralized it can be also applied as a main technology or mixed with other technology, these variety of portions make CWs fit with the national and international institutional requirements and the regulations. Considering the successful and sustainable application of full-scale CWs, future studies should focus on comprehensive evaluation of treatment plants in field trials under real life conditions, optimization of environmental and operational parameters (e.g., influent loads and tidal operation), exploration of novel enhancement technologies (e.g., microbial augmentation) and maintenance strategies (e.g., plant harvest). further research in innovative CWs considering land area requirement and enhancing the removal efficiency, research and studies on the circular economy applications with CWs, and further research are required to evaluate the non-market values and to include them with the Cost-Benefits Analysis.

Chapter 3: Application of CWs – NBS, Case studies from Mediterranean countries

This Chapter describes the water and sanitation sectors in the selected case studies in the Mediterranean region – Jordan and Italy, including the current and future perspectives and the standards and regulations controlling the sector. The chapter also summarize the application of CWs – NBS, several site visits were carried to collect data, meeting stakeholders, and to do onsite assessment for the current practices, operation, and maintenance of CWs focusing on treatment efficiencies, resilient to climate change, and circular economy practices such as resources recovery and reuse of the treated wastewater.

3.1 Case Study 1: Jordan

3.1.1 Water resources in Jordan

Jordan is a resource-starved, middle-income country with insufficient supplies of water, oil, and other natural resources. The country is classified as being a semi-arid to arid region with annual rainfall of less than 200 mm over 92% of the land. The country comprises 89,297 km^2, most of which (92%) is desert /rangeland. According to the Jordanian Department of Statistics (DOS) in 2022, the population was estimated at 11.23 million Jordanians, growing at an average rate of 1.94%, higher than the world average of 1.7% (DOS, 2022). The country is suffering from water scarcity that was caused by rapid population growth, huge influx of refugees and hydro-political tensions in the Middle East (Al-Bakri et al., 2019). Which leads to continuously increasing demand on water is exceeding the potential of the country's water resources, which is reflected in the form of increasing deficit between the demand and supply (Qdais et al., 2019). The well-known climate change impacts have worsened the Jordanian water sector through adding more challenges to the availability and variability of precipitation, extreme events, and heats waves and that creates imbalance in water management and increases the gap between the demand and the water supply (Hammouri et al., 2015).

According to the ministry of water and irrigation’s reports the main sources of water in Jordan are ground water (12 basins) as shown in Figure 3.1 below (MWI, 2017), surface water (local dams, Yarmouk River and Tiberius Lake), treated wastewater (generated from 33 wastewater treatment plants), and additional resources (desalination) (MWI, 2016b, 2017). In Jordan three main sectors are competing to water resources, domestic, agriculture and industry. Agriculture is the sector that consumes the largest share of water resources, followed by municipal sector, while the least amount goes to the industry. As illustrated in Table 3.1, in 2017 agriculture share was 52% (551.8 million cubic meters (MCM)) of the total consumption, municipal use was 45% (469.7 MCM), and industrial sector use was only 3% (32.1 MCM) (MWI, 2017).

Table 3. 1 Water uses and resources – Jordan. Adopted from MWI,2017

Uses/Resources	Surface water (MCM)	Ground water (MCM)	Treated wastewater (MCM)	Total (MCM)
Domestic	131.3	338.4	0	469.7
Agriculture	154.4	253.2	144.2	551.8
Industry	2.4	27.2	2.5	32.1
Total	288.1	618.8	146.7	10,53.6

The same table shows the amount of water allocated from different resources for each sector where the treated wastewater is mainly use in agricultural - directly or indirectly - sectors according to the Jordanian standers for water reuse JS893 - 2021 (JSMO, 2021). In order to minimize the pressure on the scarce water resources. However, nowadays, the per capita share from the renewable water resources is less than 100 m^3/capita. year, which ranks Jordan to be the second water poorest country in the world (MWI, 2017).

To overcome with this water shortage, the Jordanian government has considered several options including expands the water supply and manage the supply – demand gap (MWI, 2016b; Qdais et al., 2019). The government started with groundwater over pumping exceeding the safe yield. The annual safe yield of renewable groundwater resources is 275 MCM, while the over pumping in 2017 was 200 MCM, which accounts for 72% above the safe yield (MWI, 2016b). That unsustainable practice of intensive abstraction leads to lowering the groundwater table and deterioration of the groundwater quality due to saline water intrusion (MWI, 2016b).

A high potential for desalination as another supply option, desalination of both brackish and seawater. In 2015 the desalination contributed to about 10 MCM to the water budget supporting the 263 MCM from surface water and the 579 MCM from the groundwater and the 140 MCM from treated wastewater – the total water resources 992 MCM while the total demand at 2015 was 1401 MCM causing a deficit of 409 MCM. According to the Jordanian national strategy 2016 – 2025 the nonconventional water resources in 2025 is estimated to be 235 MCM of treated wastewater and 260 MCM of fresh water obtained by desalination and that will cover 32% of the forecasted water demand by 2025 (Hammouri et al., 2015; MWI, 2016b, 2017; Qdais et al., 2019).

Another problem in water sector faces is the non-revenue water. Non-revenue water (NRW) refers to water sent into the distribution system but is not billed (MWI, 2016b). It is one of the major issues affecting the supply of water for domestic use. This can be due to leaks in the system caused by poor-quality equipment and pipes or inadequate maintenance and/or due to non-working meters or unauthorized and illegal connections. Although 94% of Jordanian are connected to water supply and the supply was averaged of 126 liters/capita/day including NRW. It is estimated that 65 liters/capita/day remains unaccounted for each day (52%) due to physical and administrative losses. In addition, water from unauthorized groundwater abstraction or service connections is used for irrigation or sold through water tankers, which reduces the amount available for supply to customers and increases the revenue losses to government (Musa et al., 2018; MWI, 2016b).

The government started many programs to face the NRW, the results show dropped from 52% in 2000 to 44% in 2011 then increased to 52% in 2014, which represents substantial losses. Amman, Zarqa and Balqa cities have the largest total (%) losses while Ma’an and Karak show the highest NRW % along with Zarqa and Balqa. Aqaba, on the other hand has performed very well with provision of continuous supply and an NRW of 28.2% (2014). The Government targets reduction of NRW by 3-6% per year with a targeted reduction to 25% nationally by 2025 and technical losses reduced to below 15%. The strategy thus also includes strengthening the criminalization of water theft and illegal wells (Miyahuna Report, 2020).

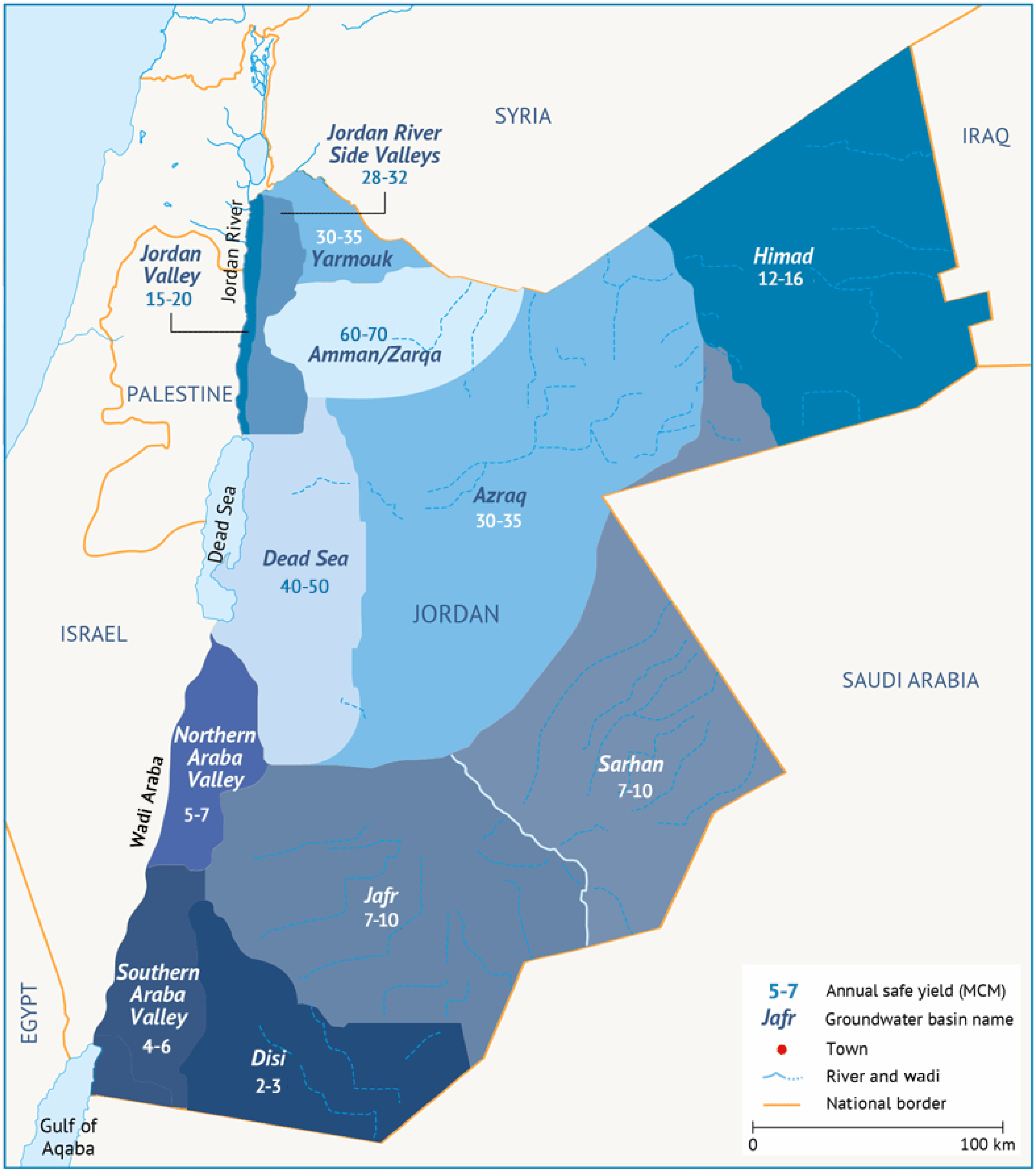

Figure 3. 1 Groundwater basins map in Jordan adopted from (MWI, 2017)

3.1.2 Sanitation in Jordan

Although 94% of Jordan are connected to water distribution system, 65% of the Jordanian are connected to sewage system (while 35% have other safe sanitation methods like septic tanks and are mainly living in rural and semi urban), the percentage is expected to reach 80% by 2030, these expansions will play a huge role in collecting wastewater which will flow and treated by the wastewater treatment plants and therefore increasing the amount of reused treated wastewater (MWI, 2016b, 2016a, 2017).

Currently, there are 33 wastewater treatment plants (WWTP) serving the Jordanian cities and towns. The 33 WWTPs receive wastewater from the sewer system in Jordan and from desludging trucks who serve the rural area. Table 3.2 below shows the list of wastewater treatment plants in Jordan and their capacities, treatment technologies (MWI, 2017). The distribution of the WWTPs' within the country is reflecting the population density in each region, 12 WWTPs' locate in the northern part of the country, 10 plants in the southern region and the 9 in the central region. Figure 3.2 shows the distribution of the treatment plants in Jordan (Breulmann M et al., 2019). The main used treatment technology is activated sludge followed by lagoons/stabilization ponds and trickling filters, details and capacity of each wastewater treatment plant are provided in Table 3.2 below.

In 2017 the total daily design capacity of the wastewater treatment plants in the country is 639320 m^3/day (223.75 MCM/year) while the daily influent of wastewater treatment plants is 137387.5 m^3/day (MWI, 2017). And the ministry expected to reach 235 MCM of treated wastewater in 2025 (Breulmann M et al., 2019; MWI, 2016b). More than 60% of such capacity belongs to As Samra plant that is serving mainly the capital city of Amman and the city of Zarqa. The total daily inflow to the treatment plants in 2017 was 478285 m^3/day, which indicates that the treatment plants working with 78% of their design capacities. The geographical distribution of the plants indicates the areas with higher wastewater reuse potential, which are the central and northern governorates, where the bulk amount of the wastewater is generated and treated (Breulmann M et al., 2019; MWI, 2017).

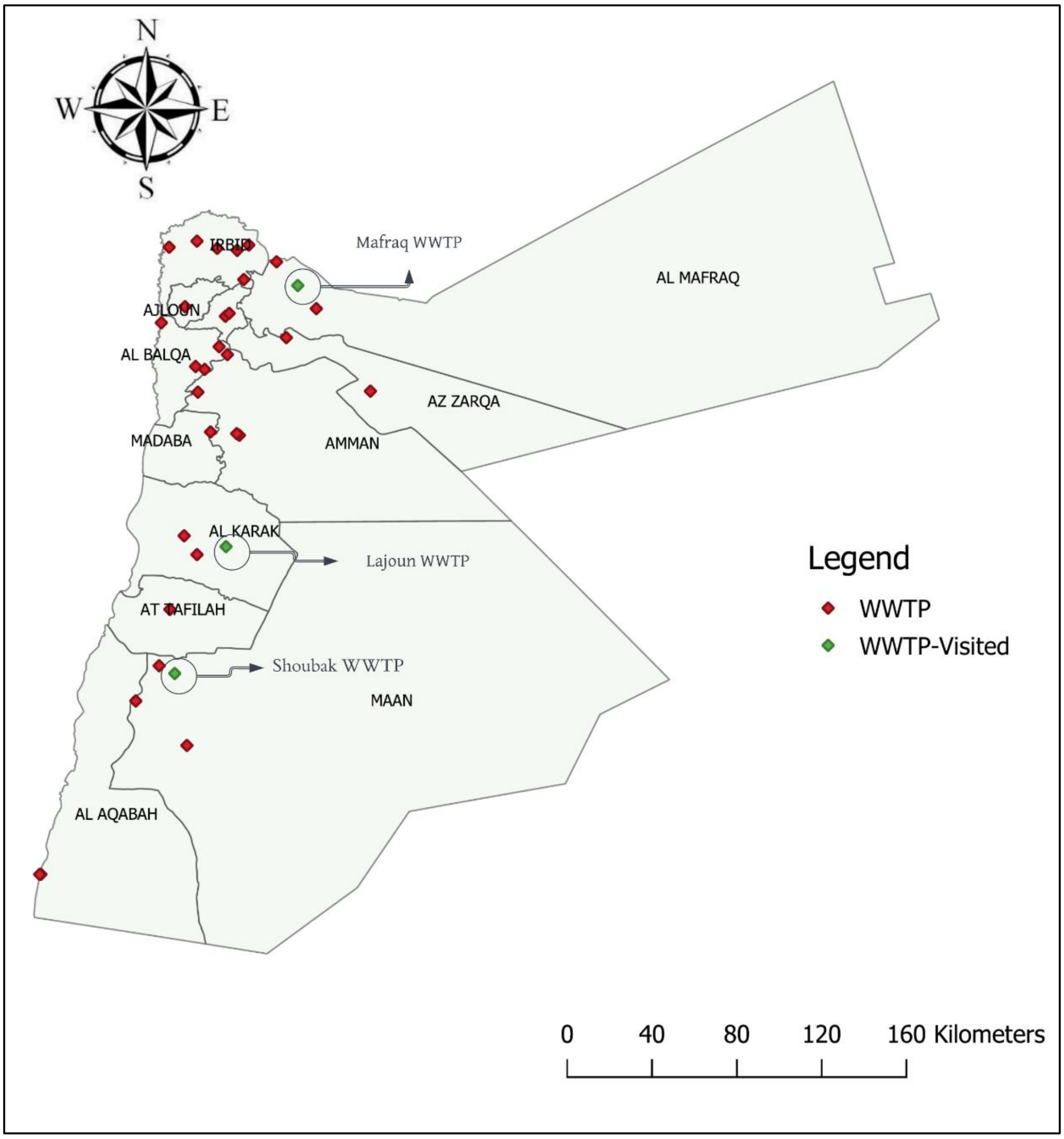

Figure 3. 2 Location of WWTPs in Jordan

Table 3. 2 Wastewater treatment plants - Jordan

No.	WWTP name	Treatment technology	BOD design (kg/d)	Design hydrological load (m^3/d)	Avg actual hydrological load (m^3/d)
1	Fuheis	Activated sludge	995	2,400	2,928
2	Jerash (East)	Activated sludge	1,200	9,800	
3	Me'yrad	Activated sludge	800	10,000	4,397
4	Al Karak	Activated sludge	800	5,500	1,321
5	Kufranja	Activated sludge	850	9,000	3,497
6	Madaba	Activated sludge	950	7,600	7,388
7	Ma'an	Activated sludge	700	7,000	2,324
8	Abu Nuseir	Activated sludge	1,100	4,000	3,385
9	Ramtha	Activated sludge	1,000	5,400	4,268
10	As Salt	Activated sludge	1,090	2,500	8,086
11	Wadi Al Arab	Activated sludge	582	21,000	12,683
12	Wadi Hassan	Activated sludge	800	1,600	1,262
13	Al Jiza	Activated sludge	900	400	383
14	As Samra	Activated sludge	600	360,000	344,548
15	South Amman	Activated sludge	750	52,000	13,517
16	Wadi Shalala	Activated sludge	762	13,750	8,421
17	Mutah-Mazar-Adnaniyyah	Activated sludge	673	7,100	1,396
18	Aqaba Mechanical	Activated sludge	500	12,000	12,719
19	Wadi Musa	Extended aeration	500	3,400	2,832
20	Za'tari Camp	MBR + TF	1,130	3,500	1,468
21	Azraq Camp	MBR + TF	1,500	1,760	
22	Mafraq	Oxidation sludge	825	5,500	3,731
23	Wadi as Sir	Oxidation sludge	670	1,7000	5,040
24	Aqaba Natural	Stabilization ponds	900	9,000	7,066
25	Al Ekeder	Stabilization ponds	1,500	4,000	2,078
26	Al Lijoon	Stabilization ponds	1,500	1,200	712
27	Shobak	Stabilization ponds	1,850	350	153
28	Al Mansorah	Stabilization ponds		50	20
29	North Shouna	Stabilization ponds	1,850	1,200	655
30	Al Baqa	Trickling filter	800	14,900	14,563
31	Irbid Central (Fo'ara)	Trickling filter & activated sludge	800	13,350	8,272
32	Tall Almanta	Trickling filter & activated sludge	2,000	400	383
33	Tafila	Trickling filter + acivated sludge	1,060	7,500	1,945

Guidelines and Reuse Standards

Utilizing of treated wastewater for agricultural purposes entails certain restrictions to be developed and applied to ensure public safety and health. In 2006 Jordan standards and metrology organization (JSMO) has launched a technical regulation (JS893/2006) that governs using reclaimed domestic wastewater. The main suggested crops to be grown under treated wastewater has been classified in three categories i) cooked vegetables, parks, playgrounds, and sides of roads within city limits. ii) represents fruit trees, sides of roads outside city limits, and landscape, and iii) represents field crops, industrial crops, and forest trees.

All natural wastewater treatment plants in Jordan, are treating wastewater to the third categories (Field crops, industrial crops, and forest trees irrigation).

In 2021 JSMO has updated the guideline and reuse standard JS893 to a more restricted standard. The main different is the new JS893/2021 prohibited reusing treated wastewater for irrigating cooked crops, other differences are in the allowable limits for different parameters of treated wastewater. Table 3.3 summarize JS893/2006 and JS893/2021 and the main differences (JSMO, 2006, 2021). In this study the two standards have been used with the analysis of the NBS WWTPs which have been visited during the research period.

Table 3. 3 Allowable limits for reuse treated wastewater - Jordan

	JS893 2006			**JS 893 2021**		
Standards	Cooked vegetables, parks, playgrounds, and sides of roads within city limits,	Fruit trees, sides of roads outside city limits, and landscape, and C represents field	**Field crops, industrial crops, and forest trees**	Parks, playgrounds, and sides of roads within city limits,	Fruit trees, sides of roads outside city limits, and landscape, and C represents field	**Field crops, industrial crops, and forest trees**
BOD_5 (mg/1)	30	200	**300**	30	100	**200**
COD (mg/1)	100	500	**500**	100	200	**300**
TSS (mg/1)	50	200	**300**	50	100	**100**
NO_3 (mg/1)	30	45	**70**	16	16	**16**
T-N (mg/1)	45	70	**100**	70	70	**70**
E. coli MPN or CFU / 100ml	100	1000	-	100	1000	-
PO_4 (mg/l)	10	10	**10**	30	30	**30**

Water and sanitation sector strategy 2016 – 2025

Under integrated water resources management program, the Jordanian MWI focus on development of water resources options including harvesting rainwater, brackish and seawater desalination, increased storage of surface water runoff, artificial recharge, where feasible, more treated wastewater and more importantly, sustaining existing levels of supply. Another major challenge is to achieve a balance between supply and demand without hindering development needs, at the same time ensuring feasibility and affordability of supply, for both water users and the Government. Some of the strategic issues that need to be addressed are a) Prevent over-exploitation of aquifers based on assessment of groundwater potential; b) Reliable estimates on trans-boundary water share; c) Maximize and sustain reuse of wastewater in agriculture; d) Reallocation based on the national priorities and e. develop sustainable and affordable treatment and desalination options (MWI, 2016b).

As part of this strategy, MWI will target an increased amount of supply. Through nonconventional water resources like desalination where is has already contributed to the water budget with 10 MCM in 2015 and it is expected to reach 260 MCM by 2025, same thing with using treated wastewater as the amount of treated wastewater will contribute to the water budget with 235 MCM by 2025. In order to that the Read Dead Sea Project (RSDSP) in its phases constitutes a major part of increased supply. The first phase of this project will add 85 MCM for the water budget while it is expected to be increased with additional 150 MCM by 2025 (MWI, 2016b; Qdais et al., 2019)

For enhancing using treated wastewater an ongoing effort to expand the sewer network and increase wastewater treatment capacity to promote access to safe sanitation facilities in households and institutions in areas outside the sewer networks. By that more steps toward sustainable management of water and wastewater for all Jordanian, targeting achieving the SDGs'. Under the sanitation and wastewater strategy the government sets a policy about decentralization systems in order to serve small communities and rural areas. However, this policy doesn't consider communities with less than 5000 inhabitants where implementing a wastewater collection system and treatment facility is not proposed unless the community are close to an existing treatments system or in case of exceptional circumstance and health consideration considering that 28% of the population falls in this category. As well as giving a priority to develop WASH in school package, aiming to provide children with adequate water, sanitation, and hand-washing facilities, considering that schools are at the center of people's sensibilities and values and thus could serve as an entry point for introducing societal changes in many areas (MWI, 2016a)

3.1.3 Application of CWs - NBS in Jordan

To understand the sustainability of CWs- NBS as a sanitation system and how to apply them in Jordan as a sustainable option, it is important to understand the current applications of this system in Jordan, site visits have been conducted in order to meet the operators, collect data and understand the challenges and obstacles in operation similar systems. As mentioned before Jordan has 33 centralized wastewater treatment plant, the main used treatment technology is activated sludge with few applications of NBS as a treatment technology (stabilization ponds and constructed wetlands) as highlighted before in Table 3.2.

Three site visits to Lajoun WWTP, Mafraq WWTP, and Shoubak WWTP have been conducted the other WWTPs could not be visited due to time constraints, legal reasons, and permission requirements. The following sections summarize the main output of these visits.

3.1.3.1 Lajjoun WWTP

Existing treatment process

Lajoun WWTP is located in Karak Governorate and operated in 2004. Lajoun WWTP serves the southern part of Jordan as described in the satellite image Figure 3.3 the plant receives the septage collected from communities unserved by sewer networks. Lajoun WWTP was designed to treat domestic septage (Transported by tankers) through waste stabilization ponds technique with a capacity of 1,200 m^3/d (USAID, 2021).

The plant currently serves 145,000 population and is expected to serve a population of 178,000 on 2035. In addition to septage, the plant receives excess sludge from Karak WWTP and sludge from Al-Karak hospital. The original plant comprises a series of anaerobic, facultative and maturation ponds. In 2010 the plant has been upgraded; the upgrading included the addition of aerators to facultative ponds. Moreover, 16 drying beds were added and tertiary treatment through constructed wetlands (Subsurface horizontal flow) was provide, the detailed layout are illustrated in Figure 3.4 below.

The following points have been summarized after visiting the treatment plant and meeting the operator in order to understand the current situation of the plants, data collection, assessing the current operation of the CWs including the challenges and obstacles and to analysis the future perspectives of applying CWs in different location in Jordan.

- Design inflow capacity is 1200 m^3/day
- Actual average inflow 900 m^3/day
- Number of served people 145,000 capita (statistics 2020)
- Horizontal flow constructed wetland (flow by gravity).
- Daily testing data not available (only the regular monthly or by monthly monitoring from the ministry)
- CW area: 2 beds, each bed 1000 m^2
- No harvesting of the reeds (the required skills and machines are not available)
- Not harvesting the reeds has no impacts on the quality of wastewater treatment.
- No accurate measurement for the sludge as the sludge disposal process is not frequent
- The final water is stored in a pond a reused directly for fodder agriculture near the treatment plant
- Source of energy electrical and solar
- From 2014 to 2020, 3000 m^3 of sludge has been produced from one anaerobic pond, for cleaning and maintenance reasons
- CWs attract wildlife especially snakes, birds, foxes.
- Local people come regularly to collect dry reeds for decoration and for implementing sunshades.

Figure 3. 3 Satellite image of Lajoun WWTP 31° 8'40.28"N 35°52'46.44"E

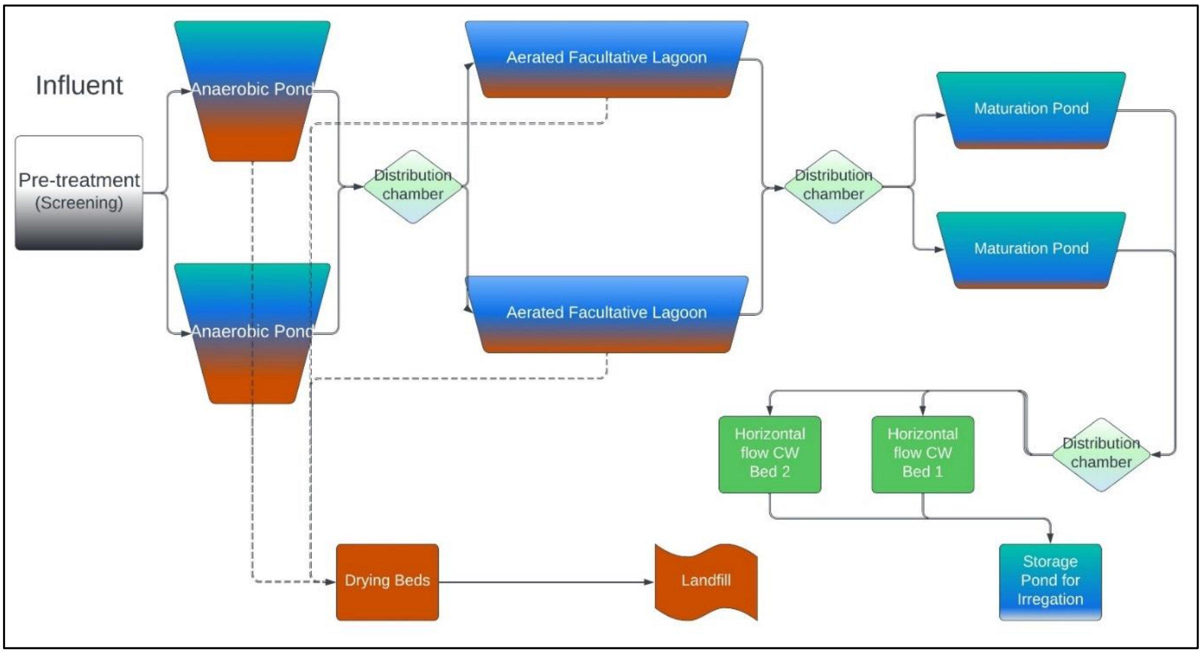

Figure 3. 4 Treatment process - Lajoun WWTP

<u>Current sludge management practices</u>

Sludge received from Karak governmental hospital is stored in plastic bags at the location of the treatment plant and does not enter the ponds. In general, no sludge is discharged from the plant, however, anaerobic ponds were cleaned last year with a total cost of 20,000 JD. Sludge drying beds were used for the purpose. Apparently, sludge is stored inside the treatment plant.

<u>Quality and quantity</u>

Quality and quantity data have been collected for years 2017, 2018 and 2019 and part of 2020. The monitoring and testing process have been affected and stopped due to Covid19 pandemic. The data has been analyzed, average monthly quality data and average daily flowrate have been calculated and used to verify the performance of WWTP against the Jordanian targeted standards.

It was noted that some parameters have a variable treatment efficiency, for example TN wasn't critical and meet the standards during 2018 while the values of TN were higher in 2017 and 2019. Also, the PO_4 values don't meet the new standards, therefore new treatment operation has to be considered.

Figures 3.5 to Figure 3.14 summarize the quantity and quality permeates checked against the Jordanian standards 893/2006 and 893/2021.

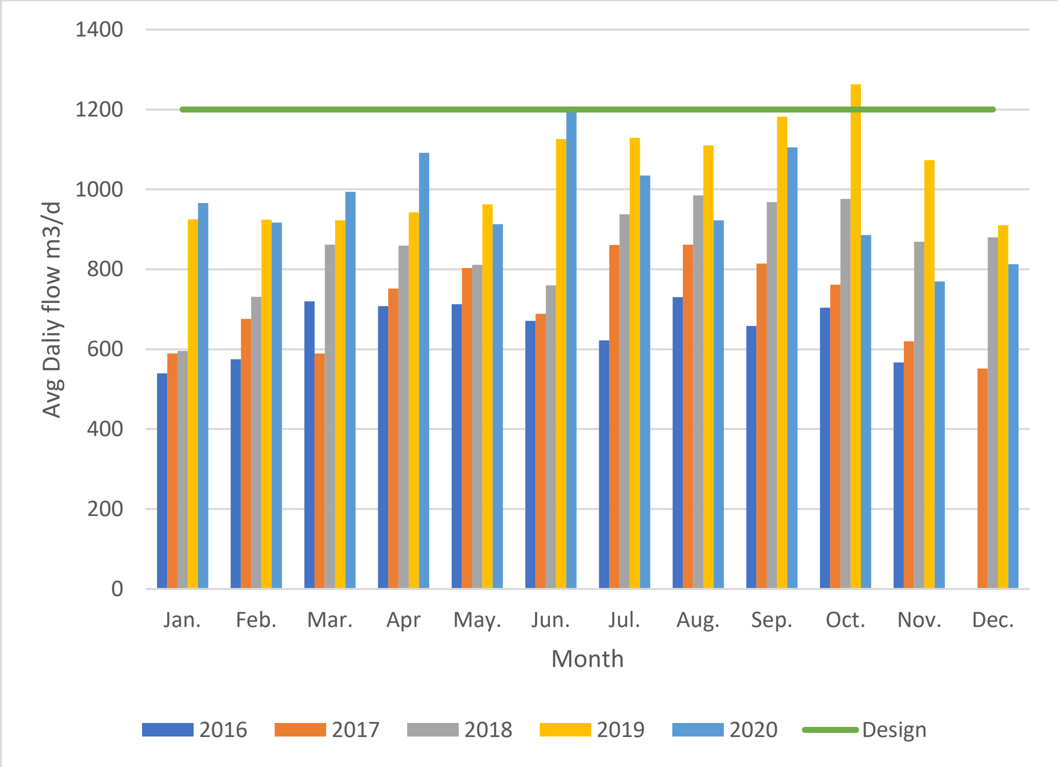

Figure 3. 5 Daily wastewater flow – Lajoun WWTP

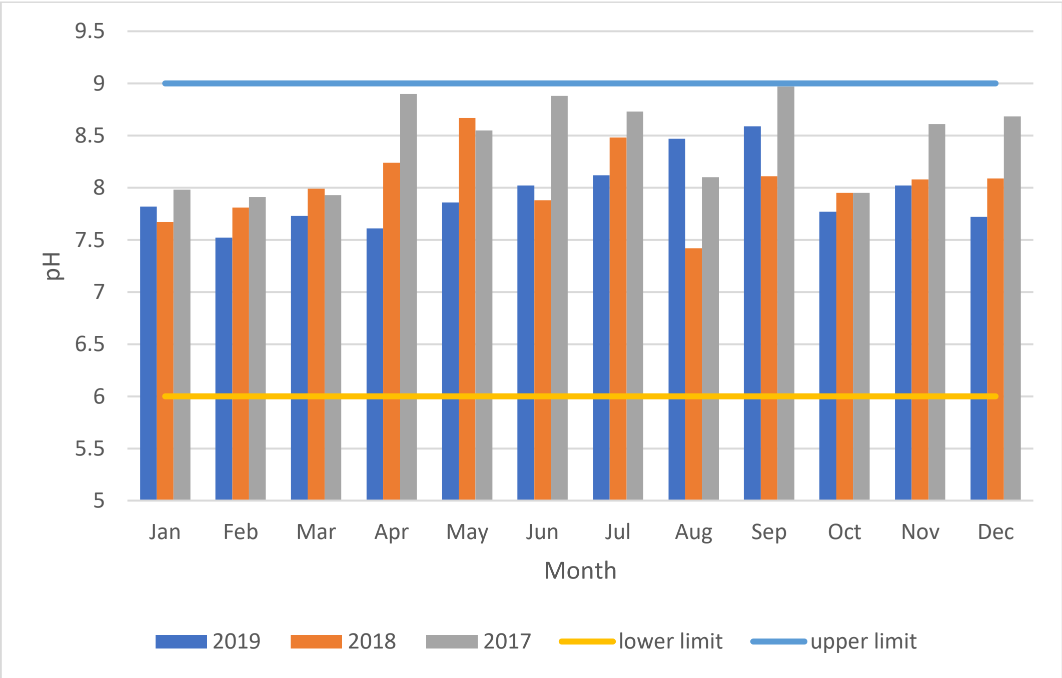

Figure 3. 6 pH values for treated wastewater – Lajoun WWTP

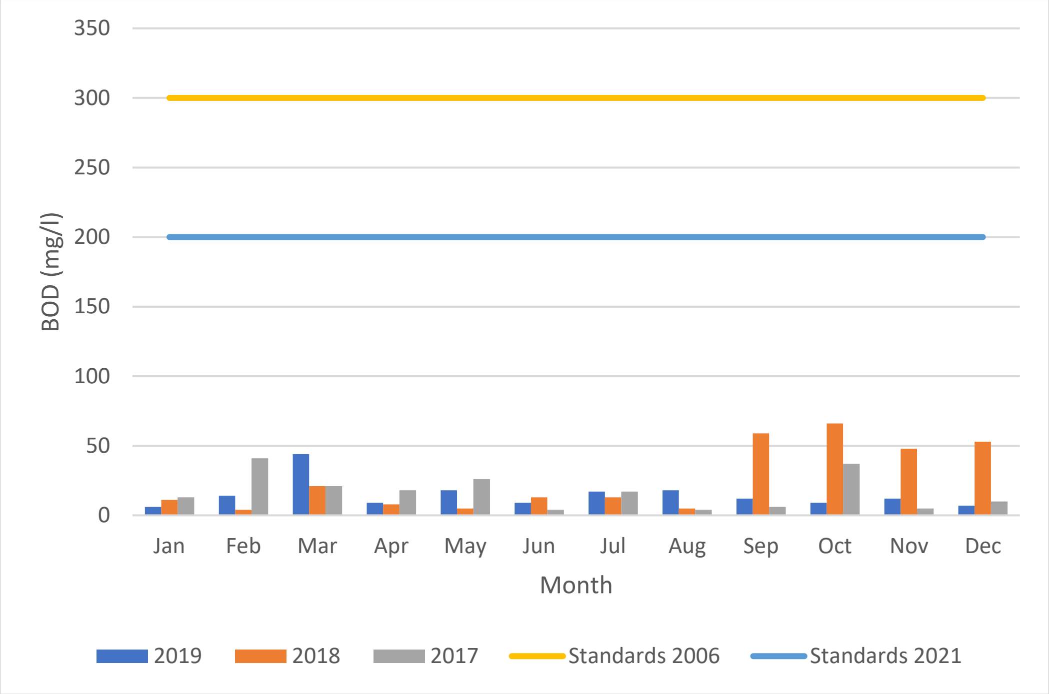

Figure 3. 7 BOD values for treated wastewater – Lajoun WWTP

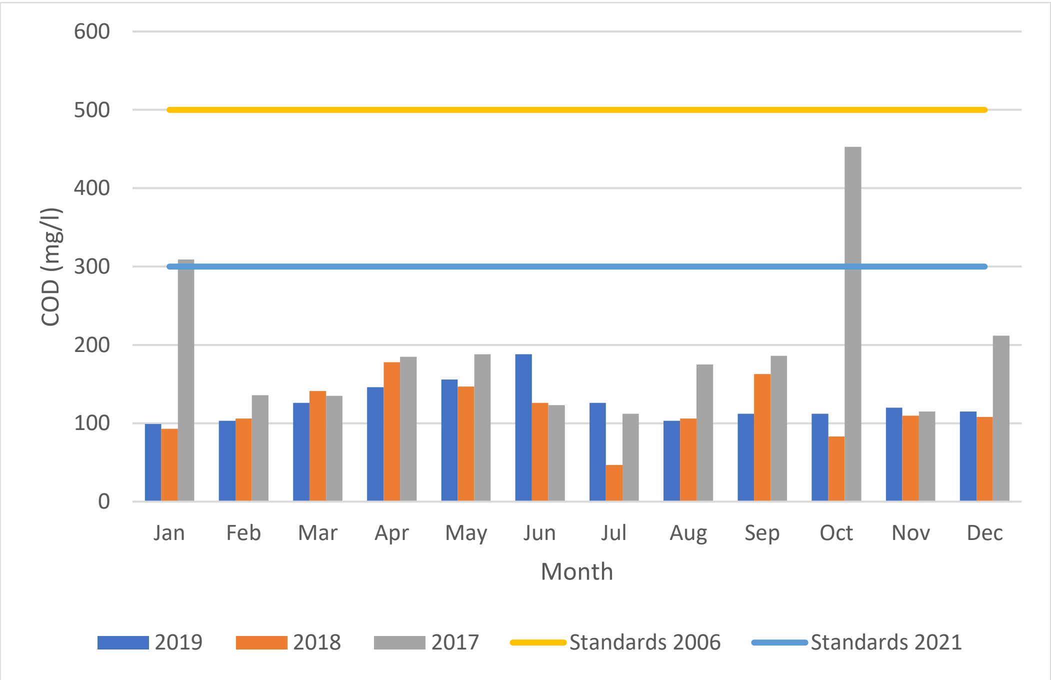

Figure 3. 8 COD values for treated wastewater – Lajoun WWTP

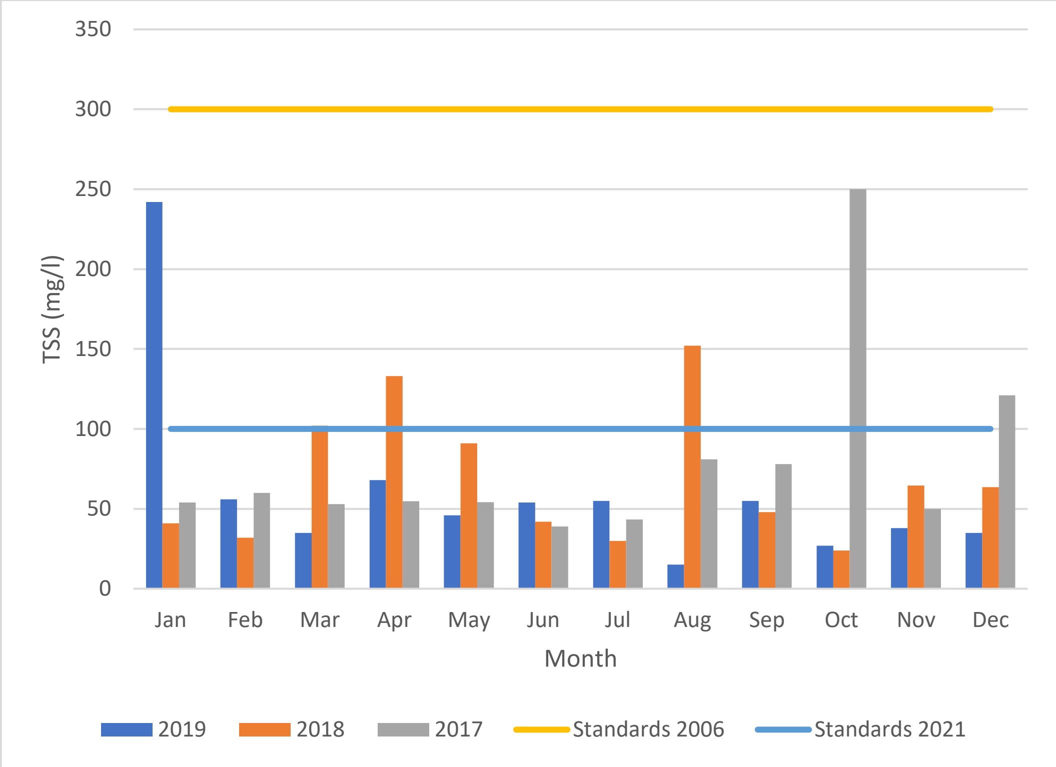

Figure 3. 9 TSS values for treated wastewater – Lajoun WWTP

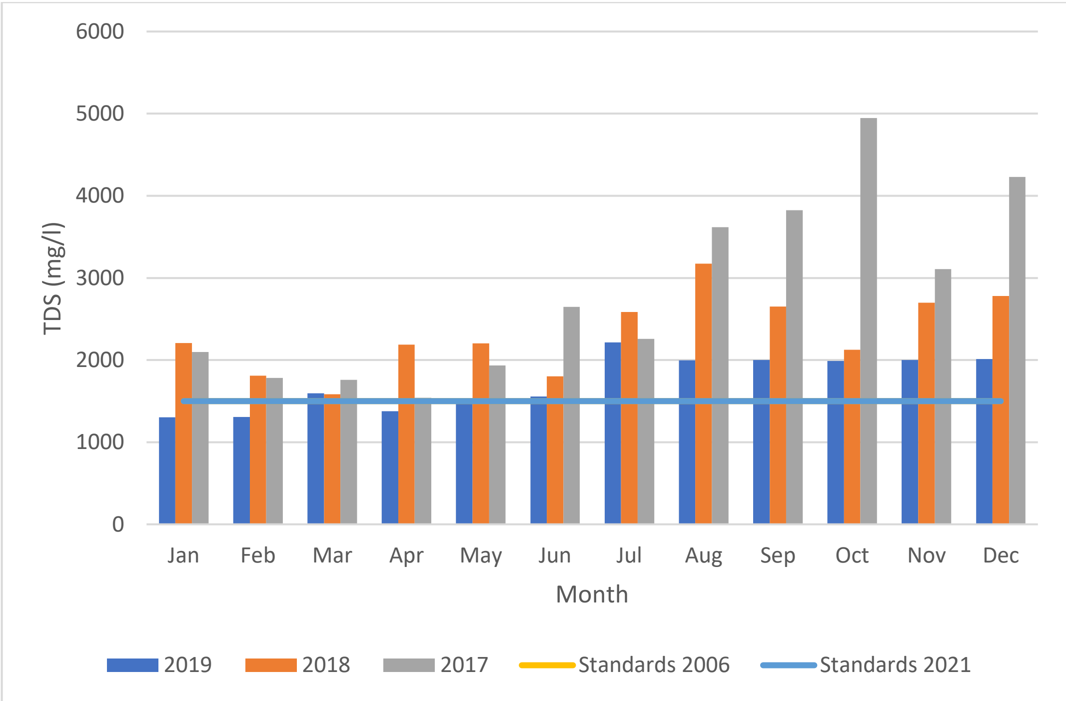

Figure 3. 10 TDS values for treated wastewater – Lajoun WWTP

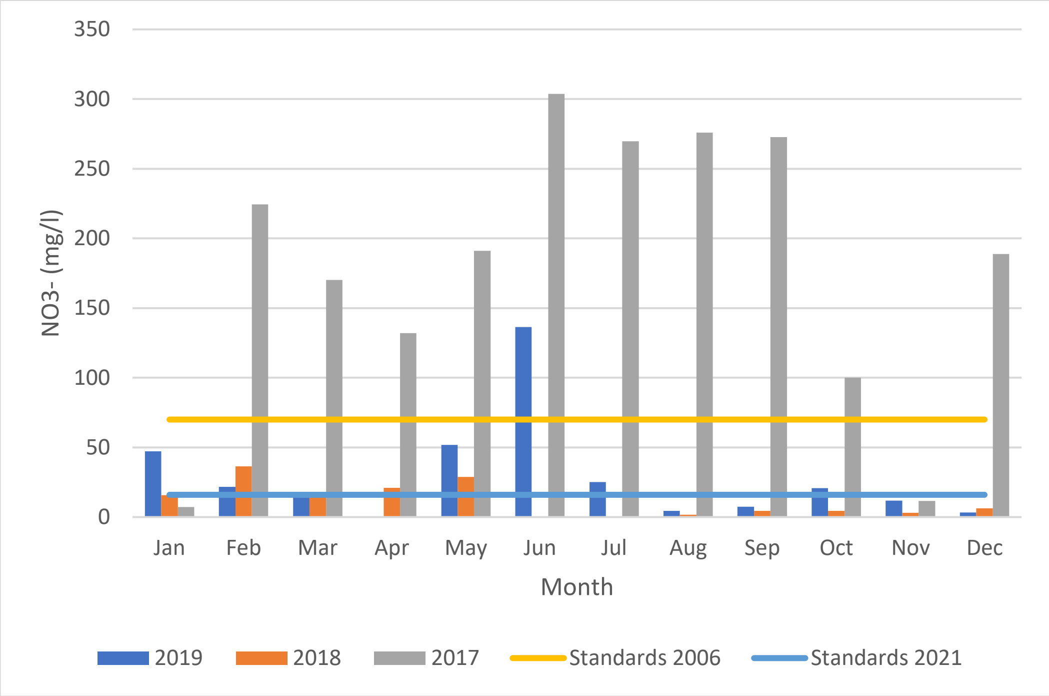

Figure 3. 11 NO3- values for treated wastewater – Lajoun WWTP

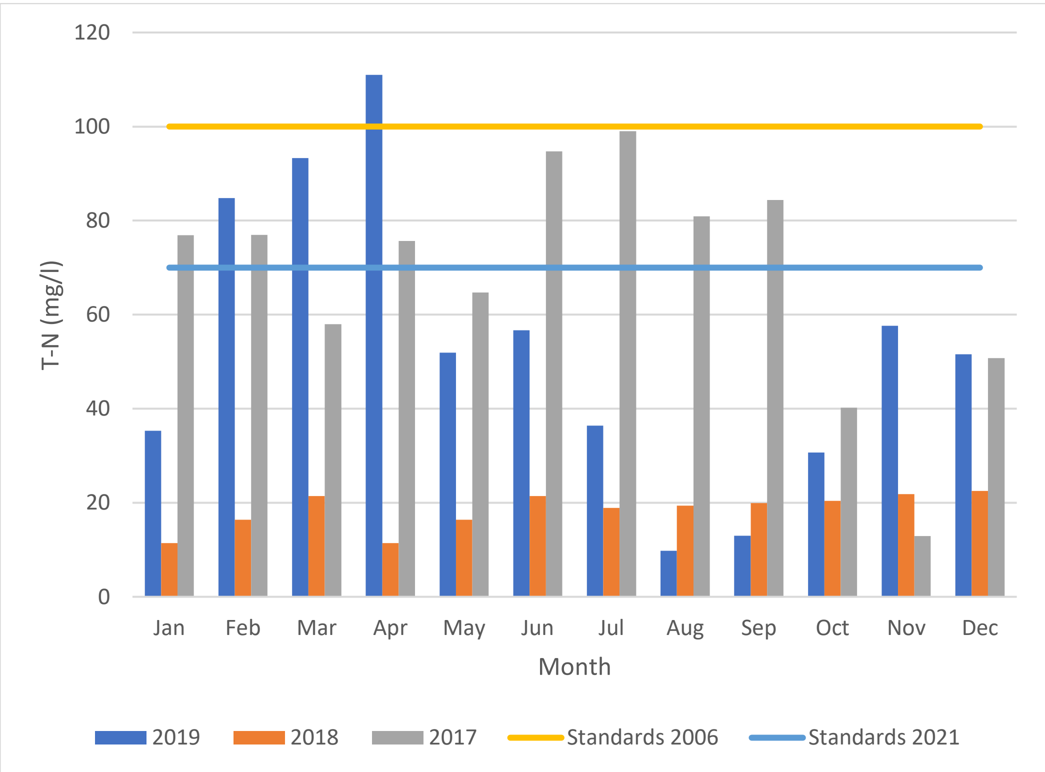

Figure 3. 12 TN values for treated wastewater – Lajoun WWTP

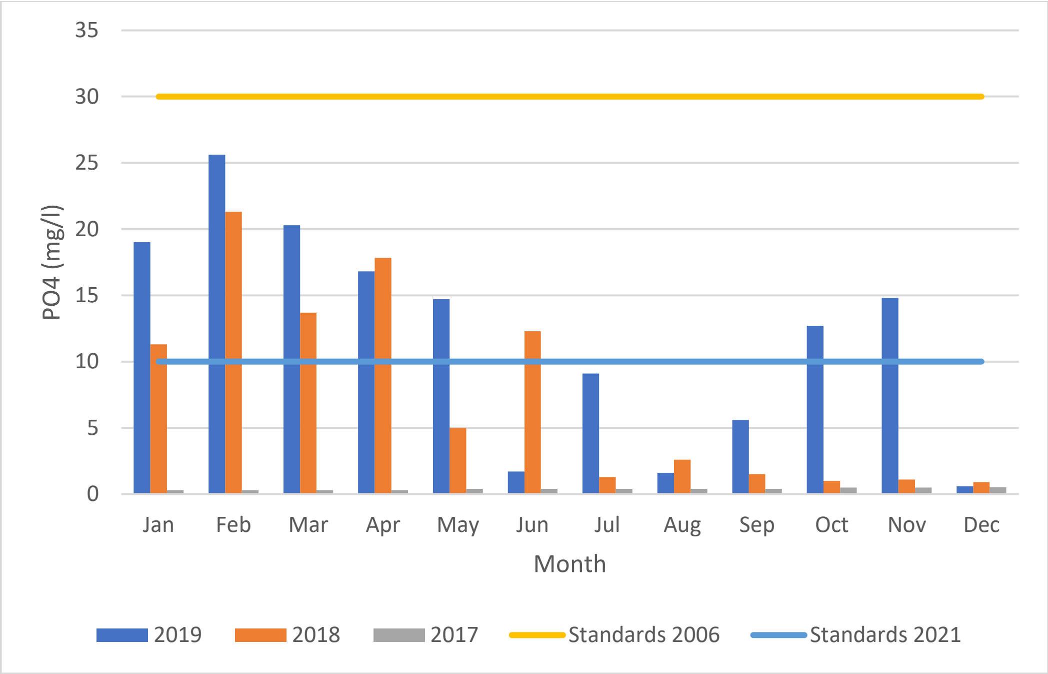

Figure 3. 13 PO4 values for treated wastewater – Lajoun WWTP

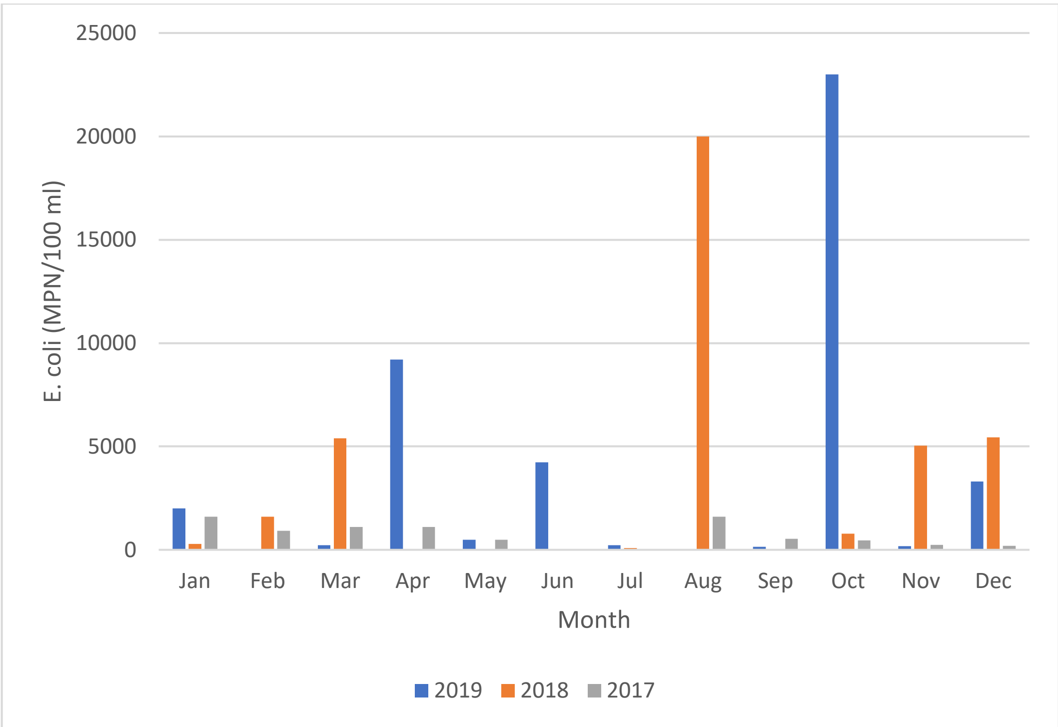

Figure 3. 14 E. coli values for treated wastewater – Lajoun WWTP

3.1.3.2 Mafraq WWTP

Existing treatment process

Mafraq wastewater treatment plant was constructed in 1985 as natural lagoons and was upgraded in 2016 to aerated lagoons system. The design capacity of the treatment plant is 6500 m^3/d. Mafraq WWTP is playing a vital role in environmental protection and in producing reclaimed water which is used for agricultural reuse according to Jordanian standards (Field crops, industrial crops, and forest trees). The treatment plant located in Mafraq city easter of Jordan as mentioned in Figure 3.15 and serving approximate 100 thousand capita (USAID, 2021).

In summary and according to the operator of Mafraq WWTP

- The design flow is 6500 m^3/d, 4740 kg of BOD per day
- At 2020 the average daily flow was 5265 m^3/d, average BOD 2675 kg/day, and average COD 5803 kg/d
- The plant has several problems with the mechanical aeration for the aerated lagoons
- One of the denitrification ponds was out of serves
- The aeration for the grit chamber was broken down
- Illegal practices from the local, as the treatment received bloods from slaughtering shops
- Regarding CWs, the operators harvest the reed annually in March
- The harvested reed transferred and disposed to the landfill
- CWs attracts wildlife, especially snakes, bird, foxes, and eagles
- Although no specific monitoring tests are conducting for the CWs, the engineer mentioned that CWs is playing a vital role in reducing the suspend solid and polishing the water.
- According to the operator CWs need almost zero maintenance and operation except for the annual reeds harvesting

Figure 3. 15 Satellite image for Mafraq WWTP 32°23'55.77"N 36°13'27.88"E

The treatment process started with regular pretreatment followed by aerated grit chamber, denitrification process, followed by ten aerated lagoons, the water is then flow to nitrification process before moving to rock and sand filtration. The tertiary treatment is being caried out by horizontal flow constructed wetland. And chlorination is being carried out before storing the treated wastewater in s storage pond. The treated wastewater is being pumped to several farmers who already had a contract with the ministry of water and irrigation to reuse the treated wastewater according to the Jordanian standards reuse for (Field crops, industrial crops, and forest trees irrigation). Figure 3.16 describes the treatment process in Mafraq WWTP

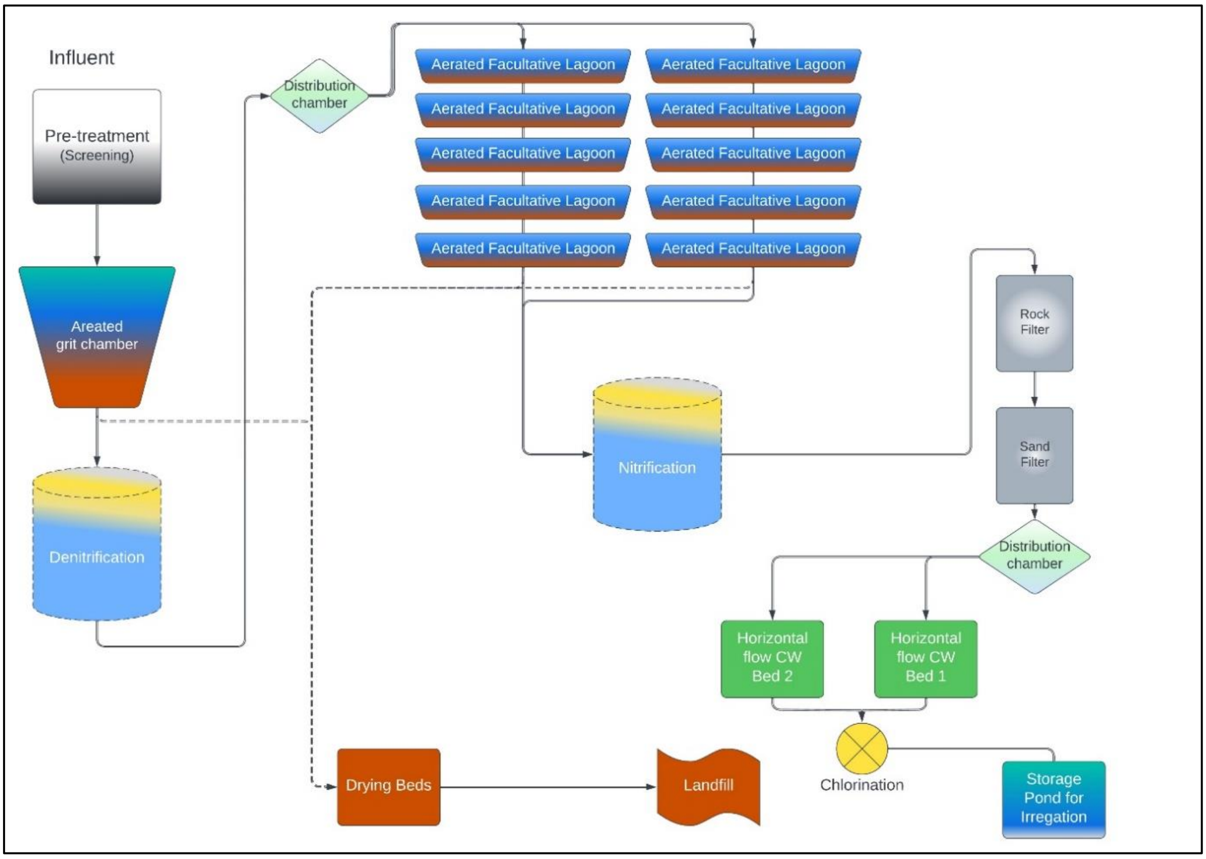

Figure 3. 16 Treatment process - Mafraq WWTP

<u>Quality and quantity data</u>

Similar to Lajoun WWTP, quality data have been collected from 2017 to 2019 for Mafraq WWTP. The monitoring and testing procedures have been affected and stopped by Covid19 pandemic; the available data have been analyzed against the Jordanian standards - Field crops, industrial crops, and forest trees irrigation 2008 and 2021.

Figures 3.17 to 3.24 shows different parameters for the treated wastewater

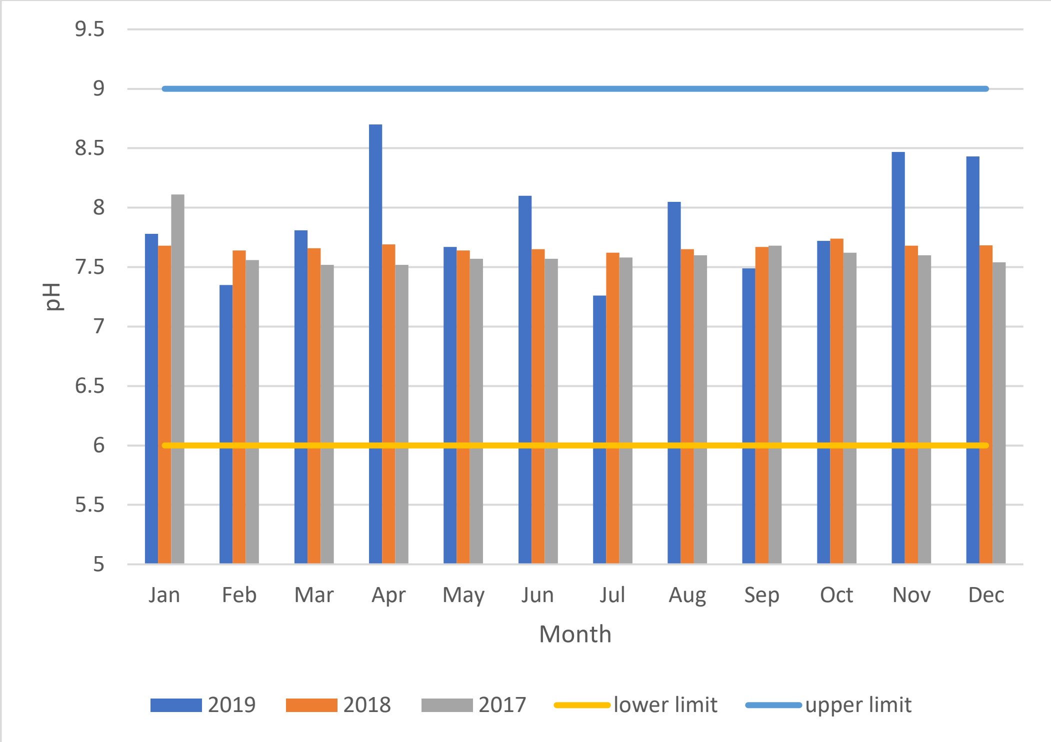

Figure 3. 17 pH values for treated wastewater – Mafraq WWTP

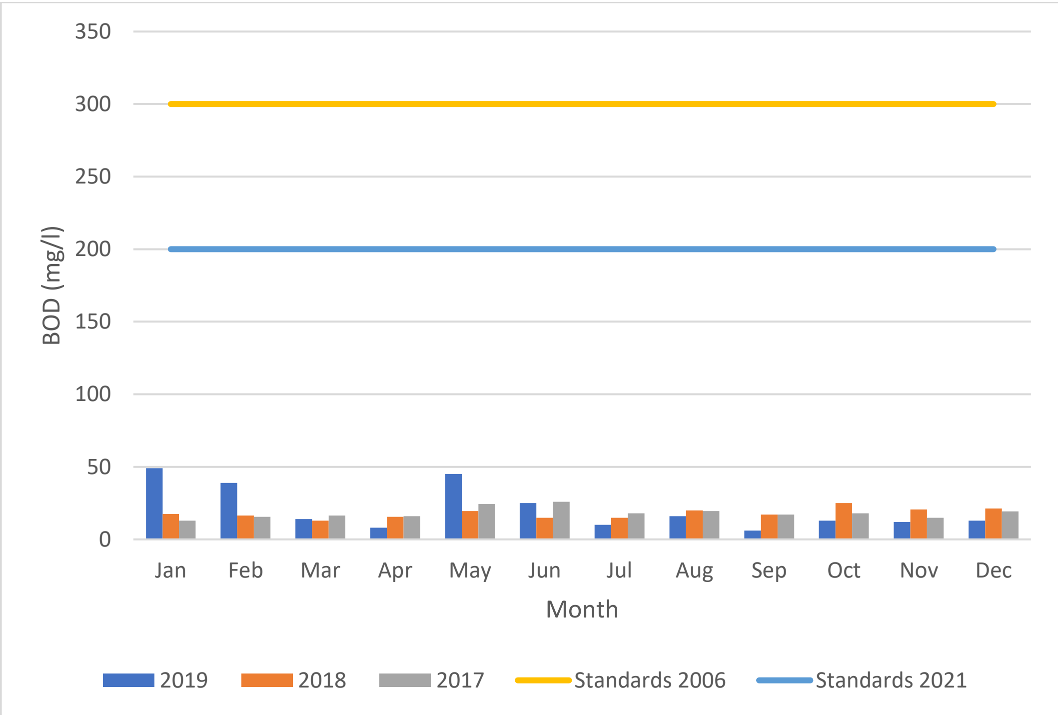

Figure 3. 18 BOD values for treated wastewater – Mafraq WWTP

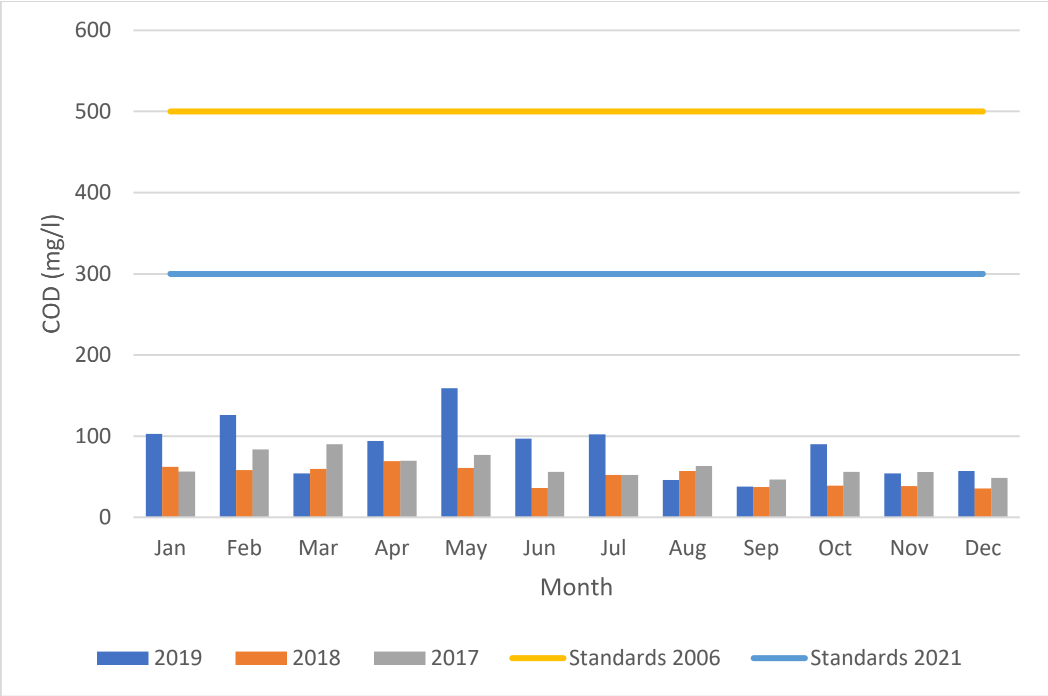

Figure 3. 18 COD values for treated wastewater – Mafraq WWTP

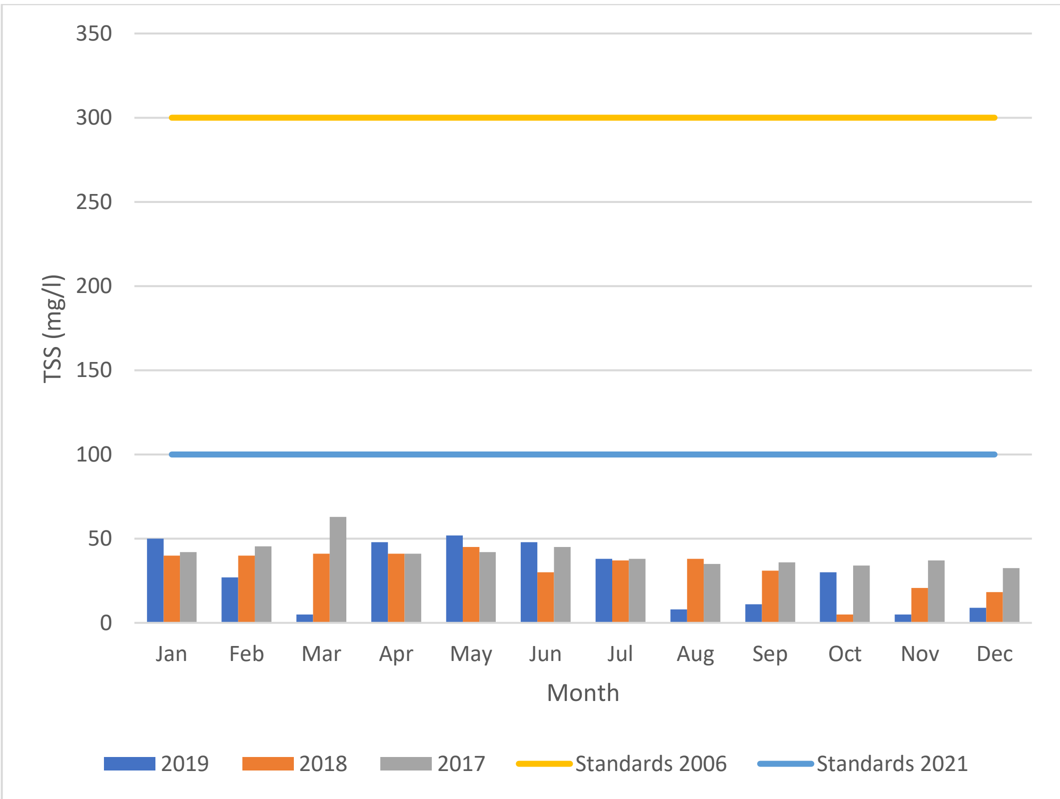

Figure 3. 19 TSS values for treated wastewater – Mafraq WWTP

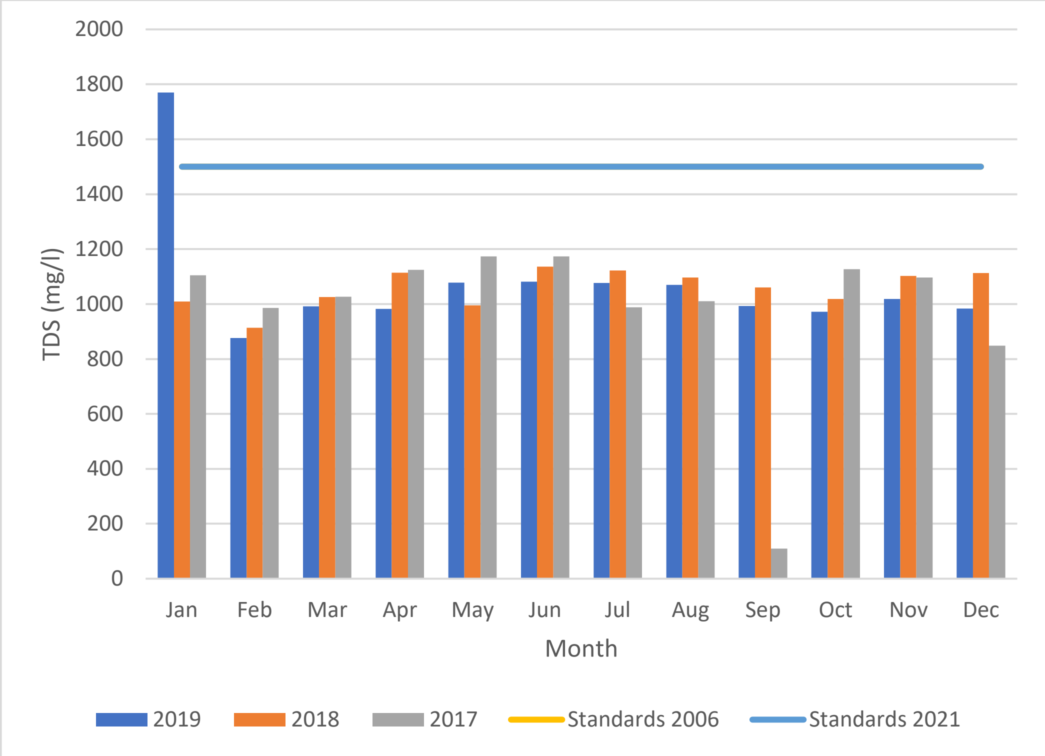

Figure 3. 20 TDS values for treated wastewater – Mafraq WWTP

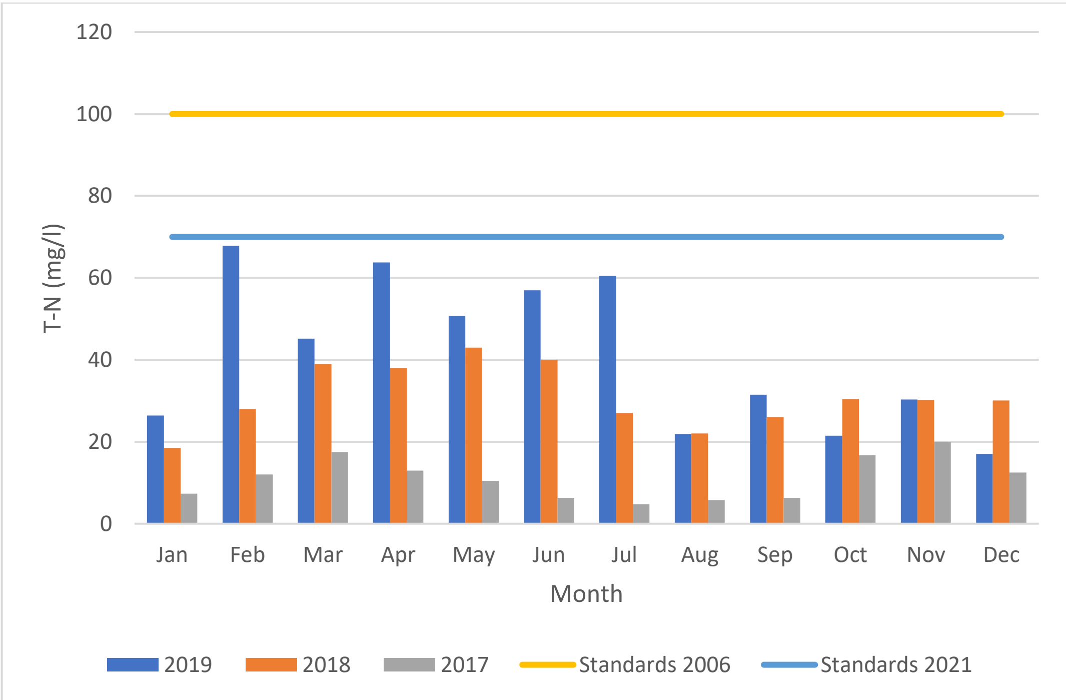

Figure 3. 21 TN values for treated wastewater – Mafraq WWTP

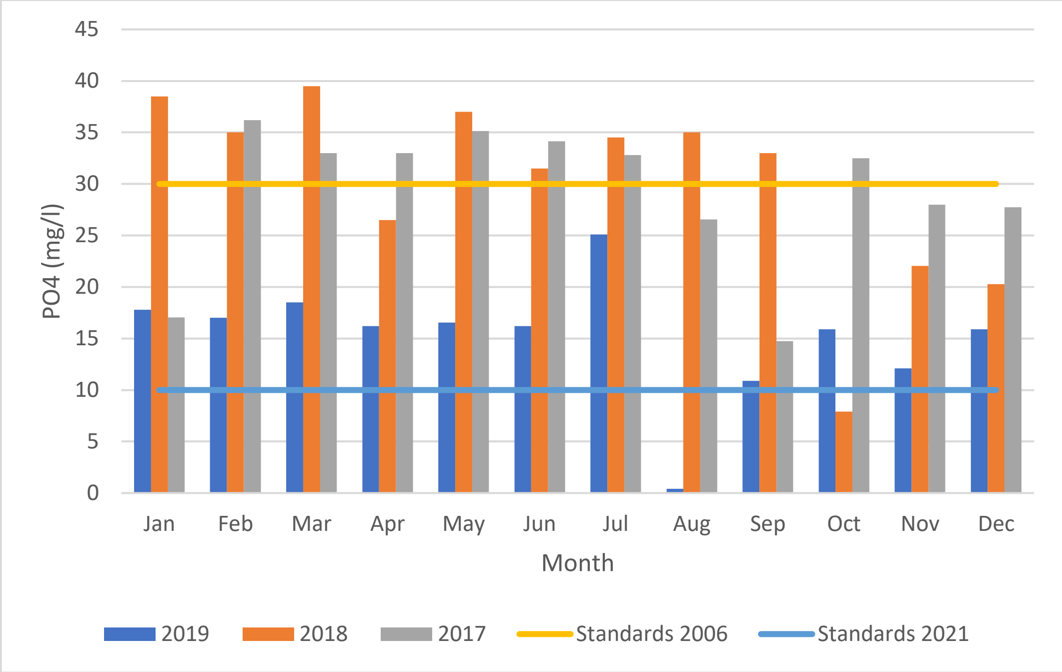

Figure 3. 22 PO4 values for treated wastewater – Mafraq WWTP

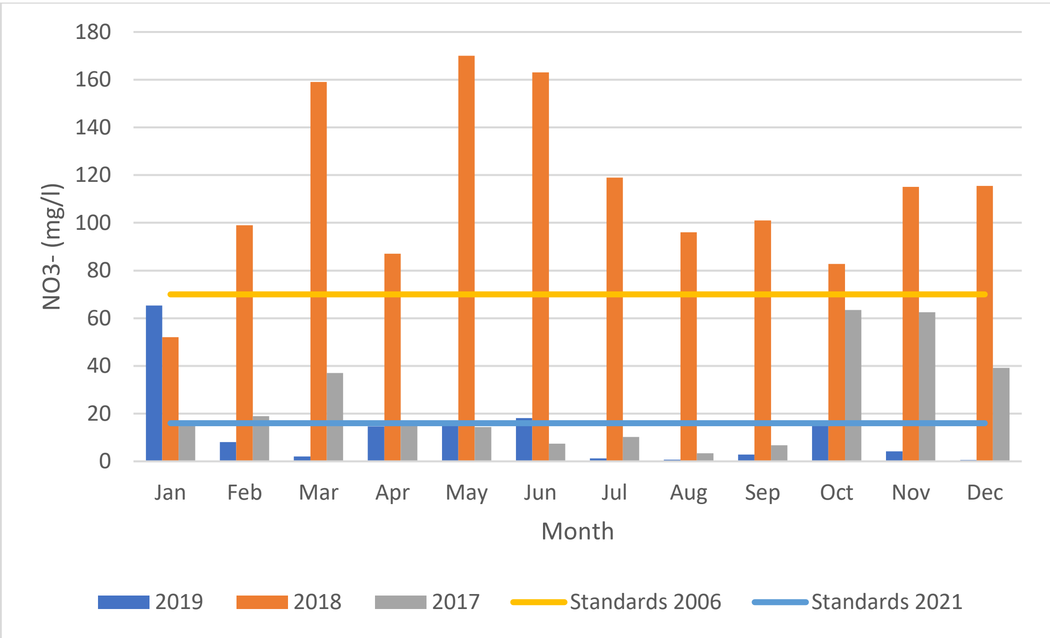

Figure 3. 23 NO3- values for treated wastewater – Mafraq WWTP

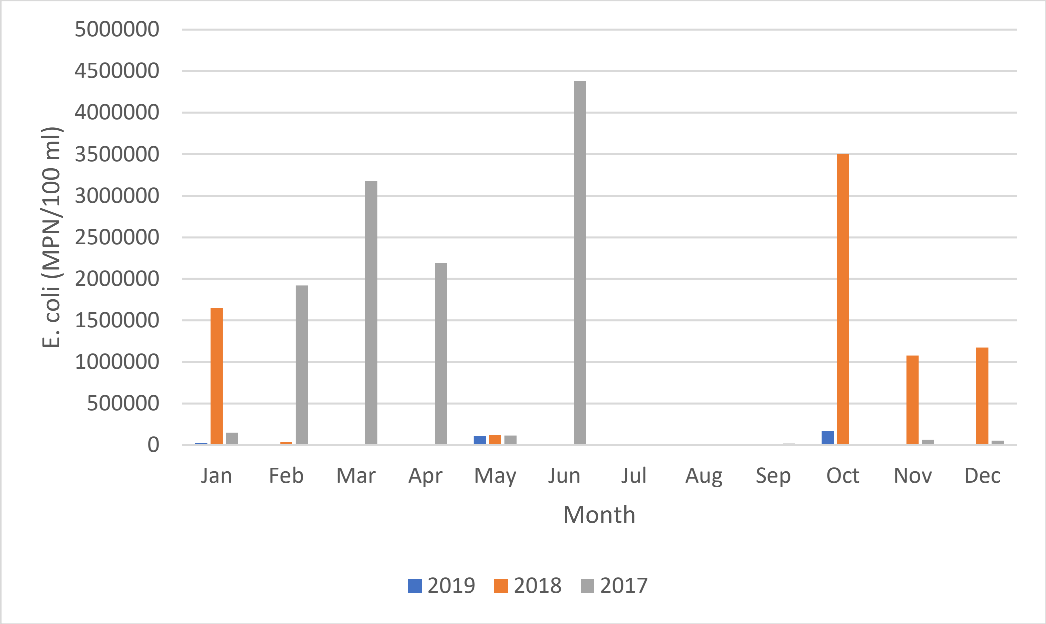

Figure 3. 24 E. coli values for treated wastewater – Mafraq WWTP

<u>Sludge Management</u>

The produced sludge is being transferred to Al-Ekaider landfill. However. It should be noted that not all produced quantities are transferred to El-Akaider dumping site since only sludge produced at the settling tank is loaded to drying beds. The other portion is stored at the treatment plant's pond private contract is responsible for collected the dry sludge from the drying beds and dispose it to the land fill. In general, no sufficient data were provided on sludge (quantities and quality).

3.1.3.3 Shoubak WWTP

<u>Existing treatment process</u>

Shoubak WWTP which is located in Ma'an Governorate/ Shoubak municipality and was operated in 2010. Shoubak WWTP serves the Southern part of Jordan as mentioned in Figure 3.25 the WWTP receives the septage collected from communities unserved by sewer systems (Shoubak, Husseiniyyeh, Hashemiyyeh, and others). Shoubak WWTP is improving the public health/sanitation and protect soil and water resources in the region by minimizing cesspit overflows and controlling current tanker disposal practices (USAID, 2021).

So far, no current practices for harvesting reed, the operation is very simple, and no major maintenance required. Attracting wildlife is very noticeable in the WWTP, several types of snakes, birds, eagles, frogs, foxes, etc. the reeds in the constructed wetlands are forming wide shelter for animals.

Figure 3. 25 Satellite image for Shoubak WWTP 30°32'6.29"N 35°38'0.08"E

Shoubak WWTP has a design capacity of 300 m^3/d. The plant comprises an Imhoff tank, a series of anaerobic pond, sand filters, reed beds, and evaporation pond the process layout are explained in Figure 3.26. The treatment plant currently, receives 76 m^3/d according to the National Wastewater Infrastructure Master plan (USAID, 2021). Plant manager stated that the current average flow is 140 m^3/d.

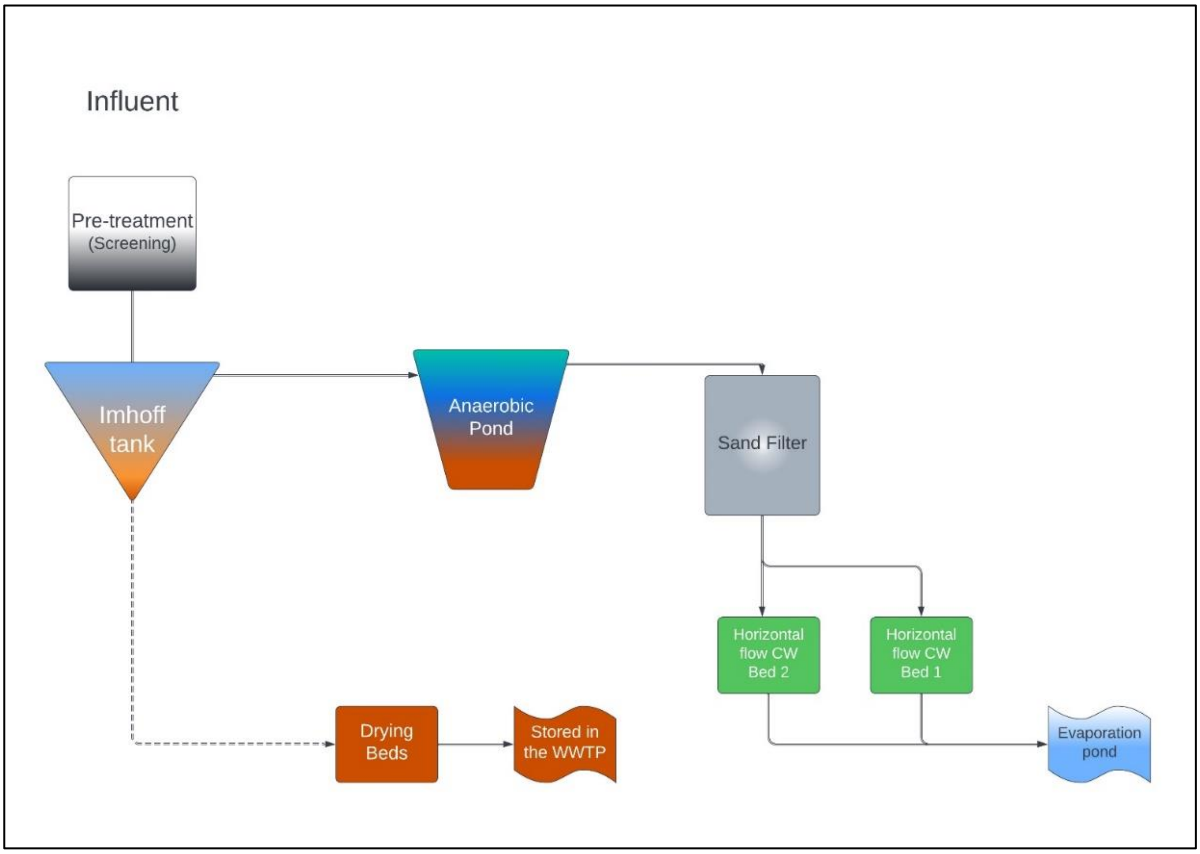

Figure 3. 26 Treatment process - Shoubak WWTP

Sludge management

Imhoff tank is the only source of sludge discharged at the treatment plant. Dried sludge is stored inside the treatment plant. It receives mostly domestic septage and no industrial activities are present in the surrounding area.

Quality and quantity

Although the treated wastewater from Shoubak WWTP is being evaporated in evaporation ponds the quality parameters has been checked in order to analyze the treatment efficiency, quality data have been collected from 2017 to 2019. The monitoring and testing procedures have been affected and stopped by covid19 pandemic; the available data have been analyzed against the Jordanian standards - Field crops, industrial crops, and forest trees irrigation 2008 and 2021.

Figures 3.27 to 3.35 shows different parameters for the treated wastewater

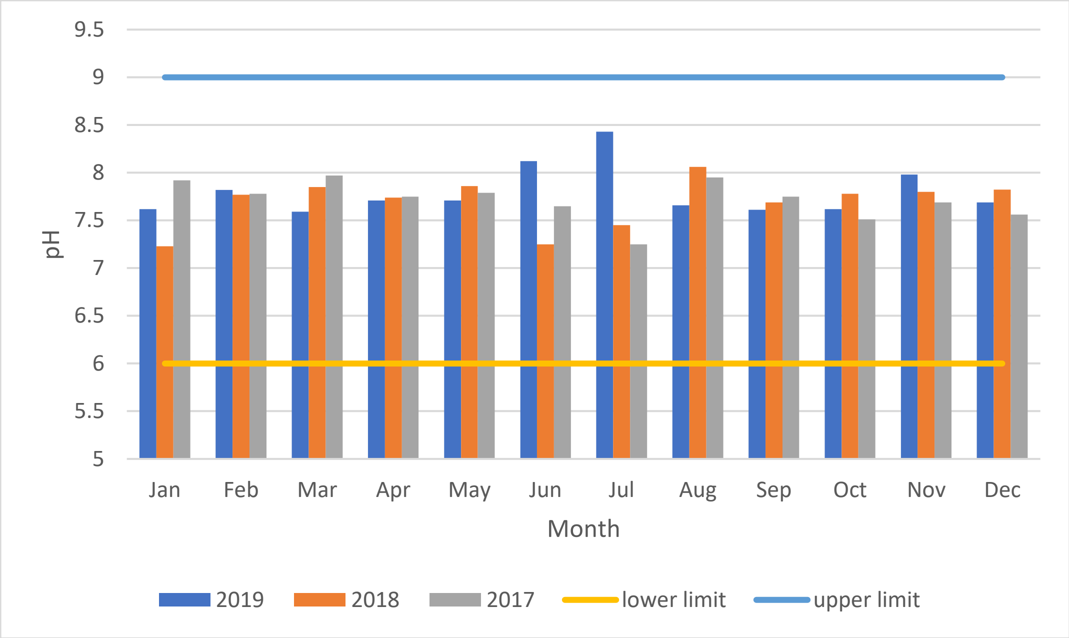

Figure 3. 27 pH values for treated wastewater – Shoubak WWTP

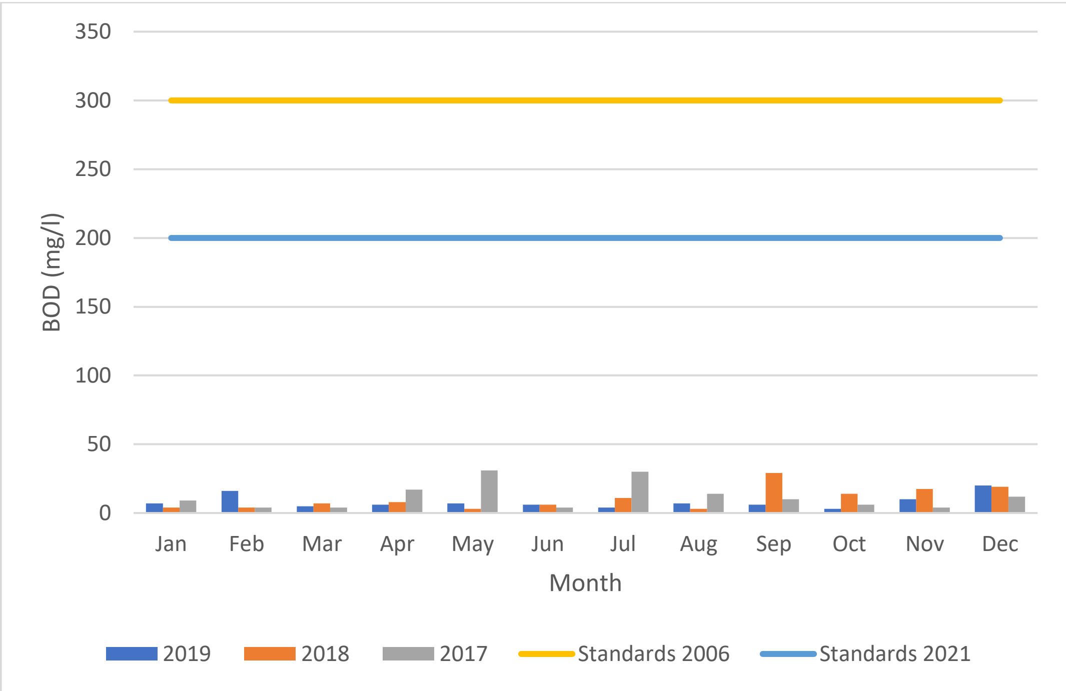

Figure 3. 28 BOD values for treated wastewater – Shoubak WWTP

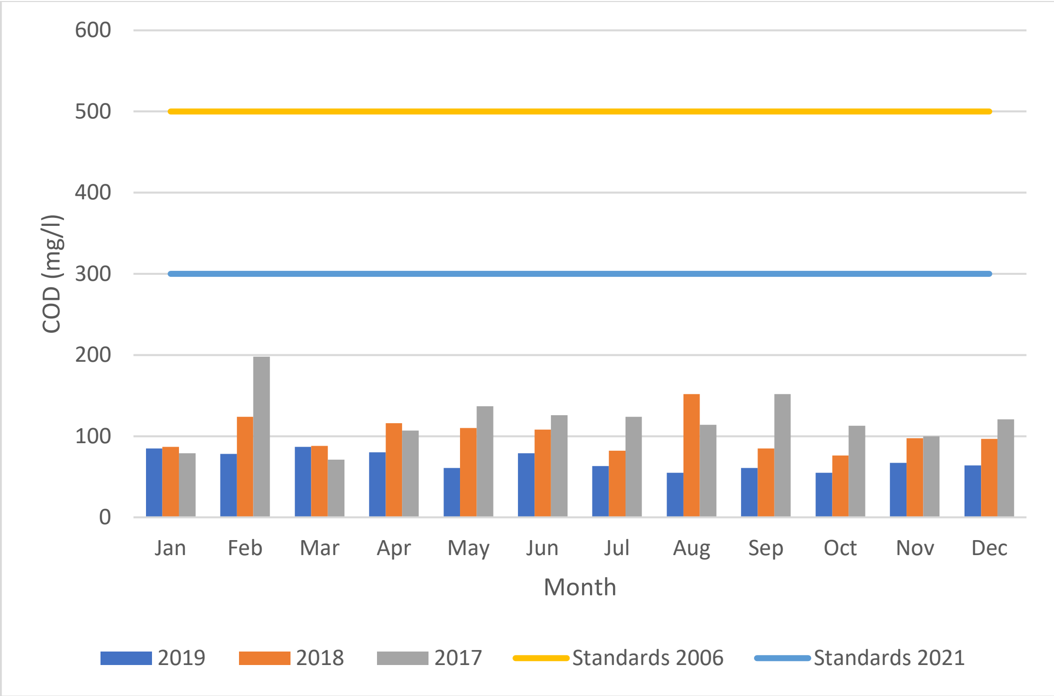

Figure 3. 29 COD values for treated wastewater – Shoubak WWTP

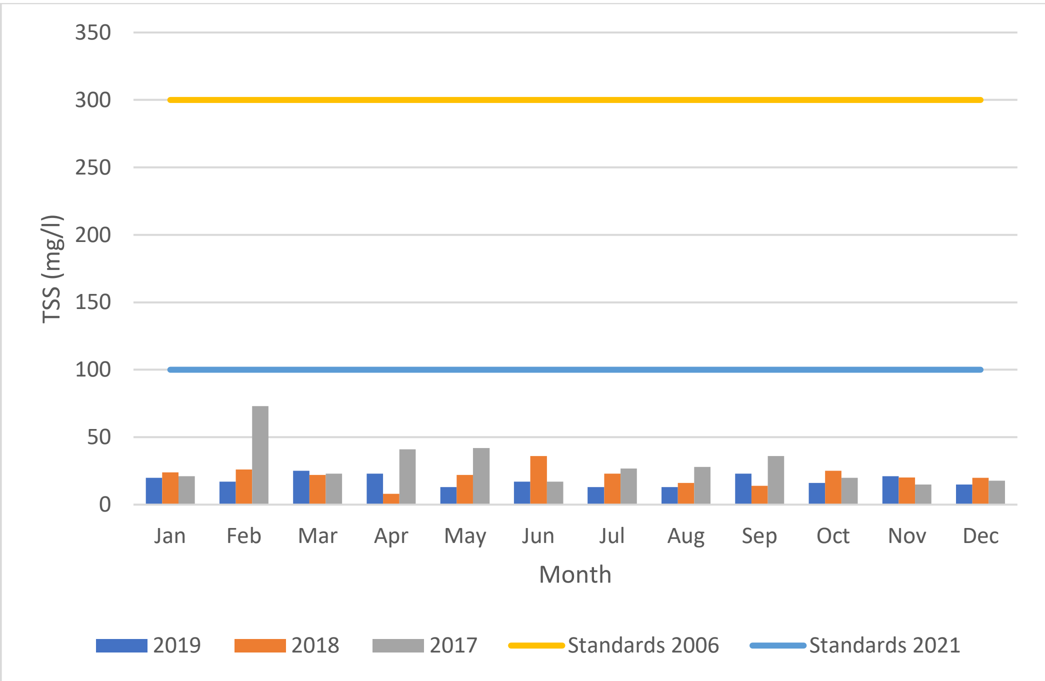

Figure 3. 30 TSS values for treated wastewater – Shoubak WWTP

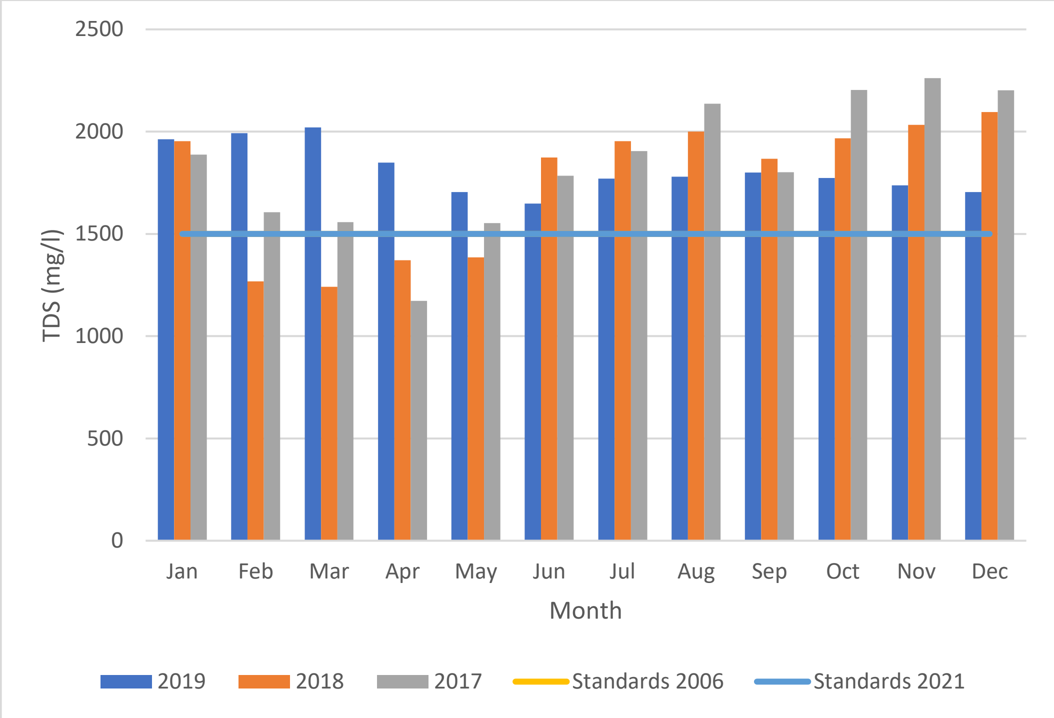

Figure 3. 31 TDS values for treated wastewater – Shoubak WWTP

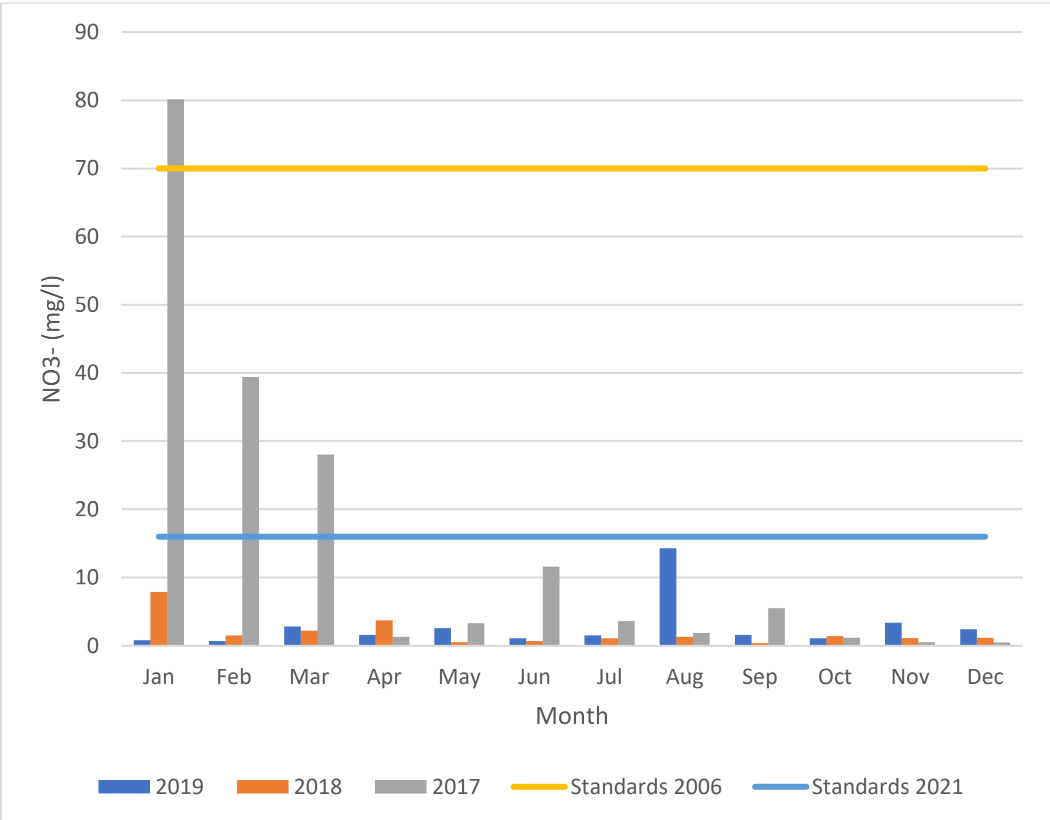

Figure 3. 32 NO3- values for treated wastewater – Shoubak WWTP

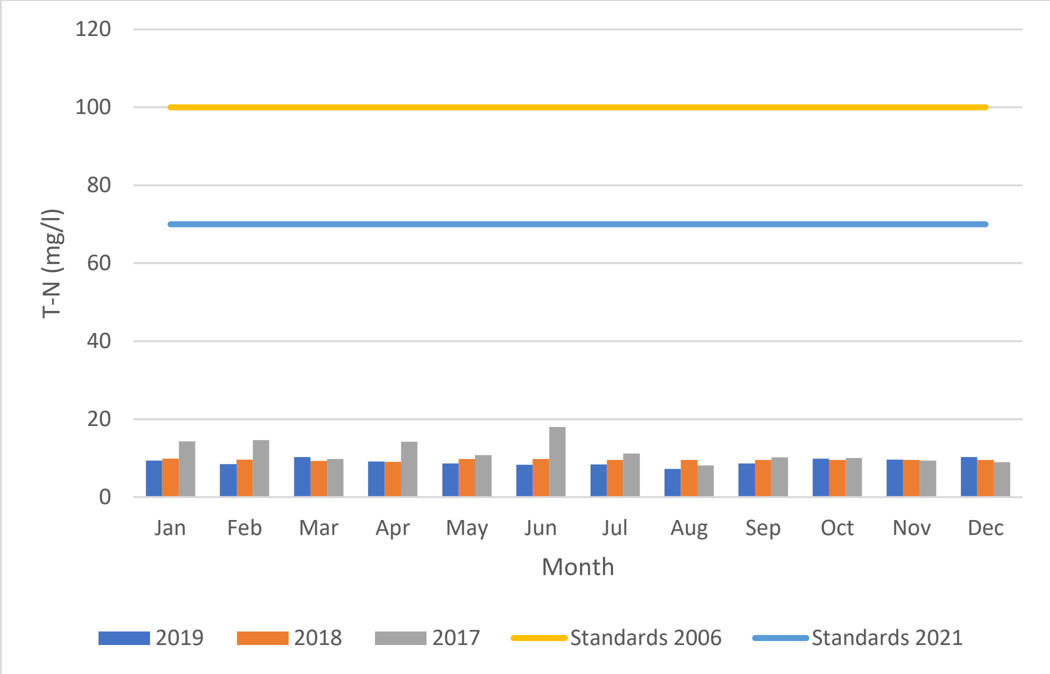

Figure 3. 33 TN values for treated wastewater – Shoubak WWTP

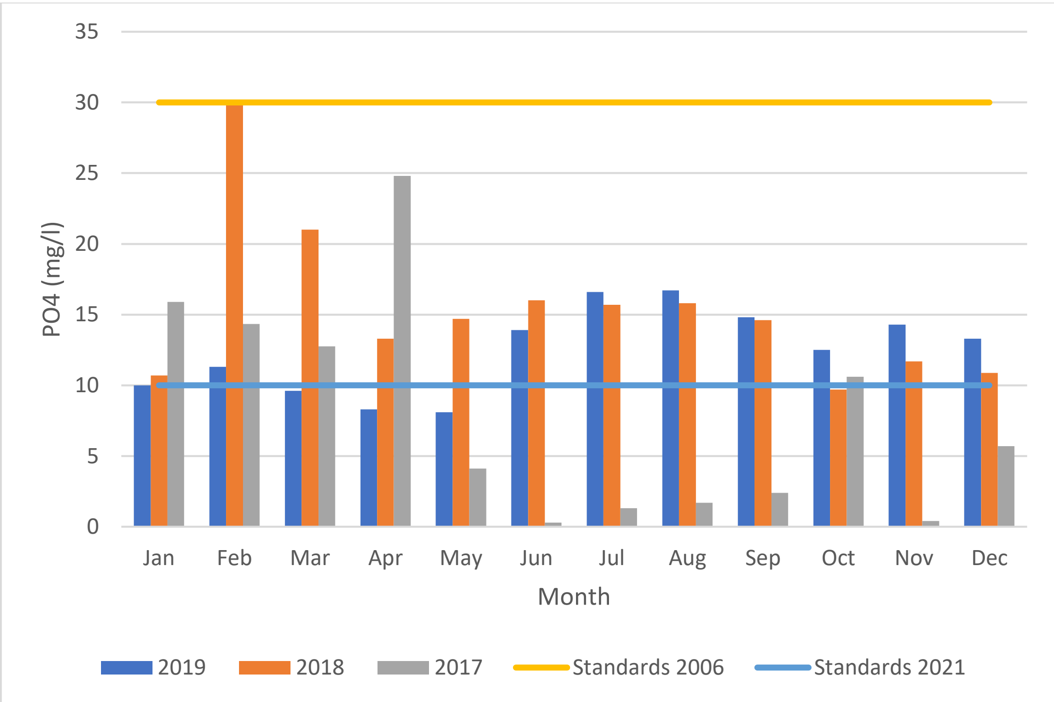

Figure 3. 34 PO4 values for treated wastewater – Shoubak WWTP

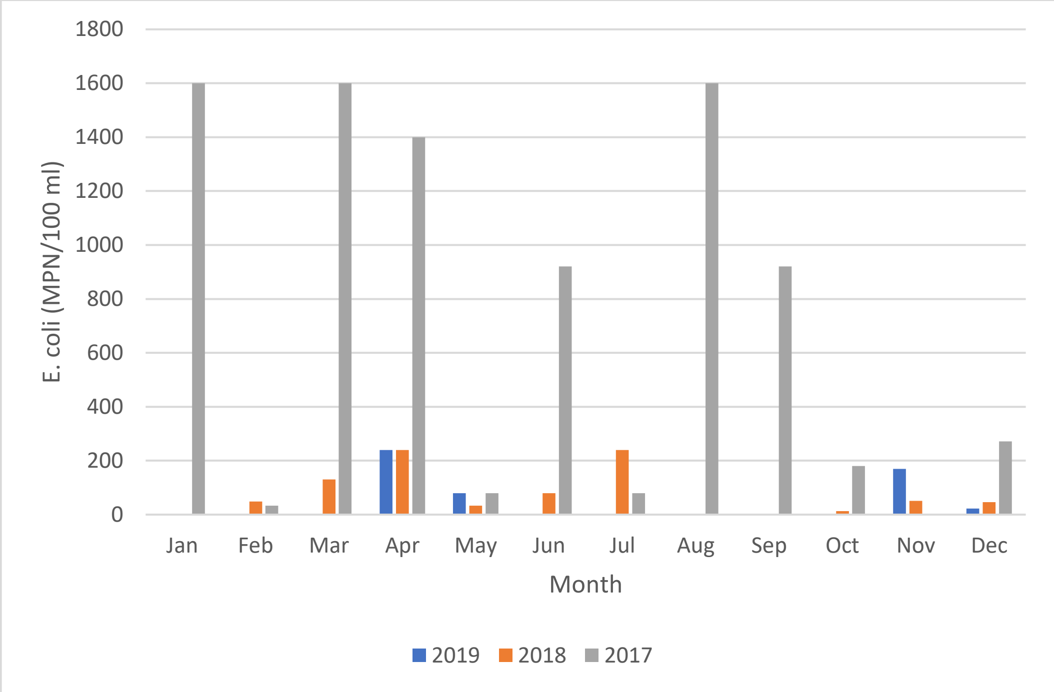

Figure 3. 35 E. coli values for treated wastewater – Shoubak WWTP

As a summary, according to the operators of the visited WWTPs, CWs don't require maintenance except for reeds harvesting which carried out yearly. Another operator mentioned that they have never harvest the reed since more than 6 years, and that has no impacts on the treatment efficiency while in some case an operator mentioned that the harvesting is important to avoid clogging and to guarantee the smooth flow of the wastewater. Operators mentioned that the potential of reusing harvested reeds are limited locally, only few people collect the reeds to implement sunshade in their household or for burning purposes.

All operators mentioned that CWs attract wildlife such as birds, eagle, rat, snakes, and foxes. Some operators have concerns related to snakes which might be dangerous. While other mentioned that different types of birds, local and immigrant birds are living and resting inside the CWs during their journey.

For the effluent quality, all WWTPs target treatment efficiency to the level of (Filed crops, industrial crops) according to JS893/2006. And based on the collected data, all the WWTPs are able to meet BOD, COD and TSS effluent standards JS893/2006 and JS893/2021. While for NO_3^-, TN, and PO_4 limits in JS893/2021, are critical for both Lajoun and Mafraq WWTP, both WWTPs are not able to meet the new standard, therefore several actions should take place in order to enhance the treatment efficiency.

Lajoun and Shoubak WWTP are storing the dried sludge within the WWTP boundaries, while Mafraq WWTP are disposing the sludge to the landfill. No accurate data about the sludge quantities and no future plan for managing the sludge differently. While Table 3.4 below summarize a comparison between the three Jordanian WWTPs, several photos from the three plants are provided in Appendix A.

Table 3. 4 Comparison between Jordanian WWTPs

Aspect	Lajoun	Mafraq	Shoubak
Meeting the treatment standards JS893/2006	Yes	Yes	Yes
Meeting the treatment standards JS893/2021	Yes, except for TN, PO_4, NO_3	Yes, except for TN, PO_4, NO_3	Yes
Resilient to climate change	Able to resist the climate change impacts and maintain the treatment efficiencies	Able to resist the climate change impacts and maintain the treatment efficiencies	Able to resist the climate change impacts and maintain the treatment efficiencies
Reuse/disposal of TWW	Filed crops, industrial crops	Filed crops, industrial crops	Filed crops, industrial crops
Sludge management practices	Dried sludge is stored within the plant boundaries	Landfilled	Dried sludge is stored within the plant boundaries
Harvesting Reeds	No, only local people harvest reeds for their own reuse	Yes, annually	No, only local people harvest reeds for their own reuse
Reuse of harvested reeds	Handcraft, decoration	Disposal to land fill	Burning and handcrafts
Energy source	Gravity	Gravity + Grid	Gravity
Conveying wastewater system	Trucks	Sewer system	Trucks

3.2 Case Study 2: Italy

3.2.1 Water resources in Italy

The Republic of Italy lies in the Mediterranean Sea across with more than 10 degrees of latitude, between the Alps in the north and the Pelagie Islands facing the African shore. The Alpine Chain, which reaches the maximum level of 4,810.90 m above sea at the Mont Blanc, is the natural border that divides the Italian territory from that of France, Switzerland, Austria, and Slovenia, characterizing the European location of the country. Italy covers an area of 302,073 km2 almost completely inserted in the Mediterranean basin except for some small alpine valleys with total area 565 km2 that belong to the Danube catchment with the mouth in the Black Sea (Batini et al. 2000). From north to south, the geographic structure of Italy consists of a large continental area surrounded by the Alps and of a long peninsula leaning into the sea, with some islands, the major of which are Sicily (25,707 km2) and Sardinia (24,090 km2). In 2019, in Italian regional capital cities – where about 16% of the Italian population lived – the total annual precipitation was about 855.4 millimeters (Rossi & Benedini, 2020).

The main water sources in Italy are ground water (wells and springs) (84.4%), surface water (15.1%) and marine and brackish water (0.1%). The three main sectors competing on the water resources are the agricultural sector uses 60% of the overall water demand; the energy and industrial sector uses 25%; the civil sector uses 15%. The 250 daily liters per capita put Italy in first place in Europe and third on a global scale after the United States and Canada. Almost all Italian municipalities had a public water supply in operation (7,937 on 7,954, 99.8%). There were only 17 municipalities without this service in 2018. In these municipalities, the population (around 79 thousand persons) resorted to self-supply, for instance with private wells (Andreani et al., 2008; ISTAT, 2020, 2021; Rossi & Benedini, 2020).

The following points illustrated some details about the water resources in Italy (ISTAT, 2020, 2021)

- Water abstraction from groundwater sources (springs and wells) is prevalent in Italy and reached shares of over 75% in all river basin districts, with the exception of Sardegna, where just a little more than 20% was withdrawn from groundwater sources.
- Water abstracted from artificial basins was equal to 901.3 million cubic meters (9.8% of the total). For the quality of the resource, the potabilization treatment was carried out on almost all the volume; the quota treated with disinfection only was minimal (mainly in the cases of dilution with water of superior quality before the supply in the network).
- Water abstracted from rivers was equal to 441.4 million cubic meters (4.8% of the total); it was mainly treated with potabilization (94.9%), while the remaining 5.1% only with disinfection.
- Water abstracted from natural lakes was equal to 47.7 million cubic meters (0.5% of the total) and underwent potabilization treatment in the 96.6% of cases (except a small percentage treated with disinfection).
- In addition to freshwater abstraction, marine or brackish waters were withdrawn in Sicilia, Toscana and Lazio to compensate water shortages and to supply small islands. This water was made available for use after a process of desalination. The volume amounted to 10.4 million cubic meters (0.1% of the total) and was almost entirely

withdrawn in Sicily. Due to the treatment process, about 40% only of the resource withdrawn remained available for the subsequent supply.

Similar to any water sector the Italian water sector faces several problems such as water shortage and water losses. For the water shortage there is a large variability in water withdrawals at the regional level. They are influenced by the weather climatic conditions and the consequent impacts on the available resource. The geography of well abstractions and withdrawals is changing, in terms of quantity and sources, especially in the areas most affected by drought events (as in 2017). The composition of the volume abstracted by source varied considerably in the period 2015-2018: in many regions more abstractions from wells, to offset the reduction in some springs and artificial basins (ISTAT, 2020, 2021; Rossi & Benedini, 2020).

Among the Italian water sector problem, not all water input into the network is actually supplied to end-users due to the losses. In 2018, comparing 8.2 billion cubic meters input into the network and 4.7 billion supplied for authorized uses, the public water supply network had a percentage of total water losses of 42.0% (41.4% in 2015), which implies that every 100 liters input into the supply system, 42 were not supplied to end-users, confirming the critical state of the water infrastructure. In the end, 3.4 billion cubic meters were lost in distribution: 156 liters per person per day which, estimating a daily consumption per capita of 215 liters (national value), would have guaranteed the water needs of about 44 million people for a whole year (ISTAT, 2020, 2021).

In detail, total water losses are due to a physical component related to corrosion or deterioration of the pipes, breakages in the pipes or faulty joints and inefficiencies and to an apparent component, attributable to unauthorized consumption and measurement errors. A certain level of water losses cannot be avoided from a technical point of view (ISTAT, 2020, 2021).

3.2.2 Sanitation in Italy

In 2018 there were 18,140 WWTPs in operation, most of them were located in the northern part of Italy. 95.7% of Italian municipalities were connected to a WWTP, which partially or totally served the municipal territory. Given the complexity of urban wastewater treatment, most of the plants (86.9%) were managed by 247 water utility companies and the remaining were managed (13.1%) by municipalities or other local authorities (Falletti et al., 2013; ISTAT, 2021).

WWTPs, are essential to reduce pollution of water bodies and ensuring public health and environmental protection, differ in the treatment level and capacity to reduce polluting loads. WWTPs with secondary or advanced treatment, even though 42.9% of the total plants, processed more than 60% of pollutant loads. The remaining 57.1% of plants were primary or Imhoff tanks. Plants with at least secondary treatment were mainly managed by water utility companies (90.4%). The main technology used for centralized treatment plants is activated sludge (ISTAT, 2020, 2021).

Although there are 18,140 urban wastewater treatment plants in Italy, around eighteen million Italian people are still not connected to public urban wastewater treatment plants. And 7.3 million people are still not connected to public sewage treatment system. The percentage of the population served by the public sewerage system, regardless of the availability of subsequent treatment plants, was estimated equal to about 88% in 2018. The service was completely absent in 40 municipalities and, when present, not always it was extended to the entire municipal territory, especially in scattered settlements, mountain areas or zones difficult to reach, or in municipalities where the sewage network was recently put in operation. Where there is no service, urban wastewater is generally treated in autonomous disposal systems, such as private Imhoff tanks. It was estimated that 7,3 million people were still not connected to public sewage system in 2018. In numbers 84.2% of Italian municipalities had a public sewerage service coverage of more than 75% of population in the area, 12.9% between 50% and 75%, 2.3% between 25% and 50%, 0.6% has coverage of less than 25% of residents and the remaining 0.5% did not have a network in operation (ISTAT, 2020, 2021).

The 18,140 WWTPs treated an average pollutant load of 15 million cubic meter annually. 65.5% of the wastewater was treated in plants with advanced (or tertiary) treatment, 29.5% in secondary plants, the remaining 5.0% in primary plants and Imhoff tanks. Pollutant loads include discharges from residents, non-residents, tourists, and productive activities with fewer than five employees.

The estimated proportion of the population connected to urban wastewater treatment plants corresponded to about 70% in 2018, about 42.3 million inhabitants. The remaining share of the population (18 million) was therefore not connected to the public sewage service or lived in municipalities that are partially served by WWTPs or where the service was completely lacking (339 municipalities) (ISTAT, 2020, 2021).

That 339 municipalities, with about 1.6 million inhabitants, without WWTP; it means that urban wastewater was not collected and treated in WWTPs. It was the case of municipalities with a medium/small population size and located in the 72.3% of cases in rural or sparsely populated areas. 66.4% of these municipalities were located in the area of South and Islands. Many plants in these regions were inactive because of lack of maintenance and the needs of renovation or re-construction (ISTAT, 2020, 2021).

Italian WWTPs are being classified based on the served population equivalent (PE). WWTP can be classified to decentralized or centralized based on number of served PE, if the PE is 2000 or less than it can be considered as decentralized while more than 2000 PE is centralized. In Italy, wastewater is treated in 3691 centralized plants across the country before it is discharged, 1762 WWTP use biological treatment with nitrogen and/or phosphorus removal, 1757 WWTP use biological treatment, and 172 WWTP have primary treatment (ISTAT, 2020, 2021).

The generated sludge from the WWTPs was approximately over 387,289 tones produced annually and treated and managed in several ways; 23.9% was reused in agriculture, 31.5% was reused in other uses, 11.4% was landfilled, 12.7% was incinerated, and 20.5% was disposed in another way (ISTAT, 2021).

CWs have been adopted by many Italian communities as a cost-effective mean of secondary and tertiary wastewater treatment, in order to meet more standards and to lower operating costs. Some small systems have now been in existence for nearly 15 years, while wetland treatment systems for larger towns and small cities have become a more recent trend. Since 1999 CWs have been “officially” recognized as a treatment technology. The newest national law concerning wastewater, D.L.152/99 officially recognizes the use of CWs for urban centers with populations in the range of 10-2000 PE discharging into freshwater, in the range of 10-10.000 PE discharging in sea water, and for tourist facilities and other point sources with high rates of fluctuation of organic and/or hydraulic loads. In 1999 the Italian Section of the IWA Specialist Group on the Use of Macrophytes in Water Pollution Control was established. This group is collecting data (process, design criteria, plant utilization, removal efficiency, economic and legislative aspects, etc.) from existing plants operating in Italy in order to develop a reference manual, in collaboration with the main public authorities, for the use of local engineers and administrators in designing and evaluating CWs. The Italian operating CWs can be subdivided into two main categories: surface-flow or subsurface-flow design. Since the 1980's over two hundred CWs, both free water and subsurface (horizontal and vertical) flow systems, have been realized in Italy. Most of the facilities are located in the northern and central part of the country. A high rate of efficiency in the removal of organic content (BOD, COD), Nitrogen (TN, $NH4^+$, $NO3^-$), Suspended Solids (TSS) and Pathogens (EC, TC) was observed, both in secondary and tertiary treatment plants, despite a general lack of monitoring data. Designs are often adapted to take account of different site characteristics, treatment goals and secondary benefits such as the reuse of the treated wastewater or the provision of wildlife habitat. Surface-flow wetlands are increasingly being favored as tertiary treatment, because of their cheaper investment costs and their higher wildlife habitat values. Subsurface-flow wetlands, however, tend to be more widely applied, due to their effectiveness at filtering out solids and removing BOD per unit land area. Therefore, the use of septic tanks and secondary treatment subsurface CWs for small populations is set to increase sharply in Italy. There are some interesting applications also concerning urban environments. Because the wastewater remains below the surface in these systems there is less possibility for human or wildlife contact with wastewaters and less potential for insect infestation. The use of hybrid designs incorporating both surface and subsurface-flow sections is now becoming more common, as well as the powerful combination of vertical and horizontal subsurface flow systems. In general, the Italian subsurface flow wetlands seem to obtain better results, probably due to the more constant and warmer climatic conditions, in comparison to most of the other European experiences (Masi, 2000).

As a summary, in Italy thousands of CWs were implemented with different applications, it started as a treatment technology to treat wastewater for decentralized communities, and nowadays CWs are being used to treat industrial wastewater, winery wastewater, combined sewer overflow (CSO) applications, raw wastewater for communities more than 2000 PE, and many other applications at different levels.

Guidelines and discharge Standards

The study of Italian legislation aims to investigate what are the discharging limits and controlling standards in the field of wastewater treatment and the possible reuse of treated wastewater permitted by law. The issuance of national decrees is based on the transposition of European directives. Furthermore, the national decrees can then be further modified at regional level.

At the European level the reference legislation on wastewater treatment is Directive 91/271 / EEC (Urban Wastewater Treatment Directive, UWWTD) which concerns the collection, treatment and discharge of urban wastewater and wastewater generating from certain industrial sectors, in order to protect the environment from the possible damage and risk. The directive essentially requires the implementation of wastewater treatment and/or collection systems for all community clusters, depending on the location, the degree of environmental risk and the capacity of the plant expressed in PE. With respect to the type of discharging areas, Directive 91/271/EC provides for the description of sensitive and less sensitive areas. Sensitive areas are defined as: "natural lakes, estuaries and coastal waters already eutrophicated or exposed to the risk of eutrophication in the absence of specific protective interventions, surface fresh water intended for the production of drinking water and all areas where a complementary treatment with respect to the secondary in order to comply with the requirements of other directives (e.g., water suitable for bathing, fish life and shellfish farming) ". As regards the environmental risk, the choice of the so-called sensitive areas and less sensitive areas has been delegated to the individual member states (di Maria et al., 2018; European Commission, 2018).

The second EU standard is Directive 2000/60/EEC (Water Framework Directive - WFD) which represents one of the most important tools for the governance and management of continental waters. It is inspired by concepts such as prevention and precaution, supported by the “polluter pays” principle; Integrated management at the river basin level is the basis of this legislation which seeks to go beyond administrative boundaries in favor of a multidisciplinary and attentive to the biological and environmental aspects of water bodies”. The goal is the protection, improvement and restoration of the state of the water bodies identified in the catchment areas by the time limit of 2015: the "good state" is to be considered in both biological and chemical-physical terms (European Commission, 2018).

At Italian level, the European Directive 91/271 / EEC has been adapted to the national level and the Legislative Decree 152/1999 known as the “Consolidated environmental law” was created, in 2006 Decree 152/1999 was updated and replaced by Decree 152/2006. The legislation identifies, first of all, the areas that require particular measures to prevent pollution or environmental remediation: sensitive areas, areas vulnerable to nitrates of agricultural origin, areas vulnerable to plant protection products, areas vulnerable to desertification, and the areas of protection. The regulations on discharges also provide that (D. Lgs, 1999; D.Lgs., 2006):

- Communities with over 2,000 PE must be equipped with wastewater networks.

- All disposals must be authorized in advance according to the quality of the final water bodies and, therefore, in compliance with the limit values mentioned in Table 3.5, Table 3.6 and Table 3.7.
- Any region can define limit values different from those reported in the legislation for both in maximum permissible concentration and in maximum quantity per unit of time.
- All drains, except domestic and similar ones, must be made accessible for sampling by the competent authorities
- Disposal on the ground or in the surface layers of the subsoil is prohibited, with appropriate exceptions subjected to the issue of a specific authorization and after appropriate technical investigations
- Direct discharge into groundwater and subsoil is forbidden, except for express exceptions.

The same rule suggests as "desirable" for communities with PE of less than 2000. The national standard (Legislative Decree 152/2006) specified three guiding criteria for identifying the desirable treatments for communities with less than 2000 PE:

- The simplicity of maintenance and management of the plants.
- The ability to adequately withstand strong hourly variations in hydraulic and organic load
- The minimization of management costs.

Appropriate treatments must therefore guarantee acceptable performance levels, guaranteeing both quality standards and health protection, they are divided into primary and secondary depending on the technical solution adopted and the level of treatment.

The Legislative Decree 152/06 establishes that all disposals are governed according to the quality objectives of water bodies and must comply with the limit values mentioned in the Table 3.5, Table 3.6 and Table 3.7 (D.Lgs., 2006). Appropriate treatment is required for wastewater generated from communities with less than 2000 PE, national legislation identifies primary treatment can be assessed through an acceptable estimate of the reduction of the pollutant load (Falletti et al., 2013; ISTAT, 2020, 2021; Masi, 2000).

Table 3. 5 Discharge limits for urban wastewater to surface water bodies– Italy. Adopted from D. GLs 2006

Population equivalent	2000-10.000	>10.000
Parameters:	Concentration (% removal)	Concentration (% removal)
BOD (mg\l)	25 (70-90%)	25 (80%)
COD (mg\l)	125 (75%)	125 (75%)
SS (mg\l)	35 (70%)	35 (90%)

Table 3. 6 Discharge limits for urban wastewater plants sensitive areas – Italy. Adopted from D. GLs 2006*

Population equivalent	10.000-100.000	>100.000
Parameters:	Concentration (% removal)	Concentration (% removal)
TP (mg\l)	2 (80%)	1 (80%)
TN (mg\l)	15 (70-80%)	10 (70-80%)

* Sensitive areas are a) natural lakes, other fresh waters, estuaries and coastal waters already eutrophic, or probably exposed to eutrophication, in the absence of specific protective measures, b) surface freshwater intended for the production of drinking water, c) areas which require, for the related discharges, additional treatment to the secondary treatment in order to comply with the requirements set out in this standard (D.Lgs., 2006).

Table 3. 7 Discharge limit values of wastewater in surface waters and sewers – Italy. Adopted from D. GLs 2006

Substances	Discharge into surface waters	Discharge into public sewer (*)
pH	5.5 - 9.5	5.5 - 9.5
Temperature (C°)	1	1
color	not perceptible with a 1:20 dilution	not perceptible with a 1:40 dilution
smell	must not be a cause of harassment	must not be a cause of harassment
coarse materials	absent	absent
TSS (mg/l)	80	200
BOD_5 (mg/l)	40	250
COD (mg/l)	160	500
Aluminum mg/l	1	2
Arsenic (mg\l)	0.5	0.5
Barium (mg\l)	20	-
Boron (mg\l)	2	4
Cadmium (mg\l)	0.02	0.02
Total chromium (mg\l)	2	4
Chromium VI (mg\l)	0.2	0.2
Iron (mg\l)	2	4
Manganese (mg\l)	2	4
Mercury (mg\l)	0.005	0.005

Nickel (mg\l)	2	4
Lead (mg\l)	0.2	0.3
Copper (mg\l)	0.1	0.4
Selenium (mg\l)	0.03	0.03
Pond (mg\l)	10	
Zinc (mg\l)	0.5	1
Total cyanides (as CN) (mg\l)	0.5	1
Free active chlorine (mg\l)	0.2	0.3
Sulfides (mg\l)	1	2
Sulfites (mg\l)	1	2
Sulfates (mg\l)	1000	1000
Chlorides (mg\l)	1200	1200
Fluorides (mg\l)	6	12
TP (mg\l)	10	10
NH_4 (mg\l)	15	30
Nitrous nitrogen (as N) (mg\l)	0.6	0.6
Nitric nitrogen (as N) (mg\l)	20	30
Animal/vegetable fats and oils (mg\l)	20	40
Total hydrocarbons (mg\l)	5	10
Phenols (mg\l)	0.5	1
Aldehydes (mg\l)	1	2
Aromatic organic solvents (mg\l)	0.2	0.4
Organic nitrogen solvents (mg\l)	0.1	0.2
total surfactants (mg\l)	2	4
Phosphorus pesticides (mg\l)	0.1	
Total pesticides (excluding phosphorates) (mg\l)	0.05	0.05
including:		
- aldrin (mg\l)	0.01	0.01
- dieldrin (mg\l)	0.01	0.01
- endrin (mg\l)	0.002	0.002
- isodrin (mg\l)	0.002	0.002
Chlorinated solvents (mg\l)	1	1
E. coli (CFU/100ml)	Note	
Acute toxicity test	the sample is not acceptable when after 24 hours the number of immobile organisms is equal to or greater than 50% of the total	the sample is not acceptable when after 24 hours the number of immobile organisms is equal to or greater than 80% of the total

For the wastewater reuse the Italian prepared a legislation law 185 of 2003 that regulating and describing technical standards for the reuse of wastewater". Italy currently reuses about 9% of its wastewater based on quality of water discharged by WWTPs, while the potential is estimated to be 60% (di Maria et al., 2018; D.Lgs., 2006)

Principles and purposes:

Reuse must take place in conditions of environmental safety, avoiding alterations to ecosystems, soil, and crops, as well as health and hygiene risks for the population and in any case in compliance with current health and safety provisions and the rules of good industrial practice and agricultural. The regulation does not regulate the reuse of wastewater in the same plant or industrial consortium that produced it (D.M, 2003).

Intended use:

The allowable reuses for the recovered wastewater are the following:

- Irrigation: for the irrigation of crops intended both for the production of food for human and animal consumption and for non-food purposes, as well as for the irrigation of green areas or for recreational or sporting activities.
- Civil: for washing streets in urban centers; for powering heating or cooling systems; for the supply of dual supply networks, separate from those of drinking water, with the exclusion of the direct use of this water in buildings for civil use, with the exception of drainage systems in toilets.
- Industrial: as firefighting, process, washing and for the thermal cycles of industrial processes, with the exclusion of uses that involve contact between the recovered wastewater and food or pharmaceutical and cosmetic products.

The recovered wastewater intended for irrigation or civil reuse must be collected, at the exit of the recovery plant, chemical-physical and microbiological quality requirements at least equal to those indicated in the legislation.

Methods of reuse:

1. Irrigation reuse is in any case subject to compliance with the code of good agricultural practice referred to in the decree of the Minister for agricultural and forestry policies of 19 April 1999, n. 86 and published in July 2003 with number 185 as summarized in Table 3.8 below (D.M, 2003).

2. In the case of multiple reuses, e.g., for different uses such as irrigation, civil and industrial uses, or with multiple users, the owner of the distribution of the recovered wastewater ensures the correct information of users on the methods of use, on the constraints to be respected and on the risks associated with improper reuse.

Table 3. 8 Reuse treated wastewater standards – Italy. Adopted from D. M 2003

Parameter	Units	Reuse (max)
pH		6-9.5
SAR		10
Coarse material		Absent
TSS	mg/l	10
BOD_5	mg/l	20
COD	mg/l	100
TP	mg/l	2
NH_4	mg NH4/l	2
TN	mg/l	15
Electrical conductivity	iS/cm	3000
Aluminum	mg/l	1
Arsenic	mg/l	0.02
Barium	mg/l	10
Beryllium	mg/L	0,1
Boron	mg/L	1,0
Cadmium	mg/L	0,005
Cobalt	mg/L	0,05
Total Chrome	mg/L	0,1
Chrome VI	mg/L	0,005
Iron	mg/L	2
Manganese	mg/L	0,2
Mercury	mg/L	0,001
Nickel	mg/L	0,2
Lead	mg/L	0,1
Copper	mg/L	1
Selenium	mg/L	0,01
Pond	mg/L	3
Thallium	mg/L	0,001
Vanadium	mg/L	0,1
Zinc	mg/L	0,5
Total cyanides as (CN)	mg/L	0,05
Sulphides	mg H2S/L	0,5
Sulfites	mg SO3/L	0,5
Sulfates	mgSO4/L	500
Active Chlorine	mg/l	0,2
chlorides	mg Cl/l	250
fluorides	mg F/l	1,5
Fat and oil (vegetables and animals)	mg/l	10
Mineral Oil	mg/l	0,05
Total Phenols	mg/L	0,1
Pentachlorophenol	mg/L	0,003
Total Aldehydes	mg/L	0,5
Tetrachlorethylene, trichlorethylene (sum of the concentrations of the specific parameters)	mg/l	0.01
Total chlorinated solvents	mg/L	0,04

Parameter	Units	Reuse (max)
Trihalomethanes (sum of concentrations)	mg/L	0,03
Total aromatic organic solvents	mg/L	0,01
Benzene	mg/L	0,001
Benzo(a) pirene	mg/L	0,00001
Total nitrogenous organic solvents	mg/L	0,01
total Surfactants	mg/L	0,5
Chlorinated Pesticides (each)	mg/L	0,0001
Phosphorus Pesticides (each)	mg/L	0,0001
Other total pesticides	mg/L	0,05
E. coli	UFC/100ml	100
Salmonella		Absent

3.2.3 Application of CWs - NBS in Italy

To understand the sustainability of CWs- NBS as a sanitation system and to analyses the application of CWs in Italy, it is important to start with understanding the current applications of this system in the country, site visits have been conducted in order to meet the operators, collect data and understand the challenges and obstacles in operation similar systems. In Italy the main used treatment technology is activated sludge and Imhoff tanks but a growing application of CWs as a treatment technology as mentioned earlier, Table 3.9 below indicates a summary of some applications of CWs in the Italian context, the table summarizes the type of wastewater, population equivalent served by each plant, type of CW, and other information about the removal efficiencies for some parameters, which reflect their treatment performance but not if they meet the reuse standards since this information weren't provided or analyzed.

A site visit to Carimate WWTP has been conducted in order to understand the operational procedure, collecting data, and meeting the operator. The following sections summarize the main output of these visit.

Table 3. 9 Summary of some CWs applications in Italy

CWs AS SECONDARY TREATMENT	Type of wastewater	PE	Flow CW	Output(mg\l) or efficiency					Area CW (m^2)
				BOD	COD	N-NH4	TN	TP	
Dicomano plant (Florence)	Domestic	3,500	2 lines HF - VF	90%	85%	20	25	<1	6,080
Celle sul Rigo plant (Siena)	Domestic from mixed sewers	620	2 lines HF - HF	95%	85%				2,100
Castel del Piano plant (Grosseto)	Domestic from mixed sewers	400	2 lines HF - HF	85%	80%				
Borgo di Tragliata plant (Rome)	Domestic	296	HF	80%	80%	3,3-23,5		0.25	1,400
Verano plant (Bolzano)	Domestic	1000	3 VF - 2 VF - collection tank	97%	96%	<1			4,100
Favogna plant (Bolzano)	Domestic	280	3 VF + accumulati on tank	98.00%	97%	100%	84%	99%	810
Montecarotto plant (Ancona)	Domestic	900	HF - VF - HF	78%	55%			42%	3,464
Vizzola Ticino plant (Varese)	Domestic and surface run-off water	800	HF - VF - FWS	80%	67%	47%		31%	3,235
S.Leo Bastia plant (Perugia)	Domestic	450	VF	90%	85%	92%	70%	30%	288
plant of the farm of Baggiolino (Florence)	Domestic not served by sewerage	30	HF	91%	85%	60%	(25,3) 65%	(1,8) 68%	109
Dozza Imolese plant (Bologna)	Domestic and crafts	120	2 HF		66%	62.00%			360
plant of Hotel Relais Certosa (Florence)	Domestic	140	HF - VF	96%			10,5 (82%)	0,1 (98%)	340
planted in Narni-Vigne (Terni)	Domestic	450	2 HF	85%	85%	37%			1,780
impaitno of Narni-Gualdo (Tenri)	Domestic	225	2 HF		85%	65%			909
Moscheta plant (Florence)	farm wastewater	200	2 HF		95%	85%	78%	55%	376
Carisolo plant (Trento)	domestic	66	HF - FWS		86%	0.04	0.93	0.05	441
Guignola plant (Florence)	domestic	150	2 HF						
Faieto di Casina plant	milking parlor waters all. bovine + civil code business	38	3 HF	93.60%	92.40%	23.3	30.5	5	150
Codemondo plant	agricultural and domestic	30	VF	97%	97%	20		3	112
Lugo di Baiso plant	Domestic from mixed sewers	100	3 HF	80-90%	76%	42.49		2.35	
Hybrid plant of Tabiano	Domestic from mixed sewers	100	HF - VF	98%	89%	7		0.91	

Bobbio's filter ecosystem		6000	3 FWS in series						
HIGH ALTITUDE PLANTS									
plant of the Abetina Reale refuge			VF - VF		90%	<1			
Cevo plant of Casa del Parco		50	2 HF	90%	90%	0,22 (90%)		1.92	144
plant of the Tonolini Refuge		20	HF	65%	65%	54%		3.27	60
plant of the Occhi Sandro all'Aviolo refuge		30	HF	63-83%	63-83%			(40-60)%	
Malonno plant (Landò)		100	HF	90%					
Cedegolo plant (secondary and tertiary)		20	HF - FWS						
CWs FOR TERTIARY TREATMENTS									
Monticolo plant (Bolzano)	domestic and artisanal \ industrial	1,250	VF	<10	<40	<1	<55	<2	1500
S. Michele Ganzaria plant (Catania)	domestic and agricultural / livestock farms	1,100	2 HF	<10 (58%)	<15 (60%)		<10	<2	4,000
Jesi plant	domestic from mixed sewers	60,000	8 HF - 2 FWS		45%		45%		
plant S. Antonio Ticino		300,000							
Cossato plant		520,000	HF	90%	90%	100%	6,5 - 5,5	1.1	
plant of S. Giovanni in Persiceto	domestic and run-off water	30,000	HF – FWS						
CSO									
Gorla Maggiore plant		2,500	VF - FWS						7,014
Merone plant		120,000	VF – FWS	70-90%	87%	93%			5,500
plant of Villa Guardia via Firenze		5,158	VF – FWS						2,700
Capiago plant		450	VF – FWS						650

3.2.3.1 Carimate Wastewater treatment plants - Case study, the current situation, and challenges.

Existing treatment process

A site visit has been conducted to Carimate WWTP, the WWTP is located in Carimate, in the province of Como in the northern part of Italy (45°41'22.8"N 9°07'17.6"E) as shown in Figure 3.36 below, and managed by “Sud Seveso Servizi SpA”, which refers to the assembly of the eleven member municipalities. The WWTP has been the subject of a feasibility study on "applying Nature based solution NBS for treating wastewater" (by the Po basin authority) that led to the implementation of CWs in 2018 for the treatment the combined sewer overflow CSO.

Figure 3. 36 Satellite image of Carimate WWTP 45°41'22.8"N 9°07'17.6"E

Carimate WWTP is treating wastewater which generated from eleven municipalities, collected by municipal sewer network, and conveyed to the plant through collectors piping systems. The sewer network of intercommunal collectors that belong to the plant is essentially made up of three 3 main systems; the plant converges two separate sewage collectors, called respectively "low" (coming from the north) and "high" (coming from the east), Table 3.10 below summarize the main information about Carimate WWTP. The basin where the plant located is large basin and is consisting of many sub-basins each regulated by a flood overflow, there are over sixty sub-basins in the territory.

Table 3. 10 Details of Carimate WWTP

PE	100.000 PE
Types of wastewater treated	Domestic (70%), industrial (textile and electroplating galvanico) 30%)
municiplaities served	11
wastewater flow IN (CONVENTIONAL TRATMENT)	2000 m^3/h
Water flow IN (CW)	1300 m^3/h
Conveying system	Trucks + Sewer lines

Before the implementation of CWs, the WWTP during rainy weather ensured a complete treatment up to 2000 m^3/h, and a partial treatment with preliminary and primary treatments of a remaining 700 m^3/h. In order to respect the discharge and disposal standards, this operation ensured overall compliance with the final limits to the discharge, except in case of having overflow, heavy rain and first flush events, or during the first flush events that follow dry time periods. It was therefore necessary to upgrade the existing plant in such a way as to ensure the complete treatment during these events, in order to eliminate the risk of overflow. For this reason, it was decided to use NBS by implementing CWs. Having CWs have allowed the treatment plant to deal with beforementioned events of overflow, although at the level of discharge limits from the primary sedimentation treatment can be considered sufficient, it is still important to treat and remove of organic and nitrogen load from the final discharge, in order to reduce the overall impact on the quality of the final disposal in Seveso River, especially when the river has the low flows. Therefore, in Carimate WWTP the need to implement a new plant came from the need to increase the treatment capacity and the retention of rainwater.

Among the possible treatment technologies to achieve this objective, CWs have also been chosen to solve the problem of the numerous complaints - mainly related to odor - by citizens living near the plant. CWs system, therefore, is now able to accumulate large volumes of water in a short time, and return them more slowly to the Seveso River in order to ensure sufficient hydraulic retention times to achieve the required treatment level, the secondary effect of this operating strategy is to store contaminated rain water, particularly on the first flush of events of overflow that may occur with the flood wave in the Seveso River: the pumping system in fact allows to transfer to CWs beds a flow up to 1300 m^3/h for a maximum of about 7 h (for a total of 9,000 m^3), flow rate that is then released with a maximum of about 500 m^3/h, with a stored volume up to about 6500 m^3. Finally, during periods of dry weather, the free flow system, to encourage the maintenance and development of a high-quality humid environment, is fed with a share of the treated wastewater, in order to maintain on the one hand, the optimal ecological conditions for the development of vegetation, on the other hand allowing a further refinement of share of the water discharged by the WWTP in dry time.

Implementation of CWs in Carimate wastewater treatment plant has not only solved the problem of receiving sewage greater than those mentioned by the regional law, CWs also increased the ecological and naturalistic values and restoring biodiversity. In addition, the area that occupied by the constructed wetland system is fully usable for multi-purpose acclivities.

<u>Treatment process in Carimate WWTP</u>

Conventional treatment process:

The wastewater influent delivered through the two main collector pipes, is pre-treated through coarse and fine screening systems, after the coarse and fine screening steps the wastewater pass through grit removal chamber and grease trap in order to remove the sand and the grease from the wastewater, then the wastewater enters the primary sedimentation tank for the removal of suspended solids (SS), here the wastewater is rotated to promote the growth of bacteria and so that the SS precipitate and accumulate at the bottom of the primary sedimentation tank and will be disposed to another treatment line. Then the wastewater flows to the biological treatment step with activated sludge for the removal of pollutants. Followed by the pre-denitrification in which carbon is added, which is necessary for the growth of the bacteria (usually the sludge works as source of carbon but having been removed from the primary sedimentation, so it is necessary to add it). The next step is the nitrification and oxidation using aerated mixture to provide oxygen. Finally, the secondary sedimentation tanks with recirculation of the accumulated sludge to the primary sedimentation tanks.

The system ends with a filtration phase using sand filters and then disinfection of the effluent by dosing sodium hypochlorite NaClO. At the end of the whole process, the treated water by this conventional system is mixed with the water treated by CWs and discharged into the Seveso stream noting that for discharge in Seveso there is currently no obligation of disinfection and microbiological parameters are not subjected to control.

The biological treatment line can receive 1800 m^3/h during the winter and up to 2600 m^3/h during the summer, the biological treatment line is more than sufficient to ensure the treatment of the wastewater during dry time periods. However, during rainy periods, the incoming flow is much greater the WWTP capacity and part of it must be transferred to the constructed wetlands system.

CWs in Carimate WWTP

The CWs system is illustrated in Figure 3.37, and it consists of:

- Vertical submerged flow system VF with total surface area of 8,500 m^2, divided into two pools and four beds with total area of 2,215 m^2.
- Free water surface system FW of total area of 4,500 m^2.

Figure 3. 37 CWs in Carimat WWTP

The effluent of the primary settling tank is sent through a separator chamber to the CWs stage using lifting station equipped with four submersible electrical pumps operating in parallel that guarantee a maximum hourly flow of 1,300 m^3. The four vertical submerged flow beds are fed through four separated pressure pipes. In case of overflow events and if the wastewater exceeds the capacity of receiving CWs, the direct drain to Seveso River is activated. The water treated by the four VFCWs are combined with the next FWS CWs, from which the treated water is returned and mixed with the treated wastewater from the biological treatment step and discharged.

In the dry summer period where the conventional treatment plant is able to receive all the wastewater, two connections points after the secondary sediment are provided to feed both the VFCWs and the FWS CWs, in order to maintain the optimal ecological conditions for the development of vegetation, and for further refinement of treated water discharged by the biological process line in dry time. Figure 3.38 below summarize the treatment process within Carimate WWTP.

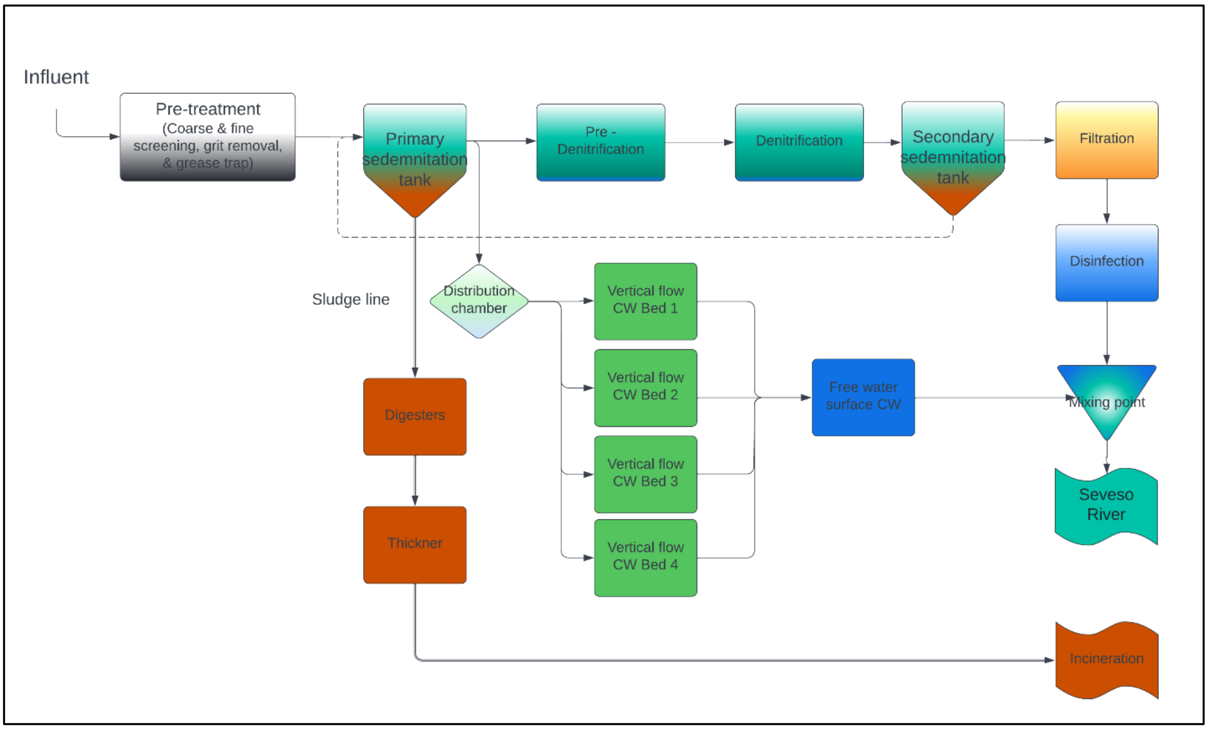

Figure 3. 38 Treatment process - Carimate WWTP

Current sludge management practices

The accumulated sludge from the secondary sedimentation tank is fed into the primary sedimentation tank, the final accumulated sludge from the primary sedimentation tank is collected and transferred to the sludge treatment line. The sludge treatment process is divided into several phases, the first is that of pre-thickening by gravity followed by dynamic thickening, the process then by of anaerobic digestion (bi-mesophilic digestion (35 C°) and thermophilic digestion (55 C°), the generated biogas is used for thermal use and heating within the treatment plants. Then the sludge is transferring to a post-thickening process by gravity and the final material is transferred to the incinerator in Brescia.

Quality and quantity

Quality data has been collected and analyzed from the WWTP operators, parameters such as COD, pH, TN, NH_4, NO_3, TP, Turbidity and other parameters are summarized and shown in Figures 3.39 to 3.43 below. Data has been collected before and after the CWs for 2019 and 2020 while during 2021 the testing frequency has been affected with the pandemic, it is worth to mention that the monitoring systems covers only the winter season when the WWTP receives overflow sewers, while in the dry season the CWs are receiving already treated wastewater as described above, therefore, quality data is available for some specific months only.

The data shows that the CWs were able to treat the wastewater with high efficiency and meet the discharge limits most of the time for TP and COD while CWs didn't meet the standards for TN in March, April, and May and that mainly in case of first flush events after dry periods. Table 3.11 below summaries the treated parameters and the treating efficiency for each parameter.

Table 3. 11 Treatment efficiency for wastewater parameters – Carimate WWTP

Parameter	Treatment efficiency
TP	70%
TN	50%
N – NH4	40%
N – NO3	46%
COD	84%
TC	47%
Cu	95%
Fe	98%
Ni	86%
Se	75%
Zn	97%
As	79%
B	38%
Al	97%
Mn	68%
S	29%
Si	20%

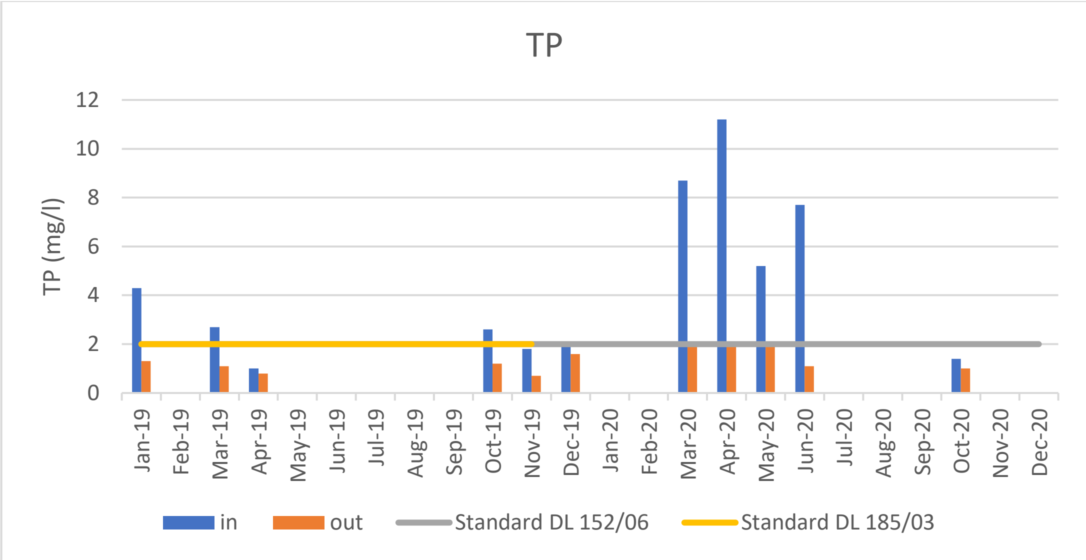

Figure 3. 39 TP values for treated wastewater – Carimate WWTP

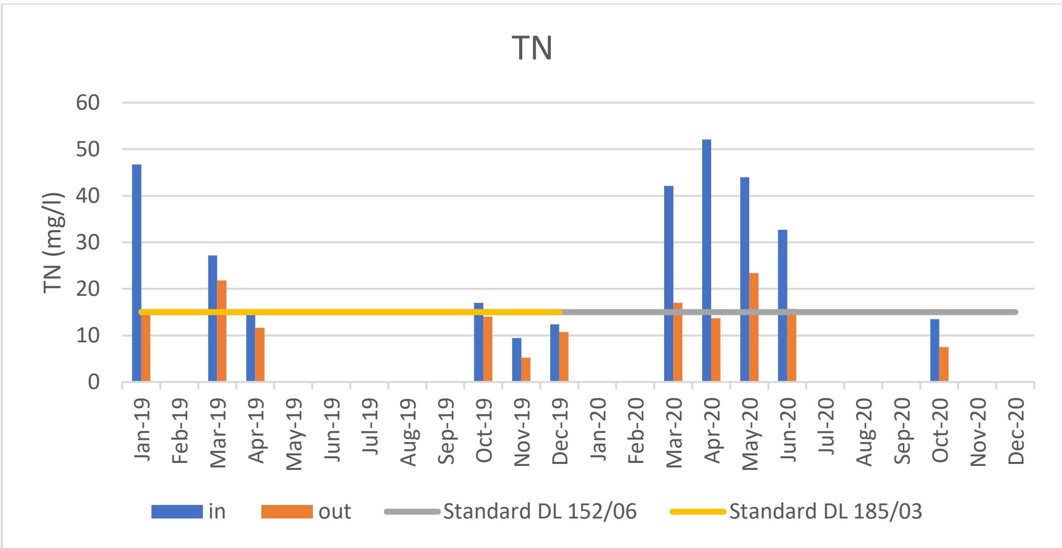

Figure 3. 40 TN values for treated wastewater – Carimate WWTP

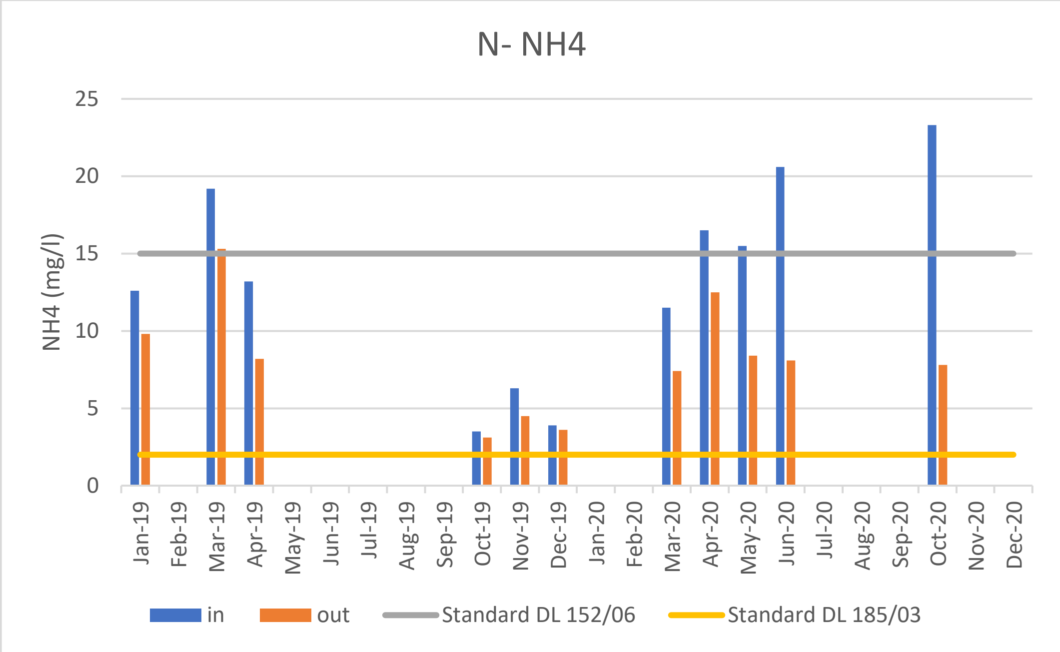

Figure 3. 41 N-NH4 values for treated wastewater – Carimate WWTP

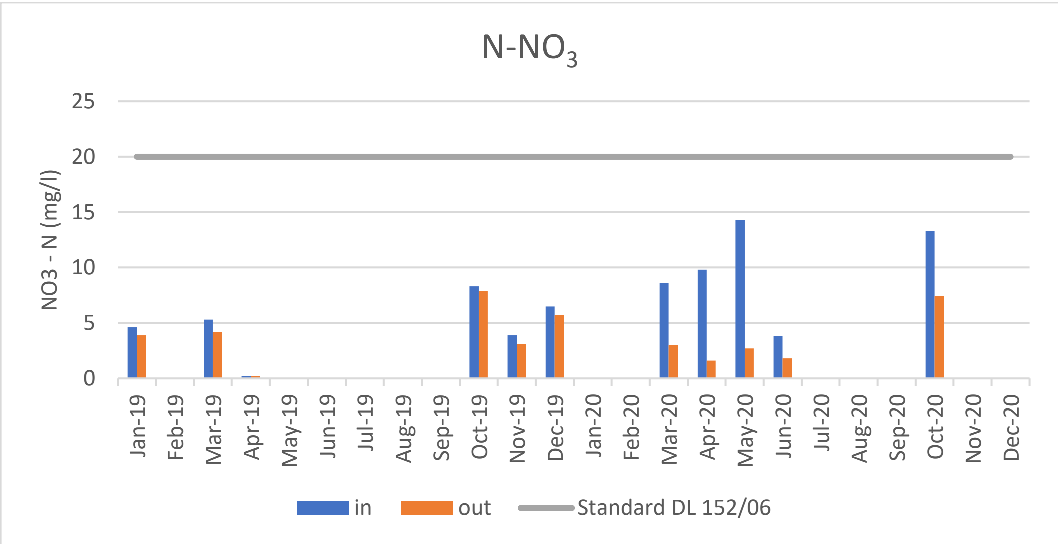

Figure 3. 42 N-NO3 values for treated wastewater – Carimate WWTP

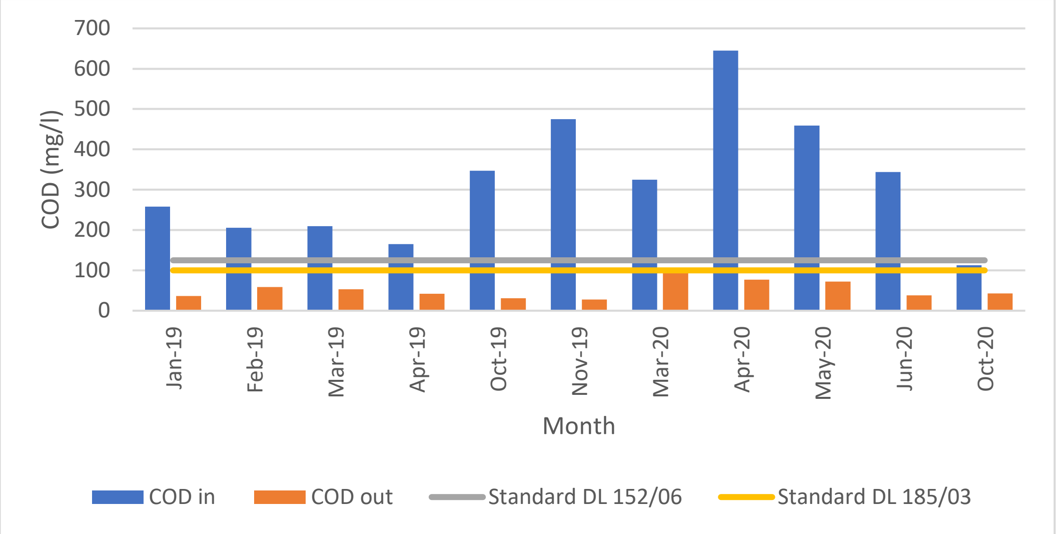

Figure 3. 43 COD values for treated wastewater – Carimate WWTP

Current practices and challenges

To understand the challenges, advantages, and disadvantages of implementing and operating CWs and during the site visit to Carimate WWTP a semi – structured interview was conducted with the manager of Carimate WWTP.

The manager has illustrated that using CWs we selected and funded by the province of Como in order to solve the problem of overflow of the combined sewer during the rainy seasons, and they have selected this system specifically due to the co-benefits of using NBS and CWs; Province of Como had received several complaints from people about the odor and general complains about having WWTP close to the residential area, and in order to have a solution for the CSO and the complaints the province decided to implement CWs. The new CWs has upgraded the WWTP capacity during winter seasons and has solved the problem of CSO, nonetheless having CWs has provide several benefits such as providing a green area and aesthetic places where people can enjoy, restoring biodiversity including frogs which help in consuming insect naturally. It is worth to mention that after implementing CWs, the complains has been stopped and the odor problem has been solved, and people usually come to enjoy the green area, play sports and having a BBQ in the summer and other social activities like school visits as described in Figure 3.44.

Figure 3. 44 Students visit to Carimate WWTP - Carimate WWTP

The manager also mentioned the technical issues they faced during implementing the CWs were minors, one of them was to import the used phragmites from Germany, and during the first phase of operation the treatment efficiency hadn't been achieved but fortunately this problem wasn't a challenge in Carminate WWTP. From operation point of view a frequent harvesting of the planted phragmites every March before the spring, the harvesting step is very important for many reasons; i) to avoid the clogging of the filtration beds, ii) to maintain the treatment efficiency, and iii) to maintain the green area and the aesthetic scenes. Around 5000 kg/year of harvested phragmites disposed and reused in composting. The new implantation of CWs didn't require of hiring new staff with certain skills, and that illustrated the easiness of operating CWs. The current system is completely operated by gravity without energy requirements.

The manager has ended the interview by summarizing that CWs, can be applied in similar conditions to treat CSO, or as a decentralized solutions for scattered and rural communities, or when you have complaints from the local people about wastewater treatment plants, while as a main treatment technology he has his concerns regarding the required land and the possibility of meeting the discharge and disposal limits.

3.3 Summary and conclusion

This chapter summarizes detailed description of the water and sanitation sector in the two selected case studies, the chapter also covers detailed analysis some of the current application of CWs – NBS in the case studies and provides comparisons between the cases. Several literatures reviews and desk research have been carried out, and a series of site visits have been conducted to meet the operators and collect the required data. In Jordan, among the 33 WWTPs in Jordan, 6 WWTPs use NBS - series of stabilization ponds – CWs. CWs are mainly used for tertiary treatment and the used type is subsurface horizontal flow CWs. Three WWTPs have been visited, quality and quantity data have been collected and analyzed. For the effluent quality, all WWTPs target treatment efficiency to the level of (Filed crops, industrial crops) according to JS893/2006. And based on the collected data, all the WWTPs are able to meet BOD, COD and TSS effluent standards JS893/2006 and JS893/2021. While for NO_3^-, TN, and PO_4 limits in JS893/2021, are critical for both Lajoun and Mafraq WWTP, both WWTPs are not able to meet the new standard, therefore several actions should take place in order to enhance the treatment efficiency. All the treatment plants showed stable performance and resilient to climate change though analyzing their performance the previous years.

Lajoun and Shoubak WWTP are storing the dried sludge within the WWTP boundaries, while Mafraq WWTP are disposing the sludge to the landfill. No accurate data about the sludge quantities and no future plan for managing the sludge differently. According to the operators of the visited WWTPs, CWs don't require maintenance except for reeds harvesting which carried out yearly. Another operator mentioned that they have never harvest the reed since more than 6 years, and that has no impacts on the treatment efficiency while in some case an operator mentioned that the harvesting is important to avoid clogging and to guarantee the smooth flow of the wastewater. Operators mentioned that the potential of reusing harvested reeds are limited locally, only few people collect the reeds to implement sunshade in their household or for burning purposes. These practices can generate income if managed properly.

All operators mentioned that CWs attract wildlife such as birds, eagle, rat, snakes, and foxes. Some operators have concerns related to snakes which might be dangerous. While other mentioned that different types of birds, local and immigrant birds are living and resting inside the CWs during their journey.

While in Italy a growing demand of using and applying CWs, thousands of CWs were already implemented to treat different types of wastewater and different levels, or to support the centralized WWTP in order to increase their capacities. The Italian government has officially integrated CWs in their standards and guidelines since 1999. Most of CWs were applied as a decentralized systems for rural areas and scattered communities. Although the wide applications of CWs – NBS in the Italian contexts, the study summarizes some applications in the water and sanitation scoter, specifically CWs as a secondary treatment, tertiary treatment, decentralized solutions in mountains, and combined sewer overflow (CSO). A site visit has been conducted to Carimate WWTP in Como province, the WWTP utilize CWs (vertical flow CWs and free water surface) for managing the CSO. According to the Carimate operator, CWs don’t require maintenance except for reeds harvesting which carried out yearly. The operator of Carimate mentioned that CWs attract wildlife such as birds, eagle, rat, snakes, and frogs and different types of birds, local and immigrant birds are living and resting inside the CWs during their journey.

The operator mentioned that several complains had been received from the surrounding communities before implementation CWs, the complains were about odor and noise. While after implementation and operation of CWs, no further complains have been received and people starts to visit and enjoy the green area of CWs.

For the effluent quality, Carimate WWTP dispose the treated wastewater to Seveso River, most of disposal limits set by the Italian law (D. Lgs, 1999; D.Lgs., 2006) were achieved with some exception for the TN and NH_4 during limited event in the year such as first flash floods. While for the reuse standards number 185/2003 (D.M, 2003), the treated wastewater is able to meet the COD and TP limits but not the TN and NH_4. The performance of CWs is being monitored mainly during winter seasons and its performance shows a resilience to climate change.

The harvested year is being used for composting, and for now no further consideration for reeds management, while the sludge collected from the settling tanks is being transferred to incineration, no sludge is being disposed from the VFCWs.

The Italian experiences in applying and utilizing CWs have preceded the Jordanian experiences, and since the two countries have the same Mediterranean climate conditions, the Italian experience could provide several successful examples to the Jordan context especially in utilizing CWs to manage the climate change impacts such as heavy rainfall events which might lead to have flooded wastewater treatment plants. The reuse of harvested reeds in composting as in Carimate WWTP can inspire the Jordanian stakeholders and the private sector to invest in reusing the harvested reeds in composting in the Jordanian market with benefiting from the Italian quality and quantity records. The easiness of operation which is illustrated by several cases in Italy can help the stakeholders for better understanding and realizing the operation scenarios and the operation costs.

This chapter has targeted operators and managers of CWs – NBS WWTPs in the two selected countries, the methodology used and the obtained results from this chapter have encouraged the research to widen the activities and to consider an extended investigation about opportunities and challenges in integrating CWs – NBS in the sectors. And that has been translated in the following chapter.

Chapter 4: Contingent Valuation method: Willingness to pay and willingness to accept for having CWs as a sanitation solution, comparison between Italy and Jordan.

The chapter covers a deep analysis and data collections to understand the stakeholder and communities' perspectives about NBS – CWs in Jordan and Italy thought extended questionnaires. Two levels of questionnaires have been used, stakeholders' level and community level. The questionnaires have been used to achieve several objectives, such as identifying the gap between stakeholders' perspectives and communities' perspectives about CWs – NBS. The questionnaires have utilized Contingent Valuation (CV) method to indicate communities' willingness to accept (WTA) and communities' willingness to pay (WTP) for having CWs and benefiting from the co – benefits. The measured WTP could be integrated with the circular economy approach. A regression models were developed to affect Communities' WTA and WTP. This analysis will help to explain the fundamental driving forces for integrating NBS – CWs in the water and sanitation sector in the studied countries.

4.1 Introduction

Nature based solution (NBS) in general and Constructed wetlands CWs in specific have been raised and proved their capability as a treatment technology with a valuable role in solving the sanitation problems and considered as an appropriate and sustainable sanitation system for different contexts whether as main technology or as combined with the conventional technologies. (C. A. Arias et al., 2021). In addition to the cost-effective CWs can provide environmental and socio-economic benefits. Benefits arising from constructed wetlands include, besides treatment capacity, provision of wildlife and habitat diversity, ability for recreational activities (e.g., bird watching), water storage, regulating weather temperatures, and aesthetic upgrade of the surrounding environment; urban or rural (A. Stefanakis et al., 2014; A. I. Stefanakis, 2019). Recently these co-benefits are playing a vital role in selecting NBS and CW as a sustainable solution, especially in the social aspect. Researchers recommended to consider these co – benefits when selecting and comparing treatment technologies, through providing values for these co - benefits in order to include them under the financial sustainability and to integrate them easily with the circular economy approach (Masi et al., 2018). But the problem is to identify the co - benefits accurately, and to express them in money values, since most of these benefits and co - benefits are usually not market priced (Adaman et al., 2011; Ostrom, 2009).

These co-benefits are giving NBS and CWs values and advantages over other treatment solutions, people usually enjoy the nature and the green spaces but at the same time they consider these places and services as **common** things for all community, they consider it as unpaid ecosystem services (Dotro et al., 2017). On the other hand, the fast-ongoing urbanization, leads to minimize the green spaces and affect the biodiversity in the cities and that raised people attention to the importance of having green area and restoring the biodiversity and ecosystem (Oral et al., 2020). Nowadays people are spending their time and money in the countryside and green parks to enjoy the nature and aesthetic places. The previous facts might lead to increase peoples' willingness to pay (WTP) to have green places near their living areas and their willingness to accept (WTA) nature-based solutions and constructed wetlands. Therefore, measuring their WTP and WTA for having CWs is important to evaluate the valuable co-benefits. Consequently, it is important to find a method to give an economical value for the non-market priced co-benefits of NBS - CWs in order to integrate these co-benefits with the general sustainability, specifically the social and financial sustainability of NBS and CWs.

Thus, this has motivated the current research to investigate the community preference to pay and accept of applying CWs in the field of sanitation and water management in the selected case studies and to understand the differences between the communities and stakeholders' perspectives within Mediterranean countries - Jordan and Italy. To address the absence of a clear market mechanism Contingent Valuation (CV) method has been used to study peoples WTP and WTA, also to understand the both the community and the stakeholders' perspectives about NBS - CWs in sanitation and water management sector. The investigation has been extended to understand the community perspectives about reusing of treated wastewater, their knowledge about climate change impacts on their country and water availability, their preferences during implementation of wastewater treatment plants and other topics.

The results are expected to help decision makers and stakeholders in the sector in understanding the community perspectives about NBS - CWs, their willing to support the government financially and socially in integrating NBS - CWs in water management, also the results will help the stakeholders in understating the gaps within the community in accepting NBS - CWs, so they can design their future programs and interventions considering these gaps in order to increase potential of having sustainable solutions without issues especially social and financial issues. Hence, the data collected will help to analyze the basis of the community perspectives (preferences and concerns) of integrating NBS – CWs in water management and sanitation and the factors governing their perspectives, as well as will help the stakeholders with their decision-making processes, so it is important to:

- understand the judgement strategies used by the community to make their decisions to accept or reject of having NBS – CWs in their town or close to their households;
- identify the factors influencing the communities' perceptions about applying NBS – CWs using recycled water;
- identify the factors influencing the communities' perceptions about reusing treated wastewater;
- identify the preferences of the selected communities during implementing sanitation systems;
- identify the area where the community needs to raise its awareness and knowledge;
- identify the potential of reuse options and investment in the harvested reeds from the NBS – CWs;

This chapter is organized as follows. Section 2 introduction the CV method and discusses its strengths and restrictions. In section 3 we present the questionnaire, methodology, and the tools that were used to analyze the data. Section 4 presents the results. And the discussion and conclusion in the final section 5.

4.2 The Contingent Valuation (CV) method

Implementing constructed wetlands have a wide of co benefits (as illustrated in the previous chapters), these co benefits considered as common things where people should enjoy it by nature and free of charge, moreover these co benefits have no market values which make it difficult to evaluate them economically when decide to implement nature-based solutions technology.

The CV method is used to estimate economic values for all kinds of ecosystem and environmental services. It can be used to estimate both use and non-use values, and it is the most widely used method for estimating non-use values. It is also the most controversial of the non-market valuation methods (Ostrom, 2009).

The CV method involves directly asking people, in a survey, how much they would be willing to pay (WTP) for specific environmental services or good. In some cases, people are asked for reimbursement they would be willing to accept (WTA) to stop using specific environmental services or good. It is called (contingent) valuation because people are asked about their WTP, contingent on a specific hypothetical scenario and description of the environmental service (Adaman et al., 2011; Alberini & Cooper, 2000; Carson, 2000).

The CV method is referred to as a (stated preference) method because it asks people to directly state their values, rather than inferring values from actual choices, as the (revealed preference) methods do. The fact that CV is based on what people say they would do, as opposed to what people are observed to do, is the source of its greatest strengths and its greatest weaknesses (Alberini & Cooper, 2000).

CV is one of the only ways to assign monetary values to non-use values of the environment; values that do not involve market purchases and may not involve direct participation (Alberini & Cooper, 2000; Ostrom, 2009). These values include everything from the basic life support functions associated with ecosystem health or biodiversity, to the enjoyment of aesthetic places and wildlife, to appreciating the option to fish or bird watching in the future, or the right to save those options to the coming generations (Dennis & Marisa, 2000).

People are willing to pay for non-use environmental benefits. However, these benefits are likely to be treated as zero unless their money value is estimated. So, how much are they worth? Since people do not reveal their willingness to pay for them through their purchases or by their behavior, the only option for estimating a value is by asking them questions (Dennis & Marisa, 2000).

However, the fact that the CV method is based on asking people questions, as opposed to observing their actual behavior, is the source of enormous controversy. The conceptual, empirical, and practical problems associated with developing money estimates of economic value based on how people respond to hypothetical questions about hypothetical market situations are debated constantly in the economics literature. CV researchers are trying to address these problems, but they are far from finished (Alberini & Cooper, 2000; Dennis & Marisa, 2000). Meanwhile, many economists, as well as many psychologists and sociologists, for many different reasons, do not believe the money estimates that result from CV are valid.

More importantly, many policymakers and stakeholders will not accept the results of CV (Afroz et al., 2009; Carson, 2000).

While the study contained two different levels of questionnaire once to stakeholder level and the other to the community, only the community were asked their WTA and WTP. The respondents of the CV method will be asked a variety of questions, the order of question allows the respondents to understand NBS – CWs and their advantages and benefits, as well as their challenges and disadvantages, followed by asking them about their WTA and WTP of having NBS – CWS and enjoying the service considering different applications of CWs in different scenarios. The data collected are mainly binary data, results when respondents simply state whether their WTP and WTA for having CWs, and raking data, results when the respondents answered ranking questions, and quantitative data represent the respondent's WTP.

In the next methodology section, the questionnaire design and implementation will be explained and the used approach to evaluate the respondents' WTA, WTP and the factors that influence this decision.

4.3 Methodology

In this section we will discuss the questionnaire design and its implementation and dissemination methods

Questionnaire design and implementation

The work plan for implementing the CV and the questionnaire for this research had seven steps, where each step indicated a full stage in this research as shown in Figure 4.1.

For the best understanding and to determine the gaps in applying CWs as an application of NBS, and for the purpose of this study it has been noticed that two types/levels of questionnaires need to be carried out ; the first survey was targeting decision makers and experts in the field of water and wastewater sector, while the second survey was targeting the community in general, these two levels of surveys have helped to identify the challenges, level of understanding and the gaps between the community and the expert stakeholders in the sectors.

The two types/levels of survey have been disseminated in the selected Mediterranean country (Jordan and Italy), one survey for the community where no specific background is required, while the second survey if for experts and stakeholders in water and wastewater sector (governments, consultants, academics, NGOs', donors, etc.)

Among Jordan NBS and CWs have raised the attention of the Jordanian stakeholders including the government, international donors and agencies working in the water and wastewater sector, although several efforts and research have been allocated for integrating NBS in the Jordanian sector, the government have several concerns related to people acceptance, the local capacities, and the financial concerns. These concerns have led the movement to adhere with the conventional solutions rather than considering new solutions. While the Italian context have preceded Jordan with integrating NBS and CWs in the wastewater sector, hundreds of applications of CWs have been implemented within the rural areas in Italy as a decentralized wastewater treatment plants or used to upgraded centralized wastewater treatment plants. the Italian government has applied CWs in order to face the combined sewer overflow, and to solve several social complains such as Carimate wastewater treatment plant in the north if Italy (C. A. Arias et al., 2021).

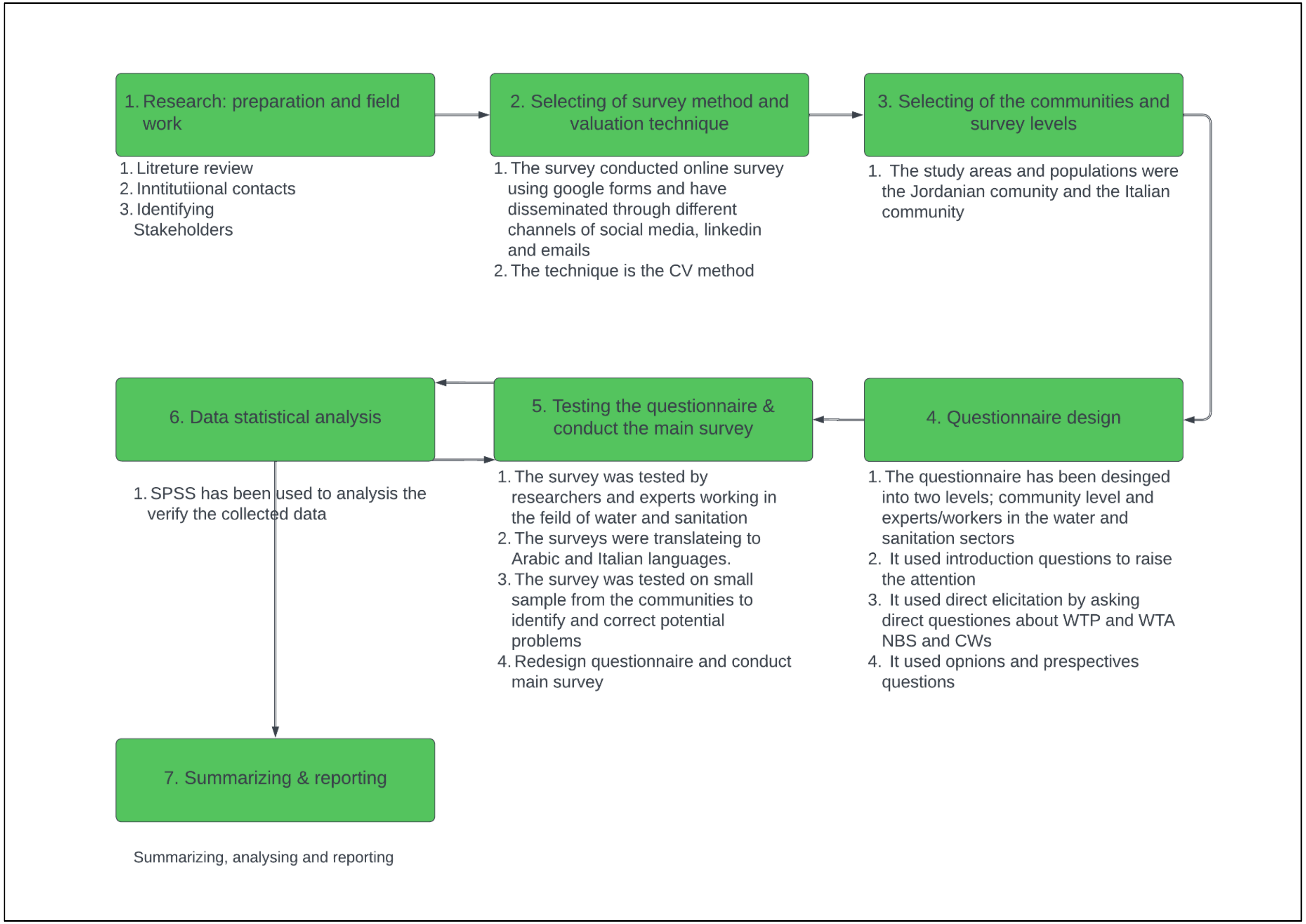

Figure 4. 1 Questionnaire methodology

The surveys have been translating to Arabic for the Jordanian and to Italian for the Italian, for Arabic language the surveys have been translated and checked by three experts and researchers in the field of environmental engineering/ water and wastewater, same procedures have been followed for the Italian surveys. All surveys have been pre-tested and redesigned several times in order to identify the challenges, level of understanding, time and easiness of filling the surveys.

Google forms have been used as a software tool and several communication channels have been used to disseminate the final survey in the Jordanian and Italian communities.

Social media, such as Facebook, WhatsApp, Instagram, and LinkedIn have been used to disseminate the surveys, hard copy posters have been prepared and posted in different places in the Italian community such as metro stations, trains stations and universities, the poster includes a QR code where people can scan it and open the survey directly. The two surveys are mentioned in detail in Appendix B.

First: Community levels

Introduction about the research and the research purpose, the introduction also includes a short description about Nature based solutions (NBS) and constructed wetlands (CWs) with a picture of a CW to help the community in understanding the technology.

The community survey contains several levels of questions:

I. personal information questions, such as gender age, educational level, etc;
II. general questions about climate change and water scarcity problems to raise the respondent's attention;
III. question about their sanitation situations of the respondents, and their sanitation knowledge including the required costs for managing wastewater for every respondent;
IV. question about the respondent's knowledge about wastewater treatment technologies with a focus on NBS and CWs;
V. questions about reuse of treated wastewater in agricultures;
VI. question about the benefits of having CWs to treat wastewater, and their preferences when having CWs project;
VII. questions about the disadvantages and challenges of applying CWs;
VIII. willing to accept questions, willing to pay questions of having CWs to treat wastewater and greywater at household level;

IX. and question about the economical evaluation and reuse of the harvested reeds;

In this study the dichotomous choice model has been selected to ask the WTA and WTP, and bidding techniques have been used for the WTP. The bidding game is a repeated process that tries to bracket the respondent's maximum WTP by presenting higher values (bids).

Finally, the community answered questions to priorities and order the benefits and co-benefits of having CWs – NBS as a wastewater treatment plant, these benefits and co-benefits are:

- protecting human health;
- biodiversity restoration and attracting wildlife;
- less gas emissions and Carbon sequestration, constructed wetlands can absorbs CO_2 a step to face the climate change;
- system that provides source of water (reusing treated wastewater);
- source of the harvested reeds/plants can be used in the local market with economic value;
- very limited energy required (almost zero) during operation;
- green area that can be aesthetical place ere people can enjoy;
- system with Very low costs in operation and maintenance;
- easy system to operate and maintain and doesn't require skilled labors;
- protecting the environment from the discharging untreated wastewater;
- creating job opportunities for people in operation the treatment wetland;

And the communities also answered question about their concerns of having CWs – NBS, such as odors problem, insect problems, land issues, etc.

Second: Stakeholder's level

The stakeholders survey contains several questions as well, starting from introduction about the research topic and goals, and general question about the respondent's information (occupation, organization, background, etc.). The introduction has been followed with several questions:

I. starting questions about the general conditions and facts about the water and wastewater sector;

II. questions related to using CWs in wastewater treatment;

III. question to scale the benefits of using CWs in treating wastewater;

IV. question related to scale the most possible challenges that might face application of CWs;

V. and lastly an open area questions for stakeholders to add their notes and comments;

A pilot survey was conducted for, to test the questionnaire in the field using ten persons. By the end of this stage the data were processed by computer system. The result of the pilot survey required some modifications on the formulation of some of the questions that were related to the community WTP. Specifically, the range of the proposed bids was modified. The actual disseminations were conducted in 2022 and for a period of five months.

Tools for data analysis

Several statistical techniques have been utilized in this study to analyze collected data through using social statistical packaging system (SPSS). Descriptive statistics were run against all variables to determine mean, median, standard deviation and frequencies of data. The percentages and frequencies were used to describe and analyses the responses, and the demographic profile of the respondents. Multiple regression has been used as a main statistical technique to explore the relationships within the data. Multiple regression is statistical technique which allows the researcher to assess the relationship between one dependent variable (WTP and WTA) and several independent variables.

The generic form of a multiple linear regression is:

$$Yi = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i22i} + \beta_3 X_{i3} \dots \beta_j X_{ij} + \varepsilon i$$

where *Y* is the dependent, *Xi1*, … *Xij* are the independents, β_0 is the constant, $\beta_1 \dots \beta_j$ are the regression coefficients, notation *i* refers to the *i-th* case in the n sample of observations, *j* represents number of independents variables and ε represents an error term (Agresti, 2007).

An important objective of regression analysis is to estimate the unknown parameters in the regression model. This process is also called fitting the model to the data. One of these techniques is the method of least squares (Agresti, 2007).

In SPSS the regression analysis calculates a p-value for each of the regression coefficients, (Agresti, 2007; Purwanto et al., 2021). The p-value indicates if each independent variable affects the dependent variable in a significant/not significant way. A low p-value (< 0.05) indicates that an independent variable that has a low p-value is likely to be a meaningful addition to the dependent variable (WTA and WTP). Equally, a larger p-value suggests that changes in the independents are not associated with changes in the dependent (Purwanto et al., 2021).

4.4 Results

This section discusses the results of these research activities. We start with a description of the WTA outcomes, followed by a univariate analysis to relate the individual explanatory variables to the WTP results. Finally, we present the findings of the ordered logit model estimates. While the following sections considered tables to represent the results, Appendix B represent the detailed figures that represent the results of each question.

4.4.1 Descriptive Statistics

4.4.1.1 Jordanian case study

First: Stakeholders level

Ninety-seven (97) Jordanian stakeholders have been filled the questionnaire and answered the three categories of questions. Descriptive statistics were run against all variables. The frequency analysis for each question has been analyzed and summarized in the flowing sections.

It was found that 52% of the stakeholders are between 31 - 45 years old while 29% have an age of more than 45 while the remaining is less than 30 years old as illustrated Table 4.1. The highest percentage of the respondents works in the governmental field 41.2 % while the second highest percentage goes for non-governmental organizations 25.8%, followed by 18.6% from the private sector, while the remaining percentage distributed between other types of occupations as illustrated in Table 4.1 below.

Table 4. 1 Frequency analysis for Jordanian stakeholder's general information

Variables	Options	Frequency	Percent (%)
Age	21-30	16	16.5
	31-45	52	53.6
	>45	29	29.9
	Total	**97**	**100.0**
Type of Organization	Academic sector	3	3.1
	Private Sector	18	18.6
	UN Agency	1	1.0
	none	2	2.1
	Non-Governmental organization NGO (international or local)	25	25.8
	Donor (National/International Agency)	5	5.2
	Government	40	41.2
	freelancer	2	2.1
	consultant	1	1.0
	Total	**97**	**100.0**

Among the Jordanian stakeholders, 72.2% mentioned that the most used treatment technology is activated sludge, while 12.4% answered that they don't know the most used technology. Most of the Jordanian stakeholders (89.7%) were aware that 35% of the Jordanian are not served with sewer network and wastewater treatment plants, while 74.2% of Jordanian stakeholders were aware that the Jordanian government consider treated wastewater in their water budget. All the stakeholders agreed that the sanitation sector in Jordan needs more sustainable solutions. The majority of Jordanian stakeholders 96% agreed that serving small towns and scattered populations might enhance the reuse if treated wastewater. 71.1% of Jordanian stakeholders trusted that CWs can be used as a main treatment technology while 28.9% had a different opinion. 69.1% of Jordanian stakeholders were aware that conventional wastewater treatment systems produce greenhouse gases and contribute to climate change, while 30.9% didn't accept that fact. Almost two third of the Jordanian stakeholder (72.2%) believed that CWs have advantages over the mechanical systems, while the remaining didn't agree with this point. Table 4.2 below summarizes the frequency analysis for this category of questions.

Table 4. 2 Frequency analysis for Jordanian stakeholder's - water sector

Questions	Options	Frequency	Percent (%)
What is the most used treatment technology in the wastewater treatment plants in Jordan?	Trickling Filter	7	7.2
	Activated Sludge	70	72.2
	Stabilization ponds	6	6.2
	Constructed wetlands	1	1
	All	1	1
	I don't Know	12	12.4
	Total	**97**	**100**
Do you know that 35% of Jordanian people are not connected to sewer system and wastewater treatment plants?	Yes	87	89.7
	No	10	10.3
	Total	**97**	**100**
Do you know that treated wastewater is one of the main sources of non-conventional water resources in the Jordanian water budget and equal to 14% of the water budget?	Yes	72	74.2
	No	25	25.8
	Total	**97**	**100**
Do you think the Jordanian sanitation situation needs more sustainable solutions?	Yes	96	99
	No	1	1
	Total	97	100
Do you believe that serving the small town and scattered population a sustainable sanitation solution will enhance the percentage of reusing of treated wastewater?	Yes	93	95.9
	No	4	4.1
	Total	**97**	**100**
Do you believe that constructed wetlands can be used as a main technology to treat wastewater?	Yes	69	71.1
	No	28	28.9
	Total	**97**	**100**
Do you think that the mechanical/ conventional wastewater treatment plants are a source of greenhouse gases contributing to climate change?	Yes	67	69.1
	No	30	30.9
	Total	**97**	**100**
Do you think constructed wetlands have advantages and benefits over the mechanical treatment technologies?	Yes	70	72.2
	No	27	27.8
	Total	**97**	**100**

The second category of questions was approaching the general benefits and matching points with applying of NBS – CWs in sanitation, stakeholders were asked to score seventeen points if they are matching and application NBS – CWs in wastewater on a scale from 1 to 5 (where 1 is the least and 5 is the most)

1. Low operational, maintenance and capital costs
2. Zero energy or Low energy requirements
3. The system requires huge land area
4. CWs require unskilled labors and operators

5. Can be used as a decentralized or semi-centralized solutions for scattered communities and rural area
6. Can be used as a centralized sanitation solution
7. Providing a source of treated wastewater that can be used in agriculture according to Jordanian standards.
8. CWs are resilient to climate change impacts (heavy rainfall, heat waves, and flash storms)
9. CWs are flexible treatment process (greatest ability to handle high variation in water quality and quantity while still meeting treated water quality objective)
10. Process robustness (avoiding incidents demanding unscheduled manual intervention or unexpected additional cost)
11. Generated less sludge and wastes comparing to the mechanical systems
12. Require less energy and costs to manage sludge and the by-products of treating wastewater
13. Protecting the environment by absorbing the CO_2 from the atmosphere
14. Restoring biodiversity and wildlife
15. Providing green area and aesthetical places where people can enjoy
16. CWs can provide source of financial resources through investment in the harvested reeds and the treated sludge
17. Adheres with the legislations and the institutional requirements

Table 4.3 below summarizes the Jordanian stakeholders' responses including the score percentage of each point. It was found that 35.1% of the Jordanian stakeholders strongly believed that CWs have low operational, maintenance and capital costs and they gave the highest score for this point while the second highest percentage for the same point was scored as 3 out of 5 by 28.9% of the Jordanian stakeholders. The minimum score for this point had a percentage of 2.1%. in the other word 2.1% of the Jordanian stakeholder didn't agree that the CWs have low operational, maintenance and capital costs. It was also found that 45.4% of the Jordanian stakeholders strongly believes that CWs consume zero or limited energy while the second highest percentage 31% of stakeholder gave 4 points for low energy consumption, and only 3.1% gave 1 point only.

40.2% of the stakeholders gave 5 point and agreed that CWs required huge area land, and 33% of the stakeholder gave 4 points, we can conclude that the majority of the stakeholders agreed that CWs required huge land area. For the capacity and skills required; 35.1% of the stakeholders gave 4 points and agreed that CWs required unskilled labors and operators, while 20.6% of the stakeholders gave 5 points and the same percentage gave 2 points only.

Other scores and percentage for the other points and benefits are summarized in Table 4.3 below, while Table 4.4 summarize the final scoring and ranking of the benefits of having CWs according to the Jordanian stakeholders.

Table 4. 3 Jordanian stakeholders' percentage score for each point - 1 to 5 scale

Item/scale (1-5)	Stakeholders' percentage scores for each scale (%)					
	1	**2**	**3**	**4**	**5**	**Total**
low operational, maintenance and capital costs	2.0	6.2	28.9	26.8	36.1	100
zero energy or low energy requirements	3.1	3.1	16.5	32	45.3	100
the system requires huge land area	4.1	3.1	19.6	33	40.2	100
CWs require unskilled labors and operators	6.2	20.6	17.5	35.1	20.6	100
can be used as a decentralized or semi-centralized solutions for scattered communities and rural area	3.1	2.1	13.4	51.5	29.9	100
can be used as a centralized sanitation solution	20.6	16.5	21.6	28.9	12.4	100
providing a source of treated wastewater that can be used in agriculture according to Jordanian standards.	0.0	7.2	20.6	32	40.2	100
CWs are resilient to climate change impacts (heavy rainfall, heat waves, and flash storms)	7.2	10.3	20.6	29.9	32	100
CWs are flexible treatment process (greatest ability to handle high variation in water quality and quantity while still meeting treated water quality objective)	6.2	13.4	19.6	40.2	20.6	100
process robustness (avoiding incidents demanding unscheduled manual intervention or unexpected additional cost)	3.1	4.1	24.7	43.4	24.7	100
generated less sludge and wastes comparing to the mechanical systems	1.0	8.2	26.8	30.9	33	99.9
require less energy and costs to manage sludge and the by-products of treating wastewater	1.0	4.1	19.6	40.2	35.1	100
protecting the environment by absorbing the CO2 from the atmosphere	4.1	5.2	16.5	43.3	30.9	100
restoring biodiversity and wildlife	4.1	5.1	18.6	37.1	35.1	100
providing green area and aesthetical places where people can enjoy	2.1	4.1	22.7	40.2	30.9	100
CWs can provide source of financial resources through investment in the harvested reeds and the treated sludge	2.1	9.3	23.7	50.5	14.4	100
adheres with the legislations and the institutional requirements	7.2	11.3	32	39.2	10.3	100

The table summarizes the percentage score for each point scored by Jordanian stakeholders on a scale from 1 – 5.

Table 4. 4 Final benefits ranking of CWs - Jordanian stakeholders

Benefits/Point	Ranking	Percentage (%)
Providing a source of treated wastewater that can be used in agriculture according to Jordanian standards.	1	6.46
zero energy or Low energy requirements	2	6.38
Can be used as a decentralized or semi-centralized solutions for scattered communities and rural area	3	6.35
Require less energy and costs to manage sludge and the by-products of treating wastewater	4	6.23
Restoring biodiversity and wildlife	5	6.13
CWs require huge land area	6	6.08
Providing green area and aesthetical places where people can enjoy	6	6.08
Generated less sludge and wastes comparing to the mechanical systems	8	6.07
Protecting the environment by absorbing the CO2 from the atmosphere	8	6.07
Process robustness (avoiding incidents demanding unscheduled manual intervention or unexpected additional cost)	11	5.99
CWs can provide source of financial resources through investment in the harvested reeds and the treated sludge	12	5.79
CWs are resilient to climate change impacts (heavy rainfall, heat waves, and flash storms)	13	5.66
CWs are flexible treatment process (greatest ability to handle high variation in water quality and quantity while still meeting treated water quality objective)	14	5.50
CWs require unskilled labors and operators	15	5.38
Adheres with the legislations and the institutional requirements	16	5.17
can be used as a centralized sanitation solution	17	4.62

The last group of question for the stakeholders indicated the challenges of applying NBS - CWs in water and wastewater sector in Jordan, Stakeholders have been asked to score each challenge on a scale from 1 to 5 where 1 indicated the least possibility while 5 indicate the maximum possibility of having the challenge. The following twenty-one challenges were collected from the literatures and previous studies and listed for the stakeholder:

1. the availability of lands;
2. the land costs in Jordan;
3. availability of funding for new wastewater treatment plant;
4. Availability of funding for operating or availability of investment scenario in operating similar technology;
5. local and international donors don't support and fund similar technologies and prefer the mechanical solutions;
6. availability of similar examples in the country that used CWs as a main treatment technology;
7. availability local experiences and skills in designing similar technology;
8. availability of skills in operation and maintain CWs- NBS;
9. the institutional situation and the unclear responsibility for ownership and operation of the plants;
10. acceptance of using this technology as main treatment technology by decision makers;

11. the variability of treatment efficiency, according to the climate, season, and wastewater characteristics (quality) and quantity;
12. achieving the treatment efficiency standards and reuse standards;
13. managing of sludge and the harvested reeds of the CWs;
14. constructed wetlands need water to be available in the beds all the time within the treatment plants;
15. availability of filter materials – substrates materials like the aggregate;
16. availability of the efficient plants to be used for the constructed wetlands locally;
17. clogging problem within the filter materials leading to overflow of untreated wastewater;
18. people acceptance of this technology and preferring mechanical treatments
19. source of odor;
20. source of insects and mosquitos;
21. the willingness of the private sector to invest through operating CWs;

Table 4.5 below summarize the Jordanian stakeholders' responses the score percentage of each challenge. It was found that 51.6 % of the Jordanian stakeholders strongly believed that the land availability is a challenge for CWs in Jordan (25.8% gave a core of 5 and 25.8% scored 4 for this challenge), while only 10.3 % agreed that the land availability is not a problem for CWs in Jordan. While 29.9% of stakeholders have strongly concerns about the land costs, 3.1% gave a score of 1 for this challenge. 35.1% of stakeholders said that availability of funding for new wastewater treatment plant is a challenge in Jordan with scale of 4 points, while 29.9% gave a score of 5 for this challenge. The challenge of availability of local experiences and skills has very little probabilities according to the Jordan stakeholders since 21.6%, 23.7% 27.8% gave a score of 1,2,3 respectively. Among the institutional challenges, 43.3% of the stakeholders agreed that the challenge of unclear responsibilities, ownership availability operating of CWs has 4 points which indicates of high possibility. Also 34% of stakeholders thought that accepting CWs by decision makers is a challenge with score of 4 points while only 8.2% of stakeholders though this is not a challenge.

Technically, 39.2% of stakeholders scored 3 points for the variability of the treatment efficiency according to the climate and seasons, while 30.9% and 14.4% believes that it can be a challenge with score of 4, 5 points respectively. This might give an indication about the lack of knowledge and absence of similar example of CWs in the country. Regarding of meeting the reuse standards, the highest score with 36.1% of stakeholders believe this can be a challenge while 10.3% of the stakeholders thought that will not be challenging for CWs to meet the reuse Jordanian standards. The availability of filter materials and plants are not challenging according to the stakeholders as illustrated in Table 4.5 below.

From social point of view, 34% of stakeholders gave 4 points, 24.7 gave 5 points and that indicated strong challenge for the social acceptance of CWs, 34% of the stake holders though CWs can be a source of odor with 4 points score, and 39.2% though CWs is an attractive place to insects and mosquitos, these high scores justified stadtholders' concerns about the social acceptance of CWs.

Other scores and percentage for the other challenges are summarized in Table 4.5, while Table 4.6 summarizes the final scoring and ranking of the challenges of having CWs according to the Jordanian stakeholders.

Table 4. 5 Jordanian stakeholders' percentage score for each challenge – 1 to 5 scale

	Stakeholders' percentage scores for each scale (%)					
Challenge/Scale (1-5)	**1**	**2**	**3**	**4**	**5**	**Total**
the availability of lands	10.3	17.5	20.6	25.8	25.8	100
the Land costs in Jordan	3.1	22.7	21.6	22.7	29.9	100
availability of funding for new wastewater treatment plant	3.1	12.4	19.6	35.1	29.9	100
availability of funding for operating or availability of investment scenario in operating similar technology	5.2	8.2	20.6	36.1	29.9	100
local and international donors don't support and fund similar technologies and prefer the mechanical solutions	16.5	18.6	33	15.5	16.5	100
availability of similar examples in the country that used CWs as a main treatment technology	11.3	26.8	38.1	14.4	9.3	100
availability local experiences and skills in designing similar technology	21.6	23.7	27.8	19.6	7.2	100
availability of skills in operation and maintain CWs- NBS	19.6	23.7	33	19.6	4.1	100
the institutional situation and the unclear responsibility for ownership and operation of the plants	5.2	6.2	18.6	43.3	26.8	100
acceptance of using this technology as main treatment technology by decision makers	8.2	8.2	27.8	34	21.6	100
the variety of treatment efficiency, according to the climate, season, and wastewater characteristics (quality) & quantity.	3.1	12.4	39.2	30.9	14.4	100
achieving the treatment efficiency and reuse standards	10.3	17.5	18.6	36.1	17.5	100
managing of sludge and the harvested reeds of the CWs	4.1	17.5	24.7	39.2	14.4	100
constructed wetlands need water to be available in the beds all the time within the treatment plants	10.3	15.5	36.1	26.8	11.3	100
availability of filter materials – substrates materials like the aggregate	27.8	27.8	24.7	13.4	6.2	100
availability of the efficient plants to be used for the constructed wetlands locally	28.9	22.7	25.8	12.4	10.3	100
clogging problem within the filter materials leading to overflow of untreated wastewater	9.3	20.6	30.9	24.7	14.4	100
people acceptance of this technology and preferring mechanical treatments	7.2	16.5	17.5	34	24.7	100
source of odor	8.2	6.2	29.9	34	21.6	100
source of insects and mosquitos	4.1	3.1	25.8	39.2	27.8	100
the willingness of the private sector to invest through operating CWs	13.4	25.8	22.7	28.9	9.3	100

The table summarizes the percentage score for each challenge scored by Jordanian stakeholders on a scale from 1 – 5.

Table 4. 6 Final Challenges ranking of CWs - Jordanian stakeholders

Challenge	Ranking	Percentage
The institutional situation and the unclear responsibility for ownership and operation of the plants	1	5.55%
Availability of funding for new wastewater treatment plant	2	5.49%
Availability of funding for operating or availability of investment scenario in operating similar technology	3	5.46%
source of insects and mosquitos	4	5.43%
The Land costs in Jordan	5	5.19%
People acceptance of this technology and preferring mechanical treatments	5	5.19%
acceptance of using this technology as main treatment technology by decision makers	7	5.16%
source of odor	8	5.06%
The variety of treatment efficiency, according to the climate, season, and wastewater characteristics (quality) and quantity.	9	5.04%
The availability of lands	10	5.00%
Achieving the treatment efficiency standards and reuse standards	11	4.83%
managing of sludge and the harvested reeds of the CWs	12	4.81%
Constructed wetlands need water to be available in the beds all the time within the treatment plants	13	4.80%
Clogging problem within the filter materials leading to overflow of untreated wastewater	14	4.60%
The willingness of the private sector to invest through operating constructed wetlands	15	4.47%
availability local experiences and skills in designing similar technology	16	4.21%
availability of skills in operation and maintain CWs- NBS	17	4.18%
Local and international donors don't support and fund similar technologies and prefer the mechanical solutions	18	4.15%
Availability of similar examples in the country that used CWs as a main treatment technology	19	4.09%
availability of the efficient plants to be used for the constructed wetlands locally	20	3.74%
Availability of filter materials – substrates materials like the aggregate	21	3.53%

Second: Community level

The questionnaire has been carried out at community level in Jordan, one hundred and nine (109) Jordanians have filled the questionnaire and answered the categories of questions. Descriptive statistics were run against all variables. The frequency analysis for each question has been analyzed and summarized in the flowing sections.

For the first question category it was found that 54.1% of the Jordanian respondents aged between 31 – 45 years, 56% of the responses belongs to males while 44% belongs to female respondents. The Majority of the Jordanian respondents have bachelor's degree with percentage of 73.4%. other details are illustrated in Table 4.7 below.

Table 4. 7 Frequency analysis for Jordanian community - general information

Questions	Options	Frequency	Percent (%)
Age	<20	1	0.9
	21-30	32	29.4
	31-45	59	54.1
	>45	17	15.6
	Total	**109**	**100**
Gender	Female	48	44.0
	Male	61	56.0
	Total	**109**	**100**
Education level	Secondary	1	0.9
	BSc	80	73.4
	MSc or PhD	28	25.7
	Total	**109**	**100**

The geographical distribution of the respondents is described in Figure 4.2 and the detailed numbers are summarized in Table 4.8 below. It was found that 47% of the responses came from Amman capital of Jordan, the second largest percentage with 29% of the responses came from Irbid, and the remaining responses have been recorded from another cities in Jordan.

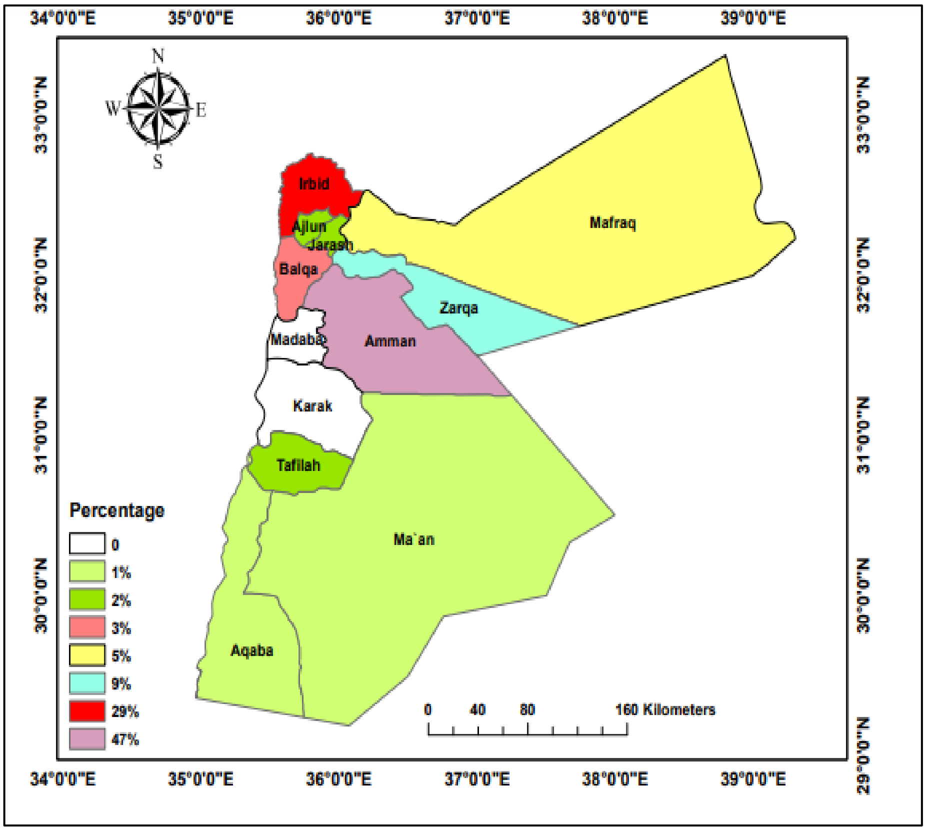

Figure 4. 2 The geographical distributions of the Jordanian respondents

Table 4. 8 Geographical distribution of the Jordanian respondents

City	# Of respondents	Percentage (%)
Amman	51	46.79
Irbid	32	29.36
Zarqa	9	8.26
Mafraq	5	4.59
Balqa - Salt	3	2.75
Tafeileh	2	1.83
Ajloun	2	1.83
Jarash	2	1.83
Azraq	1	0.92
Ma'an	1	0.92
Aqaba	1	0.92
Grand Total	**109**	

The second category of the questions consisted of general awareness questions about water sector in Jordan and the climate change impacts on the country. It was found that the majority of Jordanian responses are aware about the climate change and 98% of the respondents thought the climate change affected Jordan, 78.9% of the respondents believed that climate change has a fast impact on Jordan while 21.1% believed it has slow impact. 89% of the respondents thought and agreed that Jordan is facing water scarcity. Table 4.9 below summarize the Jordanian answers for this category of questions.

Table 4. 9 Frequency analysis for Jordanian community - general awareness

Question	Options	Frequency	Percent (%)
Are you aware about the global climate change issue?	Yes	101	92.7
	No	8	7.3
	Total	**109**	**100**
Do you think Jordan is affected by the climate change impacts?	Yes	107	98.2
	No	2	1.8
	Total	**109**	**100**
Do you think the climate change has a fast impact in Jordan?	Yes	86	78.9
	No	23	21.1
	Total	**109**	**100**
Do you think that Jordan is facing water scarcity issues?	Yes	97	89.0
	No	12	11.0
	Total	**109**	**100**

The followed category was targeting the respondent’s sanitation situation and knowledge of the Jordanian respondents in sanitation services. It was found that 78.9% of the respondents are served with sewer network while 21.1% are not, and these 21.1% are having onsite solutions like septic tank (sealed and unsealed). Only 31.2% of the Jordanian respondents knew the wastewater treatment plant which there are connected to, this low percentage reflects the lack of knowledge and lack of interests in sanitation sector. It was found that 40.4% of the respondents manage their wastewater costs every three months within the water bills, while 15.6 % manage their costs monthly thought desludging services, and 11% don't pay any costs to manage their wastewater and the remaining percentage didn't know how they manage this service. For the actual costs it was found that 24.8% of the respondents pay between 1 to 5 JD per month to dispose their wastewater, while 11% pay between 5 to 10, another 11% pay from 10 to 20 and few people pay more than 40 JD monthly. The details for this category are illustrated in Table 4.10.

Table 4. 10 Frequency analysis for the sanitation situation and knowledge - Jordanian community

Questions	Options	Frequency	Percent (%)
Is your house connected to a sewer system?	Yes	86	78.9
	No	23	21.1
	Total	109	100
Do you know the name of the wastewater treatment plant in your area/town?	Yes	34	31.2
	No	75	68.8
	Total	**109**	**100**
If your house isn't connected to the sewer system, do you have sanitation system in your household (septic tank, ciss pit …)?	Connected	84	77.1
	Yes	25	22.9
	Total	**109**	**100**
How much it costs you to manage your wastewater (monthly or every three months, please indicate the period)?	monthly	18	15.6
	every 3 months	44	40.4
	don't pay	12	11.0
	don't know	35	32.1
	Total	**109**	**100**
Cost monthly (JD)	1 - 5	27	24.8
	5 - 10	12	11.0
	10 - 20	12	11.0
	20-40	2	1.8
	>40	1	0.9
	don't pay	11	10.1
	don't know	44	40.4
	Total	**109**	**100**

The next category measured people acceptance of having wastewater treatment plants, and their awareness about nature-based solutions, it was found that 82.6% of Jordanian respondents didn't agree with having wastewater treatment plant close to their living area, and only 26.6% of the Jordanian respondents were aware about NBS before filling this survey (it is worth to mention that this survey contained an introduction that described NBs and CWs). Only 10% mentioned that NBS is already applied in Jordan and only 18.3% knew advantages of NBS and CWs over mechanical technology before filling the survey. But 67.9% of the respondents are aware that the current mechanical treatment technologies are contribution to the climate change issue. All details and percentages for this category are illustrated in Table 4.11.

Table 4. 11 Frequency analysis for the sanitation situation and knowledge Jordanian community (2)

Questions	Options	Frequency	Percent (%)
Would you accept the establishment of a Wastewater Treatment Plant (WWTP) to serve the community where you live?	Yes	90	82.6
	No	19	17.4
	Total	**109**	**100**
Do you know that the conventional mechanical wastewater treatment plants considered as source of GHG which contribute to climate change?	Yes	74	67.9
	No	35	32.1
	Total	**109**	**100**
Do you know Constructed wetlands - Nature Based Solution technology which can be used to treat wastewater?	Yes	29	26.6
	No	80	73.4
	Total	**109**	**100**
Do you know if it is applied in Jordan?	Yes	11	10.1
	No	98	89.9
	Total	**109**	**100**
Do you know any advantages and benefits of using Constructed wetlands - NBS technology over the mechanical technology?	Yes	20	18.3
	No	89	81.7
	Total	**109**	**100**

This forth category of questions have targeted the acceptance of reuse of treated wastewater. It was found that 67% of the Jordanian respondents accepted to irrigate their own crops with treated wastewater while the remaining have rejected that. 36.7 % of the Jordanian respondents have accepted to reuse treated wastewater for crops irrigations in Jordan while 19.5% don't accept that and 5.5% strongly didn't accept that. It was also found that 60% of Jordanian respondents accepted to consume products irrigated with treated wastewater while 40% rejected that. The details are illustrated in Table 4.12.

Table 4. 12 Frequency analysis for reusing treated wastewater - Jordanian community

Question	Options	Frequency	Percent (%)
Would you irrigate your crops with treated wastewater according to the Jordanian standards?	Yes	73	67.0
	No	36	33.0
	Total	**109**	**100**
How strongly do you intend to use treated wastewater for irrigation? (1 1 don't accept strongly, 2 don't accept, 3 fair, 4 accept, 5 accept strongly	don't accept strongly	6	5.5
	don't accept	21	19.3
	fair	17	15.6
	accept	40	36.7
	accept strongly	25	22.9
	Total	**109**	**100**
In case of availability of products irrigated with treated wastewater are you willing to buy and consume it in your house with your family?	Yes	65	60.0
	No	44	40.0
	Total	**109**	**100**

The followed question was created to understand the community's preferences during implementation of CWs as a wastewater treatment plant in their town, the Jordanian community has prioritized and ranked different eleven benefits according to their opinions, Table 4.13 shows the ranked benefits with percentage of ranking.

It was found that the Jordanian community ranked "protecting human health" as the first priority of having CWs followed by "the system provides source of water" and as a third option they voted for "less gas emissions and absorbing CO_2", giving these three options the priority reflects the level of awareness in the Jordanian community with the issues of waster scarcity, climate change issue and the importance of having adaptation measures. The least priority benefits were "low operation and maintenance cost: ranked as 9, followed by "protecting environment from untreated wastewater" and finally "creating Job opportunities".

Table 4. 13 Final ranking of CWs benefits as a wastewater treatment plant - Jordanian community

Benefits	Ran k	Percentage (%)
Protecting human health for diseases and illness	1	11.66
system that provides source of water (reusing treated wastewater)	2	10.75
less gas emissions and Carbon sequestration, constructed wetlands can absorbs CO2 a step to face the climate change	3	10.59
Biodiversity restoration and attracting wildlife	4	10.55
Source of the harvested reeds/plants can be used in the local market with economic value	5	8.80
Very limited energy required (almost zero) during operation	6	8.53
Green area that can be aesthetical place ere people can enjoy	7	8.30
easy system to operate and maintain and doesn't require skilled labors	8	7.88
system with Very low costs in operation and maintenance	9	7.87
protecting the environment from the discharging untreated wastewater	10	7.83
Creating job opportunities for people in operation the treatment wetland	11	7.24

The next category of questions focused on the concerns and issue that might occur with selecting and operating constructed wetlands. As a summary, 63.3% of the respondents were afraid from odor problems and 84.4% had a concern regarding attracting insects and mosquitoes, and 81.7% of Jordanian respondents thought that CWs required large land area. But 70% of the respondents didn't have a problem with restoring biodiversity in their towns. These concerns are quite normal comparing to their knowledge and experiences with the already existing technologies of treating wastewater. Table 4.14 below summarize their responses.

Table 4. 14 Frequency analysis for concerns about CWs - Jordanian community

Questions	Options	Frequency	Percent (%)
Do you think this technology can be source of odor?	Yes	69	63.3
	No	40	36.7
	Total	**109**	**100**
Do you think this technology attract insects and mosquitos?	Yes	92	84.4
	No	17	15.6
	Total	**109**	**100**
Do you think this technology requires large land area?	Yes	89	81.7
	No	20	18.3
	Total	**109**	**100**
Do you have a problem with attracting birds and restoring biodiversity in the town?	Yes	33	30.3
	No	76	69.7
	Total	**109**	**100**

The following questions were directly approached the willingness to accept of having constructed wetlands as a treatment technology. It was found that 82.6% preferred CWs over mechanical solutions, and 78.9% accepted to have CWs in their town or cities. However, 67% of the respondents rejected to have CWs close to their household, this can be justified from the current reputation of wastewater treatment plants also due to lack of treatment plant using CWs in the country. The detailed analysis is illustrated in Table 4.15.

Table 4. 15 Frequency analysis for WTA - Jordanian community

Questions	Options	Frequency	Percent (%)
Do you prefer having constructed wetlands over the mechanical one?	Yes	90	82.6
	No	19	17.4
	Total	**109**	**100**
Would you accept to have WWTP using constructed wetlands technology close to your house?	Yes	36	33.0
	No	73	67.0
	Total	**109**	**100**
Would you accept to have WWTP using constructed wetlands technology in your town/city?	Yes	86	78.9
	No	23	21.1
	Total	**109**	**100**

The next category has targeted the evaluate the future prospective of reuse of harvesting reeds from CWs within the local market in order to integrate the circularity concept with CWs. 61% of the Jordanian respondents thought the harvested reeds can be used locally. Different reuse options have been selected, validated, and summarized in Table 4.16 below.

Table 4. 16 Frequency analysis for reuse of harvesting reeds options - Jordanian community

Questions	Options	Frequency	Percent (%)
Do you think the harvested reeds/plants (which will be harvested periodically) can be used locally?	Yes	61	56.0
	No	48	44.0
	Total	**109**	**100**
Reuse Options	**Frequency**	**Ranking**	**Percentage**
Decoration and sunshades	75	1	27.27
Feeding Animals	65	2	23.64
Composting and fertilizer	60	3	21.82
Burning and heating in winter	57	4	20.73
I don't know	10	5	3.64
Nothing mentioned above	2	6	0.73
Production of Biofuel (Cellulosic Ethanol)	2	6	0.73
For drinks and food industry	1	8	0.36
Furniture	1	8	0.36
It can be used for isolation in building construction	1	8	0.36
Air purification and an aesthetic view	1	8	0.36
Total	**275**		**100.00**

The following category was measuring people willingness to pay for having CWs and enjoying the benefits and the con-benefits of having CWs. It was found that 53.2% of the Jordanian respondents were willing to support and pay for implementing CWs in their towns and cities, 27.5% accepted to pay on monthly basis and 32.1% accept to pay one time only, 11.9% are willing to pay but they didn't know how much to be paid, while 28.4% rejected to pay, it can be summarized that only 28.4% have rejected to pay while 71.6% were willing to pay for having CWs and enjoying the benefits and co-benefits. Table 4.17 below describes and summarize the derails of these questions.

Table 4. 17 WTP for having CWs - Jordanian community

Question	Options	Frequency	Percent (%)
If you believe that this technology has the previous positive impact, are you willing to pay tax for implementing this technology in your town?	yes	58	53.2
	no	51	46.8
	Total	**109**	**100**
How much would you pay for supporting implementation of constructed wetlands (monthly/fixed please specify)?	Monthly	30	27.5
	One time	35	32.1
	No payment	31	28.4
	don't know	13	11.9
	Total	**109**	**100**

The last category is approaching another application of CWs which is to treat greywater at household level, these questions were measuring people' WTA and WTP for having CWs at their household. It was found that 80.7% of the Jordanian respondents accepted to have CWs in their household as long as this CWs will provide them with a source of water for toilet flushing or irrigation. 56.9% of Jordanian accepted to pay for having CWs, the number shows that 34.9% accepted to pay up to 100 JD to have CWs, 2.8% accept to pay up to 500 JD and 1% accept to pay more than 1000 JD to have it, while 42.2 accept to have CWs but without paying. Table 4.18 is summarized the Jordanian community answers

It is worth to compare WTA of CWs to treat greywater and WTP to treat wastewater, 80.7% acceptance to use CWs for greywater comparing to 33% only.

Table 4. 18 WTP and WTA of having CWs for greywater treatment - Jordanian community

Questions	Options	Frequency	Percent (%)
If you know that Constructed wetlands can be applied in your household to treat the greywater (water coming from kitchen, sinks and washing machines), and you can use the treated water in irrigation in your yard or for toilet flushing would you willing to have this technology in your house?	yes	88	80.7
	no	21	19.3
	Total	**109**	**100**
would you accept to pay for having Constructed wetlands in your house?	yes	62	56.9
	no	47	43.1
	Total	**109**	**100**
if your answer to the previous question is yes, how much would you pay?	No payment	46	42.2
	<100	38	34.9
	100-200	17	15.6
	200-500	3	2.8
	500-1000	4	3.7
	>1000	1	0.9
	Total	**109**	**100**

4.4.1.2 Italian case study

First: Stakeholders level

Forty-two (42) Italian stakeholders have been filled the questionnaire and answered the three categories of questions. The questions are similar to the questioned used with the Jordanian stakeholders except for questions related to the Jordanian context, these questions have been replaced with similar questions but for the Italian context and Italian facts.

As with the Jordanian stakeholder analysis, descriptive statistics were run against all variables. The frequency analysis for each question has been analyzed and summarized in the flowing sections.

Among Italian stakeholders it was found that 38.1% of the stakeholders between 31- 45 years old while 45.2% has age of more than 45 while the remaining is less than 30 years old as illustrated in Table 4.19. The highest percentage of the respondents works in the academical field 42.9 % while the second highest percentage goes for the private sector 38.1%, followed by 11.9% from the governmental sector, while the remaining percentage distributed between other types of occupations as illustrated in Table 4.19.

Table 4. 19 Frequency analysis for Italian stakeholder's general information

Variables	Options	Frequency	Percent (%)
Age	21-30	7	16.7
	31-45	16	38.1
	>45	19	45.2
	Total	**42**	**100.0**
Type of Organization	Academic sector	18	42.9
	Private Sector	16	38.1
	Donor (National/International Agency)	1	2.4
	Government	5	11.9
	Non-Governmental organization NGO (international or local)	2	4.8
	Total	**42**	**100.0**

Among the Italian stakeholders 81% mentioned that the most used treatment technology is activated sludge, while 7.1% answered that they don't know the most used technology. Most of the Italian stakeholders (83.3%) are aware that 12% of the Italian people are not served with sewer network and 30% of Italian people are not connected to wastewater treatment plants, while 59.5% of Italian stakeholders are aware that the Italian government consider treated wastewater in their water budget and 40.5% are not aware. All the stakeholders agreed that the sanitation sector in Italy needs more sustainable solutions. the majority of Italian stakeholders 92.9% agreed that serving small towns and scattered populations might enhance the reuse if treated wastewater. Only 38.1 of Italian stakeholders trusted that CWs can be used as a main treatment technology while 61.9% have a different opinion, these percentages showed the opposite preceptive between Italian and Jordanian stakeholders. 83.3% of Italian stakeholders are aware that conventional wastewater treatment systems produce greenhouse gases and contribute to climate change, while 16.7% didn't agree with this fact. Almost all Italian stakeholders (92.9%) believe that CWs have advantages over the mechanical systems, while the remaining don't agree with this. Table 4.20 summarizes the frequency analysis for this category of questions

Table 4. 20 Frequency analysis for Italian stakeholder's – water sector

Questions	Options	Frequency	Percent (%)
What is the most used treatment technology in the wastewater treatment plants in Italy?	Activated Sludge	34	81
	Stabilization ponds	2	4.8
	Constructed wetlands	1	2.4
	Percolating bed	1	2.4
	Trickling filter, Activated Sludge	1	2.4
	I Don't Know	3	7.1
	Total	**42**	**100**
Do you know that 12% of Italian people are not connected to sewer system and 30% are not connected to wastewater treatment plants?	Yes	35	83.3
	No	7	16.7
	Total	**42**	**100**
Do you know that the Italian government considered treated wastewater as a part of the water budget?	Yes	25	59.5
	No	17	40.5
	Total	**42**	**100**
Do you think the Italian sanitation situation needs more sustainable solutions?	Yes	42	100
Do you believe that serving the small town and scattered population a sustainable sanitation solution will enhance the percentage of reusing of treated wastewater?	Yes	39	92.9
	No	3	7.1
	Total	**42**	**100**
Do you believe that constructed wetlands can be used as a main technology to treat wastewater?	Yes	16	38.1
	No	26	61.9
	Total	**42**	**100**
Do you think that the mechanical/ conventional wastewater treatment plants are a source of greenhouse gases contributing to climate change?	Yes	35	83.3
	No	7	16.7
	Total	**42**	**100**
Do you think constructed wetlands have advantages and benefits over the mechanical treatment technologies?	Yes	39	92.9
	No	3	7.1
	Total	**42**	**100**

Similar to the Jordanian stakeholders, Italian stakeholders answered the second category of questions was approaching the general benefits and matching points with applying of NBS – CWs in sanitation, Italian stakeholders were asked to score the same seventeen points (that used with the Jordanian stakeholders) if they are matching and application NBS – CWs in wastewater on a scale from 1 to 5 (where 1 is the least and 5 is the most). Table 4.21 below summarize the Italian stakeholders' responses including score percentage for each point. It was found that 31% of the Italian stakeholders strongly believed that CWs have low operational, maintenance and capital costs and they gave the highest score for this point while the second highest percentage was scored for scale 4 with 40.5% of the Italian stakeholders, while none of the Italian stakeholders gave a score of 1 point to this point which indicates a strong understanding that CWs have low operation and construction costs. It was found that 47.6% of the Italian stakeholders strongly believes that CWs consume zero or limited energy while the second highest percentage 31% of stakeholder gave 4 points for low energy consumption, and only 9.5% gave 1 point only.

33.3% of the stakeholders gave 5 point and agreed that CWs required huge area land, and 31% of the stakeholder gave 4 points, we can conclude that the majority of the stakeholders agreed and believed that CWs required huge land area. For the capacity and skills required; 21.5% of the stakeholders gave 5 points and agreed that CWs required unskilled labors and operators, while 40.5% of the stakeholders gave 3 points and that reflected their doubts about this point.

Other scores and percentage for the other points and benefits are summarized in Table 4.20 below, while Table 4.22 summarizes the final scoring and ranking of the benefits of having CWs according to the Italian stakeholders.

Table 4. 21 Italian stakeholders' percentage score for each point - 1 to 5 scale

	stakeholders' percentage scores for each scale (%)					
Challenge/Scores	**1**	**2**	**3**	**4**	**5**	**Total**
Low operational, maintenance and capital costs	0	4.7	23.8	40.5	31	100
zero energy or Low energy requirements	9.5	0	11.9	31	47.6	100
the system requires huge land area	0	11.9	23.8	31	33.3	100
CWs require unskilled labors and operators	0	19	40.5	19	21.5	100
Can be used as a decentralized or semi-centralized solutions for scattered communities and rural area	0	2.4	4.8	33.3	59.5	100
can be used as a centralized sanitation solution	26.2	40.5	16.7	7.1	9.5	100
Providing a source of treated wastewater that can be used in agriculture according to Italian standards.	7.2	2.4	19	38.1	33.3	100
CWs are resilient to climate change impacts (heavy rainfall, heat waves, and flash storms)	2.4	9.5	23.8	33.3	31	100
CWs are flexible treatment process (greatest ability to handle high variation in water quality and quantity while still meeting treated water quality objective)	2.5	19	21.4	35.7	21.4	100
Process robustness (avoiding incidents demanding unscheduled manual intervention or unexpected additional cost)	0	7.1	31	40.5	21.4	100
Generated less sludge and wastes comparing to the mechanical systems	0	2.4	9.5	42.9	45.2	100
Require less energy and costs to manage sludge and the by-products of treating wastewater	0	2.4	11.8	42.9	42.9	100
Protecting the environment by absorbing the CO2 from the atmosphere	0	7.1	16.7	42.9	33.3	100
Restoring biodiversity and wildlife	2.4	2.4	21.4	45.2	28.6	100
Providing green area and aesthetical places where people can enjoy	11.9	14.3	31	19	23.8	100
CWs can provide source of financial resources through investment in the harvested reeds and the treated sludge	16.7	21.4	35.7	21.4	4.8	100
Adheres with the legislations and the institutional requirements	2.4	21.4	28.6	28.6	19	100

Table 4. 22 Final benefits ranking of CWs - Italian stakeholders

Benefits/Points	Ranking	Percentage (%)
Can be used as a decentralized or semi-centralized solutions for scattered communities and rural area	1	7.12
Generated less sludge and wastes comparing to the mechanical systems	2	6.82
Require less energy and costs to manage sludge and the by-products of treating wastewater	3	6.75
zero energy or Low energy requirements	4	6.45
Protecting the environment by absorbing the CO2 from the atmosphere	5	6.37
Low operational, maintenance and capital costs	6	6.29
Restoring biodiversity and wildlife	7	6.26
Providing a source of treated wastewater that can be used in agriculture according to Italian standards.	8	6.14
the system requires huge land area	9	6.11
CWs are resilient to climate change impacts (heavy rainfall, heat waves, and flash storms)	10	6.03
Process robustness (avoiding incidents demanding unscheduled manual intervention or unexpected additional cost)	11	5.96
CWs are flexible treatment process (greatest ability to handle high variation in water quality and quantity while still meeting treated water quality objective)	12	5.62
CWs require unskilled labors and operators	13	5.43
Adheres with the legislations and the institutional requirements	14	5.39
Providing green area and aesthetical places where people can enjoy	15	5.20
CWs can provide source of financial resources through investment in the harvested reeds and the treated sludge	16	4.37
can be used as a centralized sanitation solution	17	3.69
		100.00

The last group of question for the stakeholders indicated the challenges of applying NBS - CWs in water and wastewater sector in Italy, Stakeholders have been asked to score each challenge on a scale from 1 to 5 where 1 indicated the least possibility while 5 indicate the maximum possibility of having the challenge. The same twenty-one challenges were used with Jordanian stakeholders have been modified according to the Italian context and listed for the Italian stakeholder.

Table 4.23 below summarize the Italian stakeholders' responses and the score percentage of each challenge. It was found that 69 % of the Italian stakeholders strongly believed that the land availability is a challenge for CWs in Italy (33.3% gave a core of 5 and 35.7% scored 4 for this challenge), while only 2.4 % agreed that the land availability is not a problem for CWs in Italy. While 33.4% of stakeholders have concerns about the land costs, 2.4% gave a score of

1 for this challenge, but the highest percentage scored 3 points for this challenge. 33.3% of stakeholders said that availability of funding for new wastewater treatment plant is a challenge in Italy with scale of 4 points, while 4.8% gave a score of 5 for this challenge, and 4.8% also gave the minimum possibility of this challenge. The challenge of availability of local experiences and skills has a higher probability if we compare it with the Jordanian stakeholders, according to 28.6% of the Italian stakeholders this challenge has 5 points while 9.5% of Italian stakeholders see this challenge deserve 1 point only. Among the institutional challenges, 26.2% of the stakeholders agreed that the challenge of unclear responsibilities, ownership availability operating of CWs has 4 points which indicates a high possibility. Also 31% of stakeholders thought that accepting CWs by decision makers is a challenge with score of 5 points and the highest percentage 35.7% of stakeholders gave 4 points for this challenge, while only 4.8% of stakeholders though this is not a challenge.

Technically, 28.6% of stakeholders scored 4 points for the variety of the treatment efficiency according to the climate and seasons, while 26.2% gave 2 points and that shows that Italian stakeholders are more confident in the performance of CWs than the Jordanian stakeholders, the same percentage of Italian stakeholders scored 3 points. This might be due to lack of knowledge and absence of similar example of CWs Jordan compared to Italy. Regarding of meeting the reuse standards, the highest score with 33.3% of stakeholders believe this can be a challenge while 19% of the stakeholders thought it will not be challenging for CWs to meet the reuse Italian standards. The availability of filter materials and plants are not challenging according to the stakeholders as illustrated in Table 4.23 below.

From social point of view, 35.7% of stakeholders gave 3 points, 26.2% gave 4 points while 16.7% scored 2 points and that indicated an unclear situation about this social. The highest percentage with 31% of the stakeholders though CWs is not a source of odor with 2 points score, but 31% though CWs is an attractive place to insects and mosquitos, these high scores justified stadtholders' concerns about the social acceptance of CWs.

Other scores and percentage for the other challenges are summarized in Table 4.23, while Table 4.24 summarize the final scoring and ranking of the challenges of having CWs according to the Italian stakeholders.

Table 4. 23 Italian stakeholders' percentage score for each challenge – 1 to 5 scale

	stakeholders' percentage scores for each scale (%)					
Challenge/Scores (1-5)	**1**	**2**	**3**	**4**	**5**	**Total**
The availability of lands	2.4	7.1	21.5	35.7	33.3	100
The Land costs in Italy	2.4	19	38.1	33.4	7.1	100
Availability of funding for new wastewater treatment plant	4.8	11.9	45.2	33.3	4.8	100
Availability of funding for operating or availability of investment scenario in operating similar technology	14.3	26.2	35.7	21.4	2.4	100
Local and international donors don't support and fund similar technologies and prefer the mechanical solutions	11.9	19	31	26.2	11.9	100
Availability of similar examples in the country that used CWs as a main treatment technology	11.9	21.4	31	21.4	14.3	100
availability local experiences and skills in designing similar technology	9.5	19	31	11.9	28.6	100
availability of skills in operation and maintain CWs-NBS	4.8	31	40.4	16.7	7.1	100
The institutional situation and the unclear responsibility for ownership and operation of the plants	9.5	19	28.6	26.2	16.7	100
acceptance of using this technology as main treatment technology by decision makers	4.8	4.8	23.7	35.7	31	100
The variety of treatment efficiency, according to the climate, season, and wastewater characteristics (quality) and quantity.	11.9	26.2	26.2	28.6	7.1	100
Achieving the treatment efficiency standards and reuse standards	7.2	19	26.2	33.3	14.3	100
managing of sludge and the harvested reeds of the CWs	14.3	21.4	42.9	14.3	7.1	100
Constructed wetlands need water to be available in the beds all the time within the treatment plants	14.3	26.2	45.2	4.8	9.5	100
Availability of filter materials – substrates materials like the aggregate	19	42.9	26.2	9.5	2.4	100
availability of the efficient plants to be used for the constructed wetlands locally	23.9	33.3	26.2	7.1	9.5	100
Clogging problem within the filter materials leading to overflow of untreated wastewater	14.3	28.6	33.3	21.4	2.4	100
People acceptance of this technology and preferring mechanical treatments	9.5	16.7	35.7	26.2	11.9	100
source of odor	21.4	31	23.8	19	4.8	100
source of insects and mosquitos	11.9	21.4	23.8	31	11.9	100
The willingness of the private sector to invest through operating constructed wetlands	4.8	14.3	26.1	38.1	16.7	100

Table 4. 24 Final Challenges ranking of CWs - Italian stakeholders

Challenge	Ranking	Percentage (%)
The availability of lands	1	6.11
acceptance of using this technology as main treatment technology by decision makers	2	6.00
The willingness of the private sector to invest through operating constructed wetlands	3	5.44
availability local experiences and skills in designing similar technology	4	5.18
Achieving the treatment efficiency standards and reuse standards	5	5.14
The Land costs in Italy	6	5.07
Availability of funding for new wastewater treatment plant	7	5.03
The institutional situation and the unclear responsibility for ownership and operation of the plants	7	5.03
People acceptance of this technology and preferring mechanical treatments	9	4.92
source of insects and mosquitos	10	4.85
Local and international donors don't support and fund similar technologies and prefer the mechanical solutions	11	4.81
Availability of similar examples in the country that used CWs as a main treatment technology	12	4.77
The variety of treatment efficiency, according to the climate, season, and wastewater characteristics (quality) and quantity.	13	4.58
availability of skills in operation and maintain CWs- NBS	14	4.55
managing of sludge and the harvested reeds of the CWs	15	4.36
Availability of funding for operating or availability of investment scenario in operating similar technology	16	4.25
Constructed wetlands need water to be available in the beds all the time within the treatment plants	17	4.21
Clogging problem within the filter materials leading to overflow of untreated wastewater	17	4.21
source of odor	19	3.99
availability of the efficient plants to be used for the constructed wetlands locally	20	3.84
Availability of filter materials – substrates materials like the aggregate	21	3.65
		100.00

Second: Community level

Similar to the Jordanian community the questionnaire has been carried out in the Italian community, have answered the same questionnaire. One hundred and twenty (120) Italian have filled the questionnaire and answered the question categories. Descriptive statistics were run against all variables. The frequency analysis for each question has been analyzed and summarized in the flowing sections.

The first questions category it was found that 63.3% of the Italian respondents aged between 21 – 30 years, 58.3% of the responses belongs to females while 41.7% belongs to male respondents. The Majority of the Italian respondents have master or doctorate degree with percentage of 41.7%. other details are illustrated in Table 4.25 below

Table 4. 25 Frequency analysis for Italian community - general information

Questions	Options	Frequency	Percent (%)
Age	<20	1	0.8
	21-30	76	63.3
	31-45	34	28.3
	>45	9	7.5
	Total	**120**	**100**
Gender	female	70	58.3
	male	50	41.7
	Total	**120**	**100**
Education level	Below Secondary	3	2.5
	Secondary	29	24.2
	BSc	38	31.7
	MSc or PhD	50	41.7
	Total	**120**	**100**

Different from Jordan, for the Italian geographical distribution regions were considered to represent the geographical distribution as illustrated in Figure 4.3 and Table 4.26. It was found that 75% of the responses came from Lombardi in the northern part of Italy while the remaining percentage came from other provinces in Italy.

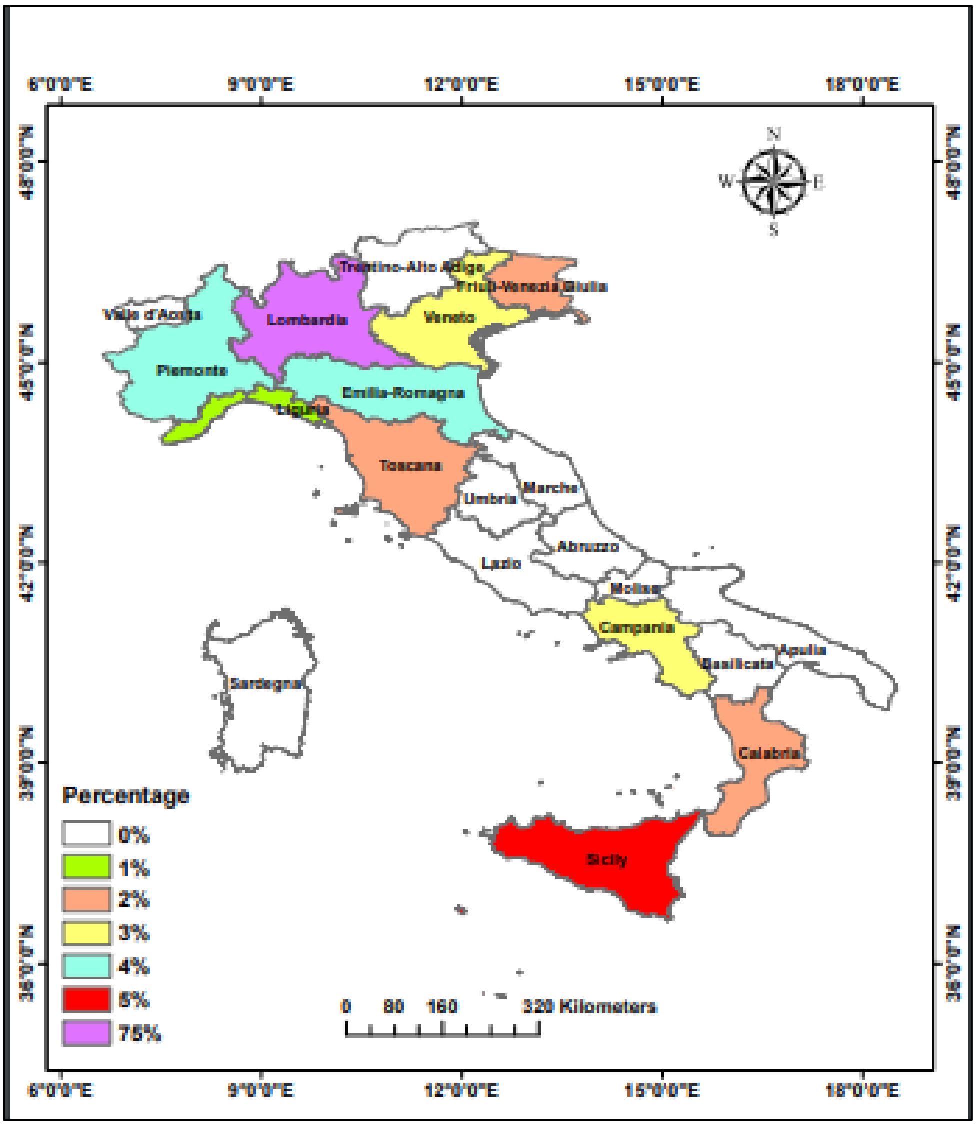

Figure 4. 3 The geographical distributions of the Italian respondents

Table 4. 26 Geographical distribution of the Italian respondents

Region	# Of respondents	Percentage (%)
Lombardia	90	75
Sicilia	6	5
Piemonte	5	4
Emilia Romagna	5	4
Campania	4	3
Veneto	3	3
Toscana	2	2
Friuli -Venezia Giulia	2	2
Calabria	2	2
Liguria	1	1
Total	**120**	**100**

The second category of the questions consisted of general awareness questions about water sector in Italy and the climate change impacts on the country. It was found that most Italian are aware about the climate change and 99.2% of the respondents thought the climate change affected Italy, 90% of the respondents believed that climate change has a fast impact on Italy while 10% believed it has slow impact. 61.7% of the respondents thought and agreed that Italy is facing water scarcity. More details and numbers in Table 4.27.

Table 4. 27 Frequency analysis for Italian community - general awareness

Questions	Options	Frequency	Percent (%)
Are you aware about the global climate change issue?	yes	114	95.0
	No	6	5.0
	Total	**120**	**100**
Do you think Italy is affected by the climate change impacts?	yes	119	99.2
	No	1	0.8
	Total	**120**	**100**
Do you think the climate change has a fast impact in Italy?	yes	108	90.0
	No	12	10.0
	Total	**120**	**100**
Do you think that Italy is facing water scarcity issues?	yes	74	61.7
	No	46	38.3
	Total	**120**	**100**

The followed category was targeting the sanitation situation and knowledge of the Italian respondents. It was found that 90% of the respondents are served with sewer network while 10% are not, and these 10% are having onsite solutions like septic tank (sealed and unsealed). Only 28.3% of the Italian respondents know the wastewater treatment plant which they are connected to, this low percentage reflects the lack of knowledge and lack of interests in sanitation sector. It was found that 27.5% of the respondents manage their wastewater costs every three months within the water bills, while 35 % manage their costs monthly, and 2.5% don't pay any costs to manage their wastewater and the remaining percentage didn't know how they manage this service. For the actual costs it was found that 5.8% of the respondents pay between 5 to 10 euros per month to dispose their wastewater, while 10.8% pay between 10 to 20 euros monthly and another 14.2% pay from 20 to 40 euros and 31.7% pay more than 40 euro monthly. The details for this category are illustrated in Table 4.28.

Table 4. 28 Frequency analysis for the sanitation situation and knowledge - Italian community

Questions	Options	Frequency	Percent (%)
Is your house connected to a sewer system?	Yes	108	90.0
	No	12	10.0
	Total	**120**	**100**
do you know the name of the wastewater treatment plant in your area/town?	Yes	34	28.3
	No	86	71.7
	Total	**120**	**100**
If your house isn't connected to the sewer system, do you have sanitation system in your household (septic tank, ciss pit …)?	Yes	13	10.8
	Connected to sewer network	107	89.2
	Total	**120**	**100**
How much it costs you to manage your wastewater (monthly or every three months, please indicate the period)?	monthly	42	35.0
	every 3 months	33	27.5
	don't pay	3	2.5
	don't know	42	35.0
	Total	**120**	**100**
cost monthly (Euro)	1 to 5	0	0.0
	5 to 10	7	5.8
	10 to 20	13	10.8
	20 to 40	17	14.2
	>40	38	31.7
	don't pay	3	2.5
	don't know	42	35
	Total	**120**	**100**

The next category measured people acceptance of having wastewater treatment plants, and their awareness about the nature-based solutions, it was found that 46.7% of Italian respondents didn’t agree with having wastewater treatment plant close to their living area, and only 40% of the Italian respondents were aware about NBS before filling this survey (it is worth to mention that this survey contained an introduction that described NBs and CWs). Only 15.8% mentioned that NBS is already applied in Italy and only 25.8% knew advantages of NBS and CWs over mechanical technology before filling the survey. But 41.7% of the respondents are aware that the current mechanical treatment technologies are contribution to the climate change issue. All details and percentages are illustrated in Table 4.29.

Table 4. 29 Frequency analysis for the sanitation situation and knowledge - Italian community (2)

Questions	Options	Frequency	Percent (%)
Would you accept the establishment of a Wastewater Treatment Plant (WWTP) to serve the community where you live?	Yes	64	53.3
	No	56	46.7
	Total	**120**	**100**
Do you know that the conventional mechanical wastewater treatment plants considered as source of GHG which contribute to climate change?	Yes	50	41.7
	No	70	58.3
	Total	**120**	**100**
Do you know Constructed wetlands - Nature Based Solution technology which can be used to treat wastewater?	Yes	48	40
	No	72	60
	Total	**120**	**100**
Do you know if it is applied in Italy?	Yes	19	15.8
	No	101	84.2
	Total	120	100
Do you know any advantages and benefits of using Constructed wetlands - NBS technology over the mechanical technology?	Yes	31	25.8
	No	89	74.2
	Total	**120**	**100**

This forth category of questions have targeted the acceptance of reuse treated wastewater concept. It was found that 89.2% accepted to irrigate their own crops in their households with treated wastewater while the remaining have rejected that. 74 % of the Italian respondents have accepted to reuse treated wastewater for agricultures and crops irrigations in Italy while 3.3% don't accept that and 25% strongly accept that. It was also found that 85.8% of Italian respondents accepted to consume products irrigated with treated wastewater while 14.2% rejected that. The details are illustrated in Table 4.30.

Table 4. 30 Frequency analysis for reusing treated wastewater - Italian community

Questions	Options	Frequency	Percent (%)
Would you irrigate your crops with treated wastewater according to the Italian standards?	Yes	107	89.2
	No	13	10.8
	Total	**120**	**100**
How strongly do you intend to use treated wastewater for irrigation? (1 don't accept strongly, 2 don't accept, 3 fair, 4 accept, 5 accept strongly	accept	74	61.7
	Strongly accept	30	25
	Fair	12	10
	Don't accept	4	3.3
	Don't accept strongly	0	0
	Total	**120**	**100**
In case of availability of products irrigated with treated wastewater are you willing to buy and consume it in your house with your family?	Yes	103	85.8
	No	17	14.2
	Total	**120**	**100**

The followed question was created to understand the community's preferences during implementation of CWs as a wastewater treatment plant in their town, as analyzed with the Jordanian community, the Italian community has prioritized and ranked the eleven benefits according to their opinions, Table 4.31 shows the ranked benefits with percentage of ranking.

It was found that the Italian community ranked "less gas emissions and absorbing CO_2" as the first priority of having CWs followed by "Protecting human health" and as a third option they voted for "biodiversity restoration", giving these three options the priority reflects the level of awareness in the Italian community with climate change impacts and the importance of restoring biodiversity. The least priority benefits were "easy system to operate and maintain and doesn't require skilled labors" ranked as 9, followed by "Source of the harvested reeds/plants" and finally "creating Job opportunities".

Table 4. 31 Final ranking of CWs benefits as a wastewater treatment plant – Italian community

Benefits	Rank	Percentage (%)
less gas emissions and Carbon sequestration, constructed wetlands can absorbs CO_2 a step to face the climate change	1	11.2
Protecting human health for diseases and illness	2	11.1
Biodiversity restoration and attracting wildlife	3	10.7
system that provides source of water (reusing treated wastewater)	4	10.6
Very limited energy required (almost zero) during operation	5	9.7
protecting the environment from the discharging untreated wastewater	6	8.9
Green area that can be aesthetical place where people can enjoy	7	8.1
system with Very low costs in operation and maintenance	8	8.0
easy system to operate and maintain and doesn't require skilled labors	9	7.4
Source of the harvested reeds/plants can be used in the local market with economic value	10	7.3
Creating job opportunities for people in operation the treatment wetland	11	7.1

This category of questions focused on the concerns and issue that might occur with selecting and operating constructed wetlands. 41.7% of the respondents were afraid from odor problems and 59.2% had a concern regarding attracting insects and mosquitoes, and 50.8% of Italian respondents thought that CWs required large land area. But 59.2% of the respondents have a problem with restoring biodiversity in their towns. These concerns and percentage contrast with the percentage recorded in the Jordanian community. Table 4.32 below summarize their responses.

Table 4. 32 Frequency analysis for the concerns about CWs - Italian community

Questions	Options	Frequency	Percent (%)
Do you think this technology can be source of odor?	Yes	50	41.7
	No	70	58.3
	Total	**120**	**100**
Do you think this technology attract insects and mosquitos?	Yes	71	59.2
	No	49	40.8
	Total	**120**	**100**
Do you think this technology requires large land area?	Yes	61	50.8
	No	59	49.2
	Total	**120**	**100**
Do you have a problem with attracting birds and restoring biodiversity in the town?	Yes	49	40.8
	No	71	59.2
	Total	**120**	**100**

The following questions were directly approached the willingness to accept of having constructed wetlands as a treatment technology. It was found that 79.2% preferred CWs over mechanical solutions, and 96.7% accepted to have CWs in their town or cities, and 63.3% of the respondents accepted to have CWs close to their household, this percentage is considered to be high comparing to Jordanian responses. This can be due to availability of CWs in the Italy comparing to Jordan. Table 4.33 summarize the details.

Table 4. 33 Frequency analysis for WTA - Italian community

Questions	Options	Frequency	Percent (%)
Do you prefer having constructed wetlands over the mechanical one?	Yes	95	79.2
	No	25	20.8
	Total	120	100
Would you accept to have WWTP using constructed wetlands technology close to your house?	Yes	76	63.3
	No	44	36.7
	Total	120	100
Would you accept to have WWTP using constructed wetlands technology in your town/city?	Yes	116	96.7
	No	4	3.3
	Total	120	100

The next category has targeted the evaluate the future prospective of reuse of harvesting reeds from CWs within the Italian market in order to integrate the circularity concept with CWs. 90%

of the Italian respondents thought the harvested reeds can be used locally. Different reuse options have been selected and validated and summarized in Table 4.34 below.

Table 4. 34 Frequency analysis for reuse of harvesting reeds options - Italian community

Questions	Options	Frequency	Percent (%)
Do you think the harvested reeds/plants (which will be harvested periodically) can be used locally?	Yes	108	90.0
	No	12	10.0
	Total	**120**	**100**
Reuse Options	**Frequency**	**Ranking**	**Percentage**
Composting and fertilizer	92	1	39.5
Burning and heating in winter	65	2	27.9
Feeding Animals	50	3	21.5
I don't know	14	4	6.0
Decoration and sunshades	11	5	4.7
Nothing mentioned above	1	6	0.4
Total	**233**		**100**

The following category was measuring people willingness to pay for having CWs and enjoying the benefits and the con-benefits of having CWs. it was found that 61.7% of the Italian respondents were willing to support and pay for implementing CWs in their towns and cities, 18.3% accepted to pay on monthly basis and 24.2% accept to pay one time only, 10% are willing to pay but they didn't know the payment process and frequency while 47.5% rejected to pay, it can be summarized that only 47.5% have rejected to pay while 52.5% were willing to pay for having CWs and enjoying the benefits and co-benefits. Table 4.35 below described and summarize the derails of these questions.

Table 4. 35 WTP for having CWs - Italian community

Questions	Options	Frequency	Percent (%)
If you believe that this technology has the previous positive impact, are you willing to pay tax for implementing this technology in your town?	Yes	74	61.7
	No	46	38.3
	Total	**120**	**100**
How much would you pay for supporting implementation of constructed wetlands (monthly/fixed please specify)?	Monthly	22	18.3
	One time	29	24.2
	No payment	57	47.5
	don't know	12	10.0
	Total	**120**	**100**

The last category is approaching another application of CWs which is to treat greywater at household level, these questions were measuring people' willingness to accept and willingness to pay for having CWs at their household. It was found that 94.4% of Italian respondents accepted to have CWs in their household as long as this CWs will provide them with a source of water for toilet flushing or irrigation. 72.5% of Italian accepted to pay for having CWs, the number shows that 27.5% accepted to pay up to 200 euros to have CWs, 23.3% accept to pay up to 500 euros and 5% accept to pay up to 2000 euros to have it, while 23.3% accept to have CWs but without paying. Table 4.36 is summarized the Italian community answers

It is worth to compare WTA of CWs to treat greywater and WTP to treat wastewater, 94.2% acceptance to use CWs for greywater comparing to 63.3% only for wastewater.

Table 4. 36 WTP and WTA of having CWs for greywater treatment - Italian community

Questions	Options	Frequency	Percent (%)
If you know that Constructed wetlands can be applied in your household to treat the greywater (water coming from kitchen, sinks and washing machines), and you can use the treated water in irrigation in your yard or for toilet flushing would you willing to	Yes	113	94.2
	No	7	5.8
	Total	120	100
would you accept to pay for having Constructed wetlands in your house?	Yes	87	72.5
	No	33	27.5
	Total	**120**	**100**
if your answer to the previous question is yes, how much would you pay?	< 200	33	27.5
	200 - 500	28	23.3
	500 - 1000	19	15.8
	1000 - 2000	6	5
	No payment	28	23.3
	Don't Know	6	5
	Total	**120**	**100**

4.4.2 Contingent Valuation (CV) method

4.4.2.1 Jordanian case study

In order to calculate the mean WTP to have CWs at the household level to treat greywater the following methodology and calculation have been followed, among the proposed financial bids, the frequency of respondents who answered "yes" for willingness to pay question for having CWs to HH level have been collected. Financial bids have been ranked from 1 to 6 based on their values (1 for zero payment/don't pay, 6 for 2000 JD the maximum proposed bid values).

WTP per bid group have been calculated by multiplying the frequency and the ranking values in order to multiply the bid values.

The mean WTP has been calculated by dividing the WTP per group to the total number of respondents as illustrated in Table 4.37 below while Table 4.18 before in *section 4.4.1.1* repents the total the percent score of the bid values - WTP for implementing CWs at HH level.

Table 4. 37 Mean WTP value for f having CWs for greywater treatment – Jordan community

BID Level (JD)	No. sub sample	No. of sample answering yes	%Answering yes for each group	value	WTP per group
0	46	5	11%	1	5
0 - 100	38	34	89%	2	68
100- 200	17	17	100%	3	51
200- 500	3	2	67%	4	8
500 - 1000	4	3	75%	5	15
>1000	1	1	100%	6	6

Mean WTP = total WTP / No of samples = 153/109 = 1.4 → (0 – 100) JD/person.

4.4.2.2 Italian case study

The same procedure has been followed for the Italian community. The mean WTP has been calculated by dividing the WTP per group to the total number of respondents as illustrated in Table 4.38 below while Table 4.36 before repents the total the percent score of the bid values - WTP for implementing CWs at HH level.

Table 4. 38 Mean WTP value for having CWs for greywater treatment – Italy community

BID Level	No. sub sample	No. of sample answering yes	%Answering yes for each group	value	WTP per group
0	28	0	0%	1	0
<200	33	29	88%	2	58
200 - 500	28	28	100%	3	84
500 -1000	19	19	100%	4	76
1000- 2000	6	6	100%	5	144
>2000	0	0	0%	6	0

Mean WTP = total WTP / No of samples = 362/120 = 3.02 → (200 - 500) euro/person

4.4.3 Regressing analysis

In order to understand the parameters that affects people willingness to pay and willingness to accept constructed wetland – NBS, regression model has been used among Jordanian and Italian communities' surveys.

Questions related to WTP, and WTA have been considered as dependent variables and other questions considered as independent variables. Since the questions have been categorized in groups as mentioned before into, several regressions have been carried out to study the correlations between each category and the dependent variables. Table 4. 39 summarize the regression.

Questions categories:

1. personal information questions, such as gender age, educational level, etc.;
2. general questions about climate change and water scarcity problems to raise the respondent's attention;
3. question about their sanitation situations of the respondents, and their sanitation knowledge including the required costs for managing wastewater for every respondent;
4. question about the respondent's knowledge about wastewater treatment technologies with a focus on NBS and CWs (benefits and advantages) and reusing the harvested reeds;
5. questions about the disadvantages and challenges of applying CWs;

While the dependent variables were

1. WTA for having CWs – NBS for wastewater treatment near the respondent's house
2. WTA for having CWs – NBS for wastewater treatment in respondent's town/city
3. WTP for having CWs – NBS for wastewater in eh respondent's town
4. WTA for having CWs – NBS for greywater treatment in the respondent's household
5. WTP for having CWs for greywater in the respondent's household

The section below summarizes the results for each category and the factors that affect people's WTA and WTP

4.4.3.1 Jordanian case study

Several regression analyses have been carried out to understand of the community's perspectives. Table 39 summarize the regression analysis carried out and their results of significance. while the details for each significant regression are explained further below.

Table 4. 39 Summary of regression analysis – Jordan community

#	Dependent	Independent variables	Significant/ not Significant
1	Would you accept to have WWTP using constructed wetlands technology close to your house?	• Age • Gender • Education level • City	Not significant
2		• Are you aware about the global climate change issue? • Do you think Jordan is affected by the climate change impacts? • Do you think the climate change has a fast impact in Jordan? • Do you think that Jordan is facing water scarcity issues?	Significant
3		• Is your house connected to a sewer system? • If your house isn't connected to the sewer system, do you have sanitation system in your household (septic tank, ciss pit …)? • How much it costs you to manage your wastewater (monthly or every three months, please indicate the period)? • monthly	Not significant
4		• Do you know that the conventional mechanical wastewater treatment plants considered as source of GHG which contribute to climate change? • Do you know Constructed wetlands - Nature Based Solution technology which can be used to treat wastewater? • Do you know if it is applied in Jordan? • Do you know any advantages and benefits of using Constructed wetlands - NBS technology over the mechanical technology? • Do you prefer having constructed wetlands over the mechanical one? • Do you think the harvested reeds/plants (which will be harvested periodically) can be used locally?	Not significant
5		• Do you think this technology can be source of odor? • Do you think this technology attract insects and mosquitos? • Do you think this technology requires large land area? • Do you have a problem with attracting birds and restoring biodiversity in the town?	Significant
6	Would you accept to have WWTP using constructed wetlands technology in your town/city?	• Age • Gender • Education level • City	Not significant
7		• Are you aware about the global climate change issue? • Do you think Jordan is affected by the climate change impacts? • Do you think the climate change has a fast impact in Jordan? • Do you think that Jordan is facing water scarcity issues?	Not significant
8		• Is your house connected to a sewer system?	Not significant

#	Dependent	Independent variables	Significant/ not Significant
		• If your house isn't connected to the sewer system, do you have sanitation system in your household (septic tank, ciss pit …)? • How much it costs you to manage your wastewater (monthly or every three months, please indicate the period)? • monthly	
9		• Do you know that the conventional mechanical wastewater treatment plants considered as source of GHG which contribute to climate change? • Do you know Constructed wetlands - Nature Based Solution technology which can be used to treat wastewater? • Do you know if it is applied in Jordan? • Do you know any advantages and benefits of using Constructed wetlands - NBS technology over the mechanical technology? • Do you prefer having constructed wetlands over the mechanical one? • Do you think the harvested reeds/plants (which will be harvested periodically) can be used locally?	Significant
10		• Do you think this technology can be source of odor? • Do you think this technology attract insects and mosquitos? • Do you think this technology requires large land area? • Do you have a problem with attracting birds and restoring biodiversity in the town?	Not significant
11	If you believe that this technology has the previous positive impact, are you willing to pay tax for implementing this technology in your town?	• Age • Gender • Education level • City	Not significant
12		• Are you aware about the global climate change issue? • Do you think Jordan is affected by the climate change impacts? • Do you think the climate change has a fast impact in Jordan? • Do you think that Jordan is facing water scarcity issues?	Not significant
13		• Is your house connected to a sewer system? • If your house isn't connected to the sewer system, do you have sanitation system in your household (septic tank, ciss pit …)? • How much it costs you to manage your wastewater (monthly or every three months, please indicate the period)? • monthly	Not significant
14		• Do you know Constructed wetlands - Nature Based Solution technology which can be used to treat wastewater? • Do you know if it is applied in Jordan? • Do you know any advantages and benefits of using Constructed wetlands - NBS technology over the mechanical technology? • Do you prefer having constructed wetlands over the mechanical one? • Do you think the harvested reeds/plants (which will be harvested periodically) can be used locally?	Not significant
15		• Do you think this technology can be source of odor? • Do you think this technology attract insects and mosquitos? • Do you think this technology requires large land area? • Do you have a problem with attracting birds and restoring biodiversity in the town?	Not significant
16	If you know that Constructed wetlands can be applied in your household to treat the greywater (water coming from kitchen, sinks and washing machines),	• Age • Gender • Education level • City	Not significant
17		• Are you aware about the global climate change issue? • Do you think Jordan is affected by the climate change impacts? • Do you think the climate change has a fast impact in Jordan? • Do you think that Jordan is facing water scarcity issues?	Not significant
18		• Is your house connected to a sewer system? • If your house isn't connected to the sewer system, do you have sanitation system in your household (septic tank, ciss pit …)? • How much it costs you to manage your wastewater (monthly or every three months, please indicate the period)? • monthly	Not significant

#	Dependent	Independent variables	Significant/ not Significant
19	and you can use the treated water in irrigation in your yard or for toilet flushing would you willing to have this technology in your house?	• Do you know Constructed wetlands - Nature Based Solution technology which can be used to treat wastewater? • Do you know if it is applied in Jordan? • Do you know any advantages and benefits of using Constructed wetlands - NBS technology over the mechanical technology? • Do you prefer having constructed wetlands over the mechanical one? • Do you think the harvested reeds/plants (which will be harvested periodically) can be used locally?	Not significant
20		• Do you think this technology can be source of odor? • Do you think this technology attract insects and mosquitos? • Do you think this technology requires large land area? • Do you have a problem with attracting birds and restoring biodiversity in the town?	Significant
21	Would you accept to pay for having Constructed wetlands in your house?	• Age • Gender • Education level • City	Not significant
22		• Are you aware about the global climate change issue? • Do you think Jordan is affected by the climate change impacts? • Do you think the climate change has a fast impact in Jordan? • Do you think that Jordan is facing water scarcity issues?	Not Significant
23		• Is your house connected to a sewer system? • If your house isn't connected to the sewer system, do you have sanitation system in your household (septic tank, ciss pit …)? • How much it costs you to manage your wastewater (monthly or every three months, please indicate the period)? • monthly	Not Significant
24		• Do you know that the conventional mechanical wastewater treatment plants considered as source of GHG which contribute to climate change? • Do you know Constructed wetlands - Nature Based Solution technology which can be used to treat wastewater? • Do you know if it is applied in Jordan? • Do you know any advantages and benefits of using Constructed wetlands - NBS technology over the mechanical technology? • Do you prefer having constructed wetlands over the mechanical one? • Do you think the harvested reeds/plants (which will be harvested periodically) can be used locally?	Not Significant
25		• Do you think this technology can be source of odor? • Do you think this technology attract insects and mosquitos? • Do you think this technology requires large land area? • Do you have a problem with attracting birds and restoring biodiversity in the town?	Significant

Details for significant regressions

It is important to remember that in SPSS the regression analysis calculates a p-value for each of the regression coefficients, (Agresti, 2007; Purwanto et al., 2021). The p-value indicates if each independent variable affects the dependent variable in a significant/not significant way. A low p-value (< 0.05) indicates that an independent variable that has a low p-value is likely to be a meaningful addition to the dependent variable (WTA and WTP). Equally, a larger p-value suggests that changes in the independents are not associated with changes in the dependent (Purwanto et al., 2021).

As illustrated in Table 39, five regressions were significant as listed below:

1. Multiple linear regression was used to test if *climate change awareness*, *knowledge about climate change on Jordan*, *if the climate change has a fast impact on Jordan* and *the knowledge about Jordanian water scarcity* significantly affect the willingness to accept of having CWs close to the household "*Would you accept to have WWTP using constructed wetlands technology close to your house?*"

The fitted regression model was WTA of CWs near H.H = 1.389 – 0.212(climate change awareness) + 0.123(Jordan affected by climate change) + 0.371(Climate change has fast impact on Jordan) – 0.60 (Jordan water scarcity)

The overall regression was statistically significant (R^2 = 0.114, F (4, 104) = 3.361, p = < .012). The details for this regression including factors and significance level are illustrated in Table 4.40 and Table 4.41

Table 4. 40 Model Summary – WTA Reg1 – Jordan Community

Model Summary									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.338[a]	.114	.080	.453	.114	3.361	4	104	.012
a. Predictors: (Constant), Do you think that Jordan is facing water scarcity issues? Are you aware about the global climate change issue?, Do you think Jordan is affected by the climate change impacts?, Do you think the climate change has a fast impacts in Jordan?									

Table 4. 41 Coefficients – WTA Reg1 – Jordan Community

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.389	.387		3.585	<.001
	Are you aware about the global climate change issue?	-.212	.171	-.118	-1.240	.218
	Do you think Jordan is affected by the climate change impacts?	.123	.348	.035	.355	.723
	Do you think the climate change has a fast impact in Jordan?	.371	.118	.322	3.154	.002
	Do you think that Jordan is facing water scarcity issues?	-.060	.148	-.040	-.406	.685
a. Dependent Variable: Would you accept to have WWTP using constructed wetlands technology close to your house?						

2. Multiple linear regression was used to test if "*Do you think this technology can be source of odor*?", "*Do you think this technology attract insects and mosquitos?*", "*Do you think this technology requires large land area?*", and "*Do you have a problem with attracting birds and restoring biodiversity in the town?*" significantly affect the willingness to accept of having CWs close to the household "*Would you accept to have WWTP using constructed wetlands technology close to your house?*"

The fitted regression model was WTA of CWs near H.H = 2.599 – 0.235(odor concerns) – 0.249(insects concerns) – 0.224(land area concern) – 0.032 (restoring biodiversity)

The overall regression was statistically significant (R2 = 0.194, F (4, 104) = 6.244, p = < .001).

The details for this regression including factors and significance level are illustrated in Table 4.42 and Table 4.43

Table 4. 42 Model Summary – WTA Reg2 – Jordan Community

Model Summary									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.440[a]	.194	.163	.432	.194	6.244	4	104	<.001

a. Predictors: (Constant), Do you have a problem with attracting birds and restoring biodiversity in the town?, Do you think this technology can be source of odor?, Do you think this technology requires large land area?, Do you think this technology attract insects and mosquitos?

Table 4. 43 Coefficients – WTA Reg2 – Jordan Community

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.599	.249		10.456	<.001
	Do you think this technology can be source of odor?	-.235	.100	-.241	-2.348	.021
	Do you think this technology attract insects and mosquitos?	-.249	.136	-.192	-1.825	.071
	Do you think this technology requires large land area?	-.224	.111	-.185	-2.025	.045

	Do you have a problem with attracting birds and restoring biodiversity in the town?	-.032	.094	-.031	-.342	.733
a. Dependent Variable: Would you accept to have WWTP using constructed wetlands technology close to your house?						

3. Another multiple linear regression was used to test if "*Do you know that the conventional mechanical wastewater treatment plants considered as source of GHG which contribute to climate change?*", "*Do you know Constructed wetlands - Nature Based Solution technology which can be used to treat wastewater?*", "*Do you know if it is applied in Jordan*?", "*Do you know any advantages and benefits of using Constructed wetlands - NBS technology over the mechanical technology?*", *Do you prefer having constructed wetlands over the mechanical one?*", and "*Do you think the harvested reeds/plants (which will be harvested periodically) can be used locally*?" significantly affect the willingness to accept of having CWs in the city/town "*Would you accept to have WWTP using constructed wetlands technology in your town/city?"*

The fitted regression model was WTA of CWs in your city/town = 0.241 – 0.049(knowledge about GHG from mechanical technology) + 0.11(knowledge about NBS-CWs) + 0.154(knowledge in NBS applied in Jordan) + 0.064 (knowledge about advantages of NBS over mechanical) + 0.352 (preference of CV over mechanical) + 0.017(if harvested reeds can be used)

The overall regression was statistically significant (R2 = 0.146, F (4, 104) = 2.901, p =< .012).

The details for this regression including factors and significance level are illustrated in Table 4.44 and Table 4.45

Table 4. 44 Model Summary – WTA Reg3 – Jordan Community

Model Summary									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.382[a]	.146	.096	.390	.146	2.901	6	102	.012
a. Predictors: (Constant), Do you think the harvested reeds/plants (which will be harvested periodically) can be used locally?, Do you prefer having constructed wetlands over the mechanical one? , Do you know that the conventional mechanical wastewater treatment plants considered as source of GHG which contribute to climate change ?, Do you know if it is applied in Jordan?, Do you know any advantages and benefits of using Constructed wetlands - NBS technology over the mechanical technology?, Do you know Constructed wetlands - Nature Based Solution technology which can be used to treat wastewater?									

Table 4. 45 Coefficients – WTA Reg3 – Jordan Community

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.241	.300		.804	.423
	Do you know that the conventional mechanical wastewater treatment plants considered as source of GHG which contribute to climate change?	-.049	.085	-.056	-.568	.571
	Do you know Constructed wetlands - Nature Based Solution technology which can be used to treat wastewater?	.109	.120	.118	.903	.369
	Do you know if it is applied in Jordan?	.154	.157	.113	.976	.331
	Do you know any advantages and benefits of using Constructed wetlands - NBS technology over the mechanical technology?	.064	.134	.061	.478	.634
	Do you prefer having constructed wetlands over the mechanical one?	.352	.100	.328	3.507	<.001
	Do you think the harvested reeds/plants (which will be harvested periodically) can be used locally?	.017	.080	.020	.208	.836

a. Dependent Variable: Would you accept to have WWTP using constructed wetlands technology in your town/city?

4. For the using CWs for treatment greywater at HH level, multiple linear regression was used to test if "*Do you think this technology can be source of odor?*", "*Do you think this technology attract insects and mosquitos?*", "*Do you think this technology requires large land area?*", and "*Do you have a problem with attracting birds and restoring biodiversity in the town?*" significantly affect the willingness to accept of having CWs in the house hold to treat

greywater "*If you know that Constructed wetlands can be applied in your household to treat the greywater, would you willing to have this technology in your house?*"

The fitted regression model was WTA of CWs in H.H = 1.734 – 0.228(odor concerns) + 0.03(insects concerns) – 0.061(land area concern) – 0.119 (restoring biodiversity)

The overall regression was statistically significant ($R2 = 0.094$, $F (4, 104) = 2.703$, $p = < 0.034$).

The details for this regression including factors and significance level are illustrated in Table 4.46 and Table 4.47

Table 4. 46 Model Summary – WTA Reg4 – Jordan Community

Model Summary									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.307[a]	.094	.059	.384	.094	2.703	4	104	.034
a. Predictors: (Constant), Do you have a problem with attracting birds and restoring biodiversity in the town?, Do you think this technology can be source of odor?, Do you think this technology requires large land area?, Do you think this technology attract insects and mosquitos?									

Table 4. 47 Coefficients – WTA Reg4 – Jordan Community

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.743	.221		7.889	<.001
	Do you think this technology can be source of odor?	-.228	.089	-.279	-2.560	.012
	Do you think this technology attract insects and mosquitos?	.030	.121	.028	.252	.802
	Do you think this technology requires large land area?	-.061	.098	-.060	-.622	.536
	Do you have a problem with attracting birds and restoring biodiversity in the town?	-.119	.084	-.138	-1.416	.160

a. Dependent Variable: If you know that Constructed wetlands can be applied in your household to treat the greywater (water coming from kitchen, sinks and washing machines), and you can use the treated water in irrigation in your yard or for toilet flushing would you willing to

5. For the using CWs for treatment greywater at HH level, multiple linear regression was used to test if "*Do you think this technology can be source of odor?*", "*Do you think this technology attract insects and mosquitos?*", "*Do you think this technology requires large land area?*", and "*Do you have a problem with attracting birds and restoring biodiversity in the town?*" significantly affect the willingness to pay of having CWs in the household to treat greywater "*Would you accept to pay for having Constructed wetlands in your house?*"

The fitted regression model was WTP of CWs in H.H = 2.143 – 0.268(odor concerns) - 0.01(insects concerns) – 0.154(land area concern) – 0.089 (restoring biodiversity)

The overall regression was statistically significant (R2 = 0.095, F (4, 104) = 2.73, p = < 0.033).

The details for this regression including factors and significance level are illustrated in Table 4.48 and Table 4.49

Table 4. 48 Model Summary – WTP Reg5 – Jordan Community

Model Summary									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.308[a]	.095	.060	.482	.095	2.729	4	104	.033
a. Predictors: (Constant), Do you have a problem with attracting birds and restoring biodiversity in the town?, Do you think this technology can be source of odor?, Do you think this technology requires large land area?, Do you think this technology attract insects and mosquitos?									

Table 4. 49 Coefficients – WTP Reg5 – Jordan Community

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.143	.277		7.728	<.001
	Do you think this technology can be source of odor?	-.268	.112	-.261	-2.403	.018
	Do you think this technology attract insects and mosquitos?	-.010	.152	-.007	-.064	.949

	Do you think this technology requires large land area?	-.154	.124	-.120	-1.244	.216
	Do you have a problem with attracting birds and restoring biodiversity in the town?	-.089	.105	-.083	-.848	.399
a. Dependent Variable: would you accept to pay for having Constructed wetlands in your house?						

6. Thae regression has been carried out based on the result of the first regression analyzed, it was found that several independent variables from different categories of questions have significantly affect the WTA of having CWs to treat wastewater near the respondent's house, due to that another regression has been carried out to study the impact of these significantly affected WTA within their categories. For this regression the independent variables were; "*Do you think the climate change has a fast impacts in Jordan*?", "*Do you think this technology can be source of odor*?", "*Do you think this technology attract insects and mosquitos*?", "*Do you think this technology requires large land area*?" while the dependent variable was "*Would you accept to have WWTP using constructed wetlands technology close to your house?*".

The fitted regression model was WTA of having CWs near your house = 2.125 + 0.268(climate change fast impact) - 0.195(odor concern) – 0.237(insects concern) – 0.202(required land area concern)

The overall regression was statistically significant (R^2 = 0.244, F (4, 104) = 8.403, p = < 0.001).

Tables 4.50 and 4.51 summarize the results and the impact of each variable to the dependent variable

Table 4. 50 Model Summary – WTA Reg6 – Jordan Community

Model Summary									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.494[a]	.244	.215	.419	.244	8.403	4	104	<.001
a. Predictors: (Constant), Do you think this technology requires large land area?, Do you think the climate change has a fast impacts in Jordan? , Do you think this technology attract insects and mosquitos?, Do you think this technology can be source of odor?									

Table 4. 51 Coefficients – WTA Reg6 – Jordan Community

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.125	.239		8.902	<.001
	Do you think the climate change has a fast impact in Jordan?	.268	.101	.233	2.662	.009
	Do you think this technology can be source of odor?	-.195	.098	-.200	-1.995	.049
	Do you think this technology attract insects and mosquitos?	-.237	.129	-.183	-1.833	.070
	Do you think this technology requires large land area?	-.202	.105	-.166	-1.931	.056
a. Dependent Variable: Would you accept to have WWTP using constructed wetlands technology close to your house?						

4.4.3.2 Italian case study

Similar rot eh Jordanian community several regression analyses have been carried out to the Italian community to understand the Italian community's perspectives and compare it with the Jordanian community perspectives. Table 52 summarize the regression analysis carried out and their results of significancy. while the details for each significant regression are explained further below.

Table 4. 52 Summary of regression analysis – Italy community

#	Dependent	Independent variables	Significant/ not Significant
1	Would you accept to have WWTP using constructed wetlands technology close to your house?	• Age • Gender • Education level • City	Not significant
2		• Are you aware about the global climate change issue? • Do you think Italy is affected by the climate change impacts? • Do you think the climate change has a fast impact in Italy? • Do you think that Italy is facing water scarcity issues?	Slightly significant
3		• Is your house connected to a sewer system? • If your house isn't connected to the sewer system, do you have sanitation system in your household (septic tank, ciss pit …)? • How much it costs you to manage your wastewater (monthly or every three months, please indicate the period)? • monthly	Not significant
4		• Do you know that the conventional mechanical wastewater treatment plants considered as source of GHG which contribute to climate change? • Do you know Constructed wetlands - Nature Based Solution technology which can be used to treat wastewater?	Not significant

#	Dependent	Independent variables	Significant/ not Significant
		• Do you know if it is applied in Jordan? • Do you know any advantages and benefits of using Constructed wetlands - NBS technology over the mechanical technology? • Do you prefer having constructed wetlands over the mechanical one? • Do you think the harvested reeds/plants (which will be harvested periodically) can be used locally?	
5		• Do you think this technology can be source of odor? • Do you think this technology attract insects and mosquitos? • Do you think this technology requires large land area? • Do you have a problem with attracting birds and restoring biodiversity in the town?	Significant
6	Would you accept to have WWTP using constructed wetlands technology in your town/city?	• Age • Gender • Education level • City	Not significant
7		• Are you aware about the global climate change issue? • Do you think Jordan is affected by the climate change impacts? • Do you think the climate change has a fast impact in Jordan? • Do you think that Jordan is facing water scarcity issues?	Not significant
8		• Is your house connected to a sewer system? • If your house isn't connected to the sewer system, do you have sanitation system in your household (septic tank, ciss pit …)? • How much it costs you to manage your wastewater (monthly or every three months, please indicate the period)? • monthly	Not significant
9		• Do you know that the conventional mechanical wastewater treatment plants considered as source of GHG which contribute to climate change? • Do you know Constructed wetlands - Nature Based Solution technology which can be used to treat wastewater? • Do you know if it is applied in Jordan? • Do you know any advantages and benefits of using Constructed wetlands - NBS technology over the mechanical technology? • Do you prefer having constructed wetlands over the mechanical one? • Do you think the harvested reeds/plants (which will be harvested periodically) can be used locally?	Not significant
10		• Do you think this technology can be source of odor? • Do you think this technology attract insects and mosquitos? • Do you think this technology requires large land area? • Do you have a problem with attracting birds and restoring biodiversity in the town?	Significant
11	If you believe that this technology has the previous positive impact, are you willing to pay tax for implementing this technology in your town?	• Age • Gender • Education level • City	Not significant
12		• Are you aware about the global climate change issue? • Do you think Jordan is affected by the climate change impacts? • Do you think the climate change has a fast impact in Jordan? • Do you think that Jordan is facing water scarcity issues?	Not significant
13		• Is your house connected to a sewer system? • If your house isn't connected to the sewer system, do you have sanitation system in your household (septic tank, ciss pit …)? • How much it costs you to manage your wastewater (monthly or every three months, please indicate the period)?	Not significant
14		• Do you know that the conventional mechanical wastewater treatment plants considered as source of GHG which contribute to climate change? • Do you know Constructed wetlands - Nature Based Solution technology which can be used to treat wastewater? • Do you know if it is applied in Italy? • Do you know any advantages and benefits of using Constructed wetlands - NBS technology over the mechanical technology? • Do you prefer having constructed wetlands over the mechanical one?	Not significant

#	Dependent	Independent variables	Significant/ not Significant
		• Do you think the harvested reeds/plants (which will be harvested periodically) can be used locally?	
15		• Do you think this technology can be source of odor? • Do you think this technology attract insects and mosquitos? • Do you think this technology requires large land area? • Do you have a problem with attracting birds and restoring biodiversity in the town?	Not significant
16	If you know that Constructed wetlands can be applied in your household to treat the greywater (water coming from kitchen, sinks and washing machines), and you can use the treated water in irrigation in your yard or for toilet flushing would you willing to have this technology in your house?	• Age • Gender • Education level • City	Not significant
17		• Are you aware about the global climate change issue? • Do you think Jordan is affected by the climate change impacts? • Do you think the climate change has a fast impact in Jordan? • Do you think that Jordan is facing water scarcity issues?	Not significant
18		• Is your house connected to a sewer system? • If your house isn't connected to the sewer system, do you have sanitation system in your household (septic tank, ciss pit …)? • How much it costs you to manage your wastewater (monthly or every three months, please indicate the period)? • monthly	Not significant
19		• Do you know that the conventional mechanical wastewater treatment plants considered as source of GHG which contribute to climate change? • Do you know Constructed wetlands - Nature Based Solution technology which can be used to treat wastewater? • Do you know if it is applied in Jordan? • Do you know any advantages and benefits of using Constructed wetlands - NBS technology over the mechanical technology? • Do you prefer having constructed wetlands over the mechanical one? • Do you think the harvested reeds/plants (which will be harvested periodically) can be used locally?	Not significant
20		• Do you think this technology can be source of odor? • Do you think this technology attract insects and mosquitos? • Do you think this technology requires large land area? • Do you have a problem with attracting birds and restoring biodiversity in the town?	Not significant
21	Would you accept to pay for having Constructed wetlands in your house?	• Age • Gender • Education level • City	Not significant
22		• Are you aware about the global climate change issue? • Do you think Italy is affected by the climate change impacts? • Do you think the climate change has a fast impact in Italy? • Do you think that Italy is facing water scarcity issues?	Not Significant
23		• Is your house connected to a sewer system? • If your house isn't connected to the sewer system, do you have sanitation system in your household (septic tank, ciss pit …)? • How much it costs you to manage your wastewater (monthly or every three months, please indicate the period)?	Not Significant
24		• Do you know that the conventional mechanical wastewater treatment plants considered as source of GHG which contribute to climate change? • Do you know Constructed wetlands - Nature Based Solution technology which can be used to treat wastewater? • Do you know if it is applied in Jordan? • Do you know any advantages and benefits of using Constructed wetlands - NBS technology over the mechanical technology? • Do you prefer having constructed wetlands over the mechanical one? • Do you think the harvested reeds/plants (which will be harvested periodically) can be used locally?	Significant
25		• Do you think this technology can be source of odor? • Do you think this technology attract insects and mosquitos?	Not significant

#	Dependent	Independent variables	Significant/ not Significant
		• Do you think this technology requires large land area? • Do you have a problem with attracting birds and restoring biodiversity in the town?	

Details for significant regressions

As illustrated in Table 52, four regressions were significant as listed below

1. Multiple linear regression was used to test if *climate change awareness*, *knowledge about climate change on Italy*, *if the climate change has a fast impact on Italy* and *the knowledge about Italian water resources* significantly affect the willingness to accept of having CWs close to the household "*Would you accept to have WWTP using constructed wetlands technology close to your house?*"

The fitted regression model was WTA of CWs near H.H = 1.55 + 0.39(climate change awareness) - 1.028(Italy affected by climate change) + 0.206(Climate change has fast impact on Italy) + 0.156(Italy water scarcity)

The overall regression was statistically can be considered as slightly significant (R2 = 0.074, F (4, 115) = 2.289, p = 0.064).

The details for this regression including factors and significance level are illustrated in Table 4.53 and Table 4.54

Table 4. 53 Model Summary – WTA Reg1 – Italy Community

Model Summary									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.272[a]	.074	.042	.474	.074	2.289	4	115	.064

a. Predictors: (Constant), Do you think that Italy is facing water scarcity issues? Do you think the climate change has a fast impacts in Italy? , Are you aware about the global climate change issue?, Do you think Italy is affected by the climate change impacts?

Table 4. 54 Coefficients – WTA Reg1 – Italy Community

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.550	.488		3.178	.002
	Are you aware about the global climate change issue?	.390	.218	.176	1.785	.077
	Do you think Italy is affected by the climate change impacts?	-1.028	.535	-.194	-1.920	.057
	Do you think the climate change has a fast impact in Italy?	.206	.152	.129	1.359	.177
	Do you think that Italy is facing water scarcity issues?	.156	.091	.158	1.721	.088
a. Dependent Variable: Would you accept to have WWTP using constructed wetlands technology close to your house?						

2. Multiple linear regression was used to test if “*Do you think this technology can be source of odor*?”, “*Do you think this technology attract insects and mosquitos*?”, “*Do you think this technology requires large land area*?”, and “*Do you have a problem with attracting birds and restoring biodiversity in the town*?” significantly affect the willingness to accept of having CWs close to the household “*Would you accept to have WWTP using constructed wetlands technology close to your house*?”

The fitted regression model was WTA of CWs near H.H = 1.877 – 0.24(odor concerns) + 0.002(insects concerns) – 0.148(land area concern) + 0.055 (restoring biodiversity)

The overall regression was statistically significant (R2 = 0.1, F (4, 115 = 3.175, p = < 0.016).

The details for this regression including factors and significance level are illustrated in Table 4.55 and Table 4.56

Table 4. 55 Model Summary – WTA Reg2 – Italy Community

Model Summary									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.315[a]	.099	.068	.467	.099	3.175	4	115	.016

a. Predictors: (Constant), Do you have a problem with attracting birds and restoring biodiversity in the town?, Do you think this technology can be source of odor?, Do you think this technology requires large land area?, Do you think this technology attract insects and mosquitos?

Table 4. 56 Coefficients – WTA Reg2 – Italy Community

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.877	.243		7.737	<.001
	Do you think this technology can be source of odor?	-.240	.093	-.245	-2.581	.011
	Do you think this technology attract insects and mosquitos?	.002	.097	.003	.025	.980
	Do you think this technology requires large land area?	-.148	.090	-.154	-1.656	.100
	Do you have a problem with attracting birds and restoring biodiversity in the town?	.055	.088	.056	.627	.532

a. Dependent Variable: Would you accept to have WWTP using constructed wetlands technology close to your house?

3. Multiple linear regression was used to test if "*Do you think this technology can be source of odor*?", "*Do you think this technology attract insects and mosquitos*?", "*Do you think this technology requires large land area*?", and "*Do you have a problem with attracting birds and restoring biodiversity in the town*?" significantly affect the willingness to accept of having CWs close to the household "*Would you accept to have WWTP using constructed wetlands technology in your town/city*?"

The fitted regression model was WTA of CWs in your town/city = 1.257 – 0.068(odor concerns) - 0.046(insects concerns) + 0.022(land area concern) - 0.053 (restoring biodiversity)

The overall regression was statistically significant (R2 = 0.08, F (4, 115 = 2.474, p = < 0.048).

The details for this regression including factors and significance level are illustrated in Table 4.57 and Table 4.58

Table 4. 57 Model Summary – WTA Reg3 – Italy Community

Model Summary									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.281[a]	.079	.047	.176	.079	2.474	4	115	.048
a. Predictors: (Constant), Do you have a problem with attracting birds and restoring biodiversity in the town?, Do you think this technology can be source of odor?, Do you think this technology requires large land area?, Do you think this technology attract insects and mosquitos?									

Table 4. 58 Coefficients – WTA Reg3 – Italy Community

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.257	.091		13.763	<.001
	Do you think this technology can be source of odor?	-.068	.035	-.186	-1.937	.055
	Do you think this technology attract insects and mosquitos?	-.046	.037	-.126	-1.255	.212
	Do you think this technology requires large land area?	.022	.034	.061	.644	.521
	Do you have a problem with attracting birds and restoring biodiversity in the town?	-.053	.033	-.145	-1.605	.111
a. Dependent Variable: Would you accept to have WWTP using constructed wetlands technology in your town/city?						

4. Another multiple linear regression was used to test if "*Do you know that the conventional mechanical wastewater treatment plants considered as source of GHG which*

contribute to climate change?", "*Do you know Constructed wetlands - Nature Based Solution technology which can be used to treat wastewater*?", "*Do you know if it is applied in Italy*?", "*Do you know any advantages and benefits of using Constructed wetlands - NBS technology over the mechanical technology*?", *Do you prefer having constructed wetlands over the mechanical one*?", and "*Do you think the harvested reeds/plants (which will be harvested periodically) can be used locally*?" significantly affect the willingness to accept to pay for having CWs to treat greywater at H.H level " *Would you accept to pay for having Constructed wetlands in your house*?"

The fitted regression model was WTP of having CWs for greywater treatment in your house = 0.519 + 0.054(knowledge about GHG from mechanical technology) + 0.138(knowledge about NBS-CWs) + 0.083(knowledge in NBS applied in Jordan) - 0.2 (knowledge about advantages of NBS over mechanical) + 0.415 (preference of CV over mechanical) + 0.131(if harvested reeds can be used)

The overall regression was statistically significant ($R2 = 0.146$, $F (6, 113) = 3.873$, $p = < 0.001$).

The details for this regression including factors and significance level are illustrated in Table 4.59 and Table 4.60

Table 4. 59 Model Summary – WTP Reg4 – Italy Community

Model Summary									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.413[a]	.171	.127	.419	.171	3.873	6	113	.001

a. Predictors: (Constant), Do you think the harvested reeds/plants (which will be harvested periodically) can be used locally?, Do you know that the conventional mechanical wastewater treatment plants considered as source of GHG which contribute to climate change ?, Do you prefer having constructed wetlands over the mechanical one? , Do you know if it is applied in Italy?, Do you know Constructed wetlands - Nature Based Solution technology which can be used to treat wastewater?, Do you know any advantages and benefits of using Constructed wetlands - NBS technology over the mechanical technology?

Table 4. 60 Coefficients – WTP Reg4 – Italy Community

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.519	.266		1.946	.054
	Do you know that the conventional mechanical wastewater treatment plants considered as source of GHG which contribute to climate change ?	.054	.092	.059	.582	.562
	Do you know Constructed wetlands - Nature Based Solution technology which can be used to treat wastewater?	.138	.105	.152	1.310	.193
	Do you know if it is applied in Italy?	.083	.126	.068	.659	.511
	Do you know any advantages and benefits of using Constructed wetlands - NBS technology over the mechanical technology?	-.200	.130	-.196	-1.541	.126
	Do you prefer having constructed wetlands over the mechanical one?	.415	.096	.378	4.312	<.001
	Do you think the harvested reeds/plants (which will be harvested periodically) can be used locally?	.131	.130	.088	1.010	.314
a. Dependent Variable: would you accept to pay for having Constructed wetlands in your house?						

4.5 Summary and Conclusion

4.5.1 Summary

In this study and to follow with better understanding about the opportunities and challenges in integrating CWs – NBs in Jordan and Italy, two levels of questionnaire have been carried: stakeholders' level and community level. The questions have been categories into sub-categories, for the community the categories consisted of 1) personal information questions, such as gender age, educational level, etc. 2) general questions about climate change and water scarcity problems to raise the respondent's attention, 3) question about their sanitation situations of the respondents, and their sanitation knowledge including the required costs for managing wastewater for every respondent. 4) question about the respondent's knowledge about wastewater treatment technologies with a focus on NBS and CWs. 5) questions about reuse of treated wastewater in agricultures. 6) question about the benefits of having CWs to treat wastewater, and their preferences when having CWs project. 7) questions about the disadvantages and challenges of applying CWs, 8) willing to accept questions, willing to pay questions of having CWs to treat wastewater and greywater at household level, 9) and question about the economical evaluation and reuse of the harvested reeds.

While for stakeholder the categories were, 1) starting questions about the general conditions and facts about the water and wastewater sector, 2) questions related to using CWs in wastewater treatment, 3) question to scale and rank the benefits of using CWs in treating wastewater, 4) question to scale and rank the most possible challenges that might face application of CWs, 5) and lastly an open area question for stakeholders to add their notes and comments

Implementing the survey in that way helped to understand the gap between the stakeholders' perspectives about CWs – NBS and the community perspectives. For instance, Jordanian stakeholders considered people acceptance to this technology is one of the challenges, while the survey showed the level of acceptance for CWs is high and people preferred CWs over mechanical solutions. The survey also will help stakeholders to understand the community perspectives and preferences regarding implementing wastewater treatment projects, thus the stakeholders can priorities and carefully select their interventions to meet the community's expectations.

Within the Jordan case study, stakeholders scored the following benefits of having CWs; providing source of treated wastewater, required low energy, can be used as a decentralization and easy to manage the sludge and by products over the other benefits, and that reflect the current Jordanian water and sanitation situation in as a limited resources country. While the least scores went for flexibility of treatment process, required unskilled labors, adheres to legislation, and can be used as a centralized solution and that also reflects limited interests in CWs as centralized solutions comparing to decentralization. Jordanian stakeholders didn't see that CWs required unskilled labors as main advantages and that can be due to the availability of local skills and experts in CWs. the same is applied for adhering with the legislation and standards but for this benefit Jordanian stakeholders have seen it as challenge rather than a benefit.

Jordanian stakeholders have ranked the institutional situations, the availability of funding for both implementation and operations as the highest challenge in integrating CWs in the Jordanian sector. These challenges can be classified as general challenge for the CWs and for any decentralization technology. The least improbable challenge is clogging problem within CWs and the willingness of private sector to invest and operate CWs, this can be justified based on the current CWs in Jordan have a good reputation and no complains have been raised about clogging, while for the private sector can be justified due to the absence of business model and clear investment vision for this kind of technology.

Most of Jordanian stakeholders gave high score to people acceptance challenge and according to their opinions, Jordanian people prefers mechanical solutions over CWs. However, the survey at the community level indicated that Jordanian community prefers CWs over mechanical solutions.

The Jordanian community considered as a highly educated community, their awareness level about climate change and water scarcity are high, and that are being reflected in their acceptance level of reusing treated wastewater as a source of water for irrigations. The general reputation of wastewater treatment plants (regardless the used technology) has affected the WTA for implementing one close people's living area, people usually reject of similar projects due to odor concern, attracting insects, and in general similar projects might reduce the land value. However, the Jordanian community is a ware about the benefits of CWs and they ranked several benefits for having CWs, the top ranking went for protecting human heath, followed by CWs provides source of water and the CWs have less gas emissions comparing to other solutions. While the least ranking went for low operation costs, protecting the environment, creating job opportunities. The previous ranking reflects the Jordanian awareness level and that can be helpful to stakeholders and decision makers to understand people's perspectives and to design their project on that basis.

Although the Jordanian people's WTA having CWs close to their houses is low, the WTA for having CWs in their town/city is higher and this is in general can be justified based on their concerns, and due to lack of examples of CWs in the country. It is worth to discuss that WTA for having CWs at H.H level for greywater is relatively high comparing to WTA for having

CWs to treat wastewater in the town. Regarding WTP around half of the Jordanian showed interests and WTP for having CWs for wastewater in the town while the WTP for having CWs for greywater is higher and this can be due to the personal benefits of having CWs at H.H level, this point can be useful for stakeholders who works in similar approach. The average WTP for having CWs in H.H was (0 – 100) JD, and this can be considering a positive potential for stakeholders.

From economy point of view and for the potential of reusing harvested reeds, several options have been suggested from the respondents of reusing harvested reeds and the total percentage showed that 56% of Jordanian considered the harvested reeds can have a value locally.

According to the regression analysis, mainly the community's concerns regarding the odor, attracting insects and the land requirements are the main factors affecting people's WTA and WTP, therefore stakeholders have to focus on these points to increase the level of WTA and WTP. Other factors are the general awareness of about climate change and water scarcity in Jordan, the regression analysis showed a significant impact of that on WTA CWs near their houses. The last category with significant impacts is the knowledge about NBs and CWs and their impacts to climate change and other benefits, hence raising awareness sessions in the phase of feasibility study for CWs projects can play a vital role in increasing WTP and WTA levels

For Italian community, the two levels of survey were also important to understand the Italian stakeholders' perspectives and the Italian community's perspectives. Similar to Jordanian case the survey also will help stakeholders to understand the community perspectives and preferences regarding implementing wastewater treatment projects, thus the stakeholders can priorities and carefully select their interventions to meet the community's expectations.

Italian stakeholders scored the following benefits of having CWs; can be used as a decentralization, generate less sludge and waste, lea energy required to manage the sludge and by products, required low energy over the other benefits, and that reflect the interests in Italian water and sanitation situation in solutions that consumes less energy. While the least scores went for providing green area, can be a financial resource with the harvested reeds, and can be centralized system and that also reflects limited interests in CWs as centralized solutions comparing to decentralization, and less interests in financial investigation.

Among the challenges, Italian stakeholders voted for land availability, WTA CWs by the decision makers, and willingness for private sector to operate and invest in CWs, as the more probable challenges to occur for CWs. It is highlight that while Italian considered the willingness f private sector to operate and invest in CWs as one of the top challenges, the Jordanian stakeholders considered that as the least challenge, that reflects the general management and orientation in water and sanitation sectors in both countries and can be a changing point for the Jordanian sector to engage the privet sector in similar contexts. The least challenges according to Italian context were clogging problems, source of odor, and availability of efficient plants for CWs, and that can be justified due to availability of several application of CWs within the country.

The Italian community also can be considered as a highly educated community, their awareness level about climate change and water scarcity are high, and that are being reflected in their acceptance level of reusing treated wastewater as a source of water for irrigations, the Italian acceptance percentage of consuming products irrigated with TWW (86%) is higher than the acceptance percentage within eh Jordanian community (60%). The general reputation of wastewater treatment plants (regardless the used technology) has a higher affected the Italian WTA for implementing one close people's living area comparing to the Jordanian one, in Jordan the acceptance percentage was 83% while in Italy was 53%. However, the Italian community is a ware about the benefits of CWs and they ranked several benefits for having CWs, the top ranking went for less gas emission and carbon sequestration, protecting human heath, followed by restoring biodiversity, and CWs provides source of water. While the least ranking went for easy to operate and maintain, source of harvested reeds, and creating job opportunities. The previous ranking reflects the Italian awareness level and the similarity with the Jordanian level.

The WTA for having CWs close to your house was 63% in Italian community while in Jordanian community was 33% only and this can be justified with the absence of CWs examples in Jordan and the availability of CWs in Italy also the knowledge level about CWs in Italian people comparing to Jordanian. WTA for having CWs at in town/city is extremely high with 97% of positive acceptance percentage. WTA for having CWs at H.H level for greywater is also high 94% comparing to 80% from Jordan. Regarding WTP around 62% of the Italian showed interests and WTP for having CWs for wastewater in the town compared to 53% from Jordan. the WTP for having CWs for greywater is 72% among Italian community comparing to 53% from Jordan. higher and this can be due to the personal benefits of having CWs at H.H level, this point can be useful for stakeholders who works in similar approach.

The average WTP foe having CWs at H.W level was (200 – 500) euros, and this is higher than the Jordanian WTP.

From economy point of view and for the potential of reusing harvested reeds, 90% of the Italian community thought the harvested reeds can be used locally compared to 56% of Jordanian community.

The regression analysis mainly showed that the almost the same factors affected the Jordanian community also affected the Italian responses. community's concerns regarding the odor, attracting insects and the land requirements are the main factors affecting people's WTA and WTP, other factors are the general awareness of about climate change and water scarcity in Italy. The last category with significant impacts is the knowledge about NBs and CWs and their impacts to climate change and other benefits, hence raising awareness sessions in the phase of feasibility study for CWs projects can play a vital role in increasing WTP and WTA levels. As a result, the Italian stakeholders can plan their interventions based on the significant factors in order to increase Italian community' WTA and WTP.

4.5.2 Conclusion

CWs and NBS have been raised and proved their capability as a treatment technology with a valuable role in solving the sanitation problems and considered as an appropriate and sustainable sanitation system for different contexts. Several benefits arising from CWs include, besides treatment capacity, provision of wildlife and habitat diversity, ability for recreational activities (e.g., bird watching), water storage, regulating weather temperatures, and aesthetic upgrade of the surrounding environment; urban or rural. Recently these co-benefits are playing a vital role in selecting NBS and CW as a sustainable solution, especially in the social aspect. through providing values for these benefits in order to include them under the financial sustainability and to integrate them easily with the circular economy approach.

This study included an extended survey to understand first the stakeholder's perspectives regarding NBS and CWs, and the community's perspectives. The survey used CV method to estimate people's WTP and WTA of having CWs – NBS. the study also analyzed the main factors that affected people's WTP and WTA.

This study has been carried out in two Mediterranean countries to understand the differences between the communities and to help the stakeholders to understand each communities' perspectives in order to plan and design their interventions carefully to assure the sustainability.

The study found that what stakeholders considered it a challenge, could have a different perspective from the community, and that identified several areas where stakeholders should consider in their project planning such as raising awareness. The study also found the level of WTA of having CWs varied according to their application, it was found that the WTA for CWs at H.H level to treat greywater has higher WTA and WTP than having CWs for wastewater near the living area or in the town/city.

The main factors affected WTP, and WTA are people's concerns related to odor, insects and land required for CWs, general awareness about climate change and water security, and important factors were the general knowledge about NBS and CWs.

Finally, it has been noticed in this chapter that the Jordanian stakeholders have concerns about the sustainability of CWs – NBS as a treatment technology in the local sector, therefore further activities have been considered in this research that focused in comparing CWs to the local treatment technologies using sustainability assessment tools and that has been translated in the next chapter.

Chapter 5: Analysis for cases in Jordan using Multi-criteria analysis (MCA) tool (Published Paper)[2].

This chapter focuses on the Jordanian context and illustrates two cases of comparison between CWs – NBS and other treatment alternatives. This research also utilized the growing demand for integrating an assessment tool to select treatment alternatives based on sustainability in the Jordanian wastewater sector. Therefore, this study proposes and develops a Multi-Criteria Analysis (MCA) tool to evaluate wastewater treatment alternatives from a sustainability perspective for two case studies, firstly a case study in Jordan - Al Azraq town level, and secondly at governmental building level – Mosque. Firstly, the study explored the decision and organizational context of the wastewater sector through several interviews. Secondly, assessment criteria and indicators were proposed to compare three proposed treatment alternatives. Finally, the Analytical Hierarchy Process was applied with composite scores to evaluate treatment alternatives. The results of this chapter have indicated the sustainability of CWs -NBs among other alternatives, the results have been also published as an article in Sustainability journal.

5.1 Introduction

In Jordan, the daily water share per capita is approximately 100 liters, this fact has ranked Jordan as the second poorest country with the water availability per person (MWI, 2017). The country is suffering from water scarcity that was caused by rapid population growth, huge influx of refugees and hydro - political tensions in the Middle East (Al-Bakri et al., 2019). This has led to continuously increasing demand on water and is exceeding the potential of the country's water resources (Qdais et al., 2019). The well-known climate change impacts have worsened the Jordanian water sector through adding more challenges to the availability and variability of precipitation, extreme events and heats waves, and that creates an imbalance in water management and widens the gap between the demand and the water supply (Hammouri et al., 2015).

As mentioned before in chapter three according to the Ministry of Water and Irrigation (MWI) reports, the main sources of water in Jordan are i) ground water ii) surface water, iii) treated

[2] The first section of this chapter (from 5.1 to 5.4) has been published as an article paper at Sustainability Journal with the following details: Masoud, A.M.N.; Belotti, M.; Alfarra, A.; Sorlini, S. Multi-Criteria Analysis for Evaluating Constructed Wetland as a Sustainable Sanitation Technology, Jordan Case Study. Sustainability 2022, 14, 14867. https://doi.org/10.3390/su142214867

wastewater (generated from 33 wastewater treatment plants), and additional resources (desalination) (MWI, 2016b, 2017).

Although the Jordanian government is considering treated wastewater as part of the annual water budget used in agriculture sector, the sanitation sector still requires upgrading and more sustainable solutions. To overcome this challenge and to enhance reusing wastewater the Jordanian government has prepared National Water Strategy 2016 – 2025, the strategy focuses on building a resilient sector based on a unified approach for a comprehensive social, economic, and environmentally viable water sector development. The policy includes a Decentralization Wastewater Management Policy which aims to activate the decentralization concept in managing wastewater for small and scattered communities to serve them with sanitation services and to enhance collection and reusing of wastewater (MWI, 2016b). MWI has established an inter-ministerial National Implementation Committee for Effective Integrated Wastewater Management (NICE) in order to develop regulatory and administrative tools for implementing and certifying decentralized wastewater management (DWWM) systems in Jordan (MWI, 2016a; UFZ & MWI, 2021). At the centralization level, MWI has prepared a plane to upgrade, modify and expand the exists wastewater treatment plants in order to increase the amount of treated wastewater (MWI, 2016b). Despite all of that, 35% of Jordanian are still not connected to sewer networks and wastewater treatment plants. They have onsite solutions like septic tanks, and this causes environmental and health risks as well as affecting the future potential for reusing treated wastewater (MWI, 2017). These 35% are living in rural and semi-rural areas, and with total population of less than 15000. Several projects and initiatives carried out by MWI and other international agencies to serve these underserved communities with a safe sanitation system that start from collection to safe disposal and reuse of treated wastewater. For this regard, MWI has prepared a decision support tool called "Assessment of Local Lowest-Cost Wastewater Solutions" (ALLOWS) decision-support tool. ALLOWS tool used to identify most cost-efficient wastewater management solutions and to determine whether a centralized or a decentralized approach is economically more appropriate for a specific case. ALLOWS tool focuses on financial indicators for different wastewater scenarios and accordingly enables planners and decision-makers to perform a comparative analysis to identify best solutions for the wastewater management problem at hand, the tool consider main factor such as the current and projected long-term demographic developments, connection degree, groundwater status and vulnerability to pollution, local reuse options, potential treatment technologies based on local wastewater quantity and quality, existing infrastructures and geographical conditions (MWI, 2016a; UFZ & MWI, 2021).

ALLOWS tool is mainly considering the financial criteria and part of technical criteria in comparing treatment scenarios without considering the other sustainability criteria such as the institutional, environmental and the social. And that justified the social rejections for sanitation projects before and justified changing the operation scenarios for other projects also. Therefore, it is necessary to integrate a sufficient analysis tool to carefully evaluate, assess, and select a sustainable wastewater treatment processes or technologies that consider a wider vision of sustainability before making the asset decision (MWI, 2016a; UFZ & MWI, 2021).

5.2 Sustainability Assessment Tools

Sustainability assessments are increasingly popular tools used in management practices and decision-making processes (Waas et al., 1990; Xue et al., 2015a, 2015b). Sustainability assessment includes a wide range of assessment tools and is basically associated with the practice of impact assessment. Typically, sustainability assessments evaluate the future consequences of current or proposed options and informs decision makers (Gasparatos et al., 2008; Pope et al., 2004). According to Hugé et al. sustainability assessment should include three main elements to assist decision making process: "interpretation, information-structuring and influence" (Hugé et al., 2011). Precisely, sustainability should be interpreted and tailored to a specific social and organizational context. Information-structuring means to develop an understanding of the complexity of sustainability in that context. Sustainability assessment should exert a strong influence on decision-making and implementation of sustainability (Waas et al., 1990).

Several tools have been developed and studied to perform sustainability assessments. (Gasparatos & Scolobig, 2012) provided an overview of three families of sustainability assessment tools based on the underlying valuation perspective (Gasparatos & Scolobig, 2012). Biophysical tools evaluate the flow of resources and environmental impacts such as life cycle assessment (LCA). Monetary and economy tools aim to provide valuations based on the subjective value preference of individuals such as the cost–benefit analysis (CBA). The last family is indicator-based tools, which include the selection of indicators, weightings, scoring and aggregation. Although assessment tools focus on a single valuation perspective are well developed, there is a demand for integrating assessment approaches with a holistic sustainability perspective which include Environmental, Social and Economic sustainability

(Padilla-Rivera et al., 2019; Xue et al., 2015b). For a better management, stakeholders are required to understand the complexity of sustainability in their relevant context and evaluate trade-offs between different sustainability criteria (Ashley et al., 2008; Ling et al., 2021). Multi-Criteria Analysis (MCA) is a collective term of methods that deal with multiple and often conflicting criteria and identify the most preferred option based on the preference systems of decision makers (Niekamp et al., 2015). MCA guides for a logical and coherent decision-making process by applying a standardized method. There is a variety of methods in MCA such as Analytical Hierarchy Process (AHP), Multi-Attribute Value Theory (MAVT) and outranking methods (Ling et al., 2021). MCA has been widely applied in the areas of environmental science and management and comprehensive reviews were provided by (Kiker et al., 2005) and (I. B. Huang et al., 2011).

Sustainability criteria and indicators are widely used in MCA to provide a measurement system. Sustainability criteria can be defined as the requirement or standards to achieve sustainable services or products in a specific context. Indicators are the specific measurements or assignments of value to reflect the fulfilment of assessment criteria and the sustainability (Pavlovskaia, 2014). Balkema et al provided a comprehensive list of indicators from previous studies to compare wastewater treatment technologies based on the environmental, technical, social-cultural and economic criteria (Balkema et al., 2002). Most common environmental indicators include energy use and pollutant removal. The amount of required energy to operate the wastewater system has a direct impact on the operational cost as well as carbon footprint. Compliance with the local discharge and reuse standard is a main objective of wastewater treatment works and therefore the pollutant removal efficiency of the treatment process are key criteria. In terms of economic indicators, both capital expenditure, operational expenditure and resource recovery are mostly used. Although environmental and economic indicators are well-developed, social indicators are often ignored due to difficulties in measurement and quantification (Ahmed et al., 2017; Balkema et al., 2002; Ling et al., 2021; Muga & Mihelcic, 2008). However, social indicators can be converted into the quantitative format using a point-based scale (Molinos-Senante et al., 2014; Popovic et al., 2013) and using willingness to accept (WTA) and willingness to pay (WTP) indicators.

Previous studies have integrated all sustainability dimension when assessing wastewater treatment technologies (Balkema et al., 2002; Molinos-Senante et al., 2014; Muga & Mihelcic, 2008). As a common multi-criteria problem, selecting between different sustainability dimensions are necessary to reach a final selection among options (Finkbeiner et al., 2010). As a result, weightings have been developed to aggregate indicators into a composite index for each option. Gherghel et al. (2020) have used a Weighted Sum Model to aggregate the performance of six criteria into a 'preference index' in order to compare different wastewater treatment systems (Gherghel et al., 2020). Molinos-Senante et al. (2014) have developed a 'Global Sustainability Indicator' to evaluate seven wastewater treatment technologies based considering environmental, social, and economic dimensions (Molinos-Senante et al., 2014). These studies illustrated that composite indicator can be a practical approach to integrate multiple sustainability criteria.

Generally, sustainability assessment methods developed from academic literature and private water companies usually haven't a clear methodology and guidance on how to adopt a sustainability assessment approach and make it usable and feasible. From the other hand the implementation of similar tools specifically for the wastewater management is still limited, especially in the Jordanian sanitation sector which is already facing several challenges. In light of such a demand, this study aims to develop and propose a sustainability assessment framework based on MCA approach to assess and compare the sustainability of different wastewater treatment options for Al Azraq town and based in the Jordanian context. In comparison to the previous MCA studies, the assessment framework developed in this study needs to be compatible with the corporate setting and the preference of stakeholders. Thus, the development process will also explore the decision-making context in the Jordanian sanitation sector.

5.3 Al Azraq Town Case study – CWs for treating wastewater

5.3.1 The current sanitation situation Al Azraq Town

Al Azraq town is one of the unserved towns in the eastern part of Jordan. It has a population of more than fifteen thousand people, who are not served with treatment system or sewer network. Residents in this town have onsite solutions at household level, and their wastewater is collected in a collection tank by gravity (Breulmann M. et al., 2020). The collection tanks have no standard size, and they can be classified into four classes i) fully sealed septic tank, ii) fully sealed septic tank with infiltration chamber, iii) Cesspits with rigid top-slab, walls and not sealed, and iv) Cesspit with make-shift top slab and not sealed. According to the Azraq

Municipality and based on the site assessments the most used is unsealed tanks, which cause seepage of wastewater. The sewage is collected via desludging trucks and disposed without further treatment to an illegal dumpsite, which contributes to pollution in the area and poses a very high risk to human health and environment.

On the other hand, Al Azraq town located over a main groundwater basin called Al Azraq Basin which is considered a unique source of fresh water for the desert, The total area of Al Azraq basin is 12,414 km^2 and extends from the Syrian borders in the north to the Saudi borders in the south, where 94% of the Azraq basin area is located in Jordan and the rest in Syria, nowadays more around 70 MCM/year of drinking water are being pumped to Amman and Zarqa from the basin and that covers 10% of the groundwater yearly abstraction in Jordan (MWI, 2017; Rakad Ta any et al., 2014). The illegal disposal causes the infiltration of not-treated wastewater in the lowest point of the dumpsite area and the risk of polluting the aquifer is very high (Musa et al., 2018). Al Azraq has also a Al Azraq Wetland Reserve in the heart of the basin where millions of migratory birds reset in every year during their travelling from Siberia to Africa and vice versa. This natural wetland has to be protected from the contamination of water and environment caused by the inappropriate sanitation system (al Qatarneh Ghada et al., 2018). Even though the municipality knows its obligation to treat the wastewater in a centralized treatment plant, the cost of the sewage trucking is not feasible, so it continues to increase the health risk related to the water contamination.

The critical situation of Al Azraq has caught the attention of many Non-Governmental Organizations (NGOs) who are working in sanitation and willing to implement projects of wastewater treatment in Jordan. An international donor has allocated a certain budget in order to serve the town a with a sustainable sanitation solution which can achieve the following benefits:

- Reduction of the health risk related to water contamination,
- Reduction of existing environmental risk,
- Provide new source of water for the community,
- Improvement of the resilience to climate change,
- Developed a model that could be repeated in future.

Although the fund has been allocated, selection of the most appropriate and sustainable treatment technology that can be suitable for the Jordanian context in general and for Al Azraq town in specific is required. A sustainability assessment tool was needed in order to help the decision makers with selecting the most appropriate technology for this context.

5.3.2 Materials and Methods

The development process adopted a mixed-methods approach based on a research paradigm. The development of the assessment framework was divided into five stages as described in Figure 5.1, firstly understanding the context; secondly development of the criteria hierarchy; thirdly development of weightings; fourthly score aggregation and options ranking and finally consistency index check. The development process was applied to compare different wastewater treatment technologies that can be sustainable and suitable for the selected case study. The results were then presented based on this structure and order (Ling et al., 2021).

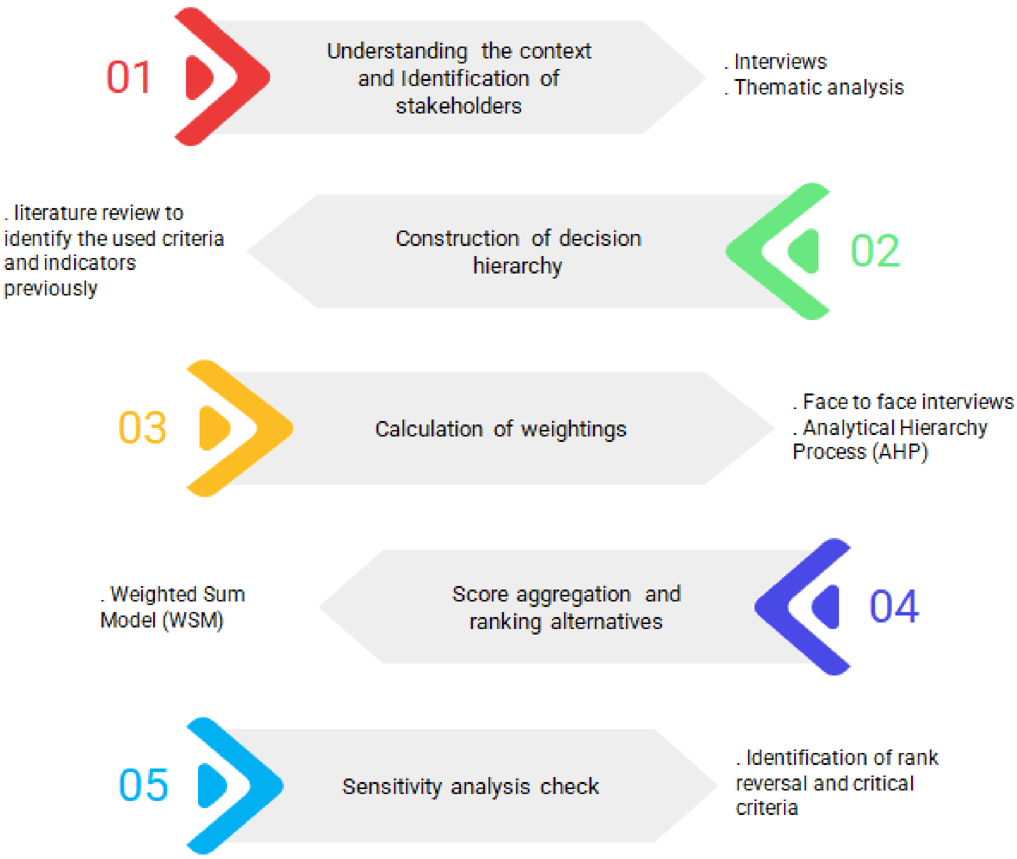

Figure 5. 1 The steps of developing of MCA

1. Understanding the context

As the first step, it is important to understand the context in detail from different aspects; the environmental, social, and economic conditions which are essential for the project development. Investigation about the town and the community has been started in order to have a general view of the current situation, identifying the gaps and the required awareness among the population about the problem in order to connect the community with the project.

The second step was the governance assessment to understand the legal framework, the local legislation and polices, and the reuse standards. This step also identifies the governmental stakeholders, their level of importance and roles within the project. The next step is the socio-economic analysis with main aim to tailor the project and the strategy to the specific selected context. Then, technical, and economic feasibility study are done to identify the cost-effective solution of the plant and the possible technical options. As a final step preliminary environmental and social impact assessment analysis were investigated to identify possible negative environmental impacts of the project.

Semi-structured interviews were conducted with stakeholders as a preliminary study to establish an understanding of the current drivers and challenges of selecting the wastewater treatment technologies for the selected case study. They also served as an opportunity to engage with key stakeholders during the development process of the assessment framework.

A stakeholder analysis was conducted to identify the key project stakeholders and their impacts to the project. Each interview included also the following key questions:

- What is your role related to the project?
- What are the current decision-making practices for selecting wastewater treatment technologies?
- What are the biggest challenges in making that decision?
- What are the alternative technologies that can be considered for the selected case?

Semi – structured interviews guideline prepared by Laforest were followed (Laforest et al., 2011) with the selected stakeholders. The interviews were conducted anonymously, each interview lasted for one hour with complete confidentiality of the answers and the gathered data and information, finally a validation of the answers with the respondent and an authorization of using the collected data were collected.

2. Development of the Criteria Hierarchy

The development and selection of a hierarchy with relevant assessment criteria and indicators is a critical part to guide multi-criteria measurements towards the main objective. For this research, a collection of relevant and most considered sustainability criteria and indicators were proposed based on information from literature review and the results from the thematic analysis of interviews with the stakeholders. First, a round of literature review and desk study were conducted to collect indicators that have been widely used to evaluate wastewater treatment technologies from previous similar studies as illustrated in Table 5.1. This list was further reviewed and discussed with stakeholders, and then refined to propose a set of relevant assessment indicators based on the key decision priorities mentioned in the interviews.

Table 5. 1 Common criteria and indicators to assess wastewater treatment technologies

Criteria	Indicator	References
Environmental	Soil and land contamination*	(Ling et al., 2021; Sabia et al., 2016)
	Greenhouse gas emission or carbon footprint*	(Ling et al., 2021; Mustapha et al., 2017; Sabia et al., 2016)
	Environmental impacts	(Kabir et al., 2014; Ling et al., 2021; Shariat et al., 2019)
	Nonrenewable raw material	(Kabir et al., 2014; Ling et al., 2021)
	Biodiversity	(A. Stefanakis et al., 2014)
	Durability	(Amorocho-Daza et al., 2019; Plakas et al., 2016; Ren & Liang, 2017)
	Stability*	(Ahmed et al., 2017; Amorocho-Daza et al., 2019; Ren & Liang, 2017; Sabia et al., 2016)
Institutional	Availability of local capabilities and local technical capabilities within the institution*	(Domínguez et al., 2019; Kabir et al., 2014; A. Stefanakis et al., 2014)
	Compatibility with the local strategies, standards*	(A. Stefanakis et al., 2014)
Technical	Pollutant's removal potentials	(Ahmed et al., 2017; Ling et al., 2021; Molinos-Senante et al., 2014; Muga & Mihelcic, 2008; Mustapha et al., 2017; Sabia et al., 2016)
	Amount of sludge produced*	(Ahmed et al., 2017; Domínguez et al., 2019; Molinos-Senante et al., 2014; Sabia et al., 2016)
	Generated By-products*	(Ahmed et al., 2017; Ling et al., 2021; Sabia et al., 2016)
	Ease of implementation	(Ahmed et al., 2017; Ling et al., 2021; Plakas et al., 2016);
	Ease of operation (ordinary and extraordinary maintenance)	(Ahmed et al., 2017; Ling et al., 2021; Plakas et al., 2016)
	Availability of local materials	(C. A. Arias et al., 2021; A. Stefanakis et al., 2014)
	Possibility to future expansion*	(A. Stefanakis et al., 2014)
	Small scale technologies used	(Ling et al., 2021; A. Stefanakis et al., 2014)
Social	Public acceptance – compatibility with general service level*	(Ahmed et al., 2017; Muga & Mihelcic, 2008; Plakas et al., 2016)
	Odor and noise impact*	(Ahmed et al., 2017; Molinos-Senante et al., 2014; Plakas et al., 2016)
	Provision of aesthetic and green places	(A. Stefanakis et al., 2014)
	Community participation and job opportunities*	(Ling et al., 2021; Molinos-Senante et al., 2014)
	Respect of local culture	(Ahmed et al., 2017; Ling et al., 2021; Mustapha et al., 2017)
	Health of the community	(Ahmed et al., 2017; Mustapha et al., 2017)
	Willingness to pay*	(Ahmed et al., 2017; Masi et al., 2018; Rizzo et al., 2020)
	Visual impact*	(Ahmed et al., 2017; Ling et al., 2021; Plakas et al., 2016)

Economic	Construction/Capital costs*	(A. R. Karimi; et al., 2011; Ahmed et al., 2017; Molinos-Senante et al., 2014; Muga & Mihelcic, 2008; Ren & Liang, 2017)
	Operation and maintenance costs*	(Ahmed et al., 2017; Molinos-Senante et al., 2014; Muga & Mihelcic, 2008; Mustapha et al., 2017)
	Land cost	(Ahmed et al., 2017; Kalbar et al., 2016; Molinos-Senante et al., 2014; Muga & Mihelcic, 2008; Ren & Liang, 2017)
	Local market incentive	(Masi et al., 2018; A. Stefanakis et al., 2014)
	Treated WW reuse*	(Kabir et al., 2014; A. Stefanakis et al., 2014)
	Land requirement*	(Ahmed et al., 2017; Ling et al., 2021; Molinos-Senante et al., 2014; Muga & Mihelcic, 2008)
	Chemical requirements	(Ling et al., 2021)
	Energy requirements*	(Ahmed et al., 2017; Molinos-Senante et al., 2014; Muga & Mihelcic, 2008)

* Also suggested by local stakeholder

3. Development of Weightings

3.1 Weighting Allocation Using Analytical Hierarchy Process (AHP)

For this study AHP, developed by Thomas Saaty, was preferred because of its simplicity in practice and its developed theoretical basis (Saaty, 1987), and it is the most widely used in MCA approach by the number of its applications (Ossadnik et al., 2016; Sipahi & Timor, 2010). The procedure of AHP is based on three components: anatomy of the problem as a hierarchical structure, pairwise comparisons and calculation of criteria priorities and weights (Bottero et al., 2011). Pairwise comparison is the main task of AHP. The fundamental question to be asked is 'how important is criteria X compared to criteria Y?' Each comparison determines the direction and degree of importance between two criteria or indicators using a semantic scale as described in Table 5.2 (Saaty, 1987). For example, a scale number 3 refers to criteria X is moderately more important than criteria Y whereas 1/3 refers to a reversed preference direction (criteria Y is moderately more important than criteria X).

Table 5. 2 The semantic scale for pairwise comparison in AHP.

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation A reasonable assumption
Reciprocals of above	If activity *i* has one of the above non - zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	
1.1-1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities

In terms of the collection of preference judgement, stakeholders were invited to a semi-structured interview to perform pairwise comparisons between criteria and indicators. Each stakeholder provided his/her preference judgements through a series of questions of pairwise comparisons.

First, the comparisons were made at the top level (i.e., criteria) of the hierarchy and then their corresponding lower level (i.e., indicators) of the hierarchy. A reciprocal matrix of $m \, X \, m$ is created based on m number of criteria (or indicators) to be compared as described in (Equation (1)).

$a_{1,m}$ indicates the judgement made between the first criteria and the m-th criteria, etc. In total, $m(m - 1)$ number of comparisons are required per matrix given the property of reciprocity in AHP. $(m + 1)$ number of matrices are required to calculate weights for each stakeholder (1 for comparisons between all criteria at the top level and m for comparisons between indicators within each criteria).

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} \\ a_{21} = 1/a_{12} & 1 & a_{23} \\ a_{31} = 1/a_{13} & a_{32} = 1/a_{23} & 1 \end{bmatrix} \qquad \text{Eq (5.1)}$$

The comparison matrix must be normalized to obtain the weight of each indicator. The method starts with the summing of each column as

$$a_{column j} = a_{1j} + a_{2j} + a_{3j} \qquad \text{Eq (5.2)}$$

and the normalized matrix is calculated by dividing each element by the sum of its column (Ling et al., 2021; Saaty, 1987).

$$A = \begin{bmatrix} 1/a_{column1} & a_{12}/a_{column2} & a_{13}/\,a_{column3} \\ a_{21}/a_{column1} & 1/a_{column2} & a_{23}/\,a_{column3} \\ a_{31}/a_{column1} & a_{32}/a_{column2} & 1/\,a_{column3} \end{bmatrix} \qquad \text{Eq (5.3)}$$

Then, the geometric mean is calculated for each row in order to calculate the weights for each indicator, Microsoft Excel has been used to calculate the geometric mean for each raw, for example the gematric mean for ***r** -th* raw is.

$$A_r = \sqrt[j]{\left(\prod_{n=1}^{j} a_{ij}\right)} = \sqrt[j]{a_{i1}a_{i2} \ldots a_{ij}} \qquad \text{Eq (5.4)}$$

At the end, the weight of each row indicator, which is called eigenvector, is given by the normalization of the mean through the ratio between the geometric mean of the row A_r divided to the sum of all the geometric means (Ling et al., 2021):

$$w_r = \frac{A_r}{\sum_{m=1}^{j} A_r} \qquad \text{Eq (5.5)}$$

The eigenvector w_r represents the weight of the indicator in a specific pairwise comparison (Ling et al., 2021; Saaty, 1987).

To verify the correctness of the procedure, the consistency ratio check is calculated for the entire comparison group to determine the consistency levels of judgements from stakeholders (Saaty, 1987). Responses with consistency ratios greater than 0.1 were revised and if CI remained greater than 0.1 then the responses is being excluded from further aggregation of the group weightings, Tolerating the 10% because the priority of consistency to obtain a coherent explanation of a set of facts must differ by an order of magnitude from the priority of inconsistency which is an error in the measurement of consistency. Thus, on a scale from 0 -1, inconsistency should not exceed 0.10 by very much (Saaty, 1987). The consistency ratio (CR) is given by

$$CR = \frac{CI}{RI} \qquad \text{Eq (5.6)}$$

Where CI is the consistency index and RI is the random index.

The CI is determined by

$$CI = \frac{\lambda - n}{n-1} \qquad \text{Eq (5.7)}$$

Where n is the number of the parameters in the comparison, criteria or indicators and λ is the principal Eigen value obtained from the summation of the product between the sum of the column $a_{columnj}$ and the normalized row geometric mean value, the eigenvector w_r.

The random index (RI) is a fixed value related to the number of indicators or criteria presents in the comparison. Table 5.3 below indicates RI values according to the literature (Lennartsson et al., 2009; Ling et al., 2021; Saaty, 1987).

Table 5. 3 Random Index RI values

N° of indicators	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

The value output of CR is compared to the fixed reference value 0.10, with this meaning:

$$if\ CR < 0.1\ the\ procedure\ is\ consistent, the\ calculated\ weight\ can\ be\ used$$

$$if\ CR > 0.1\ the\ procedure\ is\ inconsistent, check\ of\ the\ procedure.$$

3.2 Group Weightings

Each stakeholder generated one set of responses and one weighting profile. A group weighting is required to represent the collective responses on the importance of the selected criteria and indicators. According to literature, there are three ways of developing the group weighting can be used i) sharing; refers to the exchange of opinions and preference among all stakeholders and then select input of preference judgements for AHP calculation, ii) comparing; refers to the comparison of weightings developed from individual preference judgements and deciding which set of weights is the most representative, or iii) aggregating; means the aggregation and collection of individual weightings mathematically (Belton & Pictet, 1997; Ling et al., 2021). In this study mathematical aggregation was considered more suitable due to the time limitation, availability of the stakeholders and the COVID19 situation where social distancing conditions were required when this study was conducted. For this study, the geometric mean was performed to aggregate individual weightings into a group weighting as:

$$\overline{w_k^q} = \sqrt[q]{\left(\prod_{n=1}^{q} w_k\right)} = \sqrt[q]{w_k^1 w_k^2 \dots w_k^q} \qquad \text{Eq (5.8)}$$

Where $\overline{w_k^q}$ is the aggregated group wight for the k–th criteria or indicator based on q number of stakeholders, similarly to the normalization of weights from reciprocal matrix (Equation (5)), the aggregated group weights were normalized so the sum of all criteria equal to 1.

4. Score Aggregation and Options Ranking

Wastewater treatment technologies were selected for the application of the criteria hierarchy and group weightings which developed from previous stages. The name and location of the wastewater treatment plant (WWTP) was mentioned before in the study and clearly explained to the stakeholders. The proposed WWTP will be designed to serve a population of approximately 15,000. The following three treatment technologies were considered for the implementation of the treatment process:

1. Activated Sludge Process (ASP)
2. Stabilization Ponds Process (SP)
3. Constructed wetlands – (French constructed wetlands) FCW

The technologies have been selected based on the most used technologies in Jordan. Jordan has 33 centralized WWTPs (27 WWTP used ASP, and 6 WWTP used SP) while the third option FCW was proposed by the donor and the implementation partner as they are willing to evaluate using FCW as an application of NBS in the country. Several aspects have led the implementation partners to propose FCW for Al Azraq town as they have previously implemented several types CWs including FCW in the same environment and climate conditions in middle east, availability of local materials especially the tuff in Al Azraq town, availability of land area, and the simplicity of operating FCW. The treated wastewater will be used in fodder crops and uneatable agriculture according to the Jordanian standards 839 – 2021[3] (JSMO, 2021), and the selected options are able to treat the wastewater to the selected levels and this is illustrated through different WWTPs used the same technologies in Jordan and the neighboring countries. The Stakeholders validated the selected options.

[3] JS839 – 2021 is an update of JS839 - 2006 which is a technical regulation issued by *Jordan Standards and Metrology Organization (JSMO)* for Water – Reclaimed domestic wastewater (JSMO, 2006).

To compare the selected technologies, each technology needs to be included in a separate process design. Figure 5.2 shows the basic treatment process configurations of the three options to be compared. The proposed treatment processes started from pretreatment to sludge treatment and disposal. Detailed mechanical, chemical, and biological process designs are not included as the technical aspect of each wastewater treatment process is not discussed in this paper.

The criteria hierarchy and weightings developed in this study were applied to assess the overall scoring of each technology. The assessment of each indicator for each technology was provided in the format of performance ratings using a 5-point scale based on stakeholder's judgements. Then, a Weighted Sum Model (WSM) was used to generate performance ratings of indicators (v_1, v_2, . . . v_n) and their corresponding weights (w_1,w_2, . . . w_n) into a composite score Si for the i-th option as:

$$Si = \sum_{i=1}^{n} w_n v_n = w_1 v_1 + w_2 v_2 + \cdots w_n v_n \qquad \text{Eq (5.9)}$$

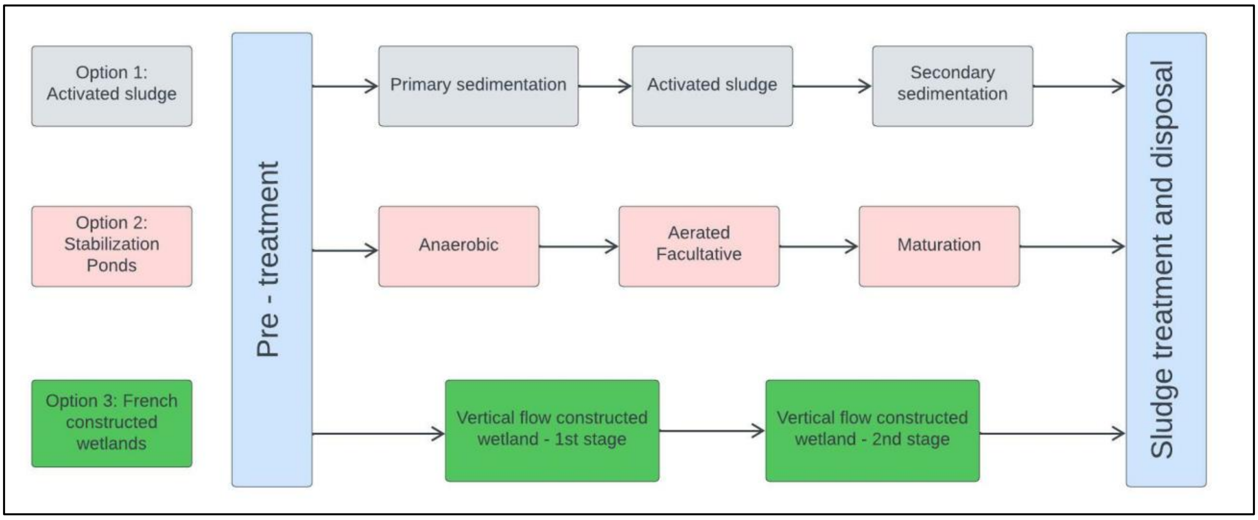

Figure 5. 2 Basic process design for the three selected technologies.[4]

5. Sensitivity analysis

It is a common practice in AHP to analyze the sensitivity of the composite score and the ranking of options to potential changes in criteria weights. This study included three elements of sensitivity analysis. First, the ranking of options was compared between using the aggregated group weightings and individual weightings to examine the consistency of rankings as a result of different weighting profiles.

[4] This study considered pretreatment, secondary and sludge treatment, and disposal according to the Jordanian standards for reuse JS893 – 2021

The second element was to identify the most critical indicator by calculating the minimum changes required in weights to cause a rank reversal. As the aim of this case study is to identify the best option, only the rank reversal between the top two options were considered. The steps for identifying the most critical indicator were based on the theorems developed by (Triantaphyllou & Sánchez, 1997) and used and illustrated by (Ling et al., 2021). The thermos said if the i-th option is the best and the j-th option is the second best by their composite scores ($S_i > S_j$), then the minimum change $\delta_{k.i.j}$ in the weight of indicator C_k to cause rank reversal between *i* an *j* can be calculated. If the performance of the *j-th* option is better than the *i-th* option with respect to the k-th indicator ($v_{jk} > v_{ik}$), then

$$\delta_{k,i,j} < \frac{S_j - S_i}{v_{jk} - v_{ik}} \qquad \text{Eq (5.10)}$$

If the performance *v* of the *i-th* option is better than the *j-th* option with respect to the k-*th* indicator ($v_{jk} < v_{ik}$), then

$$\delta_{k,i,j} > \frac{S_j - S_i}{v_{jk} - v_{ik}} \qquad \text{Eq (5.11)}$$

Additionally, the relative minimum change $\delta_{k.i.j}$ can also be expressed as:

$$\delta^{\backslash}_{k,i,j} = \left|\frac{\delta_{k,i,j}}{w_k}\right| X\ 100 \qquad \text{Eq (5.12)}$$

$\delta_{k.i.j}$ may not have a feasible value. In other words, it may be impossible to reverse the existing ranking of the alternative *i-th* and *j-th* by making changes on the current weight of criterion. This situation occurs when the value of $|\delta_{k.i.j}|$ is greater than weight value of indicator *k* (Triantaphyllou & Sánchez, 1997).

The third element used to check the sensitivity in this research is assume that the selected performance indicators have equal importance for all the stakeholders. Equally weighted criteria are a common situation, against which the sensitivity of the results is tested. In this case study the selected performance indicators are sixteen and thus each one has a weight factor of 100%/16 = 6.25%., considering the unified the weights for indicators and the composite scores from stakeholders, the final options ranking will be checked and compered to the ranking resulted from the MCA (Kabassi & Martinis, 2021; Kokaraki et al., 2019).

5.3.3 Results

- **Semi – structured interview and the thematic analysis**

Ten stakeholders from different sectors (government, academia, WWTP designers, WWTP operator donors, international NGOs, and local NGOs) participated in the study and the interview process. Firstly, the stakeholders evaluated and validated the suggested and proposed criteria and indicators, which is a summary of the thematic analysis and results from the stakeholders' interviews. Secondly the stakeholders validated and confirmed the selected technology options which illustrated in Figure 5.2.

- **Criteria hierarchy**

Based on the list of indicators summarized from literature in Table 5.1 and the results of the thematic analysis, the criteria hierarchy was proposed to the for assessing and selecting a sustainable of different wastewater treatment technology as shown in Figure 5.3.

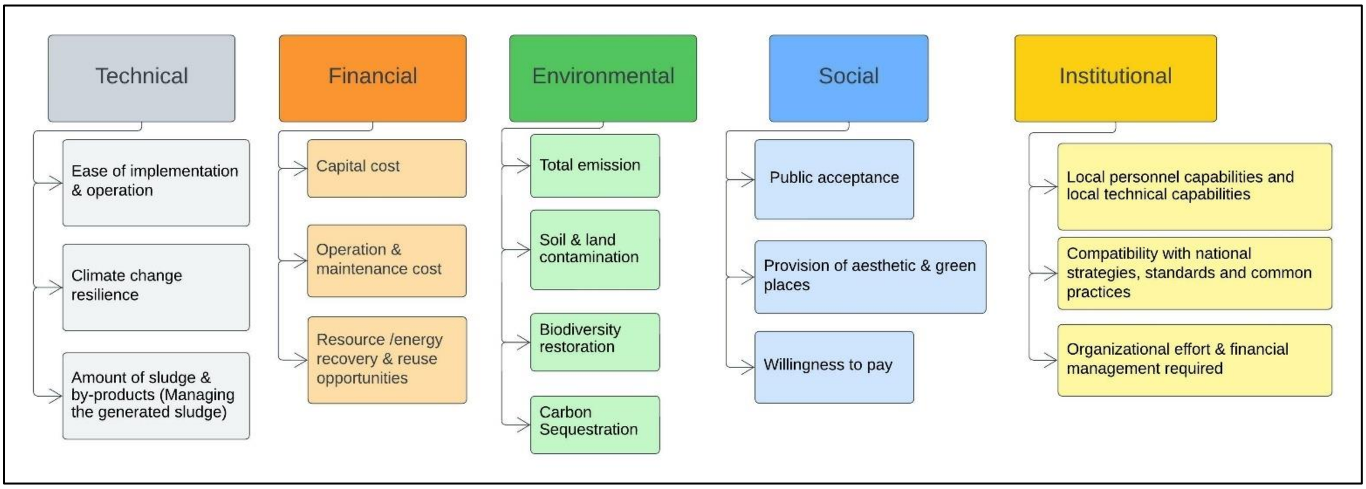

Figure 5. 3 Proposed criteria and indicators hierarchy for the sustainability assessment

The detailed definitions of selected indicators were summarized in Table C.1 in the appendix C.

The hierarchy consisting of three levels including the overarching decision objective, the second level of criteria based on the five aspects of sustainability and the lower level of assessment indicators to measure towards those criteria.

Sustainability criteria was commonly used in the previous studies (Ahmed et al., 2017; Ling et al., 2021; Mustapha et al., 2017; Plakas et al., 2016) to assess treatment technologies and using these criteria was validated by the stakeholders. Considering climate change resilience under the technical sustainability was suggested by stakeholders in order to have a resilient technology that can provide the same treatment efficiency under different climate conditions.

Management, treatment and disposal of sludge created a problem in Jordan and thus, “Amount of sludge and by-products – managing he generated sludge” has been selected as a technical indicator beside the ease of implementing and operating. Resource recovery and final reuse of the products have a priority according to the Jordanian situation in order to sustain the long-term operation under the financial sustainability criteria. The environmental sustainability has a special situation since the project will be in a Ramsar site were restoring the biodiversity has a priority and carbon sequestration as well, in order to minimize the total emission while protecting the soil and lands. For the social sustainability and based on onsite evaluation, it was found that providing an aesthetic place and green area is important indicators for the community and will enhance the possibility of willingness to accept and willingness to pay to have the service. Finally, the institutional sustainability, as the selected technology has to meet the local standards of operation and maintenance, it should be compatible with the framework if the responsible institute and within their technical and financial capacities.

- **Weightings**

Table 5.4 shows the weights of each indicator based on the results of AHP from ten stakeholders and the aggregated group weights. Based on the group weights, ‘Public acceptance’ had the highest weight (0.204) reflecting the importance of the social acceptance of similar projects and interventions. As mentioned in the preliminary interviews, meeting the social sustainably and people acceptance play a vital role in having sustainable wastewater technology and it is always one of the top priorities of the selecting of wastewater treatment system.

Operational cost was ranked second with a weight of (0.181). This was followed by ease of implementation and operation (0.103) and having aesthetic and green area (0.080). Although capital cost is also important but For Al Azraq project, the capital costs are funded through an international donation. It is worth to mention that climate change resilience, local capabilities and restoring biodiversity indicators have the least importance according to the weights as they have been ranked 14, 15, 16 respectively. On the higher level of the hierarchy, the relative weight for each criteria of sustainability criteria were obtained, as Social (0.341) had the highest weight followed by the financial criteria (0.268), then the technical (0.154), environmental (0.126) and finally the institutional criteria (0.110) as summarized in Table 5.5.

According to literatures and similar studies financial criteria has the highest weight flowed by the technical one, then the social criteria as illustrated by (A. R. Karimi; et al., 2011). Moreover, weights derived from the study by Molinos-Senante et al. they suggested that environmental criteria were the most important followed by economic and then social criteria (Molinos-Senante et al., 2014). However, comparing weighting profiles across different studies provides limited insight because decision priorities and contexts vary among studies (Ling et al., 2021). The final weights in this study were presented to stakeholders who participated in the AHP process for feedback. All stakeholders were satisfied with their own set of weights as well as the group weights.

Table 5. 4 Individual weighting of the 10 stakeholders and indicators aggregated group weightings

CRITERI	INDICATORS	STAK.1	STAK.2	STAK.3	STAK.4	STAK.5	STAK.6	STAK.7	STAK.8	STAK.9	STAK.10	GEOM MEAN	WEIGHT	Rank
technical	Ease of implementation & operation	0.228	0.089	0.107	0.057	0.184	0.052	0.069	0.143	0.070	0.065	0.094	**0.103**	**3**
	Climate change resilience	0.054	0.015	0.036	0.025	0.040	0.011	0.017	0.021	0.013	0.010	0.021	**0.023**	**14**
	Amount of sludge & by-products (Managing the generated sludge)	0.064	0.026	0.016	0.008	0.043	0.024	0.024	0.048	0.030	0.031	0.027	**0.030**	**13**
financial	Capital cost	0.036	0.110	0.030	0.024	0.026	0.028	0.019	0.019	0.063	0.059	0.035	**0.039**	**10**
	Operation & maintenance cost	0.120	0.316	0.109	0.200	0.180	0.164	0.163	0.102	0.149	0.248	0.165	**0.181**	**2**
	Resource /energy recovery & reuse opportunities	0.066	0.076	0.020	0.060	0.031	0.068	0.049	0.036	0.039	0.070	0.048	**0.052**	**6**
environmental	Total emission	0.017	0.024	0.036	0.054	0.024	0.037	0.076	0.046	0.062	0.024	0.036	**0.040**	**9**
	Soil & land contamination	0.041	0.024	0.025	0.036	0.026	0.031	0.031	0.010	0.030	0.040	0.028	**0.030**	**12**
	Biodiversity restoration	0.010	0.011	0.074	0.021	0.012	0.022	0.021	0.022	0.014	0.010	0.018	**0.019**	**16**
	Carbon Sequestration	0.012	0.037	0.074	0.054	0.031	0.037	0.037	0.025	0.016	0.012	0.028	**0.031**	**11**
social	Public acceptance	0.133	0.112	0.197	0.236	0.175	0.172	0.264	0.317	0.210	0.136	0.186	**0.204**	**1**
	Provision of aesthetic & green places	0.047	0.024	0.124	0.087	0.096	0.136	0.058	0.082	0.116	0.047	0.073	**0.080**	**4**
	Willingness to pay	0.025	0.052	0.052	0.064	0.053	0.108	0.101	0.035	0.064	0.033	0.053	**0.058**	**5**
institutional	Local personnel capabilities and local technical capabilities	0.018	0.017	0.042	0.009	0.012	0.029	0.023	0.013	0.031	0.030	0.020	**0.022**	**15**
	Compatibility with national strategies, standards and common practices	0.080	0.034	0.027	0.031	0.038	0.046	0.023	0.032	0.061	0.072	0.041	**0.045**	**7**
	Organizational effort & financial management required	0.046	0.034	0.033	0.034	0.030	0.036	0.023	0.050	0.031	0.114	0.039	**0.043**	**8**

Table 5. 5 Individual weighting of the 10 stakeholders and criteria aggregated group weightings

Criteria	STA K.1	STA K.2	STA K.3	STA K.4	STA K.5	STA K.6	STA K.7	STA K.8	STA K.9	STA K.10	GEOM MEAN	WEI GHT	Ra nk
technical	0.346	0.130	0.158	0.090	0.267	0.087	0.109	0.212	0.113	0.106	0.145	**0.154**	**3**
financial	0.223	0.501	0.158	0.283	0.237	0.260	0.232	0.157	0.251	0.377	0.253	**0.268**	**2**
environmental	0.081	0.096	0.209	0.165	0.092	0.127	0.166	0.103	0.123	0.085	0.119	**0.126**	**4**
social	0.206	0.188	0.372	0.387	0.325	0.417	0.423	0.433	0.390	0.216	0.321	**0.341**	**1**
institutional	0.144	0.084	0.102	0.074	0.079	0.110	0.070	0.095	0.123	0.216	0.104	**0.110**	**5**

- **Score Aggregation and Options Ranking**

The results of the group weights were applied to the performance ratings of indicators for score aggregation (As described previously each stakeholder scored the selected technologies on a scale from 1 to 5 to indicate its performance under each indicator). The average performance ratings of each indicator of each technology option were provided by a group of stakeholders and summarized in Table 5.6.

First, the scores of indicators were aggregated into each criteria based on the criteria hierarchy proposed in Figure 5.3 and then further aggregated into a composite score for each technology option as described in Figure 5.4. This enables decision makers to rank technology options based on their overall scores and to identify the options with the best performance under each sustainability criterion. Figure 5.5 indicated more detailed ranking for each technology option based on all indicators

- Overall: The FCW option was scored as the best option for this case study and based on its composite score (3.13) followed by SP (2.67) and finally the AS (2.07)
- Institutional criteria: FCW has the highest scores in most of the criteria except the institutional criteria where SP and AS had higher scores (0.37) while FCW scored (0.32)
- Social: FCW scored (0.75) followed by AS (0.67) and lastly SP with (0.6)
- Environment: FCW scored (0.49) and that indicated the difference between the conventional treatment systems and he nature-based solutions such as FCW
- Technical: FCW and SP had the same score (0.6) while the AS scored (0.41) due to complexity of operating AS,

- Financial: FCW scored (0.96) followed by SP (0.49) and then AS (0.46)

Table 5. 6 The average performance ratings of each indicator among 10 stakeholders.

The lowest rating '1' refers to the poorest performance of that indicator whereas '5 refers to the best

Criteria	INDICATORS	AS	SP	FCW
Technical	Ease of implementation & operation	2.7	4.4	4.2
	Climate change resilience	3.5	2.8	3
	Amount of sludge & by-products (Managing the generated sludge)	1.6	2.7	3.4
Financial	Capital cost	1.2	3.4	3.3
	Operation & maintenance cost	1.4	3	3.8
	Resource /energy recovery & reuse opportunities	3.1	2.2	2.8
Environmental	Total emission	1	3.2	4.2
	Soil & land contamination	1.8	2.7	2.9
	Biodiversity restoration	1.4	2.5	4.6
	Carbon Sequestration	1	1.7	4.8
Social	Public acceptance	2.4	1.8	1.6
	Provision of aesthetic & green places	1	1.6	3.9
	Willingness to pay	1.7	1.8	1.9
Institutional	Local personnel capabilities and local technical capabilities	4.1	4	3.4
	Compatibility with national strategies, standards and common practices	4.4	4	3.2
	Organizational effort & financial management required	2.1	2.6	2.4

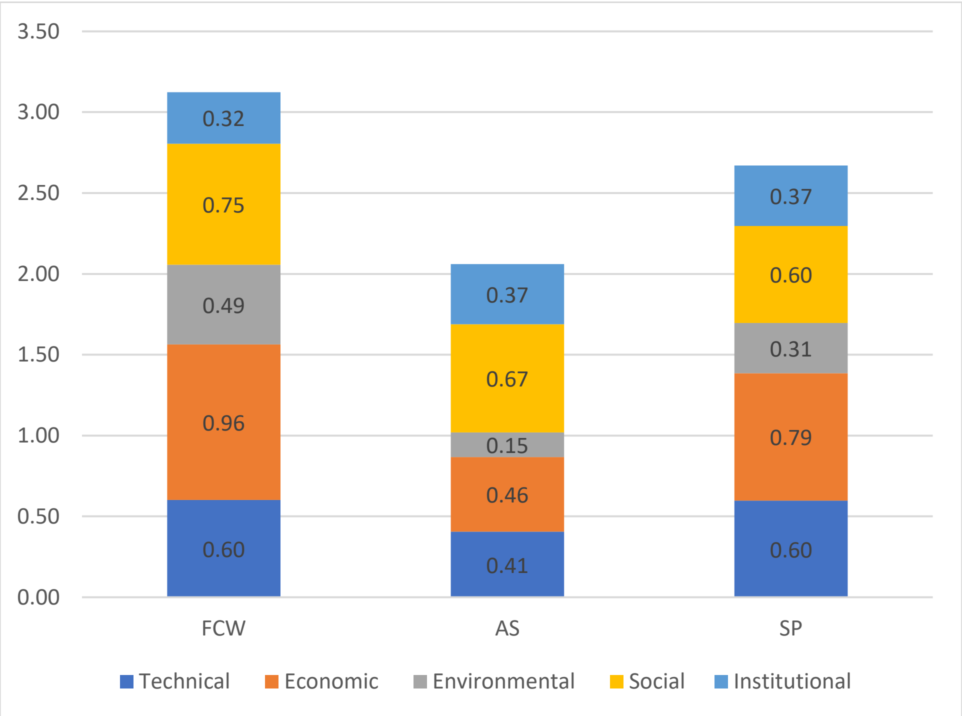

Figure 5. 4 scores of three treatment options for each assessment and the aggregated scores

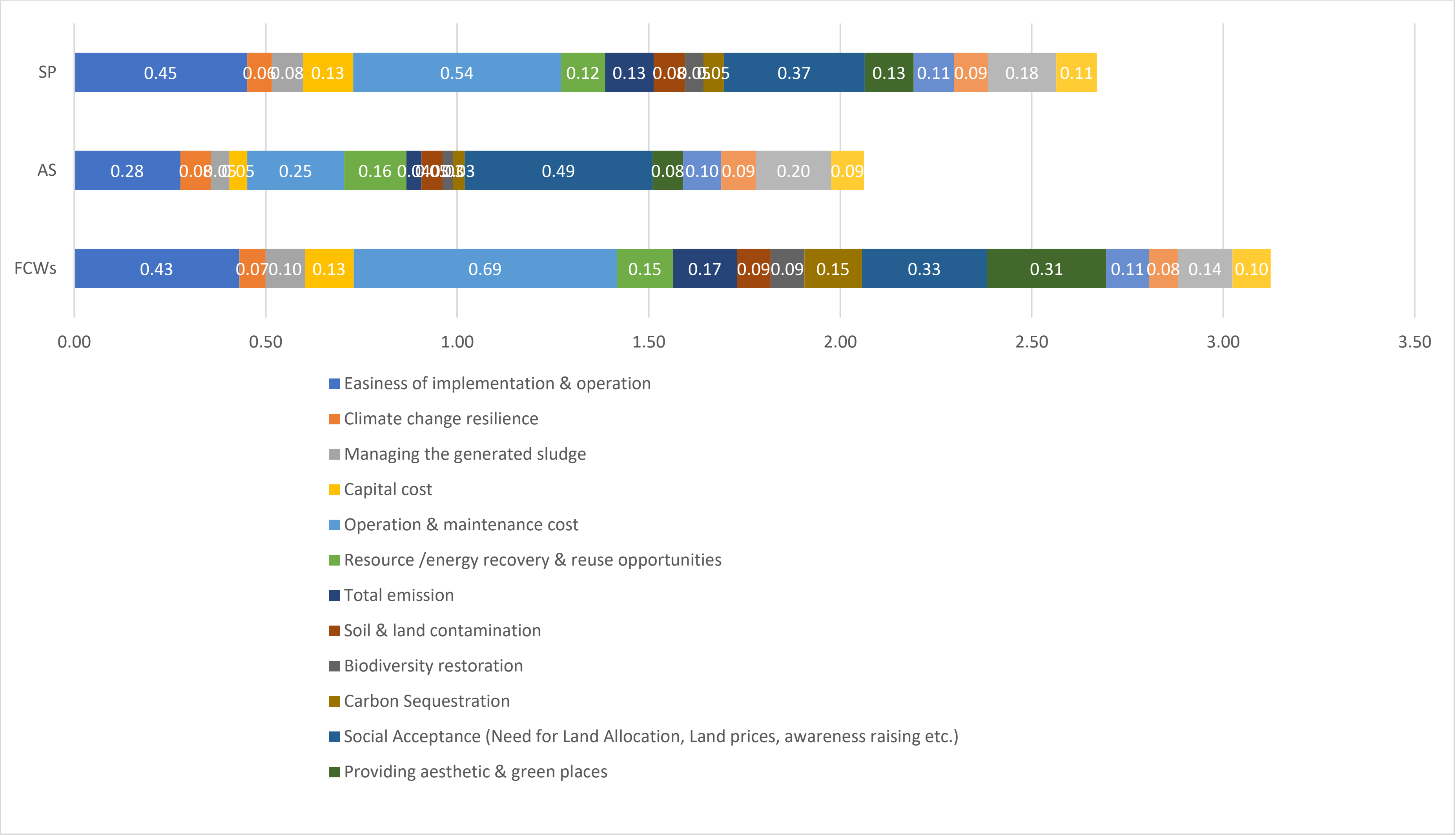

Figure 5. 5 scores of three treatment options for each individual indicator

- **Sensitivity analysis**

By re-applying different weightings profiles of stakeholder developed from the semi structured interviews, the new option rankings are shown in Table 5.7. eight out of ten weighting profiles led to a rank FCW as the best option, and the also eight out of ten ranked SP as the second-best option, and all the stakeholders agreed that AS is the last options for Al Azraq town. The results suggested that the rankings of options were generally consistent between the aggregated group weighting and individual weightings profiles. The other part of the sensitivity analysis was to calculate the minimum change in the group weight of each indicator to cause a rank reversal between the top two options. Table 5.8 shows the calculated minimum weight change $\boldsymbol{\delta}$ that required to determine if the indicator is critical or not, the calculation shows that all the indicators are **robust** and are not sensitive, in other words any changes in the indicator's weights will not change the overall options ranking. The absolute change and the relative change all indicators can withstand a value change in their weights without causing a rank reversal for this case study.

For the third part, equally weighted criteria have been applied to test the sensitivity of the results. In this case study the selected performance indicators are sixteen and thus each one has a weight factor of 100%/16 = 6.25%., considering the unified the weights for indicators and the composite scores from stakeholders. While the overall scores for all the treatment options have been increased, the final options ranking has not been affected as illustrated in Figure 5.6 below, this method provided further illustration of the robustness of the selected indicators.

Table 5. 7 The comparison of option rankings between different weighting profiles using the composite scores

Stakeholders #	FCWs	AS	SP
Stakeholder 1	1	3	2
Stakeholder 2	1	3	2
Stakeholder 3	1	3	2
Stakeholder 4	1	3	2
Stakeholder 5	1	3	2
Stakeholder 6	1	3	2
Stakeholder 7	2	3	1
Stakeholder 8	1	3	2
Stakeholder 9	2	3	1
Stakeholder 10	1	3	2
MCA Results	1	3	2

Table 5. 8 The minimum changes required in indicator weights to cause a rank shift between the best option (FCW) and the second option

Indicators	Group weight	Absolute change δ *k.i.j*	Relative change
Ease of implementation & operation	0.103	-2.3	2240%
Climate change resilience	0.023	2.3	10092%
Amount of sludge & by-products (Managing the generated sludge)	0.030	0.66	2180%
Capital cost	0.039	-4.6	11937%
Operation & maintenance cost	0.181	0.58	318%
Resource /energy recovery & reuse opportunities	0.052	0.77	1465%
Total emission	0.040	0.46	1161%
Soil & land contamination	0.030	2.3	7564%
Biodiversity restoration	0.019	0.22	1140%
Carbon Sequestration	0.031	0.15	475%
Public acceptance	0.204	-2.3	1126%
Provision of aesthetic & green places	0.080	0.2	250%
Willingness to pay	0.058	4.6	7867%
Local personnel capabilities and local technical capabilities	0.022	-0.77	3458%
Compatibility with national strategies, standards and common practices	0.045	-0.58	1289%
Organizational effort & financial management required	0.043	-2.3	5399%

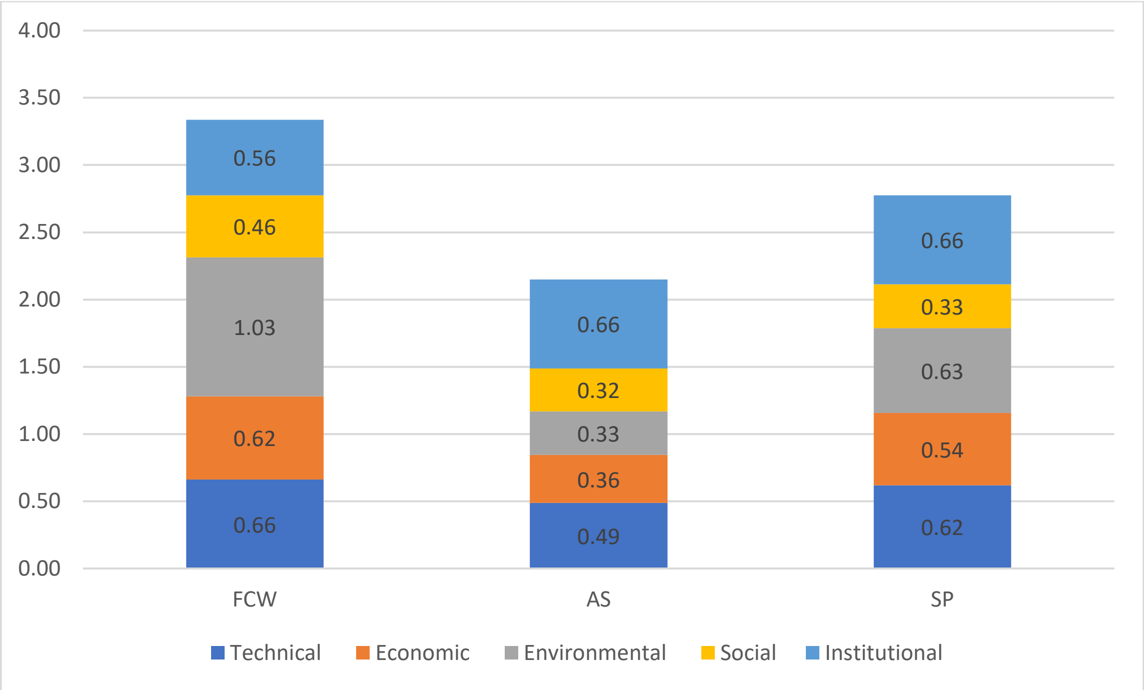

Figure 5. 6 scores of three treatment options after unifying the indicators weights.

5.3.4 Summary and Conclusions

There is a great demand to serve the underserved community in Jordan with a sustainable sanitation solution, parallel to that there is also a great demand for integrated sustainability assessment tool in the Jordanian water and wastewater sector, in order to support the decision makers in comparing, assessing and selecting the best sustainable options. This study has developed a multi-criteria analysis (MCA) framework for stakeholders to compare and select wastewater treatment options for the case study of Al Azraq town in the eastern part of Jordan. The MCA framework provides a user-friendly and simple approach for stakeholders to rank the options by composite scores aggregated and adopted from sustainability criteria and indicators.

It was found that the AHP approach combined with the semi – structured interviews with each stakeholder can be the feasible and practical approach to develop the weights. The results of composite and aggregated scores can be visualized easily and can be used to select between the alternatives. The case study showed that FCW was identified the best treatment technology for Al Azraq town comparing to the AS and SP.

Another highlight is that engagement of stakeholder should also be included in the early development stages of the methodology, enabled by qualitative methods. The use of interviews and thematic analysis can develop a basic understanding of the current method for evaluating and selecting treatment technology, this information can be used to select the criteria and indicators which lead to having an assessment tool which is compatible with the stakeholder's preference and decision-making context in the water and wastewater sector.

The development and optimization of the sustainability assessment tool will also help and support donors and international agencies who are working in the sectors, in understanding the local context and selecting the appropriate and sustainable treatment option for each context with minimizing the risk potential.

The development and optimization of the sustainability assessment tools is an explorative and iterative process, and it will be reviewed, modified, and updated progressively. Although the criteria hierarchy and weights presented in this research were developed for a specific case study, the methodology can be generalized to perform sustainability assessments for other cases or projects within the water and wastewater sector.

In this study sustainability criteria have been used for evaluating different treatment technologies, each criterion has been divided into indicators that summarize the importance of each criterion. Although the sustainability criteria have been widely and effectively used for similar comparisons, the number of selected indicators is limited due to the accuracy of MCA process. Therefore, selecting indicators are crucial in MCA. In this study the criteria and indicators have been selected after a deep understanding of the local context, conducing several site visits, and engaging the stakeholders while implementing MCA tool. From the local context, it was understood that for similar cases where the population count is moderate (5000 to 15000), the operators of the treatment plant can be the local municipality, however this operation scenario is rare in Jordan (the usual operators is the Ministry of water and Irrigation or Private companies), due to that the *ease of implementation and maintenance* and *managing the generated sludge* are highly important technical indicators for selecting treatment technology. That operation scenario has highly affected the selecting indicators process, not just technical indicators but also finical and social indicators, such as *operation and maintenance costs*, *resource recovery/reuse opportunities* in order to integrate suitable business models for and socio-economic plans. The importance of environmental indicators has higher level of importance, some indicators are matching the national climate change adaptation plan such as *carbon sequestration* and total emissions indicators, while other indicators linked with the social criteria such as *restoring biodiversity* indicators. However, some indicators weren't included in this study such as odor problems and attracting insects and mosquitoes, these indicators might affect the social acceptance, but according to stakeholders these problems can be avoided by selecting a proper location of the treatment plant.

While including stakeholder engagement is crucial, the experience from this study highlighted that introducing a new assessment approach to inform decisions is challenging. Firstly, time availability of the stakeholders was a huge practical factor to be considered when developing the MCA. Ideally, engaging with as many stakeholders as possible would be useful for developing representative and generalizable results. However, stakeholders were often occupied and the opportunities for engagement were not always available. To facilitate the engagement, the value of developing and using a sustainability assessment tool have been communicated to stakeholders through the implementing partners. Secondly, while introducing new assessment tool wasn't challenging for Jordanian stakeholders, the first impression of practicing AHP and pairwise comparison was confusing and controversial for some stakeholders. Conducting MCA and pairwise comparison with stakeholders through face-to-face interview has helped in solving their confusing. The majority of Stakeholders expressed a strong interest in AHP and the composite score approach because it was a new approach for them to make comparisons and it initiated deeper discussion, all stakeholders expressed their interests with MCA after seeing the final results and figures.

5.4 Abudullah Al Azab Mosque, Zarqa City – CWs for treating greywater[5]

5.4.1 The current situation of greywater treatment and reuse

Reclamation of greywater has gradually become one of the key strategies adopted in Jordan to improve the efficiency of the water management cycle, greywater reuse for irrigation purposes can significantly reduce the pressure on freshwater resources and mitigate pollution in recipient water bodies. In this perspective, The Jordanian government is making enormous efforts to implement projects for greywater reuse using economic, effective, and environmentally friendly systems (Abdelhay & Abunaser, 2021). The government has also prepared a detailed standard to control the treatment and reuse the greywater mainly in cooked vegetables, parks, playgrounds, and roadsides within cities, food crops intended for human consumption including raw consumption, and Toilets flushing (JSMO, 2013). Several greywater treatment and reuse projects have been widely applied in Jordan at household level, and at different institutional levels, schools, campuses, mosques, etc (al Arni et al., 2022; Al-Mashaqbeh et al., 2012).

Several local and international organization and entrepreneurs work in greywater treatment supported by several donors who have allocated funds and resources in order to capacitate the Jordanian with the technical requirements for greywater treatment technologies and to raise awareness about the importance of reusing greywater. The Jordanian academic sector and researchers have validated different treatment technologies for treated greywater and have published several articles in that field. Currently different technologies in being implemented and tested and the innovation door is still open for treating greywater.

This case study covered implementing greywater treatment system in a mosque, implementing greywater treatment system at mosque has several benefits and can achieve several objectives. Mosques in Jordan are public facilities and managed by the government, the government usually assigns minimum of two persons to every mosque for services and managing activities.

[5] This new part was not included in the published paper. However, the same methodology used as the published paper but in different context.

Despite the fact that the water consumption in mosques is relatively high (due to ablution practices), mosques as sacred places can deliver sacred messages such as water conservation) and have an influence on people behavior and practices (water consumptions) and acceptance of reusing treated greywater, mosques in general are not places only for religious purposes, but they are culture centers; people usually gather there for praying and for discuss social and local issues.

Based on the above-mentioned idea Fondazione Sipec – Italian donor has allocated fund to develop the implementation of greywater system at a mosque in Jordan in order to support the Jordanian with facing the water scarcity and to support this study with implementation a pilot scale project, monitoring and validating the results.

This activity has been implemented with two main objectives:

- providing a new source of water that can be used at the mosque (as a replicable example in other mosques in the community);
- raising awareness in the community about acceptance of reuse concept of treated wastewater, water conservation, and the adaptation to the climate change.

This section is focusing on using MCA tool to select a sustainable greywater treatment technology for the case study and to evaluate CW – NBS and compare it with other used treatment, while the implementation details and monitoring are coved in the next chapter.

5.4.2 Materials and methodology

The same previous methodology described in section 5.3.2 has been applied. While different indicators have been selected, different stakeholders have been identified and different treatment technologies were proposed to the stakeholders. The same semi structured interviews procedures have been followed, pairwise comparison AHP, and MCA tool used to select the most sustainable treatment technologies.

<u>Treatment technology</u>

Three treatment technologies have been selected for this project, according to the stakeholders among the options that are most widely used for similar purpose at mosques and schools in Jordan. Each option has a specific name in the Jordanian market which is basically the name of the designer entity. However, the treatment technology is being used and described in this study. The fourth option was proposed by this study in order to evaluate and integrate the CW – NBS with different application in the water sector.

The four options are listed below while the description for the treatment processes is illustrated in Figure 5.7:

1. Barrels in series
2. Zeolite filter layers
3. Disk filter treatment
4. Constructed wetland – horizontal flow

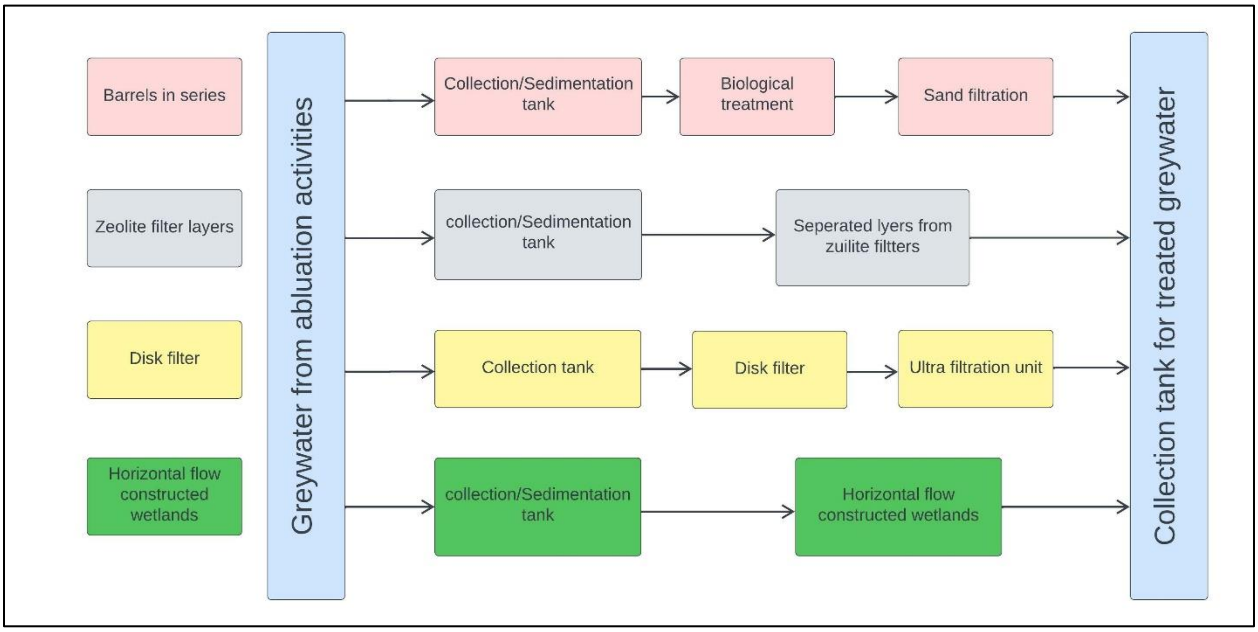

Figure 5. 7 Greywater treatment technologies evaluated in this study

5.4.3 Results

- **Semi – structured interview and the thematic analysis**

Six stakeholders from different sectors (government – Ministry of Awqaf and religious affairs, mosque committee, donors, academia, international NGOs, and local NGOs) participated in the study and the interview process. Firstly, the stakeholders evaluated and validated the suggested and proposed indicators, which is a summary of the thematic analysis and results from six stakeholders' interviews. Secondly the stakeholders validated and confirmed the selected technology options which illustrated in Figure 5.7.

- **Criteria hierarchy**

The final criteria hierarchy was proposed for assessing and selecting a sustainable greywater treatment technology as shown in Figure 5.8 below.

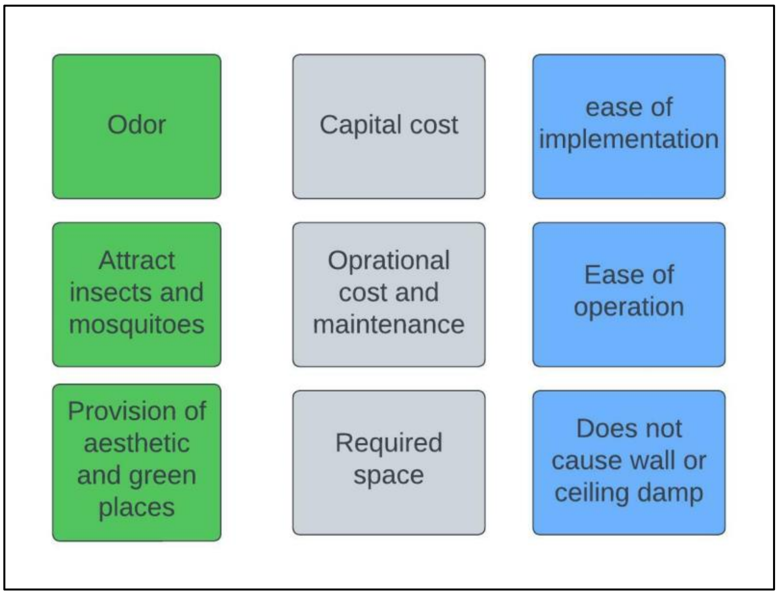

Figure 5. 8 Proposed criteria and indicators hierarchy for the sustainability assessment - greywater technologies

The simplified hierarchy consisting of one level of indicators to distinguish between the treatment options. While the operation and capital costs are considered as main parameters for sustainability the space required is very critical in this case since not all mosques or public institutions have free land area, in general public institutions used to have free areas on the roof tops, but with the recent installation of solar panels to generate electricity the availability of free area becomes critical. Greywater treatment system will be close to the mosque users and will integrate with their daily practices, therefore, to have a system without odors and without mosquitos and playing a vital role of accepting or rejecting the system, people also will accept systems that provide an aesthetic view and green area, this point is highly important and will increase the willingness to accept the system. Easiness of operating and implementing have been selected upon recommendations from stakeholders, the system will be operated by unskilled labors due to that the easiness of operation is highly important. The last indicator "Doesn't cause wall or celling damp" have been selected since this concern was a main concern for the public users and in somes cases several projects have been rejected due to this indicator.

- **Weightings**

Table 5.9 below shows the weights of each indicator based on the results of AHP from six stakeholders and the aggregated group weights. Based on the group weights, "odor" had the highest weight (0.23) reflecting the importance and the criticizer of this indicators which will highly affect the social acceptance of similar projects. The second important indicator is "Attract insects and mosquitoes" with score of (0.2), the importance of these indicators is quite higher than other indicators because the greywater treatment plant will be within their living area.

Both "ease of operation" and "the space requirement" indicators scored the same level of importance and ranked as third with (0.13). While the last scores went for "ease of implementation" and "provision of aesthetic places and green area" indicators with (0.04). Table 5.9 illustrated the final weight for each indicator.

Table 5. 9 Individual weighting of the 6 stakeholders and aggregated group weightings on the indicators and the final ranking of group weights

GROUP AGGREGATION									
INDICATORS	**STA K.1**	**STA K.2**	**STA K.3**	**STA K.4**	**STA K.5**	**STA K.6**	**GEOM MEAN**	**WEIG HT**	**Ra nk**
Operation cost and maintenance	0.12	0.14	0.11	0.16	0.18	0.05	0.12	**0.12**	**5**
Capital cost	0.04	0.04	0.04	0.05	0.05	0.03	0.04	**0.04**	**7**
ease of operation	0.15	0.08	0.11	0.14	0.15	0.14	0.13	**0.13**	**3**
ease of implementation	0.03	0.05	0.05	0.05	0.05	0.02	0.04	**0.04**	**8**
Required space	0.08	0.20	0.16	0.11	0.08	0.17	0.13	**0.13**	**4**
Odor	0.28	0.19	0.24	0.18	0.20	0.24	0.22	**0.23**	**1**
Attract insects and mosquitos	0.20	0.19	0.20	0.14	0.22	0.22	0.19	**0.20**	**2**
Provision of aesthetic and green places	0.03	0.04	0.04	0.03	0.04	0.04	0.04	**0.04**	**9**
Doesn't cause wall & celling damp	0.06	0.06	0.05	0.13	0.03	0.08	0.06	**0.06**	**6**

- **Score Aggregation and Options Ranking**

The results of the group weights were applied to the performance ratings of indicators for score aggregation (As described previously each stakeholder scored the selected technologies on a scale from 1 to 5 to indicate its performance under each indicator). The average performance ratings of each indicator of each technology option were provided by a group of stakeholders and summarized in Table 5.10.

First, the scores of indicators were aggregated into each criteria based on the criteria hierarchy proposed in Figure 5.9 and then further aggregated into a composite score for each technology option as described in Figure 5.9. This enables decision makers to rank technology options based on their overall scores and to identify the options with the best performance under each sustainability criterion.

- Overall: The horizontal flow CW and disk filter options scored as the best option for this case study and based on its composite score (3.28) followed by Zeolite filter layers (3.26) and finally the barrels in series (2.78)
- Although the scores were the same for CW and for the disk filter, CW option has been selected for the project in order to integrate NBS in water sector, and for the purpose of this research.

Table 5. 10 The average performance ratings of each indicator among six stakeholders.

The lowest rating '1' refers to the poorest performance of that indicator whereas '5 refers to the best.

	Final score of greywater technology options			
Criterion	Barrels in series	Zeolite filter layers	Disk filter	CW Horizontal flow
Operational cost	0.54	0.47	0.43	0.54
capital cost	0.18	0.14	0.13	0.18
Easiness to operate and maintain	0.58	0.44	0.46	0.55
Easiness of implementation	0.10	0.14	0.13	0.13
The required space for the system	0.24	0.41	0.39	0.24
Odor	0.46	0.76	0.76	0.76
Insects and mosquitoes	0.37	0.60	0.66	0.46
Providing aesthetic system not system that people don't like to see	0.04	0.10	0.10	0.17
Doesn't cause wall or ceiling damp	0.29	0.20	0.20	0.24
Total score	2.78	3.26	3.28	3.28

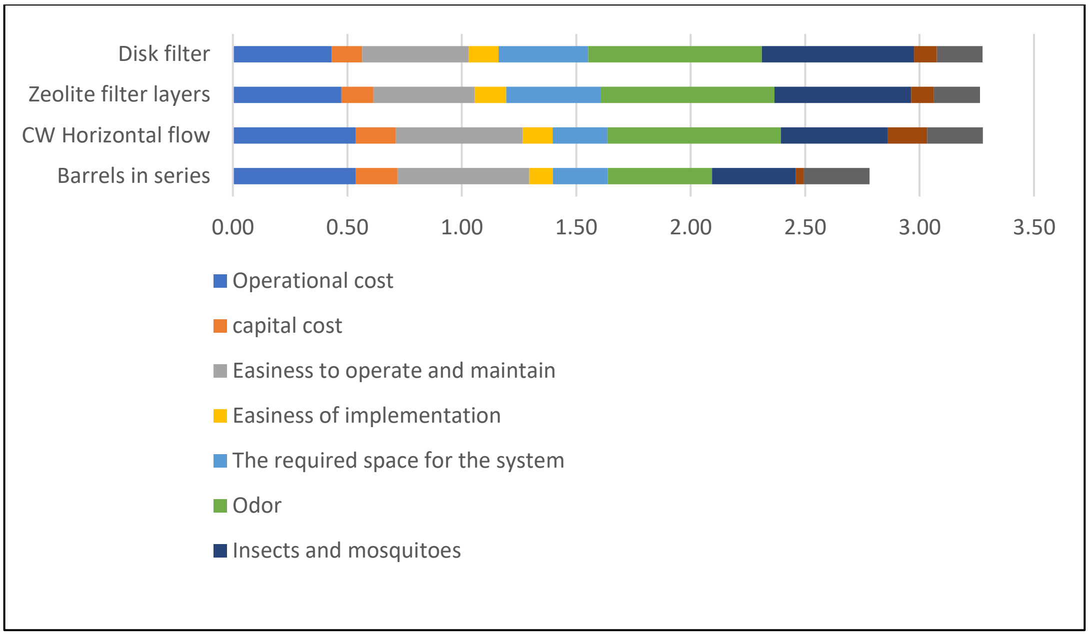

Figure 5. 9 scores of four treatment options for each indicator

- **Sensitivity analysis**

Using the mythology described in section 5.3.2. the sensitivity analysis has been considered among the top three options, three rounds of sensitivity analysis have been carried out, firstly between HFCW and Disk filter, HFCW and Zeolite filter, and thirdly between zeolite filter and disk filter. Both the minimum weight change in both absolute and relative terms were calculated, and the results are illustrated in Table 5.11 to 5.13 below.

For the first sensitivity analysis between the best option and the second-best option the absolute term, "Provision of aesthetic system" was the most critical indicator, with the smallest value δ of 0.0005. Hence, if the weight of "Provision of aesthetic system" (0.0372) is decreased by any value larger than 0.0005, the rank reversal between the best option and second-best option occurs. In the relative term, "insect attraction" was the most sensitive indicator as a 0.5% change in the value of its original weight would cause the rank reversal.

Table 5. 11 The minimum changes required in indicator weights to cause a rank shift between the best option (HFCW) and the second best option (Disk filter)

Indicator	Group weight	Absolute change	Relative change
opex	0.1237	0.0012	0.97%
capex	0.0440	0.0010	2.27%
easy to operate	0.1328	0.0015	1.13%
easy to implement	0.0415	NA	NA
required space	0.1305	-0.0009	0.66%
source of odor	0.2277	NA	NA
insects attraction	0.1991	-0.0010	0.50%
aesthetic system	0.0372	0.0005	1.34%
cause wall damp	0.0635	0.0015	2.36%

NA: Same score - zero in the denominator

For the second sensitivity analysis between the best option and the third-best option the absolute term, "Provision of aesthetic system" was the most critical indicator, with the smallest value δ of 0.006. Hence, if the weight of "Provision of aesthetic system" (0.0372) is decreased by any value larger than 0.006, the rank reversal between the best option and third-best option occurs. In the relative term, "required space" was the most sensitive indicator as a 7.06% change in the value of its original weight would cause the rank reversal.

Table 5. 12 The minimum changes required in indicator weights to cause a rank shift between the best option (HFCW) and the third best option (Zeolite filter)

Indicator	Group weight	Absolute change	Relative change
opex	0.123652	0.024581546	19.88%
capex	0.043976	0.014748928	33.54%
easy to operate	0.132822	0.014748928	11.10%
easy to implement	0.041544	-0.073744639	177.51%
required space	0.130497	-0.00921808	7.06%
source of odor	0.227661	NA	NA
insects attraction	0.199121	-0.01843616	9.26%
aesthetic system	0.037237	0.006145387	16.50%
cause wall damp	0.06349	0.01843616	29.04%

NA: Same score - zero in the denominator

For the third sensitivity analysis between the second-best option and the third best option the absolute terms, "opex" and "insect attraction" were the most critical indicator, with the smallest value δ of 0.034. Hence, if the weight of "opex" (0.1236) or "insect attraction" (0.199) is decreased by any value larger than 0.034, the rank reversal between the second-best option and third-best option occurs. In the relative term, "insect attraction" was the most sensitive indicator as a 17.01% change in the value of its original weight would cause the rank reversal.

Table 5. 13 The minimum changes required in indicator weights to cause a rank shift between the second-best option (Disk filter) and the third best option (Zeolite filter)

Indicator	Group weight	Absolute change	Relative change
opex	0.123652	0.033871884	27.39%
capex	0.043976	-0.067743768	154.05%
easy to operate	0.132822	0.067743768	51.00%
easy to implement	0.041544	-0.067743768	163.07%
required space	0.130497	-0.067743768	51.91%
source of odor	0.227661	NA	NA
insects attraction	0.199121	0.033871884	17.01%
aesthetic system	0.037237	NA	NA
cause wall damp	0.06349	NA	NA

NA: Same score - zero in the denominator

The last sensitivity analysis check was applied with equal weights method, same weight was given to all indicators with value of (1/9) and the final composite scores shows that the ranking has been revered between the second and the third option while the best option has the highest score as illustrated in Figure 5.10 below

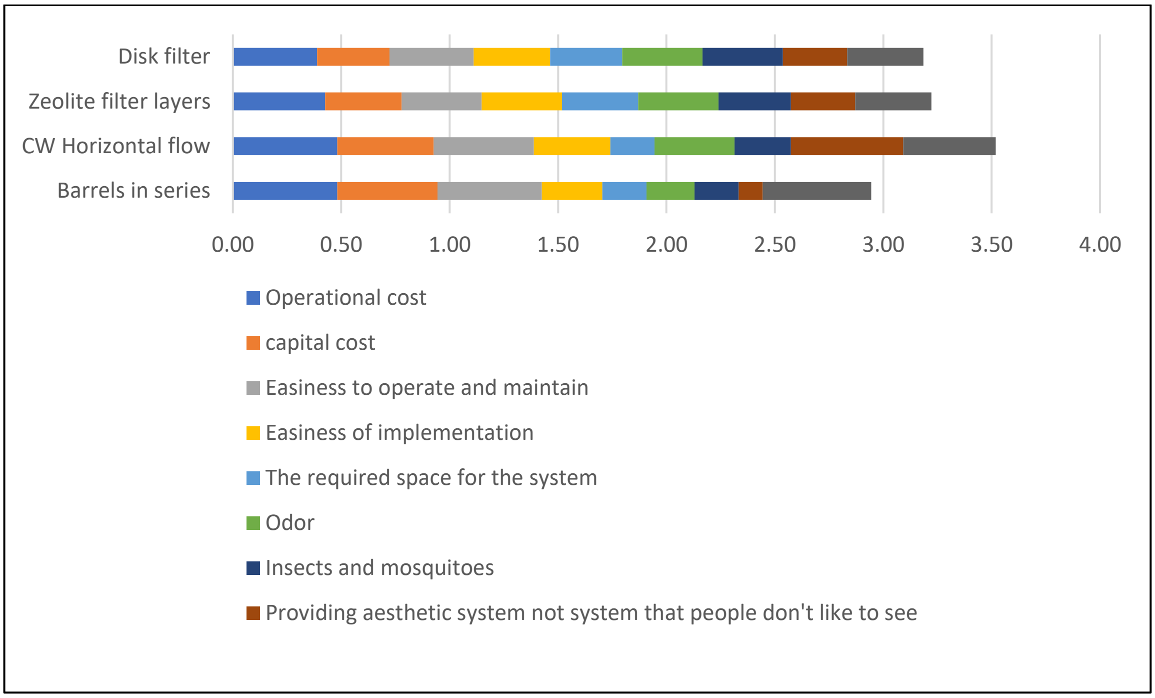

Figure 5. 10 scores of four treatment options for each indicator – unified indicators weight

5.4.4 Summary and Conclusion

Due to a growing interest in treating and reusing greywater generated from public facilities in Jordan, several governmental, private, and international organizations have started several initiatives and allocated resources to increase the investment in this approach.

Several treatment technologies are being developed locally in Jordan to be used for this purpose. However, selecting the best technology is highly important for the sustainability of the system, to maximize the benefits with minimize the complicity.

In this part of the research, MCA tool has been used to compare and select between several greywater treatment technologies for Aduullah Al Azab Mosque in Jordan.

Several indicators have been selected by the stakeholders, pairwise comparisons have carried out by the stakeholders and scoring process for each technology based on the preselected indicators.

In this study different greywater treatment technologies have been evaluated and compared according to list of indicators preselected and validated by the stakeholders. The selected case study has a unique situation since the mosque has an important impact to the local people, and the treatment system will be in a direct contact with people. Therefore, selecting the treatment technology and the indicators are crucial in MCA.

Among the selected nine indicators, *odor*, *attracting insects and the easiness of operation* have been ranked the top important indicators, while the least important indicators were the *capital cost*, *easy to implement and the provision of aesthetic and green places*. The previous can be justified as usually similar project is being funded and implemented by external organizations or being prefabricated in a factory and only the system installation is being carried out to the final destination.

It was found that the results of the MCA showed close final scoring among the technologies, CWs and Disk filter scored the same with (3.28) followed by the Zeolite filters (3.26) while barrels in series scored (2.78). while the close scoring can be justified due to the early stage of the growing approach of treating and reusing greywater, and the limited but growing stakeholder’s knowledge. While the least score for the last option can be justified due to the unfavorable view of using several plastic barrels.

It was found that the CWs – NBS have a huge potential to be utilized at household and small building levels. The simplicity of operating and the high removal efficiencies beside the people acceptance have proved the suitability and sustainability of CWs – NBS as a treatment technology. The results of the MCA were also simple and easy to be presented for the stakeholders, especially the community members.

Chapter Six: Implementation and operation of CW for greywater treatment – Abdullah Al Azab Case study, Jordan

As mentioned in the chapter five section 5.4 this chapter covers the design, implementation, monitoring, and evaluation activities carried out in Jordan regarding design and implementation of CW in Jordan to treat greywater generated from a mosque. The chapter covers details of designing and implementation, monitoring and analyzing the reuse potentials, evaluating the projects impacts, lessons learnt and challenges, and future developments.

6.1 Introduction

As mentioned before reclamation of greywater has gradually become one of the key strategies adopted in Jordan to improve the efficiency of the water management cycle, greywater reuse for irrigation purposes can significantly reduce the pressure on freshwater resources and mitigate pollution in recipient water bodies. In this perspective, The Jordanian government is making enormous efforts to implement projects for greywater reuse using economic, effective, and environmentally friendly systems (Abdelhay & Abunaser, 2021). The government has also prepared a detailed standard to control the treatment and reuse the greywater mainly in cooked vegetables, parks, playgrounds, and roadsides within cities, food crops intended for human consumption including raw consumption, and Toilets flushing (JSMO, 2013). Several greywater treatment and reuse projects have been widely applied in Jordan at household level, and at different institutional levels, schools, campuses, mosques, etc. (al Arni et al., 2022; Al-Mashaqbeh et al., 2012).
Several local and international organization and entrepreneurs work in greywater treatment supported by several donors who have allocated funds and resources in order to capacitate the Jordanian with the technical requirements for greywater treatment technologies and to raise awareness about the importance of reusing greywater. The Jordanian academic sector and researchers have validated different treatment technologies for treated greywater and have published several articles in that field. Currently different technologies in being implemented and tested and the innovation door is still open for treating greywater.

This case study covered implementing greywater treatment system in a mosque, implementing greywater treatment system at mosque has several benefits and can achieve several objectives.

Mosques in Jordan are public facilities and managed by the government, the government usually assign minimum of two persons to every mosque for services and managing activities. Despite the fact that the water consumption in mosques is relatively high (due to ablution practices), mosques as sacred places can deliver sacred messages such as water conservation, mosques also have an influence on people behavior and practices (water consumptions) and acceptance of reusing treated greywater, mosques in general are not places only for religious purposes, but they are culture centers; people usually gather there for praying and for discuss social and local issues.

This activity has been implemented with two main objectives:

- providing a new source of water that can be used at the mosque (as a replicable example in other mosques in the community);
- raising awareness in the community about acceptance of reuse concept of treated wastewater, water conservation, and the adaptation to the climate change;

The required fund for this activity has been allocated from Fondazione di Sipec, an Italian nongovernmental organization based in Brescia and has an agreement with the CeTAmb center at University of Brescia. The project has been implemented based on a project agreement between three parties: University of Brescia – CeTAmb center, Sipec foundation, and Climate Action Now (CAN). CAN is a Jordanian NGO who is actively working in the field of water treatment, water reuse and climate change. The project and research activities have been covered with collaboration of Marika Bellotti (MSc. Student).

While section 5.4 in chapter five has described the selection treatment technology process, this chapter will describe in detail the implementation, operation, monitoring, and further activities carried out

6.2 Literature Review

Generally, in CW systems the water treatment process line is similar to the biological treatment plants: a preliminary treatment stage is needed, which essentially depends on the characteristics of the raw wastewater, while the system of CW is the secondary treatment stage. The main difference between CW and traditional treatment systems is the sludge treatment line: in a traditional biological plant the sludge produced by the treatment system are partially recirculated and partially treated, while in the CW the only and possible sludge are those produced by the primary sedimentation, which are generally removed and disposed, and the sludge accumulated within the CW is being degraded by the natural process and the disposal might be needed in the long term – 8 to 10 years (Dotro et al., 2017; Kadlec & Wallace, 2009). The plant configurations can be many and the choice of one of these depends on numerous factors such as treatment objectives, type of the wastewater, etc. Some examples are shown below (Dotro et al., 2017; Kadlec & Wallace, 2009; A. Stefanakis et al., 2014):

- The horizontal submerged flow HFCW system is optimal for users medium, when a high organic load reduction is desired, solid suspended and bacterial load, but not of nitrogenous substances.

- The vertical submerged flow VCW system is optimal for interventions on small users with oscillating loads, when an effective reduction is required ammonia nitrogen, in addition to organic load and suspended solids, or for harsh climates, when the biological processes typical of horizontal flow systems are strongly slowed.

- The hybrid CW systems, consisting of a VCW followed by a HFCW system, has the purpose of obtain a more efficient denitrification of the effluent leaving the system vertical.

- The hybrid CW systems, consisting of a HFCW followed by a VFC system, leads to the first system to remove a large part of the organic load and suspended solids and in the according to strong oxidation and effective nitrification; to get one more efficient denitrification of the effluent is possible to provide a recirculation in plant head.

The choice of treatment technology and therefore of its plant configuration it must be developed in such a way as to satisfy the needs of the population, in relation to the available resources and the local factors that characterize them the project area (Dotro et al., 2017; Kadlec & Wallace, 2009; A. Stefanakis et al., 2014).

CW were the first NBS applied for greywater treatment. The efficiency of CWs in greywater treatment is due to a strong interaction among plants, biofilms, substrate, atmosphere, and nutrients from wastewater. The contact among roots, substratum, and biofilm favors different mechanisms of pollutant and pathogen removal, such as sedimentation and filtration as physical processes, precipitation and adsorption as chemical processes, and microbiological degradation and plant uptake as biological processes (Boano et al., 2020).

Among CWs categories, different types of CWs have been used to treat greywater, for instance, Collivignarelli et al. 2020 have studied the application of horizontal subsurface flow constructed wetland (HFCW) to treat greywater, thy have obtained very high removal yields on turbidity (>92%), (TSS >85%), (COD >89%), and (BOD_5 >88%) (Collivignarelli et al., 2020). Boopathi and Kadarkari, (2022) have also studied the performance of HFCW to treat greywater in India, their lab scale study has achieved maximum removal efficiency of BOD, COD, TSS, and TN was 77.78–90%, 69.92–81.20%, 82–91.06%, and 75.83–84.02%, respectively (Boopathi & Kadarkarai, 2022). While the HFCWs studied by (Qomariyah et al., 2022) have treated greywater to the following efficiencies 94.13% and 96.84% for BOD; 95.04% and 95.62% for TSS; 97.11% and 94.61% for detergent. Hachicha et al., (2022) have studied the performance of VFCW to treat greywater, they have used two beds planted with Phragmites australis and the removal efficacies they had for TSS, COD, and BOD_5 were 94±13, 86±5.7, and 93±7%, respectively, the ammonium overall removal rate was 71.4±19.1%. for TP it was 52 % and for e. coli clearance has ranged from 1.24 to 2.40 logs (Hachicha et al., 2022). Table 6.1 summarize the previous examples.

Table 6. 1 Examples of CWs for treating greywater

Study title	**Area (m^2)**	**Type of CW**	**Removal efficiency (%)**							**Reference**
			COD	BOD	TSS	TN	Turbidity	NH_4	TP	
Horizontal Flow Constructed Wetland for Greywater Treatment and Reuse: An Experimental Case	0.48	HF	89	88	85		92			(Collivignarelli et al., 2020)
A laboratory-scale study of residential greywater treatment with sugarcane in a constructed wetland	0.56	HF	90 to 81	77 to 90	82 to 91	76 to 84				(Boopathi & Kadarkarai, 2022)
Constructed wetlands with Cyperus alternifolius as a sustainable solution for household greywater treatment	1.2	HF	97	94	95					(Boopathi & Kadarkarai, 2022)
Graywater Treatment with Two Planted Vertical Constructed Wetlands in Series: A Pilot Study	1	VF	86	93	94			74	52	(Hachicha et al., 2022)

The use of CWs for the treatment of greywater has identified as key option to promote a sustainable water management in accordance with circular economy (Masi et al., 2018). Within this framework, (Arden & Ma, 2018) have revies and listed 13 different applications of CWs in treating greywater and the following ranges of removal efficiency: BOD_5 (63–98%); TSS (64–98%); turbidity (47–97%); TN (44–59%); TP (24–63%); around 1–2 log removal for bacteria, protozoa and viruses. Despite high pathogen removal, the authors recommended the need of some additional disinfection steps to meet strict water reuse standards (Arden & Ma, 2018). Additionally, (Arden & Ma, 2018) have found that the widely used modeling approaches and performance databases is the P-k-C* model (Kadlec & Wallace, 2009).

Most of the literature deals with pilot systems and very small applications, with only a few works referring to full-scale systems (Boano et al., 2020). A growing research and studies in treating greywater through green walls and green roofs which involves the simultaneous presence of a wide range of biological and physico-chemical processes, according to the operation mode of CW (Kadlec & Wallace, 2009)

6.2 Methodology

6.2.1 Onsite assessment

In order to select a proper mosque and prober location of the project onsite assessments have been carried out between April and June onsite assessment by a team of engineers, assessment form has been prepared, revised, and followed in order to collect and assess each mosque and select the proposer mosque for the project. The assessment form has covered the following sections:

1. mosque name, location, number of beneficiaries, and contact numbers of the focal point;
2. detailed description of the location; city, governorate, and road conditions;
3. internal and the Adjoining Spaces to the mosque, such as the available area and the general conditions of the mosque structure and infrastructure, etc;
4. sketch and drawing of the mosque;
5. institution characteristics, functionality, and number of staff,
6. WASH infrastructure status assessment;
7. water consumption;
8. irrigation Systems if any;
9. protection and security;
10. power supply and energy consumption;

11. cost estimation;

The detailed assessment form and results are attached in appendix D

6.2.2 Data collection

Different types of data have been collected for the selected mosque (Abdullah Al Azab Mosque) such as:

- water bills;
- number of daily users;
- number of trees and irrigation area;
- greywater characteristics;
- possible reuse options;
- peak hour, peak day, peak month;

6.2.3 Design and preparation

Introduction

The collected flow data and the characteristics of the raw greywater have been used to design the treatment system. Subsurface HFCW was selected for this project due to, easiness of implementation and operation, and the greywater has a minimal load of nitrogen. Several literatures have illustrated the efficiency of HFCW in treating greywater. Plug flow k-C* method was selected to design the CW and calculate the CW's dimensions. According to (Dotro et al., 2017) several methods can be used for designing CW and plug flow k-C* has proved several successful examples and cases (Dotro et al., 2017; Kadlec & Wallace, 2009).

The proposed simple treatment process for our case included:

Collection/Sedimentation tank >>> HFCW >>> Collection tank

Design instructions and recommendations from Jordanian standard for reclaim and reuse treated greywater JS 1776/2013 has been followed and considered in our design.

Usually, a Preliminary step is being provided but, in our project, and treatment system preliminary treatment is not needed. Preliminary treatment mainly separates the coarsely dispersed solids out of the liquid phase. The preliminary treatment prepares wastewater influent for further treatment in wetland by reducing or removing problem wastewater characteristic that could otherwise delay operation or increase maintenance of the further treatment steps like pumps. The typical problem characteristics include large solids and rags; grit; odors etc. The preliminary treatment of wastewater comprises of mainly screen and grit chamber. A screen is a device with openings, generally of uniform size, that is used to retain solids found in the influent wastewater to the treatment plant, which removes coarse materials from the wastewater. Grit chambers remove grit: sand, gravel, or other heavy sold materials that have specific gravities much greater than those of the organic solids in the wastewater (Kadlec & Wallace, 2009). The project is treating greywater that is directly coming from sinks and ablution practices and during the feasibility and assessment phase several samples have been collected and tested in order to determine the necessity of preliminary step. The outcome of this was having preliminary treatment wasn’t needed.

Primary treatment

For primary treatment separates the suspended matter by physical processes mainly sedimentation. Raw greywater contains suspended particulate heavier than water; these particles tend to settle by gravity. Primary treatment reduces suspended solids, organic load to the CW and equalizes raw greywater quality and control the flow to the CW (Dotro et al., 2017; UN-HABITAT, 2008) .

In our treatment system collection tank has been used as a collection tank and septic tank. Septic tank is the most common primary treatment used in small-scale CW worldwide. A single-compartment septic tank was used with a capacity of one cubic meter.

Septic tanks will generally need to be desludged, otherwise they produce very poor effluents with high suspended solids content, which can be unfavorable to the CW (clogging of beds). To ensure continuous effective operation, the accumulated material must therefore be emptied periodically. This should take place when sludge and scum accumulation exceed 30% of the tank’s liquid volume (Kadlec & Wallace, 2009; UN-HABITAT, 2008).

Although the collection and septic tank can reduce the suspended solid and BOD, in the raw wastewater 50% and 30% respectively (Kadlec & Wallace, 2009), that removal percentage weren’t considered in designing the CW for many reasons, firstly to consider safety factor in designing and calculating the required dimensions of CW, and secondly to consider lack of proper operation of the collection tank.

Horizontal flow constructed wetland (HFCW)

Plug-flow k-*C**

The HFCW has been designed based on the first-order Plug-flow k-C* approach proposed by (Kadlec & Wallace, 2009a; Nivala et al., 2017). This approach considers influent and effluent concentrations as well as background concentration but assumes ideal plug-flow hydraulics.

Background concentration C* is an irreducible effluent concentration that results from internal biogeochemical cycling within wetlands. For example, for organic matter, C* could represent the refractory or non-biodegradable fraction. The background concentration C*, which is often inferred from a large collection of data, effectively sets a lower limit to the effluent concentration of a CW (Co). This means that even for a wetland that has an infinitely long retention time, the theoretical effluent concentration Co will never be less than C* (Dotro et al., 2017; Kadlec & Wallace, 2009). Value of C* for different parameters are varied according to the treatment stage, for example for BOD removal for primary effluent C* = 10 mg/l, while for secondary effluent C* = 5 mg/l and for tertiary effluent C* = 1 mg/l (Kadlec & Wallace, 2009)

In this approach wetland area, A, can be calculated as follows (Equation 6.1):

$$A = -\frac{Q_{in}}{k_T} \ln\left(\frac{C_{in} - C^*}{C_{out} - C^*}\right) \qquad \text{Eq 6.1}$$

Where A [m^2] is the area of the CW

Q_{in} is the discharge [m^3/d]

C_{in} [mg/L] the inlet pollutant concentrations

C_{out} (mg/L) The target output concentrations

C* the background concentration.

K_T is the modified first-order areal rate coefficient, m/d measured at T °C, the coefficient can be modified according to the temperature based in equation 6.2

$$k_T = k_{20}\vartheta^{(T-20)} \qquad \text{Eq 6.2}$$

Where k_{20} is the rate coefficient at water temperature at 20 C temperature and its value varied according to each parameter while θ is the modified Arrhenius temperature factor (dimensionless) equal to 1.06 (average) and is T is the temperature of the liquid in the system [°C] (Kadlec & Wallace, 2009).

The required area for to treat each parameter (BOD, COD, TSS, etc.) has been calculated separate, and the largest areas has been selected for the final design and implementation.

Several design parameters have to be checked, such as hydraulic retention time, hydraulic loading rate, mass loading rate, and cross-sectional loading rate. All design checks are described below (Dotro et al., 2017; Kadlec & Wallace, 2009)

For the hydraulic retention time (HRT) as

$$HRT = \frac{A*H*\varepsilon}{Q_{in}} \qquad \text{Eq 6.3}$$

Where HRT is the hydraulic retention time (days)

A is the area of CW (m^2)

H is the depth of CW (m)

ε is the porosity of the filter material (m^3/m^3)

and Q_{in} is the fixed discharge (m^3/d).

The depth of the HFCW is varied and depends on the application of CW, for secondary treatment the depth is between 0.35 to 0.7 m (Dotro et al., 2017; Kadlec & Wallace, 2009).

For the hydraulic loading rate (HLR) is expressed as [m/d] and can be calculated according to the flowing equation

$$HLR = \frac{Q}{A} \qquad \text{Eq 6.4}$$

The mass loading rates M.L [kg/m^2d] represents the amount of mass loaded to the CW daily and can be calculated as:

$$M.L. = \frac{Q*C_{in}}{A} \qquad \text{Eq 6.5}$$

The check of cross-sectional organic loading rate (CSL) ($gBOD_5/m^2d$) is fundamental to avoid clogging problem during the operation. It is measured as:

$$CSL. = \frac{BOD_{5,in}}{C.S.} \qquad \text{Eq 6.6}$$

Where $BOD_{5,in}$ is the BOD_5 (g/d) which enters in the CW tank and C.S. (m^2) is the cross-sectional area determined as

$$C.S. = W*H \qquad \text{Eq 6.7}$$

Where W is the width of CW (m), and H represents the saturated depth of the HF wetland (m). The CSL must not exceed 250 ($gBOD_5/m^2d$), otherwise clogging problem might occur (Dotro et al., 2017).

The recommended length-to-width ratio (L: W) for HF-CW should vary from 2:1 to 4:1. In order to maximize the cross-sectional area and reduce clogging potential with the higher hydraulic rates applied, HFCW systems are generally constructed with a longitudinal sloped base (1%) to facilitate draining of the bed if needed (Dotro et al., 2017; Kadlec & Wallace, 2009).

Several design guidelines and manuals have estimated and set design limits to guarantee an efficient performance of CWs, the Table 6.1 below summarizes some design limits as adopted from different resources (Dotro et al., 2017; Kadlec & Wallace, 2009)

Table 6. 2 Design limits for CWs

Parameter	Free water Surface CW	Vegetated submerged CW
Organic loading rate, kg BOD/ha day)	5-110	10 - 200
Nitrogen loading rate, kg N/ha. day (Kg/ha day)	0.5-60	2-80
HRT (d)	3-10	2-7
HLT (cm/d)	2.5-10	2.5-20
water depth from the surface **(cm)**	20-50	2-10
L/W	4:1-6:1	2-1
bed depth (cm)	-	30-90

Finally, it is possible to estimate the efficiency of plant considering the different pollutants using the simplified equation

$$\eta = \frac{C_{in} - C_{out}}{C_{in}} \qquad \text{Eq 6.8}$$

Advantages of the plug-flow *k*-*C** approach:

- It takes into account influent concentration (*C*i), background concentration (*C**), HLR (*q*) and areal reaction rate coefficient (*k*A).
- It can take into account temperature correction factor (θ).

Disadvantages of the plug-flow *k*-*C** approach:

- It does not account for non-ideal flow, which creates a large risk, especially when low effluent concentrations must be achieved (Kadlec and Wallace, 2009).
- There is no guidance as to which *k*A-value to choose (for example, when a range of reaction rate coefficients are reported).

Media selection

The filter media perform several roles in CWs, they are rooting material for vegetation, they help to evenly distribute and collect flow at inlet/outlet, also they provide surface area for microbial growth, and they act as filter and trap particles (Dotro et al., 2017; Kadlec & Wallace, 2009).

Very small particles have very low hydraulic conductivity and create surface flow. Very large particles have high conductivity but have little wetted surface area per unit volume of microbial habitat. Large and angular medium is inimical to root propagation. The compromise is for intermediate-sized materials generally characterized as gravels. It is recommended that the gravels are doubled washed to remove fines that could block the void spaces (Dotro et al., 2017; Kadlec & Wallace, 2009; A. Stefanakis et al., 2014).

For HFCW it is reported that the diameter size of media used varies from 0.2 mm to 40 mm (C. A. Arias et al., 2021; Dotro et al., 2017; Kadlec & Wallace, 2009; A. Stefanakis et al., 2014). It is also recommended that the media in the inlet and outlet zones should be between 40 and 80 mm in diameter to minimize clogging and should extend from the top to the bottom of the system. For the treatment zone, it does not appear to be a clear advantage in pollutant removal with different sized media in the 10 to 60 mm range (Dotro et al., 2017; Kadlec & Wallace, 2009; A. Stefanakis et al., 2014).

Implementation

After finalizing the design, several approvals and permits were required from the governmental authorities. Detailed explanations for the design and the components of the systems have been explained to the stakeholders. Technically, bill of quantities (BoQ) has been prepared and the treatment system has been implemented in collaboration with local contractor in Jordan, the selected contractor has wide experiences in implementing greywater systems in Jordan.

Monitoring

While sampling process has been carried out by local expert engineers who followed sampling procedures of “STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER, 23RD EDITION” (Rodger B. Baird et al., 2017), tests are being carried in laboratories of Water, Energy, and Environment Center, ay University of Jordan. The testes were performed also according to “STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER, 23RD EDITION” (Rodger B. Baird et al., 2017).

Training and guidelines

Guidelines for operation and maintenance have been prepared. A full day training was conducted to the responsible operator with explanation for the process and operation procedure, the training concluded explanation bout the regular daily operation and maintenance, while for major maintenance a focal point engineer from the local partner will be responsible to follow the major maintenance. Appendix F describes the detailed operation and maintenance manual.

6.3 Results

6.3.1 Assessment and mosque selection

More than eleven mosques have been assessed during the onsite assessment activities, the assessment covered Amman, Zarqa and Irbid city. The assessment focused mainly on i) available space for implementing the system, ii) potential of reuse of the treated greywater, iii) availability of local staff to operate the system in the long term. Tables in Appendix D summarizes the main assessment results.

Among the eleven mosques, two mosques where the most suitable mosques for the project, Ayed Al Laozi Mosque in Amman, and Abdullah Al Azab Mosque in Zarqa city. While the first several social issues and concerns have been raised from the community in Amman, the community in Zarqa showed high interests in the project. Therefore, the second mosque has been selected for this research, with consideration of evaluation and analysis of the social issues raised in the first mosque.

Abudullah Al Azab mosque is located in Zarqa city in the easter part of Jordan, Zarqa city considered as semi-arid – arid climate with less than 250 mm/year rainfall. The mosque is located in the easter part of the city with harder climate conditions, the area is considered as a desert with very limited rain occasions. The city and the mosque received fresh water from the drinking water network, the water is being used mainly for ablution and for irrigate the green area within the mosque building, the water bill is paid by the Mistry of Awqaf and religious Affairs and that leads to increase the consumption rate. It is worth to mention that the water supply in Jordan is intermittent supply, the water is being supplied only one or two times a week and people store the water into water tanks and use it until the next water supply. For drinking purposes mosque is used bottled water, and this practice is common practice in Jordan. The water demand is variable during the year and its peak is in the summertime (July – August – September). The peak month during the year is Ramadan time and Friday is the peak day during the week, especially during the noon time.

The total available land area of the mosque is around 2,154 square meters, where 540 square meter is vegetated with different types of tress and crops, mainly olive trees, fig trees and other fruits tress and local herbs. The remaining area is not vegetated mainly due to the limitation of water availability. The estimated water consumption for irrigation is about 6-9 m^3/week to irrigate around 65 tress and other crops. Figure 6.1 shows the mosque details while Figure 6.2 shows top view of the mosque's facilities.

Figure 6. 1 Abdullah Alazab mosque's vegetated and unvegetated area

The irrigation is done manually with drinking water from the tank connected to the public service. The estimation of the water consumption for irrigation is about 6-9 m^3 per week to irrigate around 65 tress and other crops. Drinking water is used for the plants and vegetation because is the only source of water available for the mosque. Due to the lack of water only half of the land area is vegetated while the other half of is empty, without trees nor vegetation. A possible reuse of the treated greywater is the irrigation of the existing garden, and it could be possible also to increase the green area with new plants and vegetation to irrigate with the new source of water. With the plant and the generation of a new source of water, the drinking water save is estimated around the 30%. The water conservation will be checked after the implementation and the operation comparing water wills before and after.

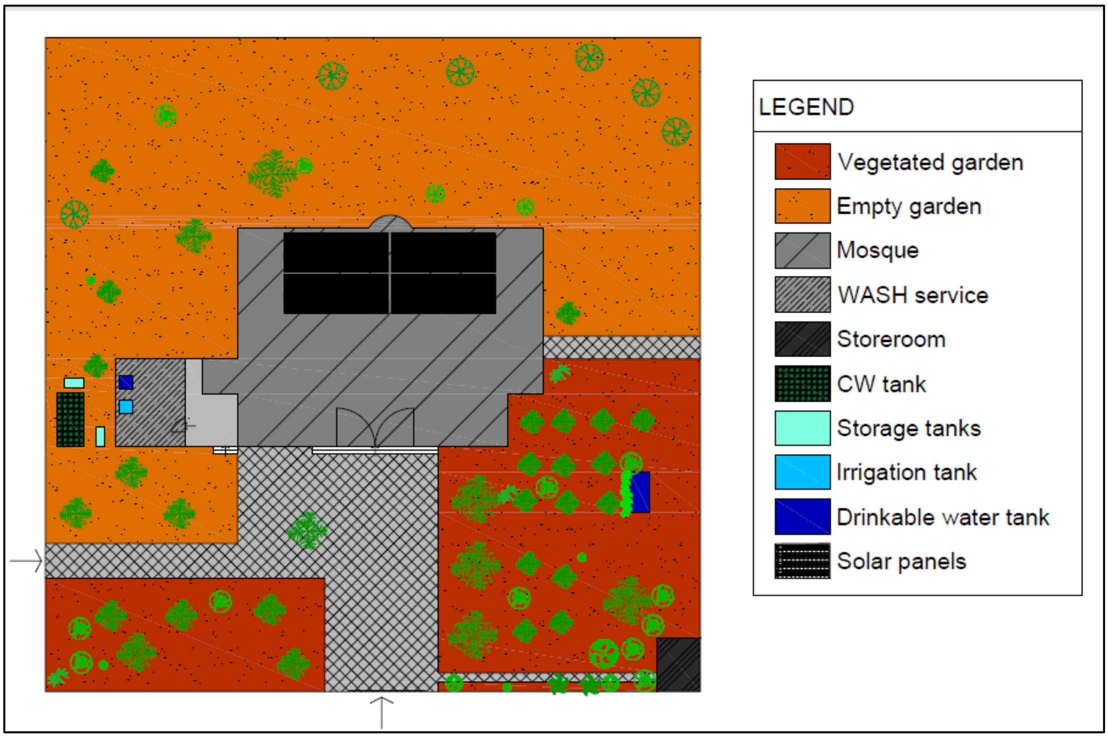

Figure 6. 2 Abudllah Alazab mosque Top view sketch

The WASH units are separated from the main building and the general conditions are good, the wastewater is being disposed by gravity to the sewer network. The WASH units building is relatively new with external plumbing, and that considered advantage point for the easy separation of the greywater and blackwater. Figures 6.3 shows the general condition of the WASH units.

Figure 6. 3 WASH unit – ablution area

Although the mosque receives electricity from the local electricity grid, the mosque has a solar system on the roof top to generate electricity and reduce the energy consumption costs. As illustrated in Figure 6.4

Figure 6. 4 Solar system – Roof top

The willingness of acceptance in the mosque staff is high, the staff is cooperative guarantying the availability to follow the training, operating and the ordinary maintenance of the greywater treatment plant.

6.3.2 Data collections

Table 6.2 below summarize the water consumption in the mosque for the last three years, as mentioned the water is only being used for ablution practices, toilet flushing and garden irrigation. For drinking water, the mosque provides bottled water for all users. The water consumptions considered relatively high and reusing treated greywater could not just reduce the water consumptions but also can increase the green area with new plants and vegetation. The collected data will be used to calculate the water saving after the implementation and operation on the CW.

The mosque is located near a shopping center, gas station and field workers/cleaners from the municipality gather in the mosque facility on a daily basis to have some rest, use the toilets, wash their hands and faces for refreshments especially during summer.

Table 6. 3 Water consumption – Abdullah Al Azab Mosque

Year	Duration	Water consumption (m^3)	Costs (JD)
2020	First Quarter	45	23.0
	Second quarter	200	409.3
	Third quarter	68	53.5
	Fourth quarter	217	462.4
2021	First Quarter	108	141.7
	Second quarter	97	113.6
	Third quarter	326	791.6
	Fourth quarter	99	118.7
2022	First Quarter	147	251.0

6.3.3 Detailed design

<u>Raw graywater Characterization,</u>

As a first step for designing CWs, the characteristics of the raw greywater have been identified. Sampling have been collected over three days and a composite sample has been tested and analyzed in the laboratories of Water, Energy, and Environment Center, ay University of Jordan. All testing process in this research have been carried out in that research center, the research center is an authorized lab in Jordan, the laboratories perform wastewater testes according to “STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER, 23RD EDITION” (Rodger B. Baird et al., 2017). Table 6.3 Shows the raw greywater parameters that have been used for the design of the HFCW.

Table 6. 4 Raw greywater characteristics

Characterization of Raw wastewater		
Parameter	Unit	Raw greywater
BOD	mg/l	100
COD	mg/l	170
TSS	mg/l	200
NH_4	mg/l	less than 4.4
NO_3-	mg/l	12.96
Turbidity	NTU	15.9
Temperature	C	25

The main parameters considered for design the CW were TSS and the BOD.

The target effluent concentrations have been determined according to the Jordanian standards for reclaimed and reuse treated greywater JS 1776/2013. Table 6.4 below shows the acceptable limits for reuse the treated greywater. For this research “Food crops intended for human consumption including raw consumption” reuse options have been considered. The daily greywater influent considered to 1 cubic meter daily, Although the mosque generates more greywater during the peak time, the flow has been selected due to the limited budget available.

Jordanian standards

The Jordanian government has established a standard for reusing and treating greywater in 2013, the standards describe some obligatory conditions, for example to use the treated greywater for toilet flushing a chlorination is obligatory. Table 6.4 below summarize the main parameter and reuse limits for treated greywater for different reuse purposes.

Table 6. 5 Jordanian standard for greywater reuse JS 1776/2013

Parameter	Cooked vegetables, parks, playgrounds, and roadsides within cities.	Food crops intended for human consumption including raw consumption	Toilets flushing
BOD_5 (mg/l)	60	60	<10
COD (mg/l)	120	120	<20
TSS (mg/l)	100	100	<10
pH	6 - 9	6 - 9	6 - 9
NO_3^- (mg/l)	70	70	70
TN (mg/l)	50	50	50
Turbidity NTU	undefined	undefined	< 5
E. coli (CFU/100 ml)	10000	1000	<10
Helminth eggs (egg/l)	<1	<1	<1
Fat, Oil, & Grease (FOG) (mg/l)	8	8	8

Area calculation

By using equation 6.1 the area required to treat BOD from 100 to 60 mg/l and the area required to treat TSS from 200 to 100 mg/l have been calculated.

$$A = -\frac{Q_{in}}{k_T} \ln\left(\frac{C_{in}-C^*}{C_{out}-C^*}\right) \qquad \text{Eq 6.1}$$

C* is can be calculated for the BOD and TSS with the same equations but different constant values according to (Abdel Razik Ahmed Zidan & Mohammed Ahmed Abdel Hady, 2018) as

$$C^*_{BOD} = 3.5 + 0.053 * C_{BOD,in} \qquad \text{Eq 6.8}$$

$$C^*_{TSS} = 5.1 + 0.16 * C_{TSS,in} \qquad \text{Eq 6.9}$$

Therefore, C* for BOD = 3.5+.053*100 = 8.8 mg/l

C* for TSS = 5.1 + 0.16*200 = 37.1 mg/l

While the value C* for BOD equal from 1 to 10 mg/l depending on the treatment stage and for TSS equal to 37 mg/l according to (Dotro et al., 2017; Kadlec & Wallace, 2009; Merriman et al., 2017; A. Stefanakis et al., 2014). The value of the C* is affected by the temperature, initial concentration of the raw wastewater, and the treatment stage (primary, secondary, or tertiary) (Dotro et al., 2017).

For this design higher values of C* have been considered in order to maximize the required area. The removal coefficient rate K_{20} have been selected and adapted to the water temperatures according to (Dotro et al., 2017; Kadlec & Wallace, 2009).

For BOD

- K_{20} = 36.5 (m/y)
- K_T = K_{20} * 1^ 25-20 = 36.5 m/y
- C* = 8.8 mg/l
- C_{in} = 100 mg/l
- C_{out} = 60 mg/l
- Q = 1.1 m^3/day
- Area = 6.26 m^2

While for TSS

- K_{20} = 30
- K_T = 30*1.1^ (25-20)
- C* = 37.1 mg/l
- C_{in} = 200 mg/l
- C out = 100 mg/l
- Q = 1.1 m^3/day
- Area = 7.91 m^2

Table 6.5 summarize the design parameters and the final calculated area for the selected parameter (BOD and TSS)

Table 6. 6 Design parameters and the final calculated areas

	K_{20} (m/y)	Q (m^3/day)	T (°C)	K_t (m/y)	C_{in} (mg/L)	C* (mg/L)	C_{out} (mg/L)	A (m^2)	Expected η (%)
BOD	37	1.1	25	37	100	8.8	60	6.26	40
TSS	30	1.1	25	48.31	200	37.1	100	7.91	50

The depth of the filter material has been selected to be 50 cm, and the water depth below the surface with 10 cm in the inlet and 20 cm in the outlet. Jordanian tuff has been selected as a filter material, several studies have recommended tuff due to its texture which is a favorable location for microbial growth, tuff are available locally with low cost. The media selected for all the CW tank, have a porosity ε=0.60 (al Dwairi et al., 2018) and L: W has been selected equal to 2:1.

The final dimensions for the CWs have been selected and illustrated in Table 6.6 below. free board is required, due to that 0.3 m has been added to the total depth of the CW.

Table 6. 7 Final dimensions of HFCW

HF-CW tank size	
High (m) (including 0.3 m free board)	0.8
Width (m)	2.0
Length (m)	4.0
Area (m^2)	8.0
Volume (m^3)	6.4

The CSL determined is less than maximum value possible suggested by literature is equal to 250 [$gBOD_5/m^2d$].

The other design parameters such as HRT, HLR, ML, and CSL have been calculated and checked according to equations illustrated in section 6.2.3. The results are summarized in Table 6.7 below

Table 6. 8 Design parameter check

AREA (m^2)	**Saturated depth (m)**	**ε (porosity)**	**HRT (d)**	**HLR (m^3/d)**	**ML – BOD (kg/ha.d)**	**CSL rate ($gBOD5/m^2d$)**
8.00	0.4	0.6	1.8	0.14	13.75	**137.5**

The parameters are achieving the recommended limits in (Dotro et al., 2017; Kadlec & Wallace, 2009) for the HRT and based on the operation mechanisms of CW, a dosing system have been installed to supply the greywater from the collection tank to the CW during the day, the dosing system can be regulated in order to achieve he treatment efficiency, for the first operation it was selected to dose the CW with (0.1 m^3) every two hour, depends on the availability of greywater in the collection tank.

Prefabricated polyethene water tanks have been used in this project, three tanks with capacity of 1 m^3 each have been used, the first tank used for as a collection /sedimentation tank for the raw greywater, the second tank used to collect greywater from the CW, and the third one used for storing the treated greywater which is connected to irrigation network. Figures 6.5 to 6.7 illustrated the detailed design for each tank.

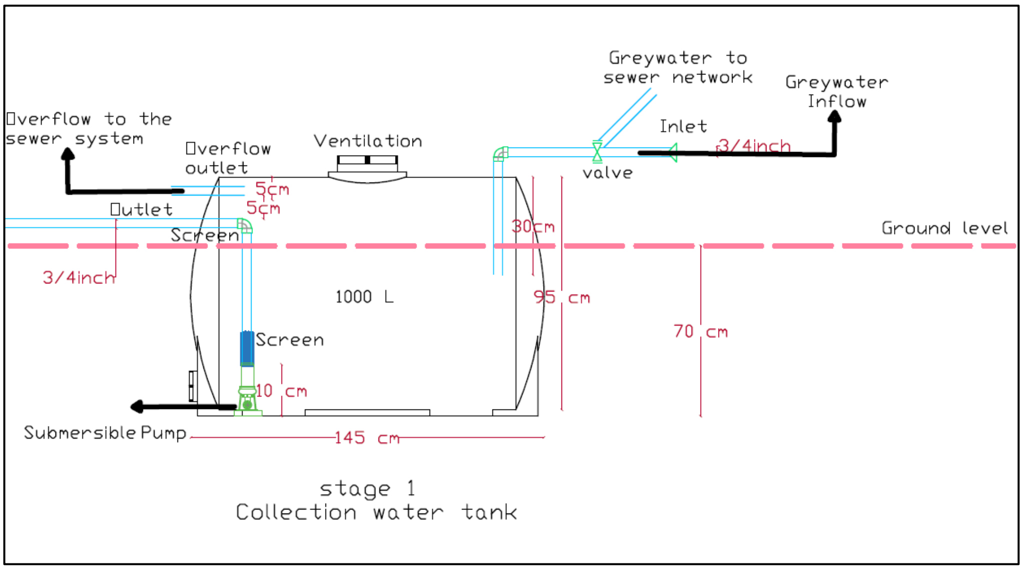

Figure 6. 5 First collection tank

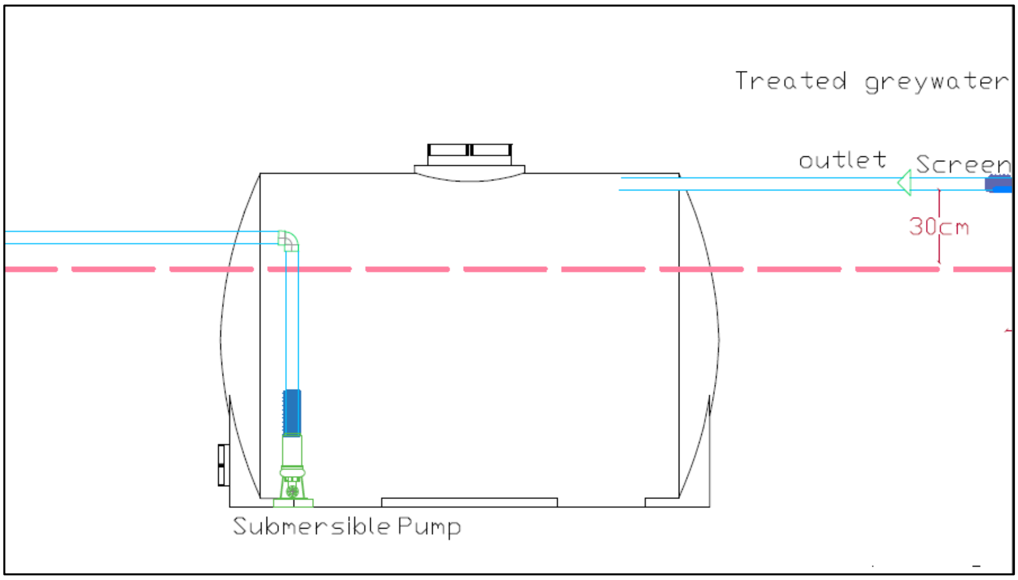

Figure 6. 6 Second Collection tank

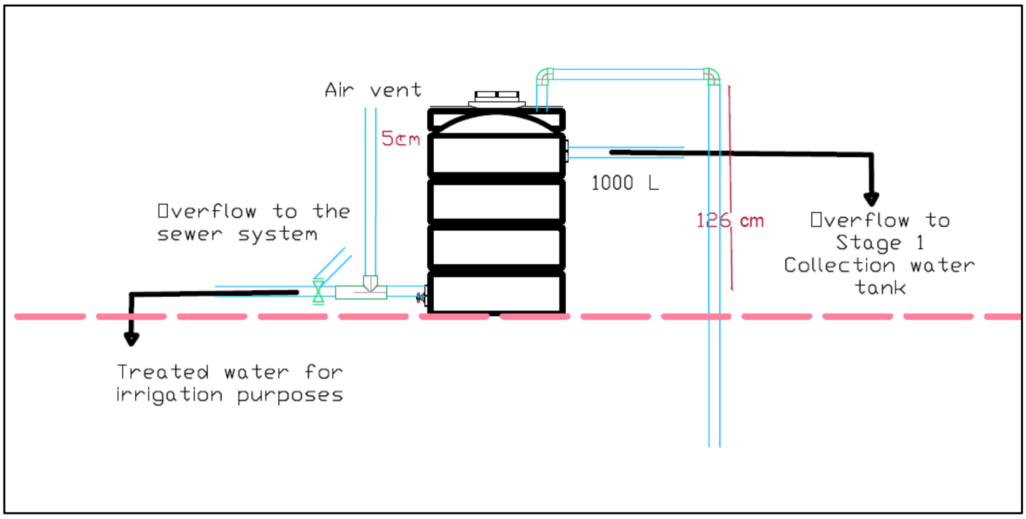

Figure 6. 7 Treated greywater Storage tank

The HFCW has been implemented by using prefabricated galvanized steel water tank, with polyethylene isolation sheets as illustrated in Figures 6.8 and 6.9. The inflow and out flow within the HFCW bed have been designed in a way that guarantees to use all the CW bed without dead zones as illustrated in Figures 6.10, The filleter material has been distributed as follow, the first 40 cm and the last 40 cm of the tank length, course tuff with dimeter of 4 cm has been used. While for the remaining 3.2 meters, tuff has been used also but with 2 cm diameter.

The inlet pipe has been installed 10 cm below the tuff surface, while the outlet pipe has been installed 20 cm below the tuff source in order to guarantee the flow direction. The slope of the bed is 1% towered the outlet.

Phragmites Australis and Arounda have been used in the wetland, distances of 25 cm to 50 cm between each reed were considered.

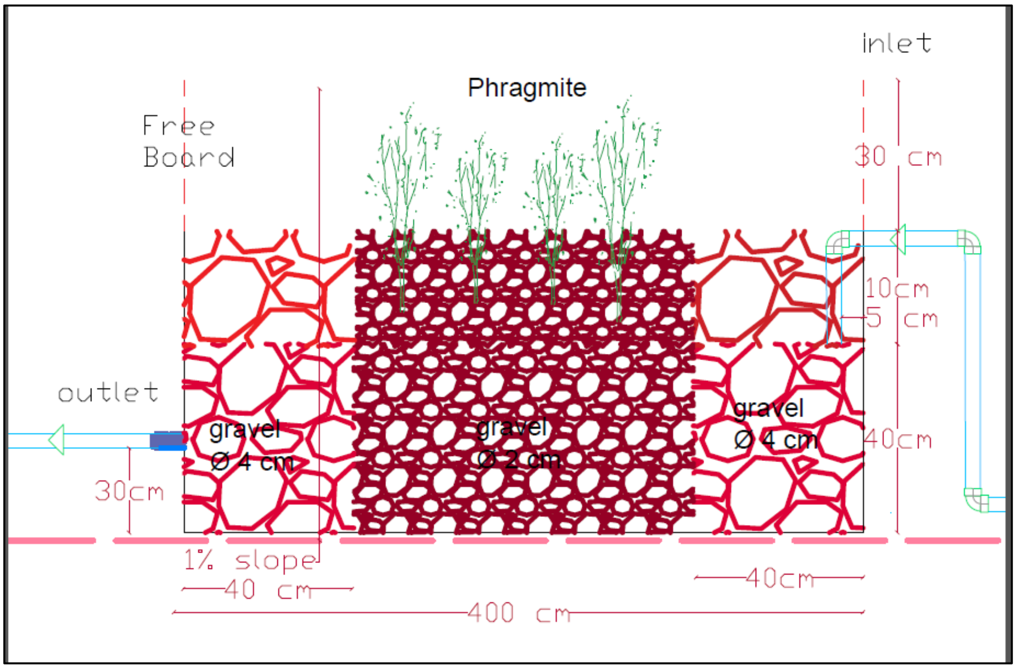

Figure 6. 8 Side view HFCW

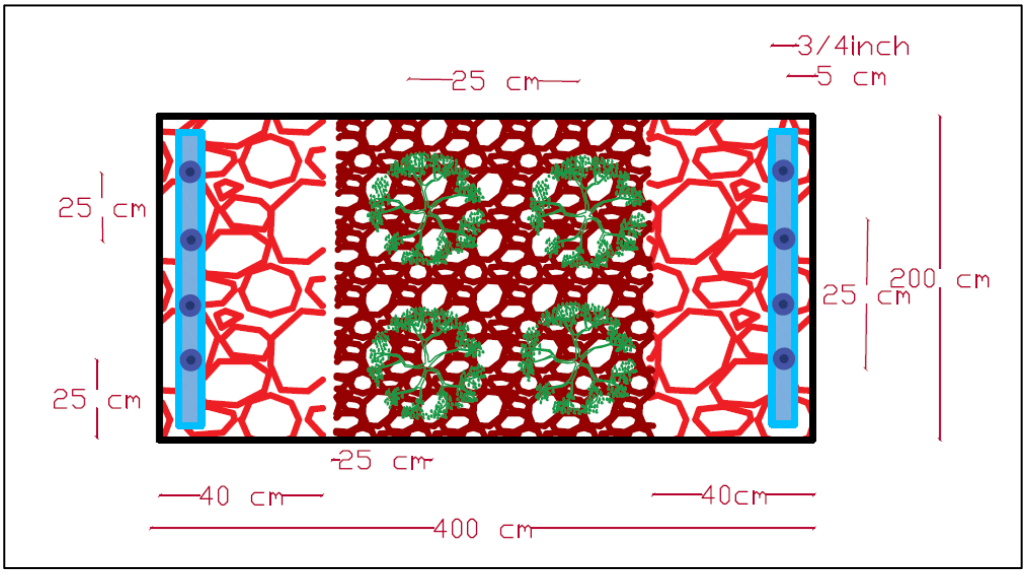

Figure 6. 9 Top view of HFCW

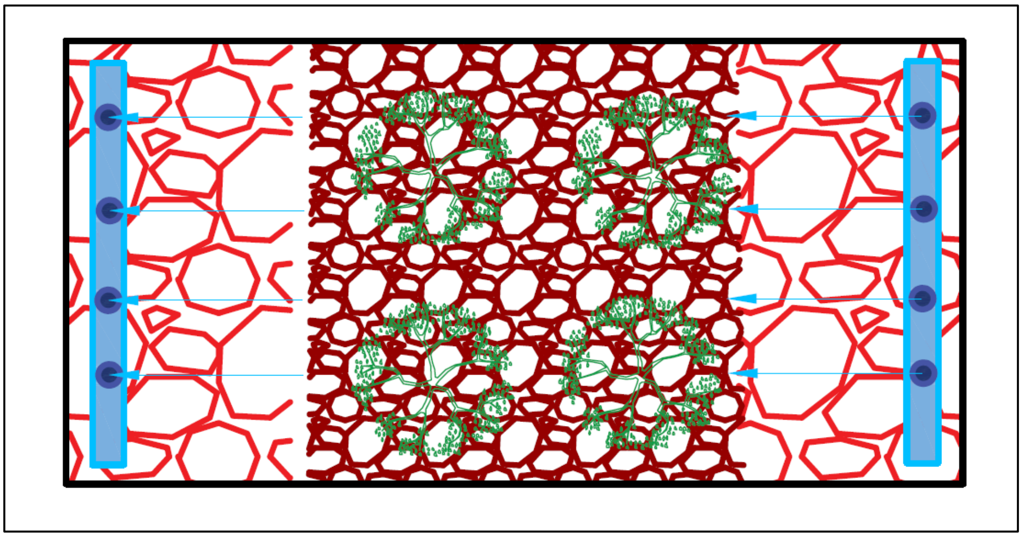

Figure 6. 10 Flow within the HFCW bed

The design also contained a recirculation system which serve several benefits, to dilute the concentrations of the raw greywater with treated one, to maximize benefiting of the treated greywater so the water can be stored and circulated within the system instead of discharge it to the sewer in case the reuse option is not needed, finally to assure that the CW has enough water inside.

The system contains an overflow to the sewer system from the first collection tank, so in case of overloading the system or in case of pump failure the greywater will flow by gravity to the sewer system smoothly.

Another overflow has been provided in the second tank which collected treated greywater from the CW, the overflow can go directly to the trees in the garden because the greywater considered to be treated in that stage.

The final collection tank in the roof of the building has an overflow connected to the first collection tank to achieve the circulation mentioned before.

The full detailed design is provided in Appendix E and more photos of implementations are attached in appendix G.

6.3.4 Monitoring plan, laboratory details

<u>Testing greywater samples have been</u>

First of July 2022 was the first day to operate the system, and accordingly the monitoring programs started after one month of operation. Samples were collected from the first collection tank – pretreatment and from the (second tank) treated greywater tank – collection tank. As mentioned earlier tests were carried out by laboratories of Water, Energy, and Environment Center, ay University of Jordan. The testes were performed according to "STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER, 23RD EDITION" (Rodger B. Baird et al., 2017). The frequency of testing has been affected with the limited budget and the research time deadline. Therefore, four rounds of sampling and testing have been carried out on monthly basis in order to cover different climate conditions. Table 6.8 below shoes the testing results and the treatment efficiencies for the four testing cycles while Table 6.9 shows the treatment efficiencies being compared to the Jordanian standards. It is worth to mention that the HFCW and the whole graywater treatment systems are able to meet all the Jordanian reuse limits and standards.

Table 6. 9 Removal efficiencies for the main parameters – HFCW

Parameter	01 August		Efficiency	02 September		Efficiency	05 October		Efficiency	12 November		Efficiency
	Raw	Treated		Raw	Treated		Raw	Treated		Raw	Treated	
BOD_5 (mg/l)	100	30	70%	57	4	93%	91	9	90%	84	10.1	88%
COD (mg/l)				146	17	88%	160	12	93%	139	11.3	92%
TSS (mg/l)	200	6	97%	183	12	93%	156	5	97%	138.7	0	100 %
pH		8		7.3	8.3		7.1	7.8		7.2	7.6	
NO_3^- (mg/l)	13	12.28	6%	36	24	33%	31	23	26%	39	27	31%
TN (mg/l)				39	30	23%	36	26	28%	41	29	29%
Turbidity NTU	16	7	56%	57	3	95%	16	0	100 %	17	0	100 %
E. coli (MPN/100 ml)		<1		763	213	72%	661	190	71%	310	146	53%
Helminth eggs (egg/l)				NA	NA	-	NA	NA		NA	NA	
FOG (mg/l)				NA	NA	-	NA	NA		NA	NA	

Table 6. 10 Parameters for the treated greywater vs reuse limits

Parameter	Treated greywater				JS 1776/2013- Reuse of treated graywater		
	01 August	02 September	05 October	12 November	Cooked vegetables, parks, playgrounds, and roadsides within cities.	Food crops intended for human consumption including raw consumption	Toilets flushing
BOD_5 (mg/l)	30	4	9	10.1	60	60	<10
COD (mg/l)		17	12	11.3	120	120	<20
TSS (mg/l)	6	12	5	0	100	100	<10
pH	8	8.3	7.8	7.6	6 - 9	6 - 9	6 - 9
NO_3^- (mg/l)	12.28	24	23	27	70	70	70
TN (mg/l)		30	26	29	50	50	50
Turbidity NTU	7	3	0	0	undefined	undefined	< 5
E. coli (CFU/100 ml)	<1	213	190	146	10000	1000	<10
Helminth eggs (egg/l)		NA	NA	NA	<1	<1	<1
Fat, Oil & Grease (FOG) (mg/l)		NA	NA	NA	8	8	8

Green Color indicates that the standard is achieved, red color the standards are not achieved

6.4 Post implementation

6.4.1 Performance evaluation

To evaluate the overall impact of this interventions, a series of site visits have been carried out to the plant location with stakeholder who participated before in the MCA evaluations described in chapter 5 the site visits have been carried out in November after four months of operation. A survey was prepared to collect the feedback and to evaluate the project, the survey was adopted from the MCA and covered the same indicators that used before and extended to cover more indicators.

Stakeholders were asked to give a score from 1 to 5 for the performance of the CW according to some selected indicators, and after that an open question to collect the feedback and potential of future developments. Table 6.10 below shows the performance scores by the stakeholders, and Figure 6.11 below represents a comparison between the average performance of the HFCW before and after implementation as scored by the same stakeholders.

Clearly stakeholders were convinced more with the performance of HFCW and showed interests in applying the same technology in different locations and different applications.

Table 6. 11 Performance ratings on (1 - 5) scale – post implementation and operation

Indictors/Stakeholders	After Implementation					
	Stak.1	Stak.2	Stak.3	Stak.4	Stak.5	Stak.6
Odor	5	5	5	5	5	5
Attract insects	5	5	5	5	4	5
Provision of aesthetic and green places	5	5	5	4	4	5
Capital cost	5	3	5	5	5	4
Operation and maintenance cost	5	5	5	5	5	5
Required space	4	5	4	4	5	4
Ease of implementation	5	5	5	4	5	5
Ease of operation	5	5	5	5	5	5
Does not cause wall or ceiling damp	5	5	5	5	5	5
treatment efficiency	5	5	4	5	5	4
Potential or duplicate the project	5	5	5	5	5	5
reusing of harvested reeds	5	5	4	5	4	4
regulating temperatures	5	5	4	4	4	5
increasing the green area	5	5	5	5	4	4
increasing the agriculture production	5	5	5	4	4	3
consuming almost zero energy	5	5	4	4	5	4

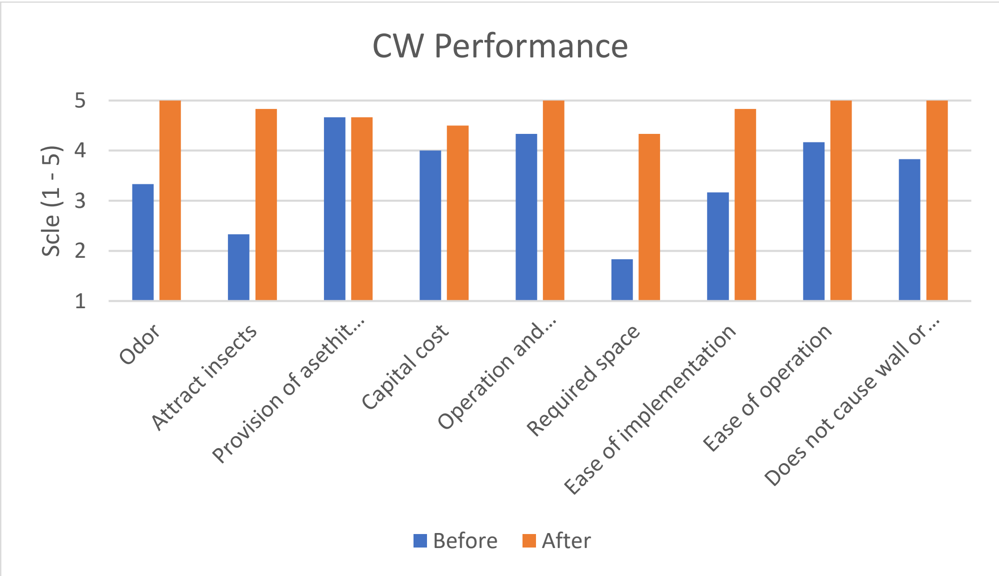

Figure 6. 11 Performance of HFCW before & after implementation & operation – average scores

6.4.2 Water Saving

According to the water bill after the implementation the total water consumption for the period from July to September 2022, which represents the summer period in Jordan, was 97 m^3 with total cost of 113.63 JD. Comparing to the last year 2021 for the same period, the water consumption was 326 m^3 with total cost of 791.6 JD. As a result, the HFCW was able to save around 70% of the water consumption as illustrated in Figure 6.12 and save 85% of the water expenses.

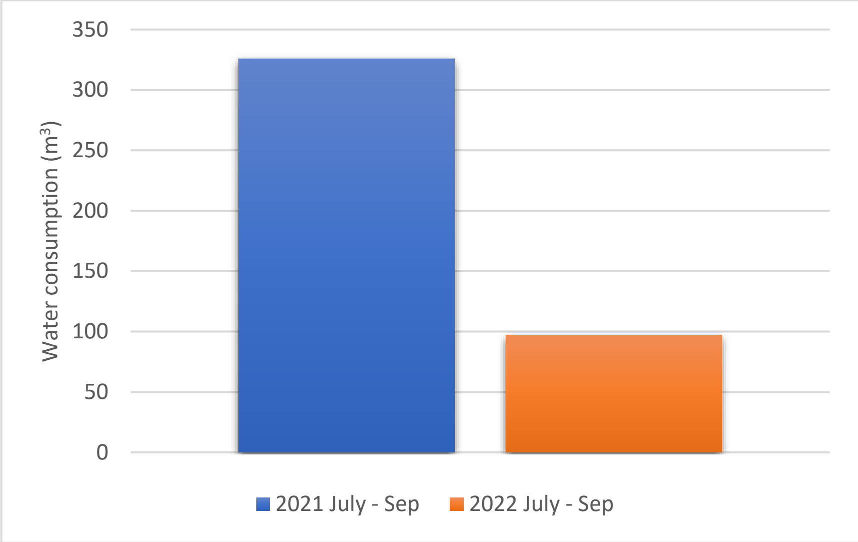

Figure 6. 12 Water Saving - before & after HFCW

6.4.3 Lessons learnt

- Raising awareness before implementation; raising awareness sessions should be carried out not just to the operators but to the surrounding community before the implementation in order to increase the willingness to accept the intervention and avoid any rejections at a later stage.
- Organizing and obtaining the required permits from all the legal entities, in order to avoid any delay or legal conflicts, all the required permits should be governed at the country level and the city level.
- Security fence should be provided, for the security and to avoid any vandalisms, fence and security measures should be provided to protect the system.
- Engaging the local community with the implementation, in order to increase the sense of ownership and for better disseminating the idea of the project, engaging the local community is vital.

6.5 Summary and conclusion

This chapter represent the technical part of CWs – NBS, this activity translated the growing interest in treating and reusing greywater generated from public facilities in Jordan. An assessment took place to select the situatable mosque for the project; Abduallah Al Azab mosque was selected among other eleven mosques due to the potential or reuse of treated greywater, availability of space for the CW bed, willingness to have the project by the community, etc. During the assessment stage it was found that the community has many concerns related to greywater treatment and reuse projects their concerns are mainly related to health and safety concerns. However, suitable awareness raising would be able to solve the issue and raise the acceptance level. It was found that people in rural area are more flexible to accept similar interventions than people in urban area.

Involving stakeholders and obtaining the required permits from all authorities have delayed the project. Therefore, a complete understanding of the required permits and predefined all the stakeholders is a must for the future interventions.

HFCW has been selected among other alternatives as resulted from chapter five before, the system consists of sedimentation tank followed by HFCW, collection tank and finally an elevated irrigation tank. Dosing pump has been used to feed the HFCW bed in order to maintain a sufficient hydraulic retention time to treat the greywater. The treatment system was able to meet the Jordanian standards for reuse treated greywater for irrigating uncooked vegetables, cooked vegetables, parks, playgrounds, and roadsides within cities, while for reusing treated greywater in toilet flushing the Jordanian standard required additional disinfection step for this reuse option. The system, according to the preliminary monitoring program, has proved its capacity to treat greywater with removing efficiency of 85% for BOD_5, 97% for TSS, 91% for COD, and 65% for E. coli. The testing period was limited due to availability of budget and due to time constrains, the research tried to cover summer and winter seasons to monitor the performance of the system. Further testing rounds are recommended to be taken in the future. It was found that the system was able to save 70% of the water consumption comparing to the same period last year and that resulted in saving 85% of the water bills for that period.

Chapter 7: Conclusion

The current research aimed to investigate and to determine the potential for integrating CWs – NBS in the water and environmental sector, and to analysis their sustainability as a wastewater treatment solution, by recognizing the best practices of CWs - NBS in sanitation and water management in Mediterranean countries and to identify current limitations of applying CWs – NBS. In addition, assessing their resilience to climate change and analyzing the potential of connecting CWs – NBS with the circular economy in Jordan and in Italy. For achieving these aims, several activities have been carried out, those activities were always aligned and performed under the sustainability criteria (technical, financial, environmental, social, and institutional). The main activities were:

- identifying the current practices and the current challenges that face the operation of CWs – NBS in Jordan and Italy.
- disseminating questionnaires to identify the stakeholders' perspectives and the communities' perspectives about CWs – NBS and to identify the gaps between them.
- identifying the practices that show potential to be integrated with circular economy, focusing on the reuse of harvested reeds, the value of reusing treated wastewater, and monetizing the benefits of CWs – NBS.
- comparing CWs – NBS with other treatment technologies for specific selected case studies.
- implementing and monitoring a pilot scale CWs to treat wastewater and to evaluate its performance according to the reuse and treatment standards.

The main activities that were carried out in this research have been translated into seven chapters. While the first chapter represents the introduction, the main research objective, and research activities, the second chapter represents a comprehensive review on CWs – NBS as a sustainable sanitation solation (published paper), including definitions, classification, treatment mechanisms, etc. The third chapter represents a detailed description of the water and environmental sectors in the selected case studies, several site visits have been conducted to collect primary and secondary data and to understand the current applications and operational practices and challenges of CWs – NBS as well as the future perspectives and opportunities of integrating CWs- NBS in the sector. The methodology used and the obtained results from this chapter have encouraged the research to consider an extended investigation and to disseminate questionnaires among all stakeholders working in the sector, the questionnaires also have considered the communities in order to understand all perspectives of integrating CWs – NBS in the sectors. And that has been translated into chapter four. In Chapter four, disseminated questionnaires (between stakeholders and communities) among the two selected countries have been utilized to understand the opportunities and challenges of integrating CWs – NBS in the sector. The community level questionnaire aimed to also measure the communities' knowledge and awareness about several topics such as climate change, water scarcity, sustainable sanitation and treatment technologies including CWs – NBS. In this chapter the Contingent Valuate (CV) method has been utilized to measure communities' willingness to accept and willingness to pay for benefiting of the co – benefits of CWs – NBS. It has been noticed in this chapter that the Jordanian stakeholders have concerns about the sustainability of CWs – NBS as a treatment technology in the local sector, therefore further activities have been considered in this research that focused in comparing CWs to other local treatment alternatives as explained in following chapter. Chapter five represents a detailed evaluation and a comparison between CWs – NBS with other treatment technologies for selected case studies using Multi – Criteria Analysis as a sustainability assessment– indicators-based tool (published paper); the evaluation has been applied for two selected case studies in a selected country, the first at a town level and the second at a governmental facility level, following to that and for additional emphasizing a technical chapter has been considered as chapter six. Chapter six represents a detailed technical design, implementation, monitoring, and evaluation of a pilot scale CW used to treat greywater in the governmental facility which was evaluated in chapter five before. Finally, chapter seven represents a general conclusion of the research works.

The results of this research showed several gaps between the stakeholders' and the communities' perspective about CWs – NBS, such as stakeholders considered people acceptance as a main challenge for implementing CWs while the research shows that communities preferred CWs over other treatment technologies. The CV method used to monetize the co – benefits of CWs and to identify the communities' willingness to accept and willingness to pay for benefiting of CWs – NBS, has indicated a promising willingness to pay by the communities to have CWs – NBS in their towns and their households. The results also identified the main factors that affected the level of willingness to accept and willingness to pay such as the "awareness level about climate change impacts", "communities' concerns regarding the odor and the insects", and the communities' knowledge about the benefits of CWs – NBS".

Regarding the financial sustainability and the circular economy approach, the research focused on three points; firstly, the potential of reuse the harvested reeds locally, several reuse options have been identified and validated by the communities, such as burning and heat generation, composting, feeding animals, etc. Secondly the economic benefit of reusing wastewater which has been treated with low operational costs using CWs – NBS, and thirdly the measured willingness to pay by the communities for having CWs – NBS, communities have expressed their willingness to pay for having CWs – NBs close to their towns and even in their households. The unique part of this research was utilizing CV method to monetize the co – benefits of CWs – NBs and linking the results with the circular economy approach.

The part of this research that focused in the Jordanian wastewater sector has emphasized the sustainability of CWs – NBs as a sanitation solution at both centralized and decentralized levels. The Multi – Criteria Analysis (MCA) tool which utilized with sixteen indicators which were selected and validated by the Jordanian stakeholders, Analytical Hierarchy Process (AHP) has been used to develop the indicators' weights and weighted Sum Model (WSM) has been used to score aggregation and ranking the alternatives. The results obtained by the MCA in the first case study showed that French CW was identified the best sustainable treatment technology for the selected case study (Al Azraq town) comparing to the activated sludge and stabilization ponds. Similar methodologies have been used at governmental facility level (Abudallah Al Azb mosque); the results also emphasized the sustainability of CW as a decentralized treatment option.

Although MCA tool is widely used and studied in academic field, it is still not integrated in the practical decision-making process in the environmental sectors; in fact, the research showed a great potential of integrating this sustainability assessment tool with the decision-making process in the studied cases.

Finally, the research emphasized the sustainability of CWs as a treatment solution through implementing, monitoring, and evaluating a pilot scale CW to treat the greywater generated from Abdualla Al Azab mosque. The eight square meter horizontal flow CW has been able to treat the greywater and remove 90% of the BOD, 90% of the COD and 98% of the TSS. By that the CW allowed the operator to reuse the treated greywater for irrigating cooked vegetables, parks, playgrounds, and roadsides within cities according to the Jordanian standards, leading to save 70% of the water consumption and 85% of the water costs. At the social level, the pilot project has been used to raise awareness among the local communities toward reuse the treated wastewater and toward NBS and CWs benefits.

Although the challenges that have been raised during the research period such as Covid19, the lockdown, availability of data, availability of stakeholders, limited budget, etc., this research has provided new approach to study and to investigate the role of CWs – NBs in sustainable sanitation and water management. The research approach covered all sustainability criteria through the research activities, hence the research paved the road for further researchers to apply the same methodologies and tools in different contexts, and to emphasize a greater potential of applying CWs – NBS at different levels and different scales, as well as to illustrate the importance of integrating Multi – Criteria Analysis in the decision-making process in the environmental sectors. The research results will support and enlarge the vision of stakeholders about integrating CWs – NBS in water and environmental sector, as well as minimize their concerns about these solutions.

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Appendices

Appendix A. Photos of CWs - NBS in the selected case studies

First: Jordan

Photos of Lajoun WWTP

The following Figures from 3.15 to 3.24 describe different facilities and units within Lajoun WWTP

Figure A. 1 Tank receiving station - Lajoun WWTP

Figure A. 2 Anaerobic Pond - Lajoun WWTP

Figure A. 3 Aerated facultative pond - Lajoun WWTP

Figure A. 4 Sludge harvesting boat - Lajoun WWTP

Figure A. 5 Maturation pond - Lajoun WWTP

Figure A. 6 Rock filter - Lajoun WWTP

Figure A. 7 CWs - Lajoun WWTP

Figure A. 8 CWs - Lajoun WWTP - a

Figure A. 9 Reuse harvested reeds – Lajoun WWTP

Figure A. 10 Final storage pond – Lajoun WWTP

Photos for Mafraq WWTP

The following Figures 3.36 to 3.47 describe different facilities and units within Mafraq WWTP

Figure A. 11 Grit removal – Mafraq WWTP

Figure A. 12 Aerated Lagoons – Mafraq WWTP

Figure A. 13 Denitrification Pond – Mafraq WWTP

Figure A. 14 Sludge drying beds – Mafraq WWTP

Figure A. 15 Dry sludge – Mafraq WWTP

Figure A. 16 Nitrification Pond – Mafraq WWTP

Figure A. 17 Rock filter bed

Figure A. 18 HFCW – Mafraq WWTP

Figure A. 19 HFCW – Mafraq WWTP

Figure A. 20 Treated wastewater storage pond – Mafraq WWTP

Figure A. 21 Treated wastewater pumps – Mafraq WWTP

Figure A. 22 Final reuse – Mafraq WWTP

Photos for Shoubak WWTP

The following Figures 3.59 to 3.62 describe different facilities and units within Shoubak WWTP

Figure A. 23 Imhoff Tank – Shoubak WWTP

Figure A. 24 Sludge drying beds – Shoubak WWTP

Figure A. 25 Evaporation Pond – Shoubak WWTP

Figure A. 26 CWs – Shoubak WWTP

Second: Italy

Photos of Carimate WWTP

Figure A. 27 VFCWs during Spring season – Carimate WWTP

Figure A. 28 VFCWs during winter season - Carimate WWTP

Figure A. 29 FWS CWs during Spring season - Carimate WWTP

Figure A. 30 FWS CWs during winter season - Carimate WWTP

Appendix B. Questionnaires, Results as Figures

Community Level (*in both countries, the highlighted question asked for Italian only)*

1	Age	
2	Gender	
3	Education level	
4	Occupation	
5	City	
6	Are you aware about the global climate change issue?	Yes/No
7	Do you think Jordan/Italy is affected by the climate change impacts?	Yes/No
8	Do you think the climate change has a **fast impact** in Jordan/Italy?	Yes/No
9	Do you think that Jordan/Italy is facing water scarcity issues?	Yes/No
10	Is your house connected to a sewer **system?**	Yes/No
11	do you know the name of the wastewater treatment plant in your area/town?	Yes/No
12	What is the name **of the** wastewater treatment plant in your area/**town? (**In case you don't know write I don't know)	
13	If your house isn't connected to the sewer system, do you have sanitation **system in** your household (septic tank, ciss pit …)?	Yes/No
14	How much it costs you to manage your wastewater (monthly or every three months, please indicate the period)?	
15	monthly	
16	Would you accept the establishment of a Wastewater Treatment Plant (WWTP) to serve the community **where** you live?	Yes/No
17	Do you know that the conventional mechanical wastewater treatment plants considered as source of GHG which contribute to climate **change?**	Yes/No
18	Do you know Constructed wetlands - Nature Based Solution technology which can be used to treat wastewater?	Yes/No
19	Do you know if it is applied in Jordan?	Yes/No
20	Can you name the WWTP using this constructed wetland or where is **its** location? (**In** case you don't know write I don't know)	
21	Do **you know** any advantages and benefits of using Constructed wetlands - NBS technology over the mechanical technology?	Yes/No
22	Would you irrigate your crops with treated **wastewater** according to the Jordanian/Italian standards?	Yes/No
23	How strongly do you intend to use treated wastewater for irrigation?	(1 don't accept strongly, 2 don't accept, 3 **fairs**, 4 accept, 5 accept strongly

24	In case of availability of products irrigated with treated wastewater are you willing to buy and consume it in your house with your family?	Yes/No
25	according to your opinion and future perspective and in case of having a wastewater treatment plant using CWs in your town, rank the following benefits according to your opinion	1) Protecting human health for diseases and illness 2) Biodiversity restoration and attracting wildlife 3) less gas emissions and Carbon sequestration, constructed wetlands can absorbs CO2 a step to face the climate change 4) system that provides source of water (reusing treated wastewater) 5) Source of the harvested reeds/plants can be used in the local market with economic value 6) Very limited energy required (almost zero) during operation 7) Green area that can be aesthetical place ere people can enjoy 8) system with Very low costs in operation and maintenance 9) easy system to operate and maintain and doesn't require skilled labors 10) protecting the environment from the discharging untreated wastewater 11) Creating job opportunities for people in operation the treatment wetland
26	Do you think this technology can be source of odor?	Yes/No
27	Do you think this technology attract insects and mosquitos?	Yes/No
28	Do you think this technology requires large land area?	Yes/No
29	Do you have a problem with attracting birds and restoring biodiversity in the town?	Yes/No
30	Do you prefer having constructed wetlands over the mechanical one?	Yes/No
31	Would you accept to have WWTP using constructed wetlands technology close to your house?	Yes/No
32	Would you accept to have WWTP using constructed wetlands technology in your town/city?	Yes/No
33	Do you think the harvested reeds/plants (which will be harvested periodically) can be used locally?	Yes/No
34	Based on your opinion which of the following uses can harvested reeds be used in? (You can choose more than one option)	
35	If you believe that this technology has the previous positive impact, are you willing to pay tax for implementing this technology in your town?	Yes/No
36	How much would you pay for supporting implementation of constructed wetlands (monthly/fixed please specify)?	
37	If you know that Constructed wetlands can be applied in your household to treat the greywater (water coming from kitchen, sinks and washing machines**), and** you can use the treated water in irrigation in your yard or for toilet **flushing would** you willing to have this technology in your house?	Yes/No
38	would you accept to pay for having Constructed wetlands in your **house?**	Yes/No
39	if your answer to the previous question is yes, how much would you **pay?**	

Stakeholder Level (*in both countries, the highlighted question asked for Italian only*)

1	**Name (optional)**	
2	Age	
3	Email	
4	Phone number (optional)	
5	Occupation	
6	Organization Name	
7	Type of Organization	
8	Please indicate whether you would be willing to be contacted for further discussion and clarification	Yes/No
9	What is the most used treatment technology in the wastewater treatment plants in Jordan/Italy?	
10	Do you know that 35% of Jordanian people are not connected to sewer system and wastewater treatment plants? Do you know that 12% of Italian people are not connected to sewer system and 30% are not connected to wastewater treatment plants?	Yes/No
11	Do you know that treated wastewater is one of the main sources of non-conventional water resources in the Jordanian water budget and equal to 14% of the water budget? Do you know that the Italian government considered treated wastewater as a part of the water budget?	Yes/No
12	Do you think the Jordanian sanitation situation needs more sustainable solutions?	Yes/No
13	Do you believe that serving the small town and scattered population a sustainable sanitation solution will enhance the percentage of reusing of treated wastewater?	Yes/No
14	Do you believe that constructed wetlands can be used as a main technology to treat wastewater?	Yes/No
15	Do you think that the mechanical/ conventional wastewater treatment plants are a source of greenhouse gases contributing to climate change?	Yes/No
16	Do you think constructed wetlands have advantages and benefits over the mechanical treatment technologies?	Yes/No
17	On a scale from 1 to 5 (where 1 is the least and 5 is the most) and according to your opinion and experiences give a score to the following points based if they are matching with using Constructed Wetlands for treating wastewater	1) Low operational, maintenance and capital costs 2) zero energy or Low energy requirements 3) the system requires huge land area 4) CWs require unskilled labors and operators 5) Can be used as a decentralized or semi-centralized solutions for scattered communities and rural area 6) can be used as a centralized sanitation solution 7) Providing a source of treated wastewater that can be used in agriculture according to Jordanian standards. 8) CWs are resilient to climate change impacts (heavy rainfall, heat waves, and flash storms) 9) CWs are flexible treatment process (greatest ability to handle high variation in water quality and quantity while still meeting treated water quality objective)

		10) Process robustness (avoiding incidents demanding unscheduled manual intervention or unexpected additional cost) 11) Generated less sludge and wastes comparing to the mechanical systems 12) Require less energy and costs to manage sludge and the by-products of treating wastewater 13) Protecting the environment by absorbing the CO2 from the atmosphere 14) Restoring biodiversity and wildlife 15) Providing green area and aesthetical places where people can enjoy 16) CWs can provide source of financial resources through investment in the harvested reeds and the treated sludge 17) Adheres with the legislations and the institutional requirements
18	On a scale from 1 to 5 (where 1 is the least possibility and 5 is maximum possibility, give a score to the following challenges that might be faced while applying constructed wetland CWs – NBS in Jordan	1) The availability of lands 2) The Land costs in Jordan 3) Availability of funding for new wastewater treatment plant 4) Availability of funding for operating or availability of investment scenario in operating similar technology 5) Local and international donors don't support and fund similar technologies and prefer the mechanical solutions 6) Availability of similar examples in the country that used CWs as a main treatment technology 7) availability local experiences and skills in designing similar technology 8) availability of skills in operation and maintain CWs- NBS 9) The institutional situation and the unclear responsibility for ownership and operation of the plants 10) acceptance of using this technology as main treatment technology by decision makers 11) The variety of treatment efficiency, according to the climate, season, and wastewater characteristics (quality) and quantity. 12) Achieving the treatment efficiency standards and reuse standards 13) managing of sludge and the harvested reeds of the CWs 14) Constructed wetlands need water to be available in the beds all the time within the treatment plants 15) Availability of filter materials – substrates materials like the aggregate

		16) availability of the efficient plants to be used for the constructed wetlands locally 17) Clogging problem within the filter materials leading to overflow of untreated wastewater 18) People acceptance of this technology and preferring mechanical treatments 19) source of odor 20) source of insects and mosquitos 21) The willingness of the private sector to invest through operating constructed wetlands

Results and Figures

First: Jordanian case study

Jordanian Stakeholders

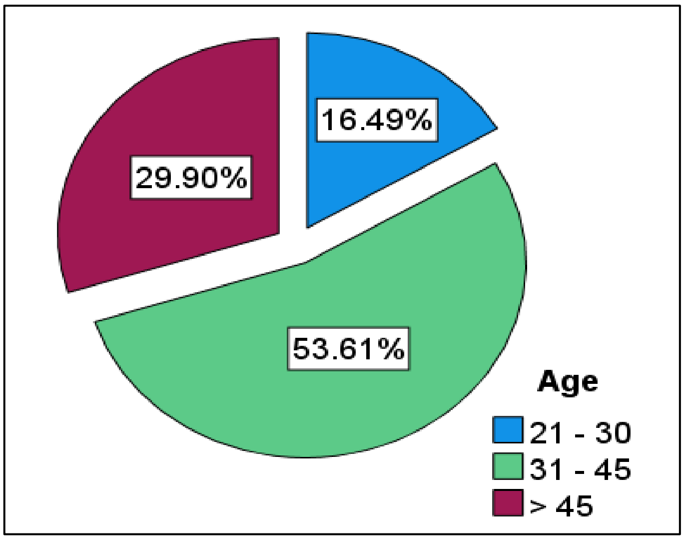


Figure B. 1 Jordanian stakeholder's age distribution

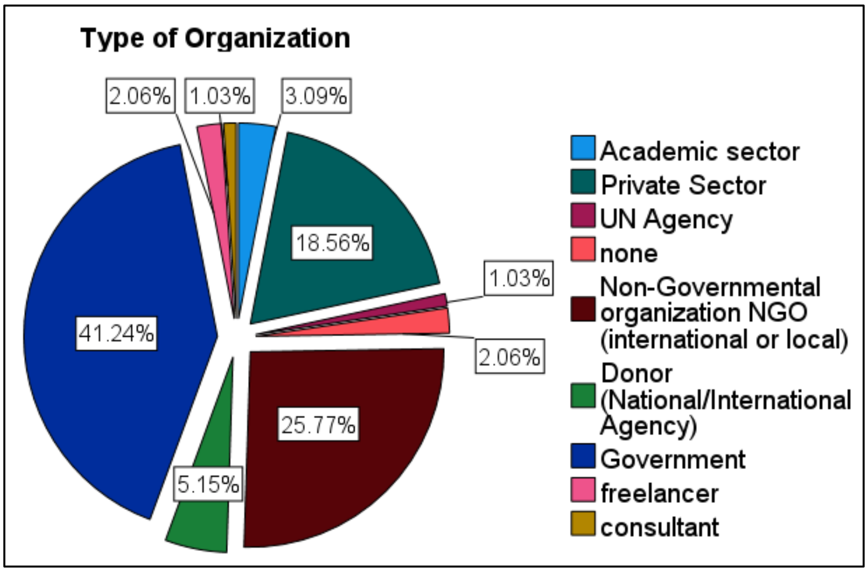


Figure B. 2 Types of organization - Jordanian stakeholder

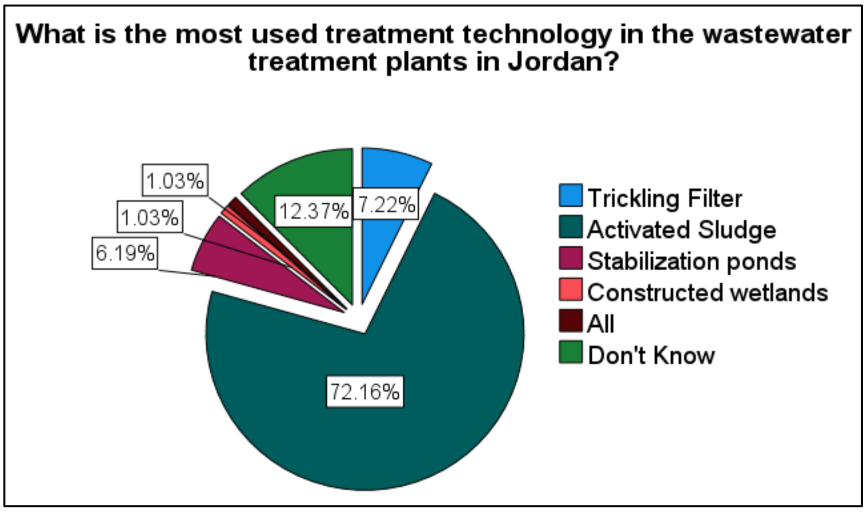


Figure B. 3 Most used treatment technology in Jordan - Jordanian stakeholder

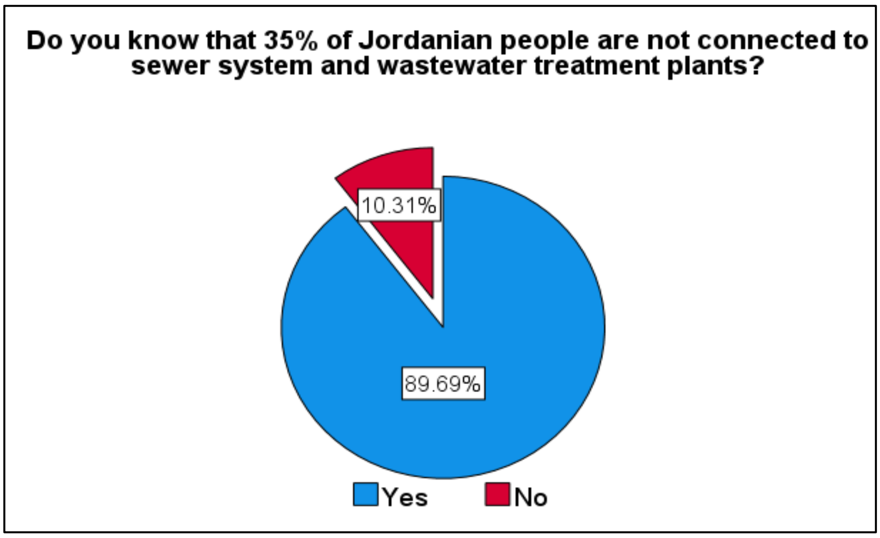


Figure B. 4 Percentage of unserved people with sewer - Jordanian stakeholder

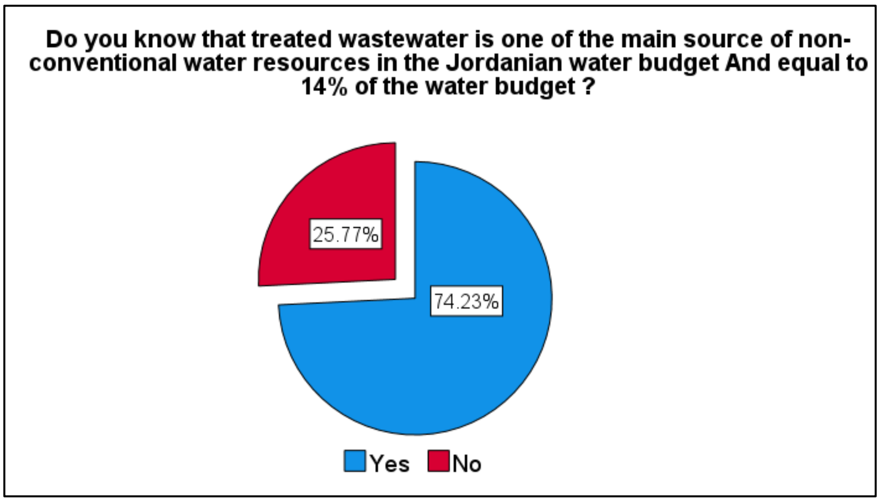


Figure B. 5 Percentage of TWW in Jordanian water budget - Jordanian stakeholder

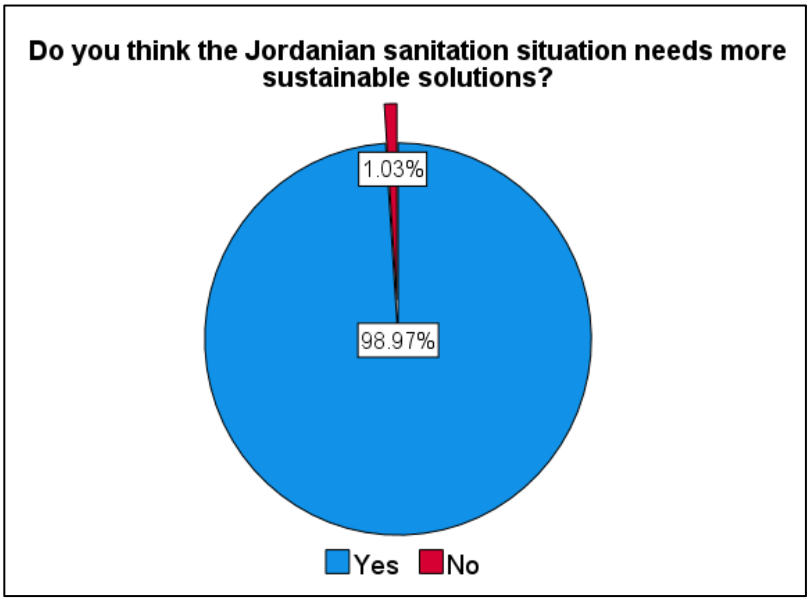


Figure B. 6 Sanitation sector needs upgrading - Jordanian stakeholder

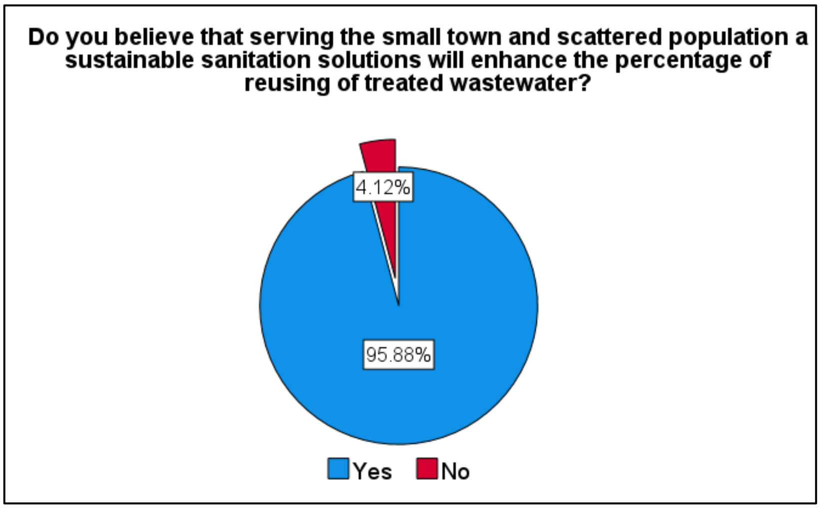


Figure B. 7 Serving scattered communities and water reuse - Jordanian stakeholder

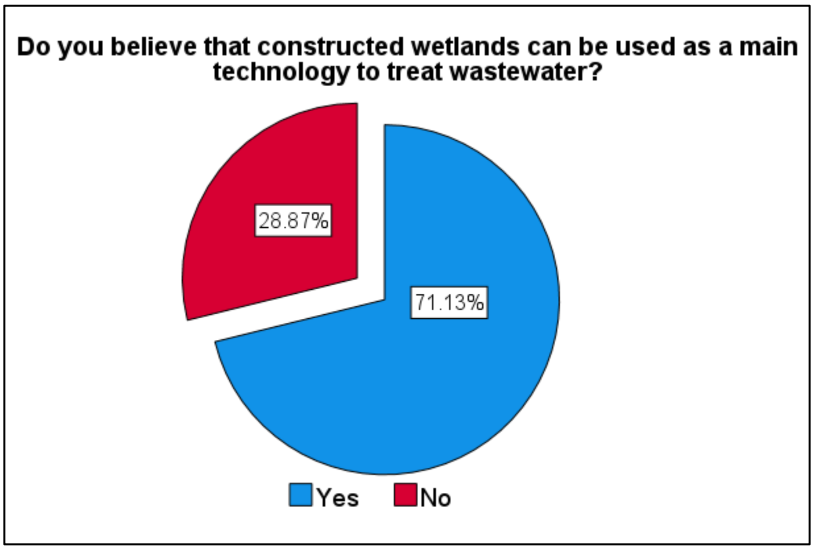


Figure B. 8 Constructed wetlands as a main technology - Jordanian stakeholder

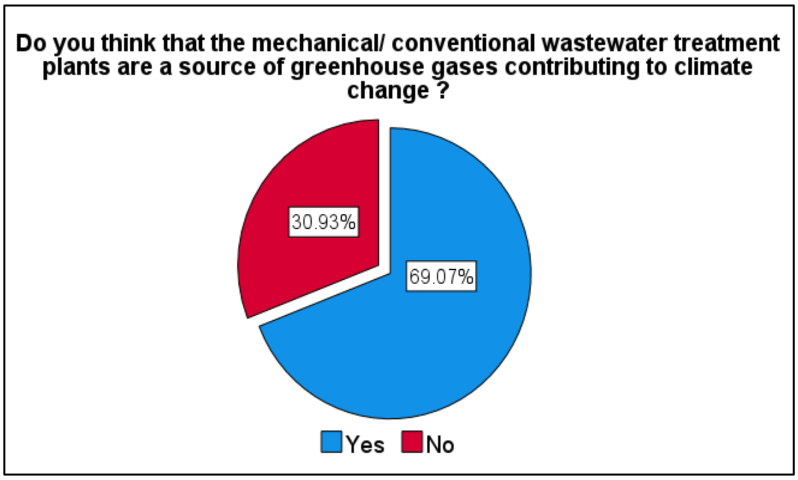


Figure B. 9 GHG emissions from mechanical technology - Jordanian stakeholder

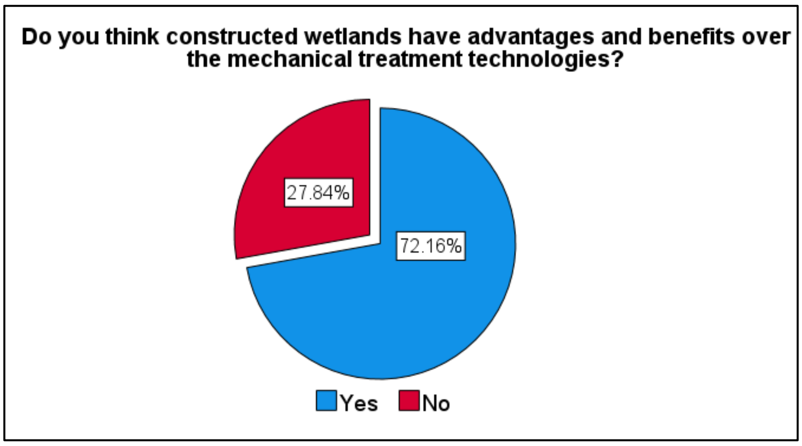


Figure B. 10 Advantages of constructed wetlands - Jordanian stakeholder

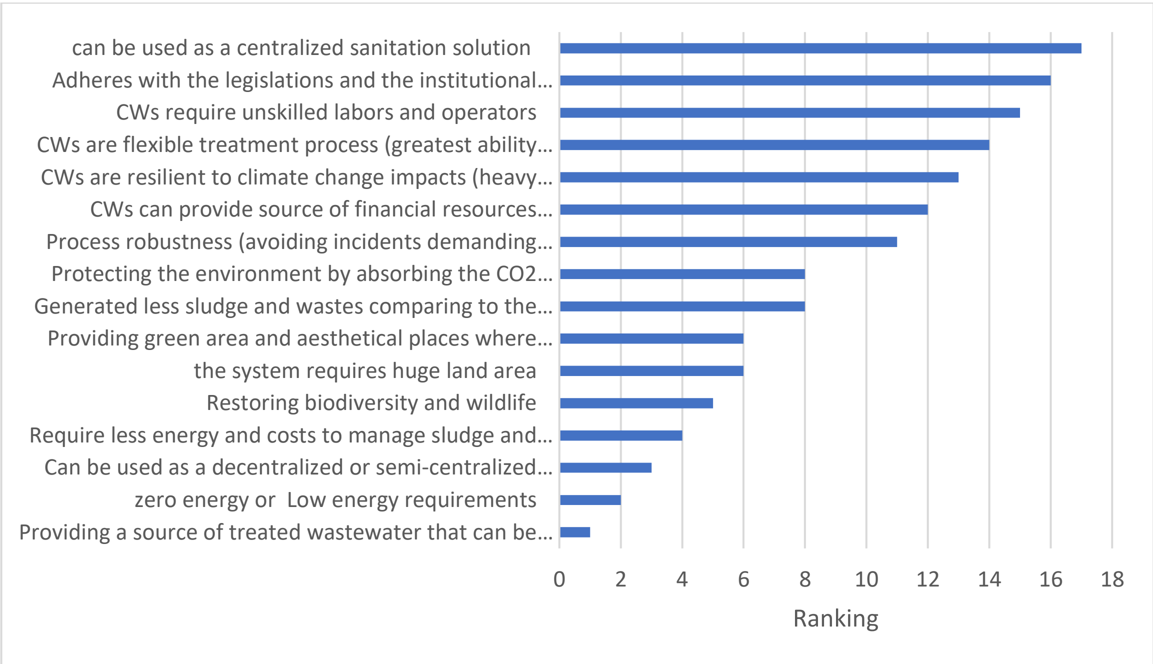


Figure B. 11 Final ranking of CWs benefits - Jordanian stakeholders

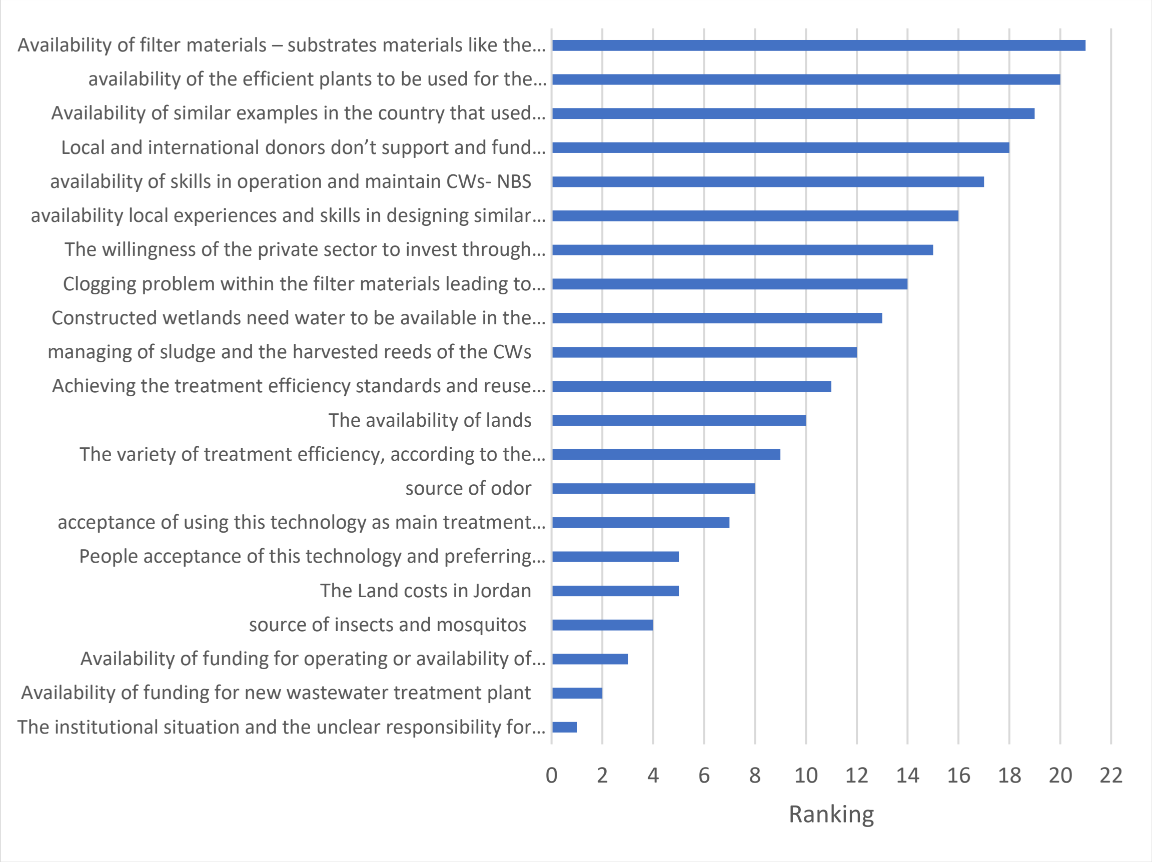


Figure B. 12 Final ranking of challenges of having CWs - Jordan stakeholders

Jordanian Community

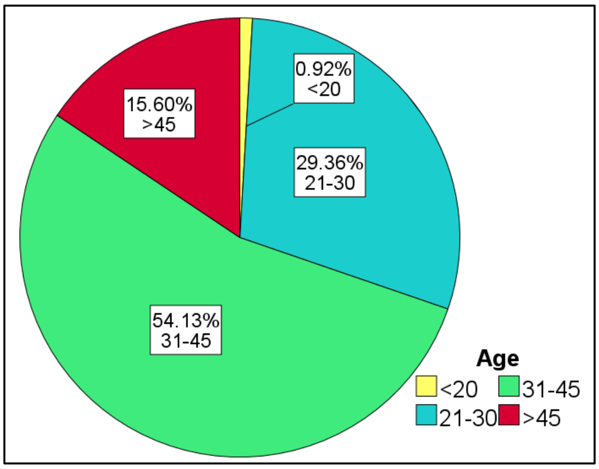


Figure B. 13 Jordanian respondents age distribution

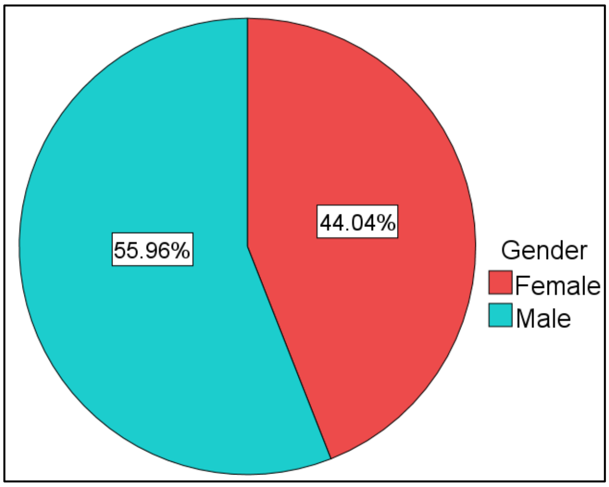


Figure B. 14 Gender percentage – Jordan community

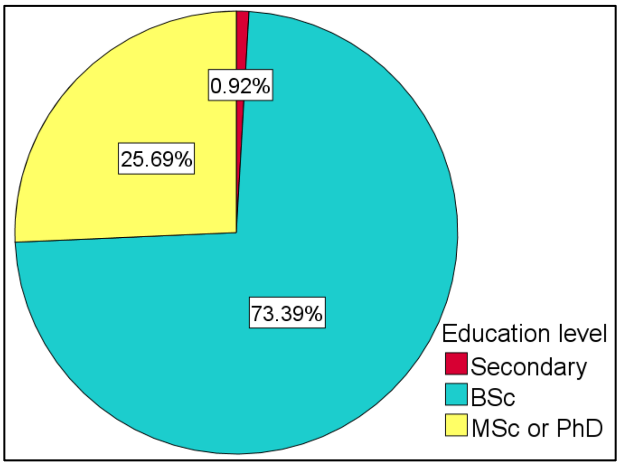


Figure B. 15 Education level – Jordan community

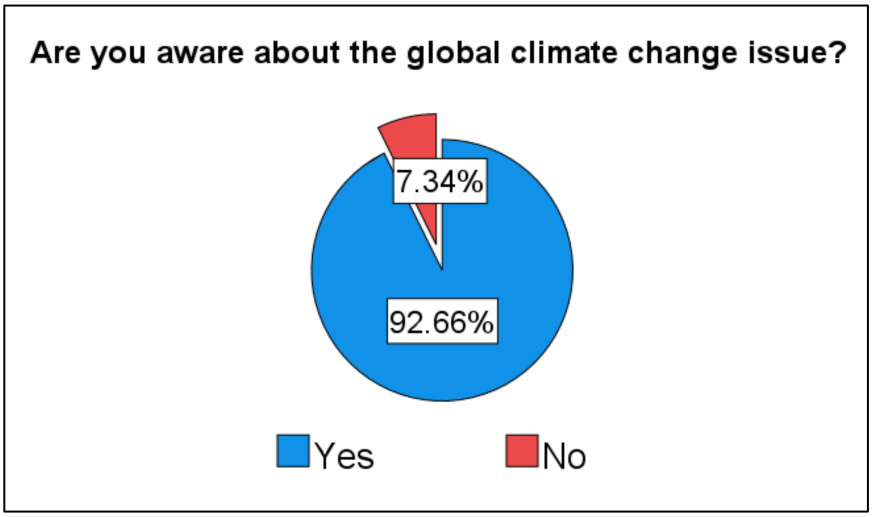


Figure B. 16 Climate change awareness – Jordan community

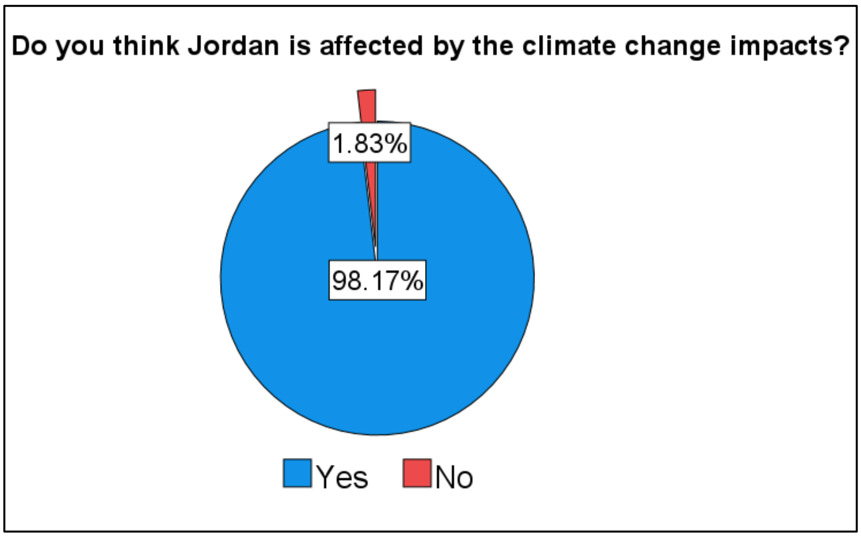


Figure B. 17 Climate change impacts – Jordan Community

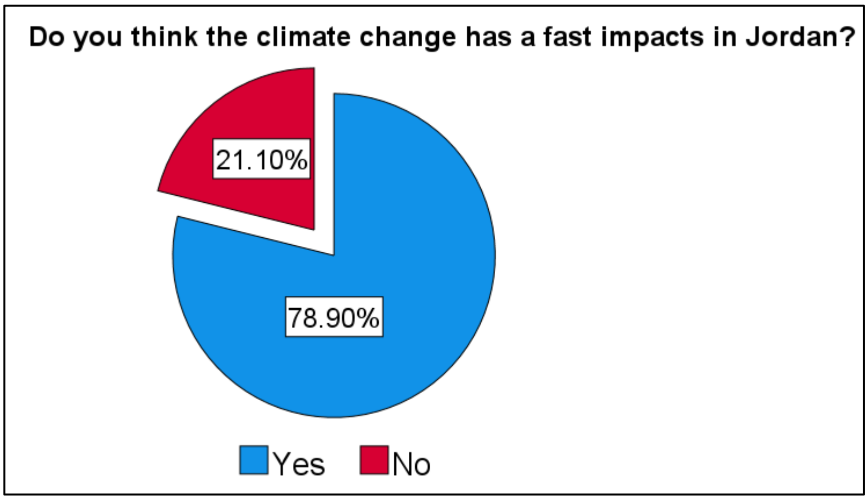


Figure B. 18 Climate change fast impact – Jordan community

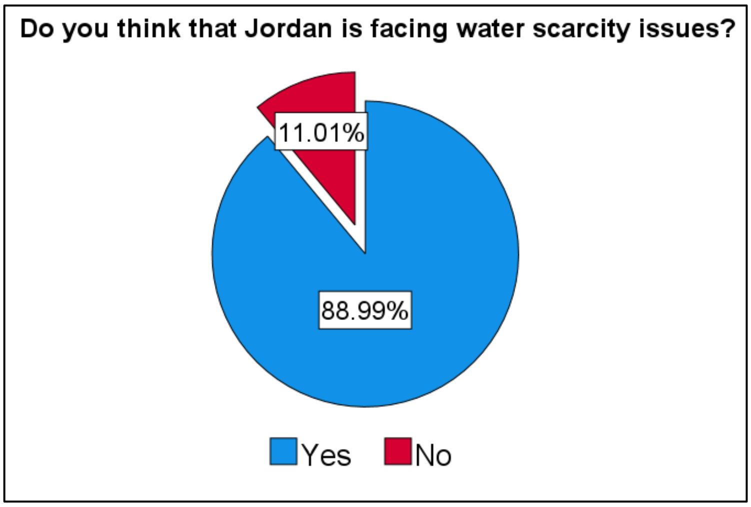


Figure B. 19 Water scarcity – Jordan Community

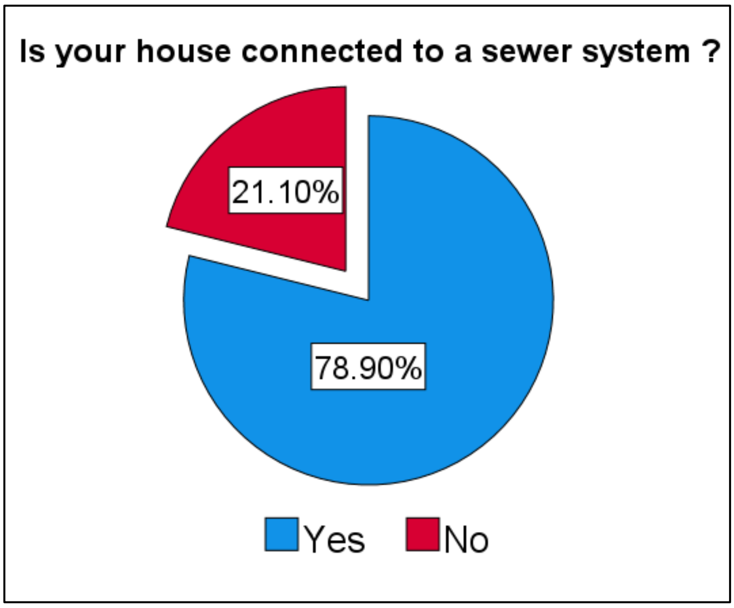


Figure B. 20 Household connection to sewer – Jordan Community

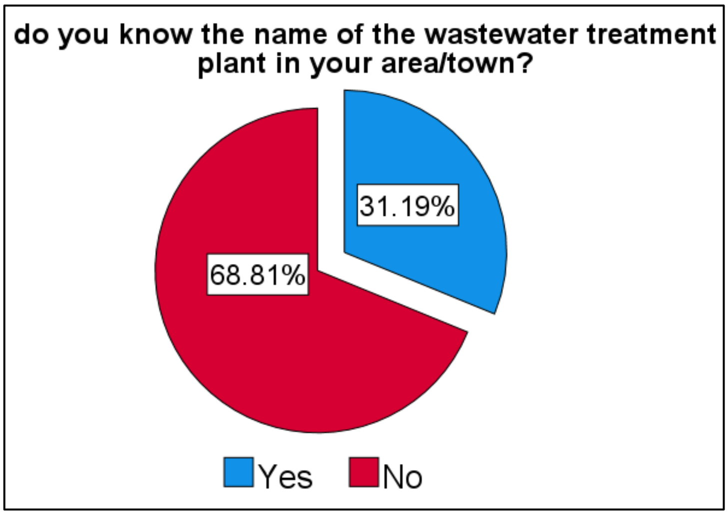


Figure B. 21 Name of WWTP – Jordan community

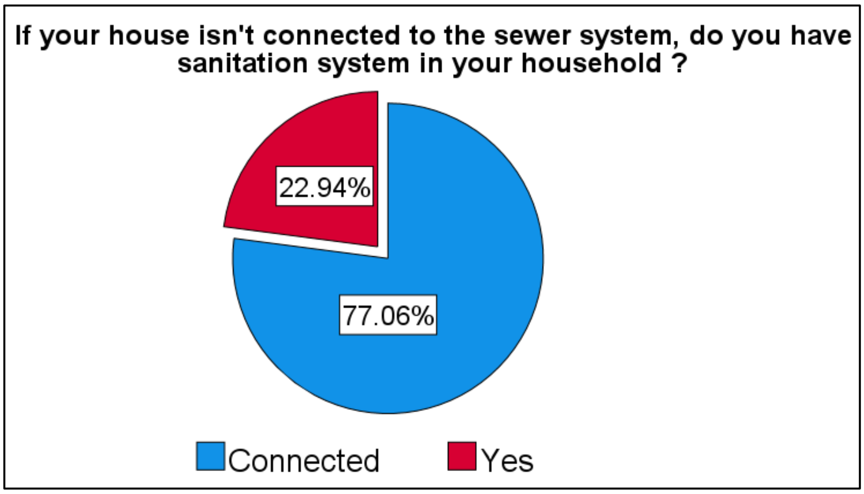


Figure B. 22 Sewer connection vs Septic tank – Jordan community

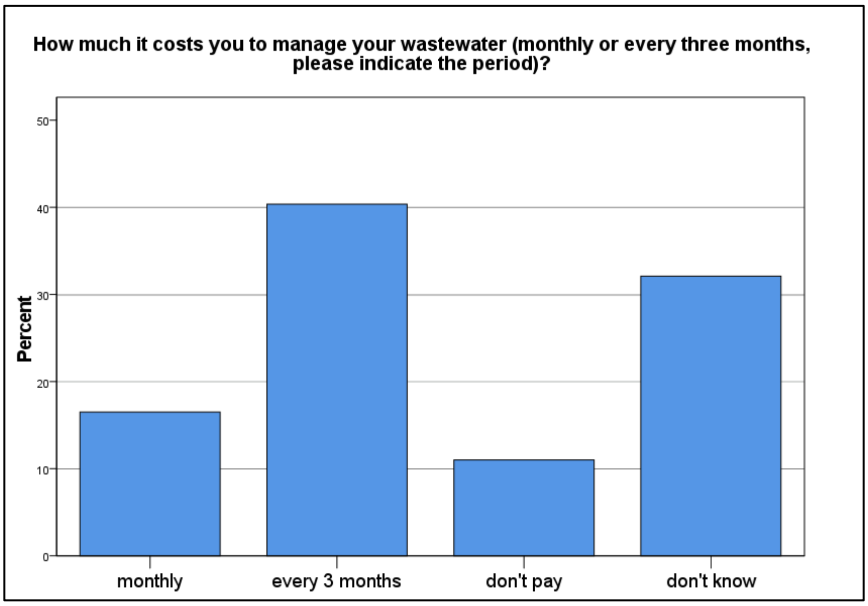


Figure B. 23 Duration for managing wastewater – Jordan community

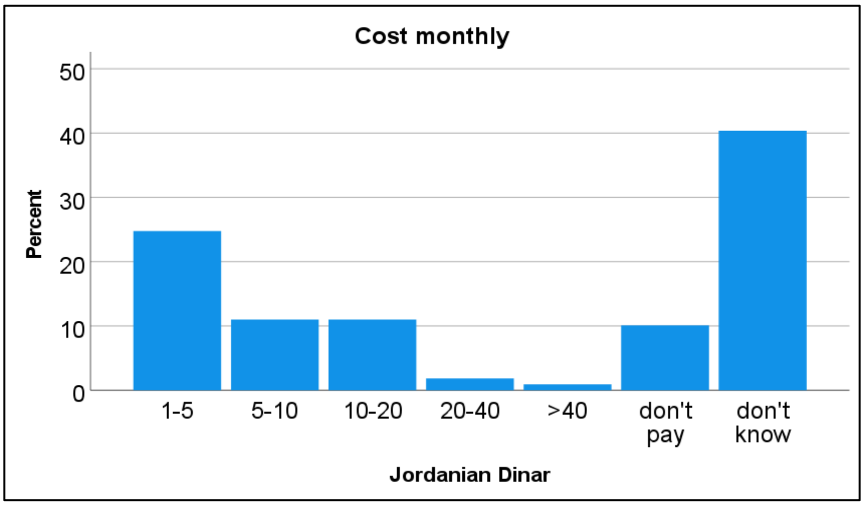


Figure B. 24 Actual costs for managing wastewater – Jordan community

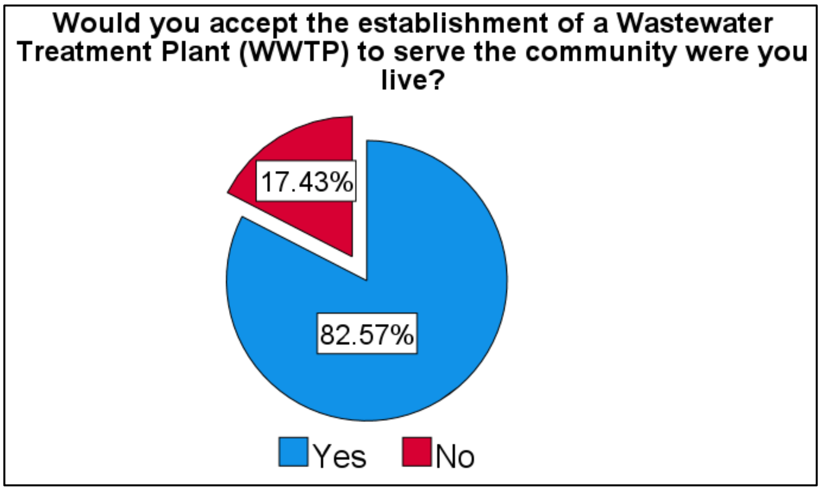


Figure B. 25 WTA of establishing WWTP – Jordan community

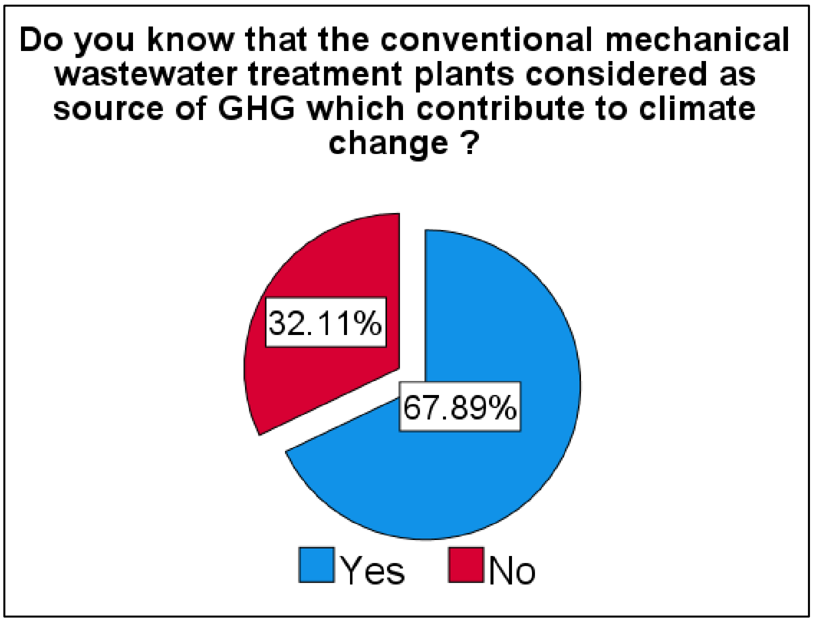


Figure B. 26 WWTP as a source of GHG – Jordan community

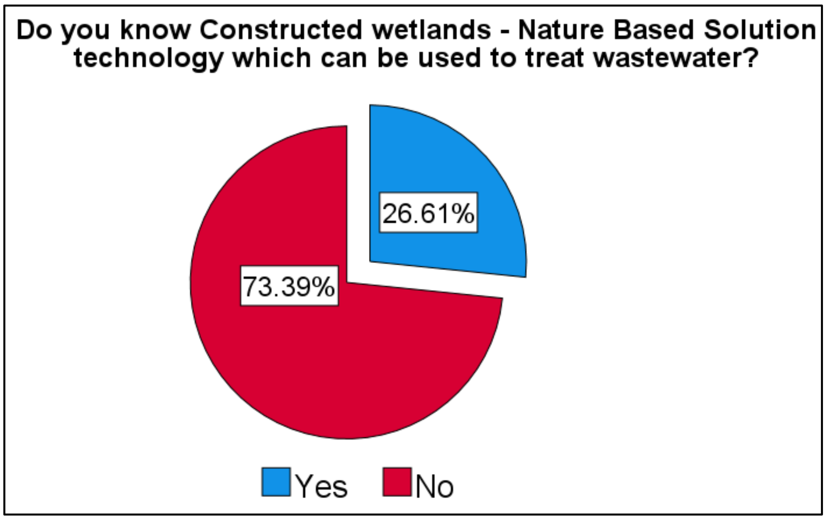


Figure B. 27 Knowledge about NBS - CWs – Jordan community

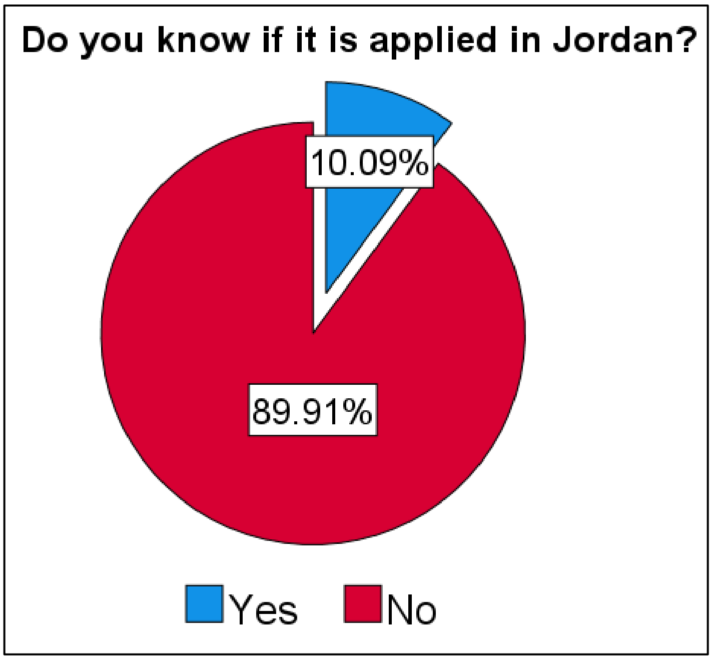


Figure B. 28 Knowledge of applying NBS - CWs – Jordan community

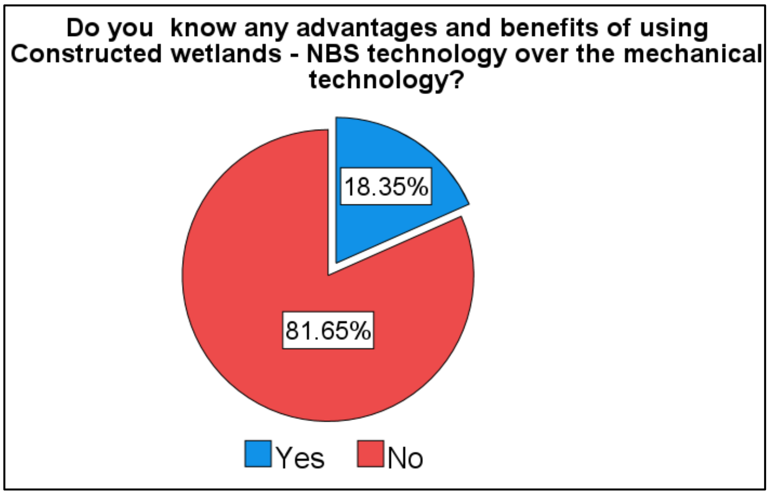


Figure B. 29 Knowledge of advantages of NBS - CWs – Jordan community

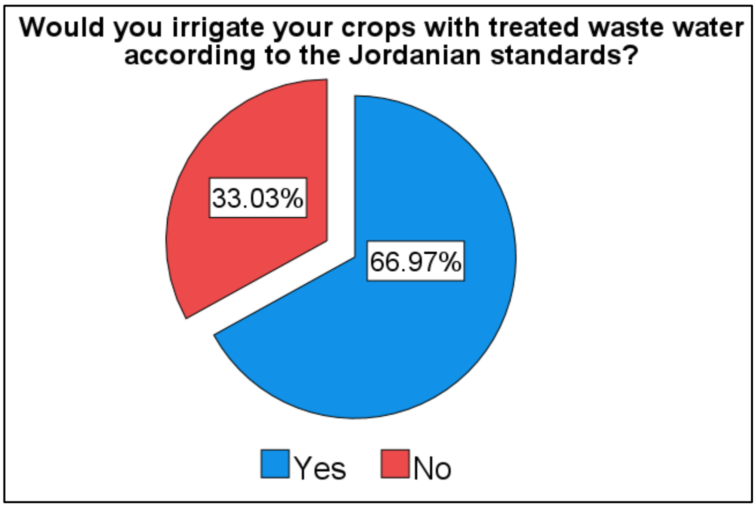


Figure B. 30 Reusing TWW with respondent's crops – Jordan community

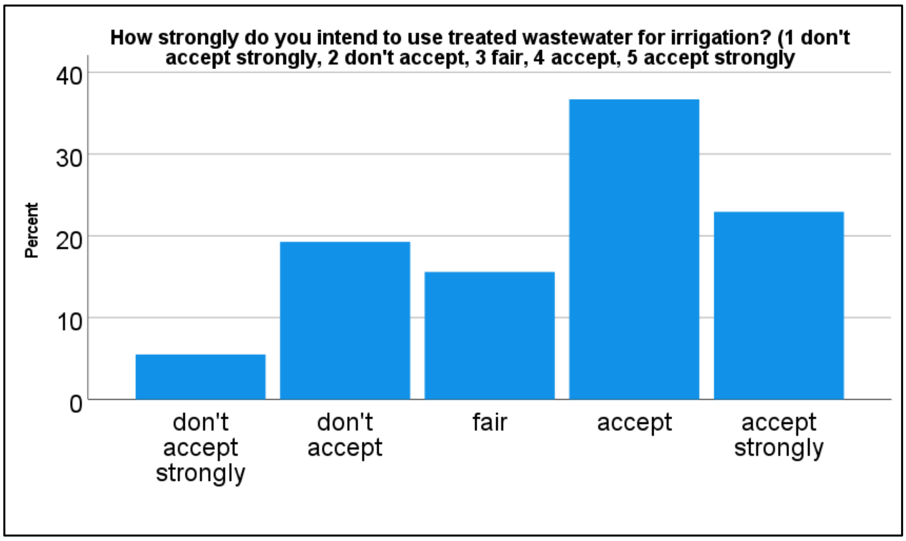


Figure B. 31 How strongly do you intend to use treated wastewater for irrigation General– Jordan community

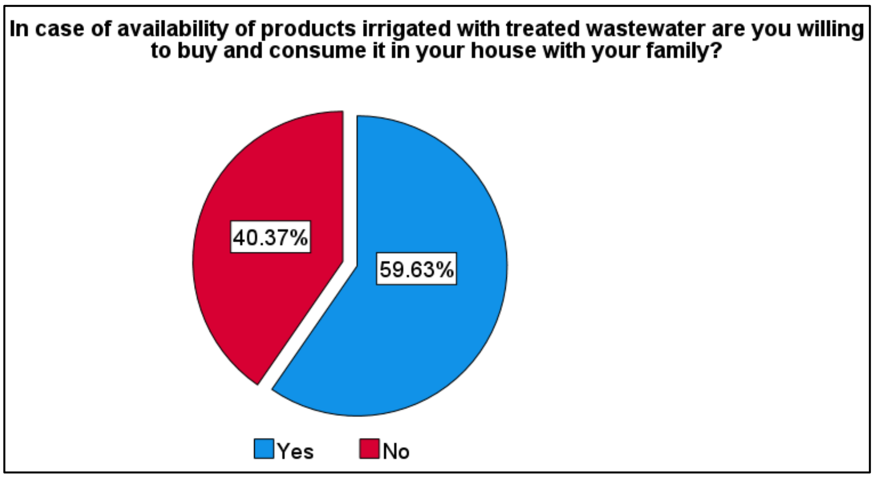


Figure B. 32 Consuming products irrigated with TWW – Jordan community

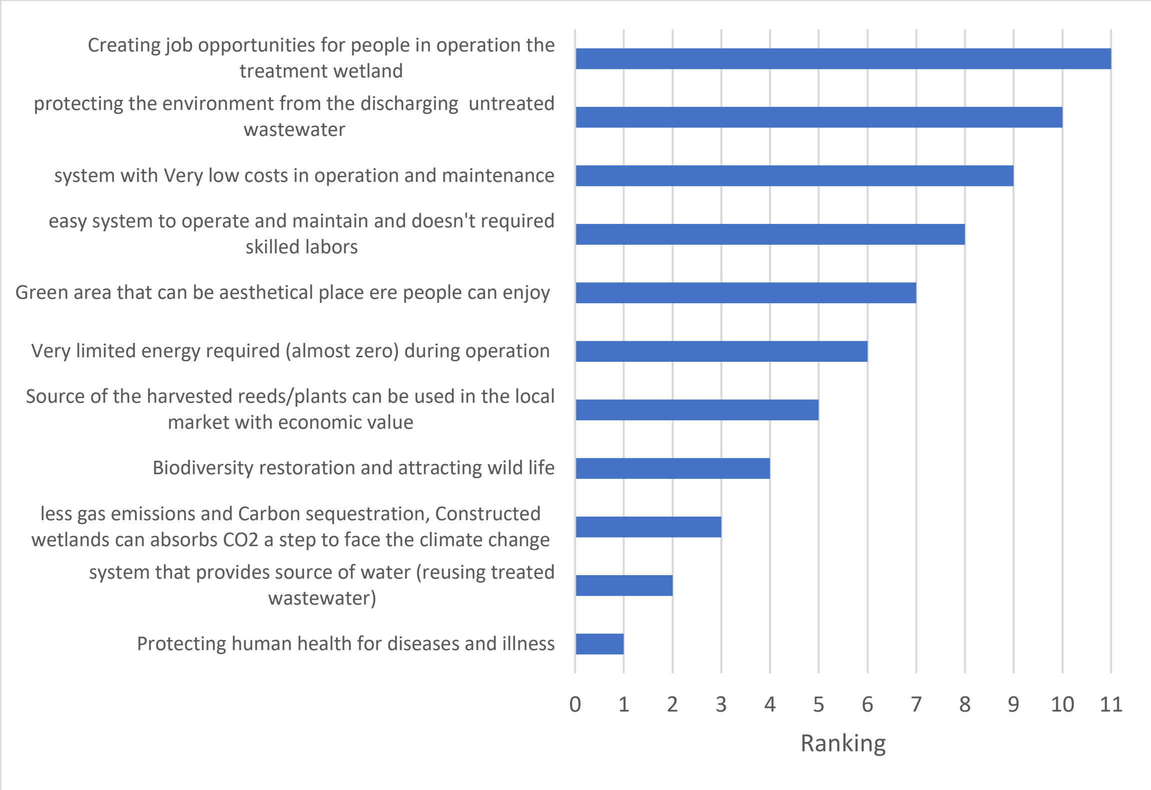


Figure B. 33 Final ranking of CWs benefits according to Jordanian community

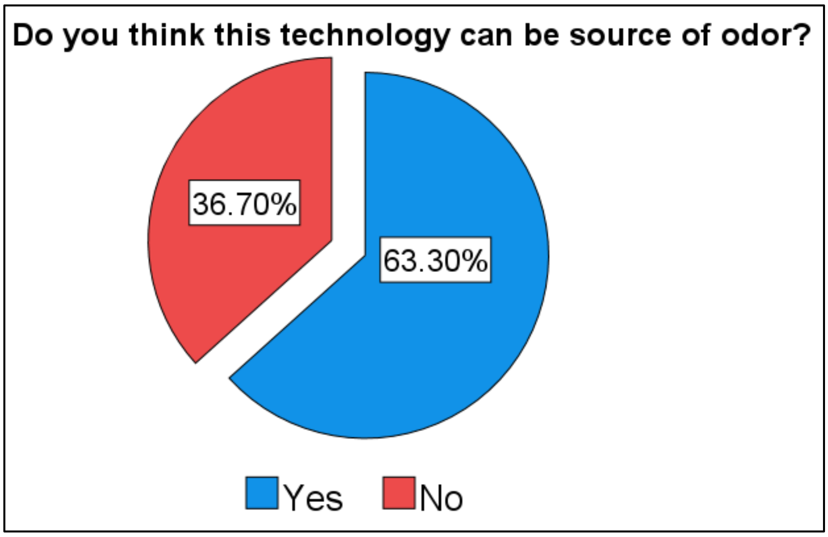


Figure B. 34 Source of odor - Jordanian community.

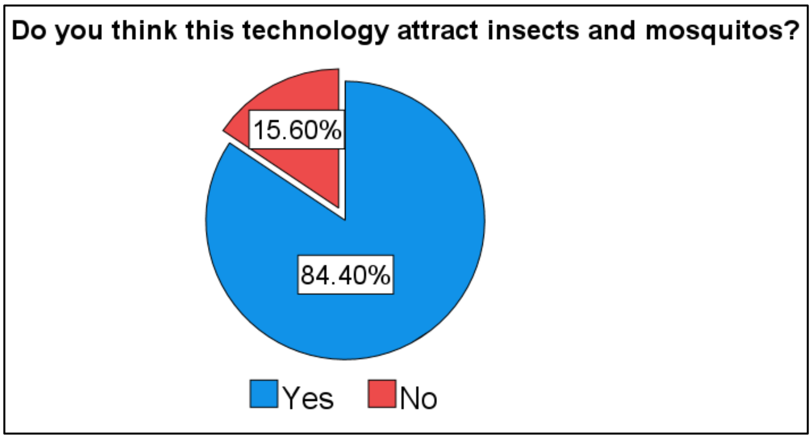


Figure B. 35 Attracting insects - Jordanian community

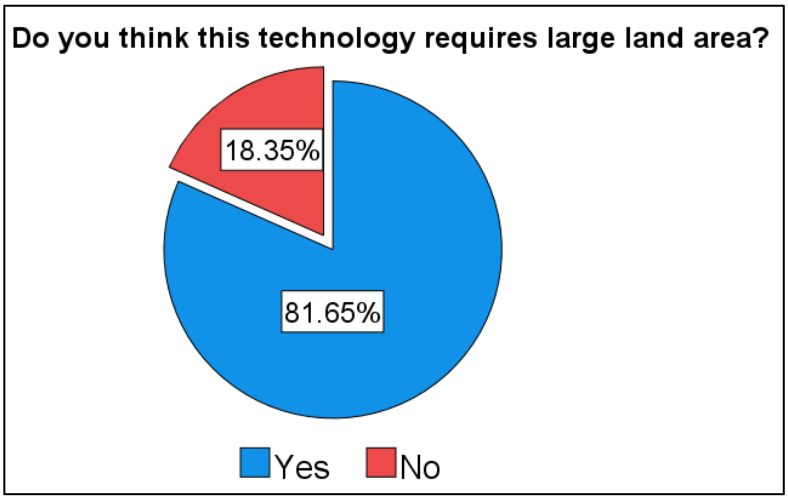


Figure B. 36 Required large area - Jordanian community

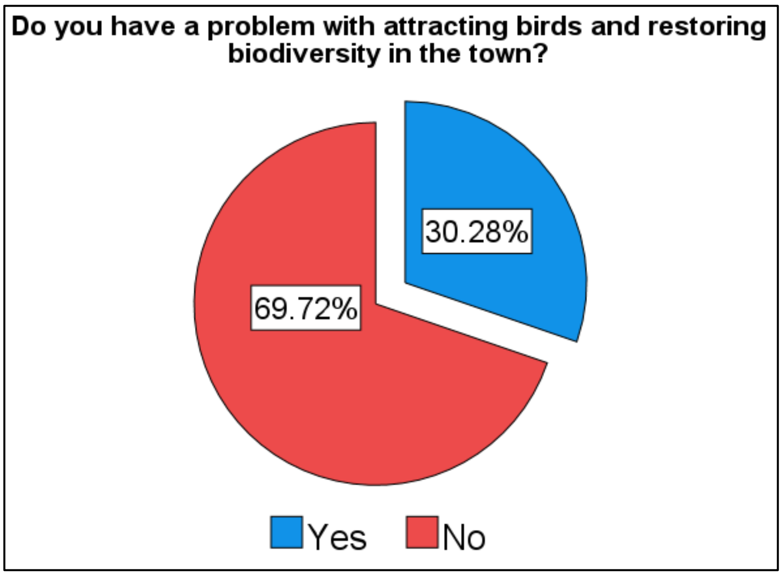


Figure B. 37 Restoring biodiversity - Jordanian community

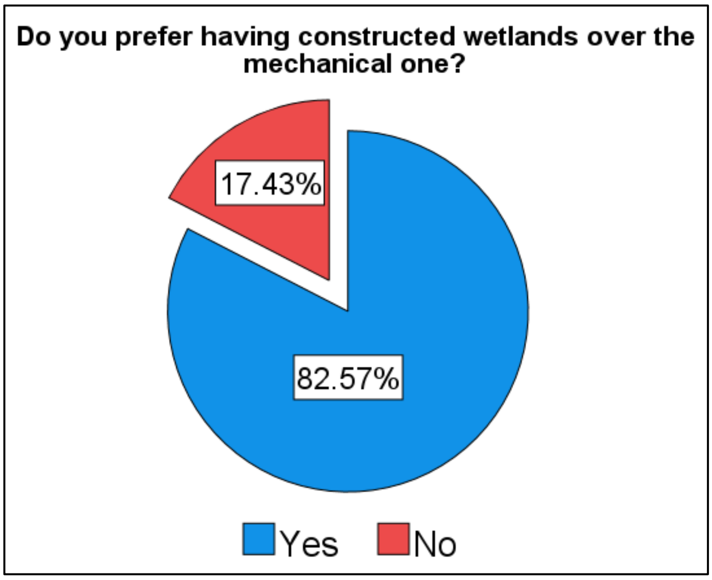


Figure B. 38 CWs vs Mechanical preferences - Jordanian community

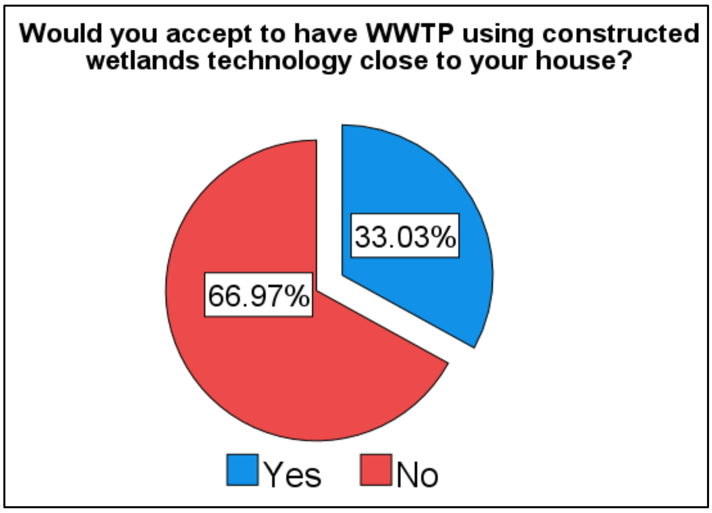


Figure B. 39 WTA of CWs near house - Jordanian community

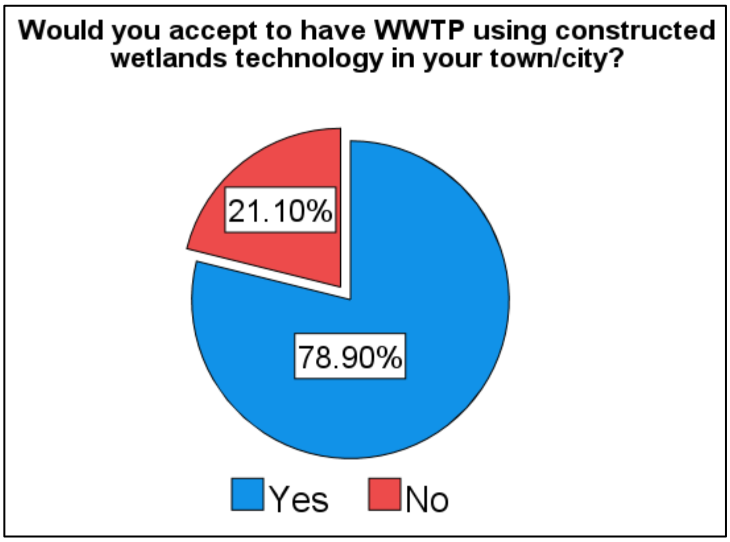


Figure B. 40 WTA of CWs in town/city - Jordanian community

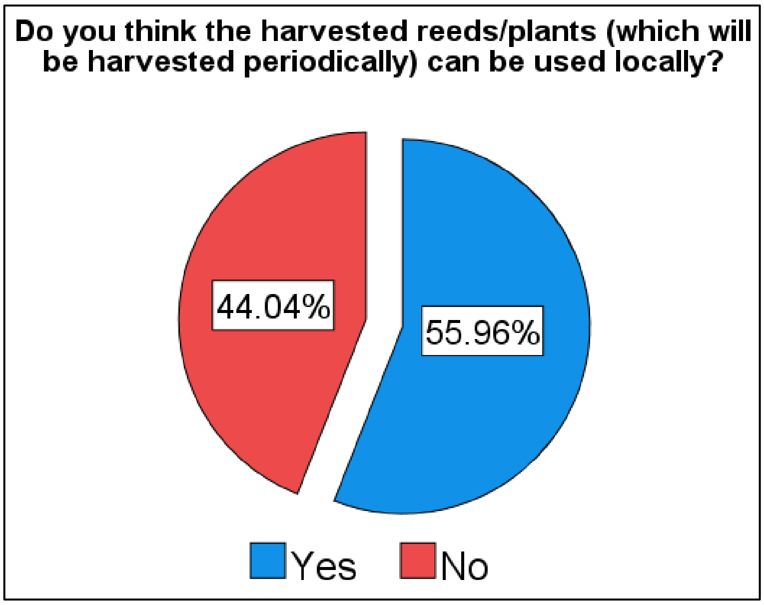


Figure B. 41 Reusing harvested reed locally - Jordanian community

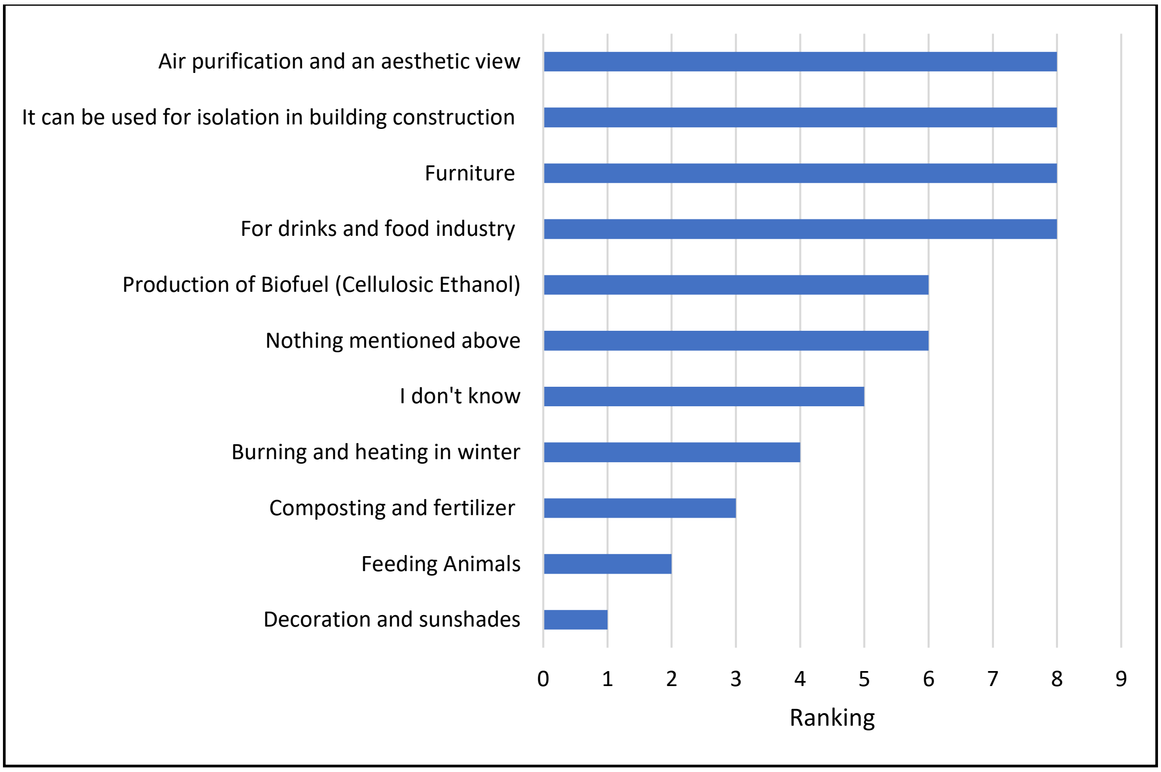


Figure B. 42 Priority of reuse of harvested reeds options - Jordan community

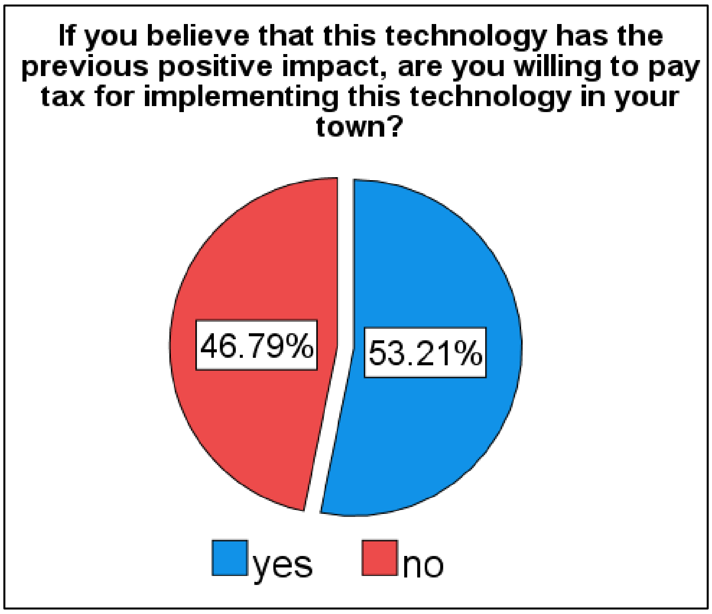


Figure B. 43 WTP for implementing CWs - Jordan community

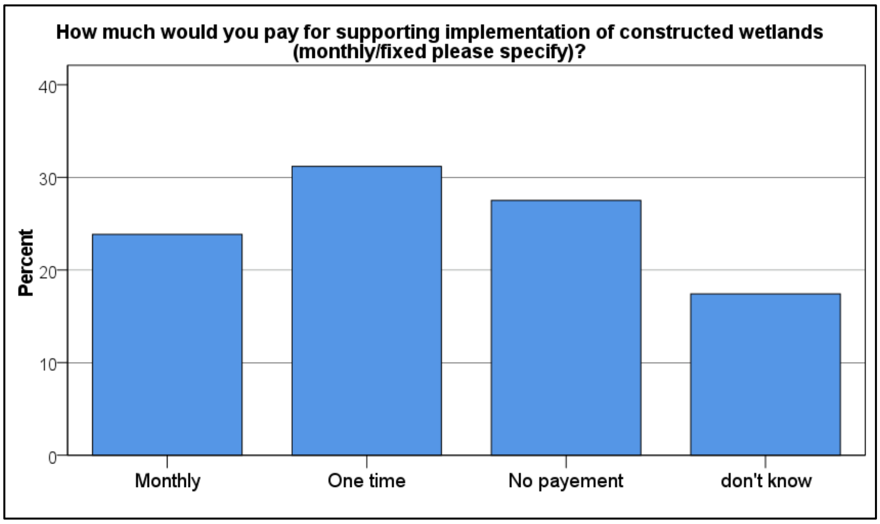


Figure B. 44 WTP for implementing CWs - Jordan community

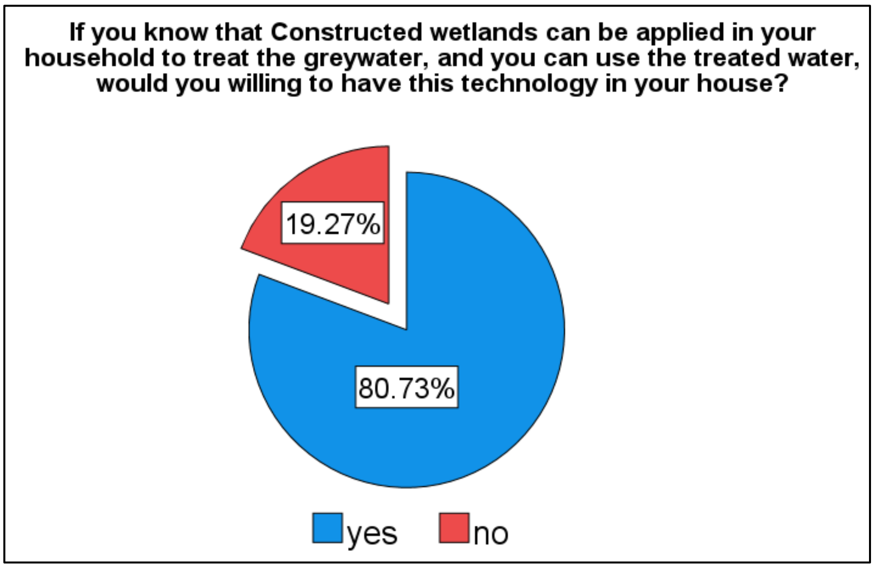


Figure B. 45 WTA for implementing CWs at HH level - Jordan community

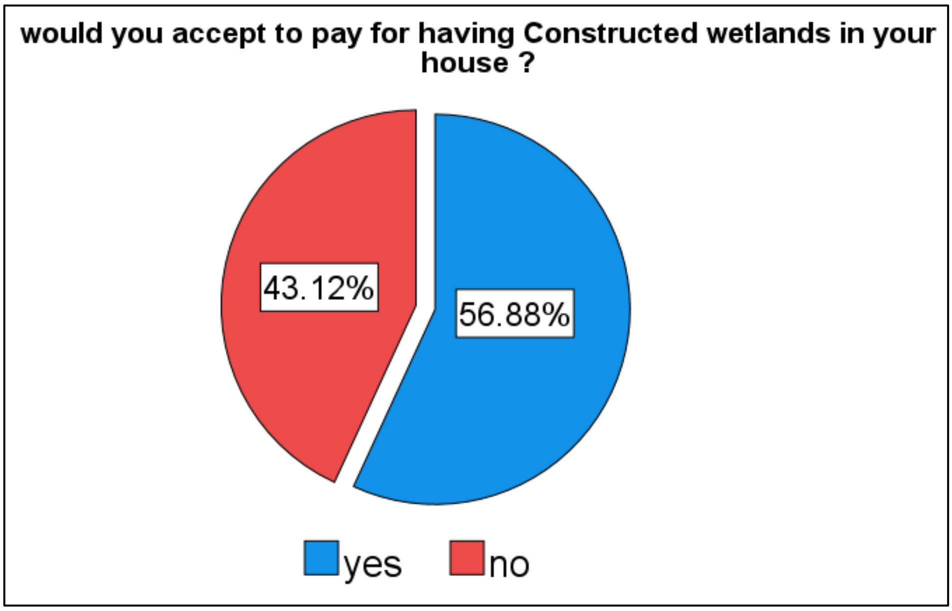


Figure B. 46 WTP for implementing CWs at HH level - Jordan community

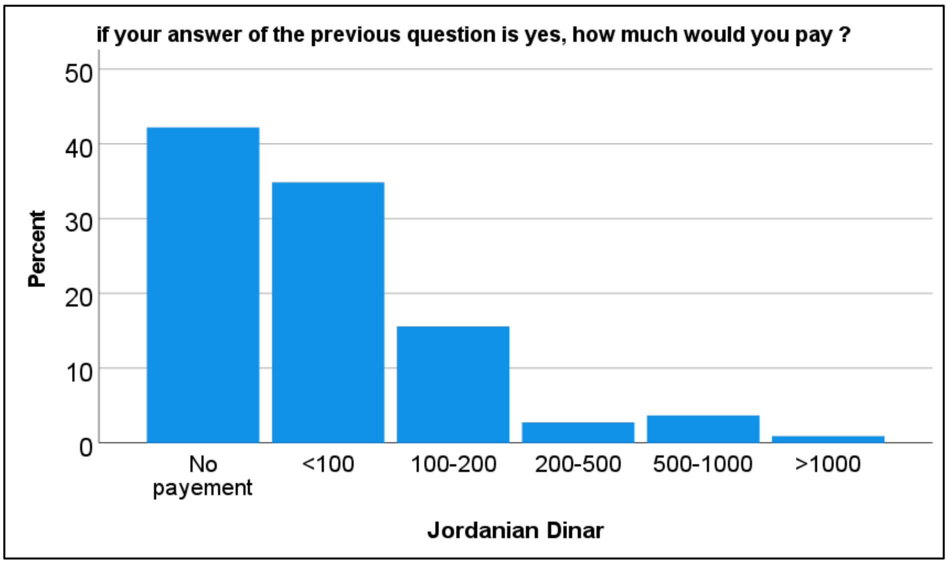


Figure B. 47 Bid values - WTP for implementing CWs at HH level - Jordan community

Italian Case Study

Italian stakeholders

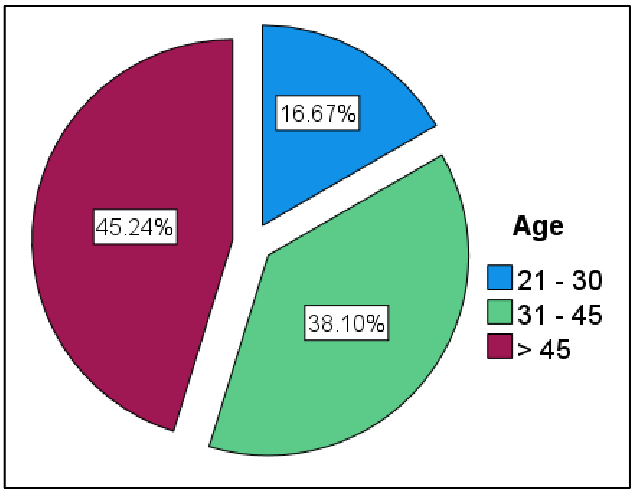


Figure B. 48 Italian stakeholder's age distribution

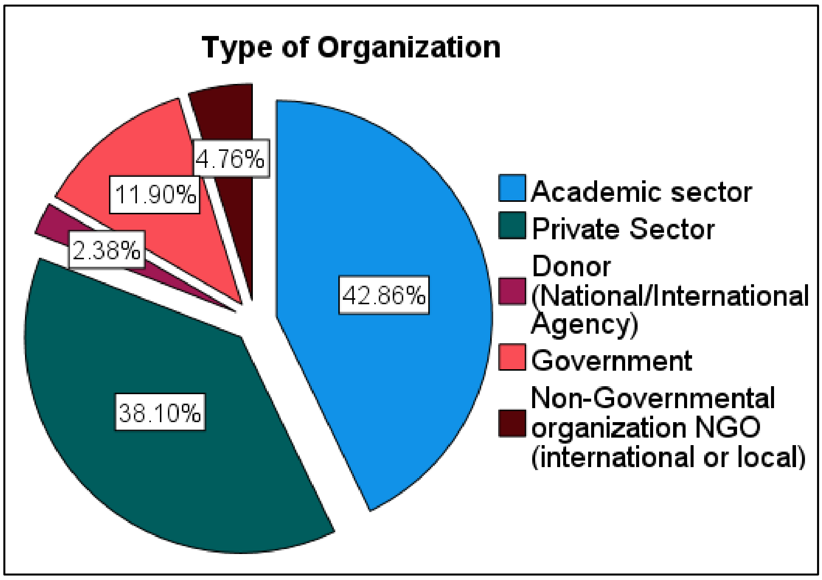


Figure B. 49 Types of organization - Italian stakeholder

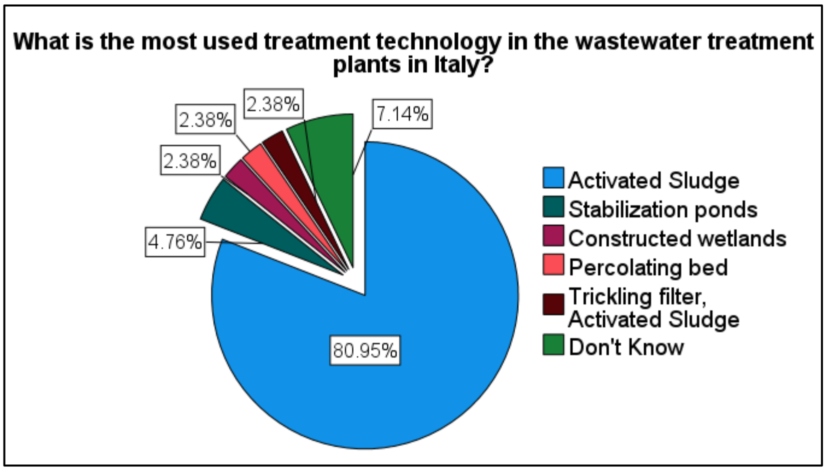


Figure B. 50 Most used treatment technology in Italy - Italian stakeholder

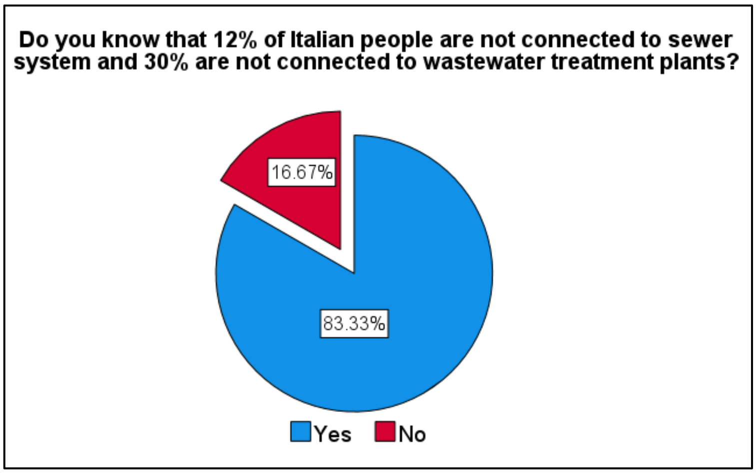


Figure B. 51 Percentage of unserved people with sewer - Italian stakeholder

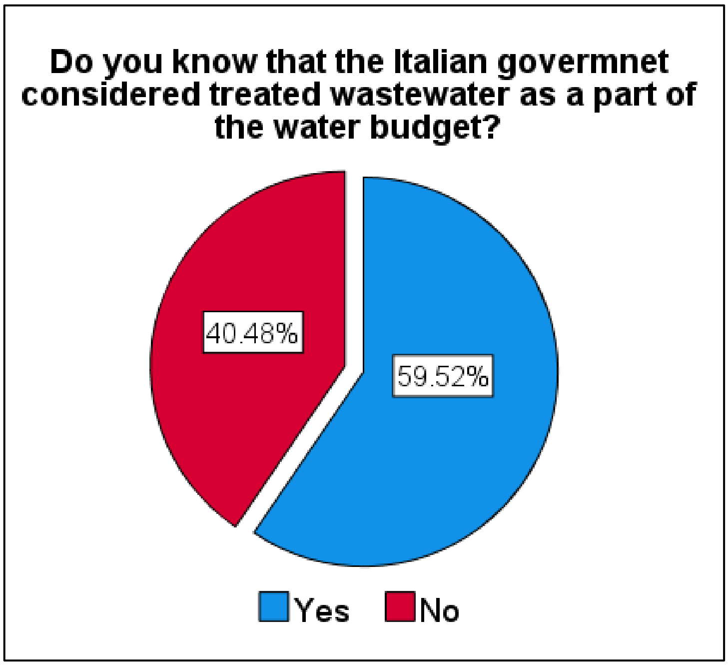


Figure B. 52 TWW in Italy water budget - Italian stakeholder

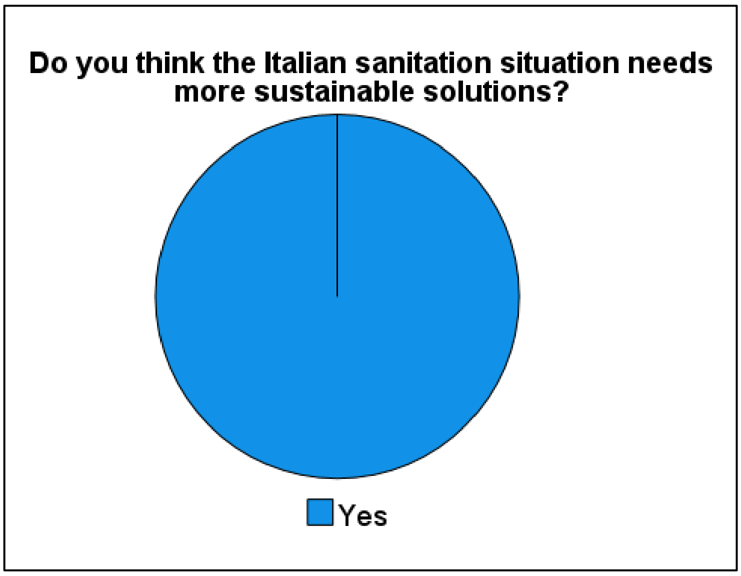


Figure B. 53 Sanitation sector needs upgrading - Italian stakeholder

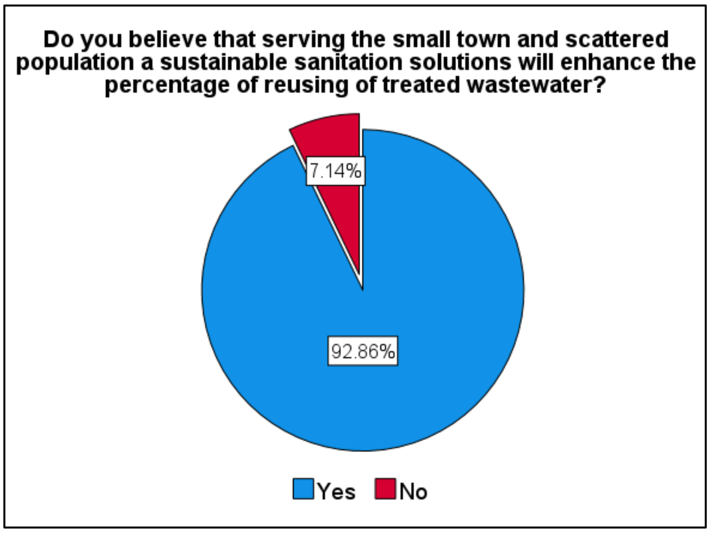


Figure B. 54 Serving scattered communities and water reuse - Italian stakeholder

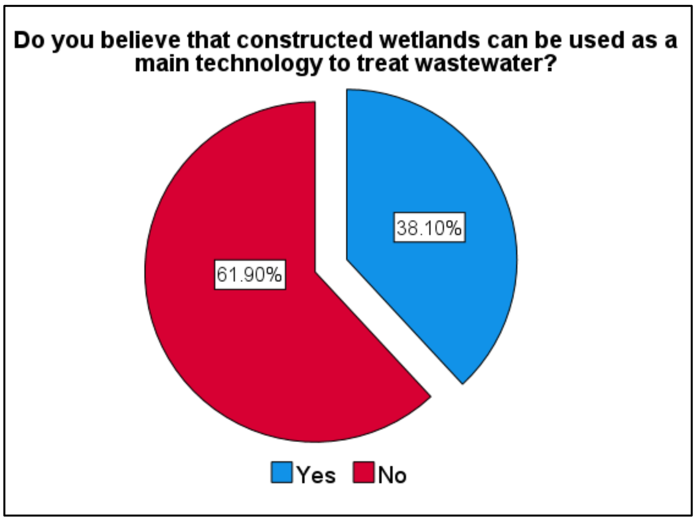


Figure B. 55 Constructed wetlands as a main technology - Italian stakeholder

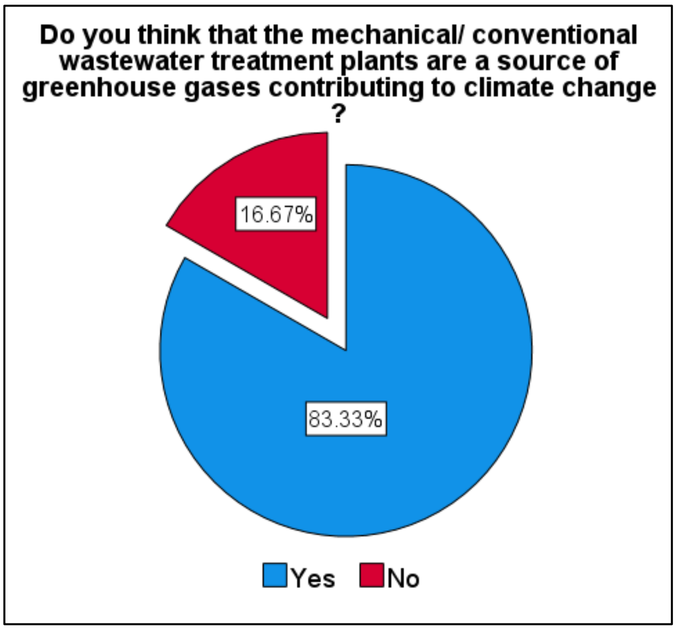


Figure B. 56 GHG emissions from mechanical technology - Italian stakeholder

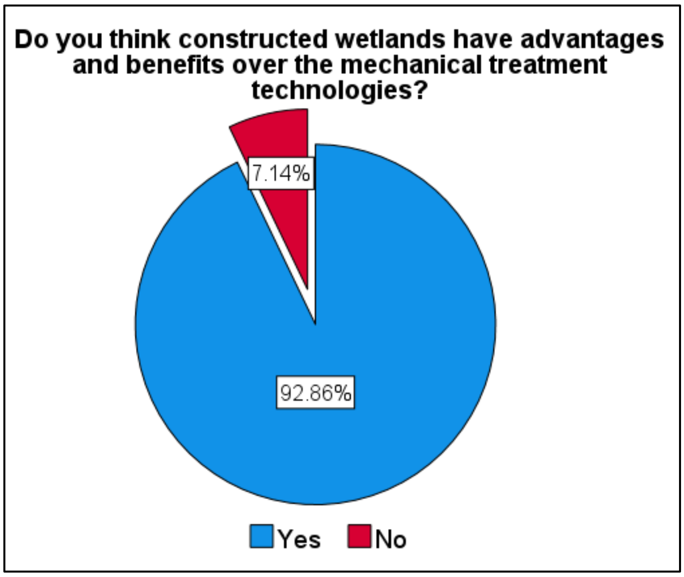


Figure B. 57 Advantages of constructed wetlands - Italian stakeholder

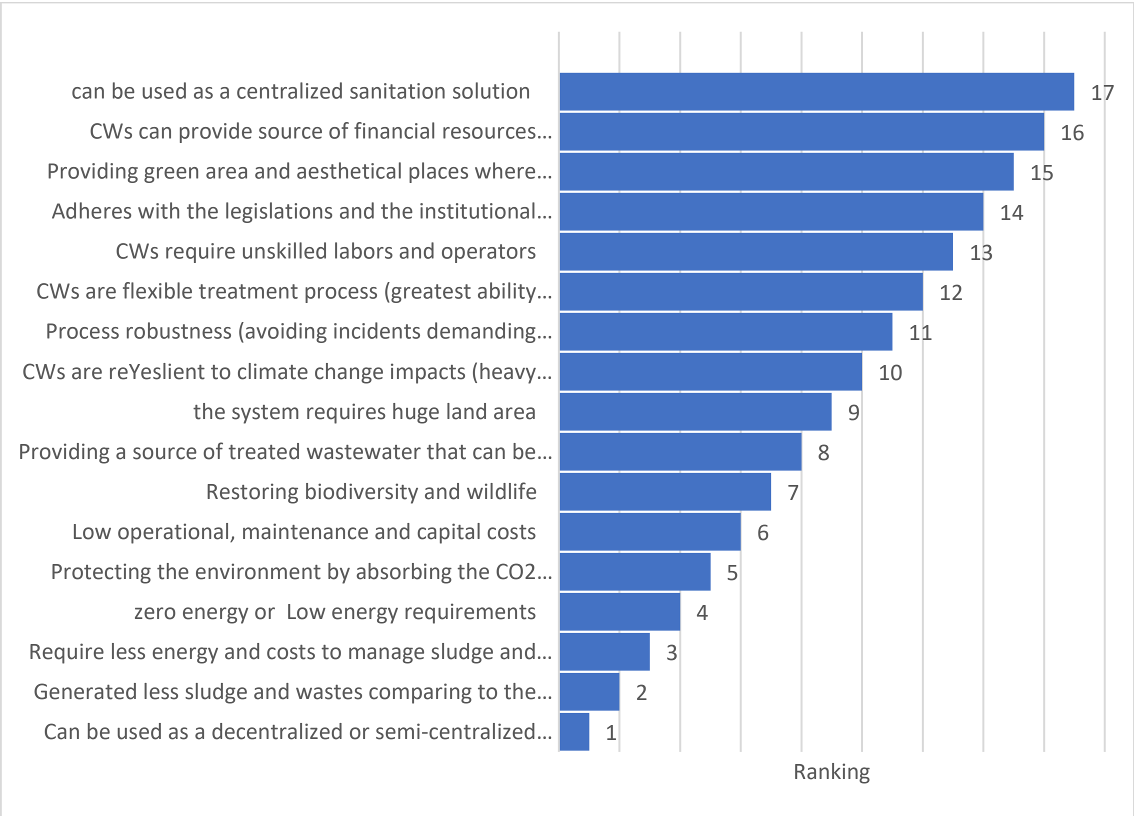


Figure B. 58 Final ranking of CWs benefits - Italian stakeholders

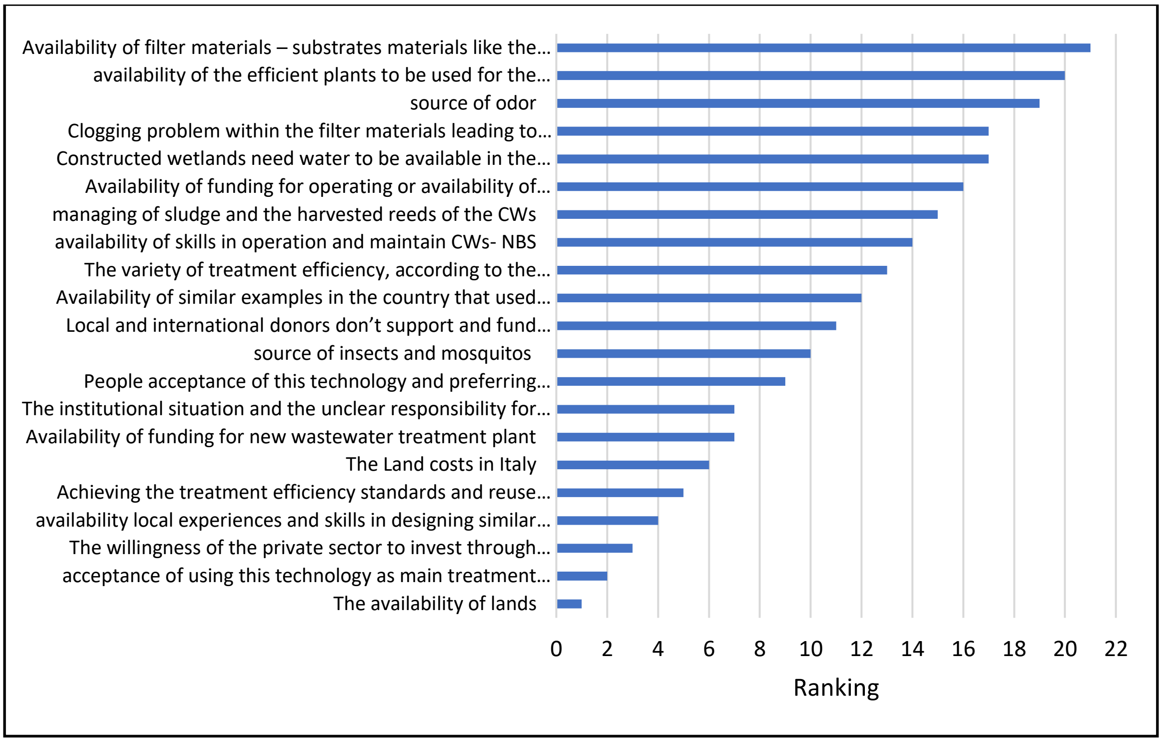


Figure B. 59 Final ranking of challenges of having CWs - Italian stakeholders

Italian community

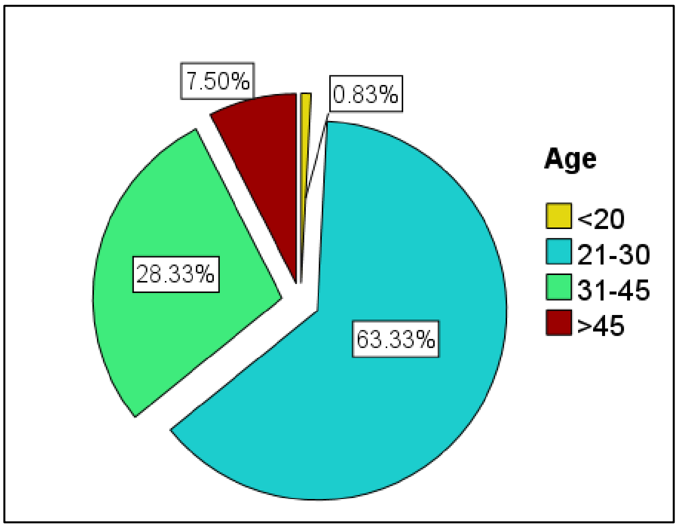


Figure B. 60 Jordanian respondents age distribution

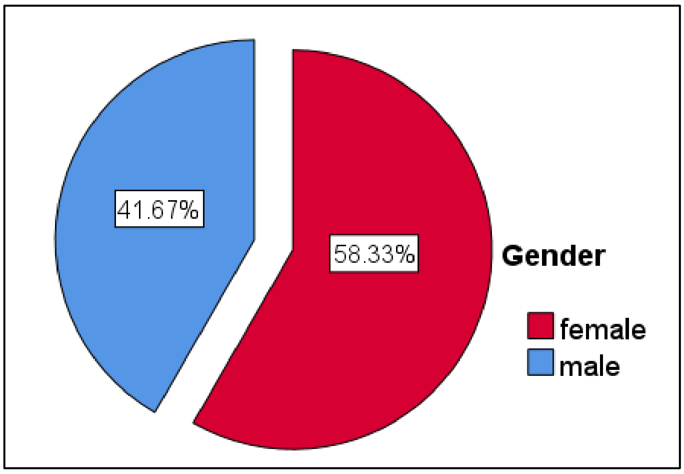


Figure B. 61 Gender percentage – Jordan community

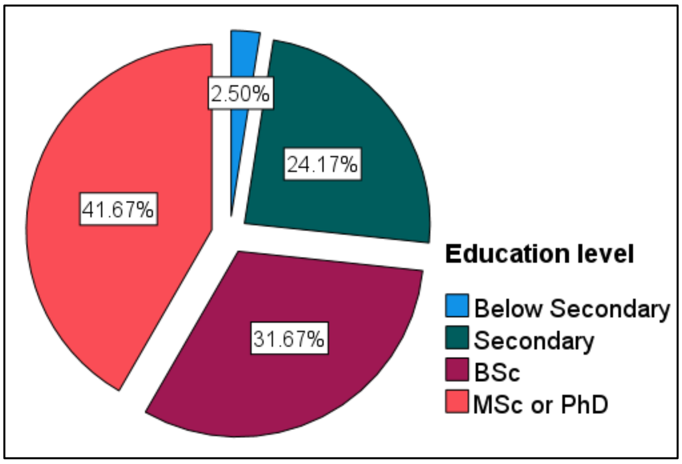


Figure B. 62 Education level – Jordan community

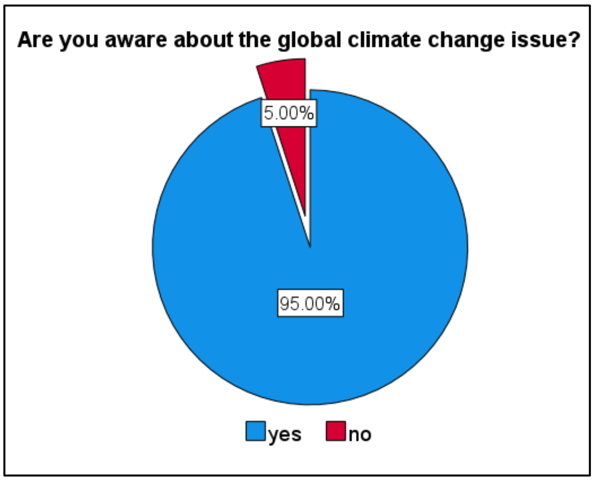


Figure B. 63 Climate change awareness – Italy community

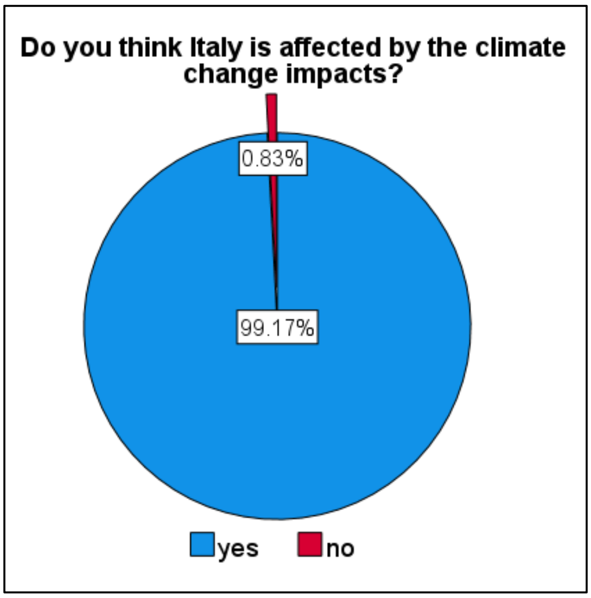


Figure B. 64 Climate change impacts – Italy Community

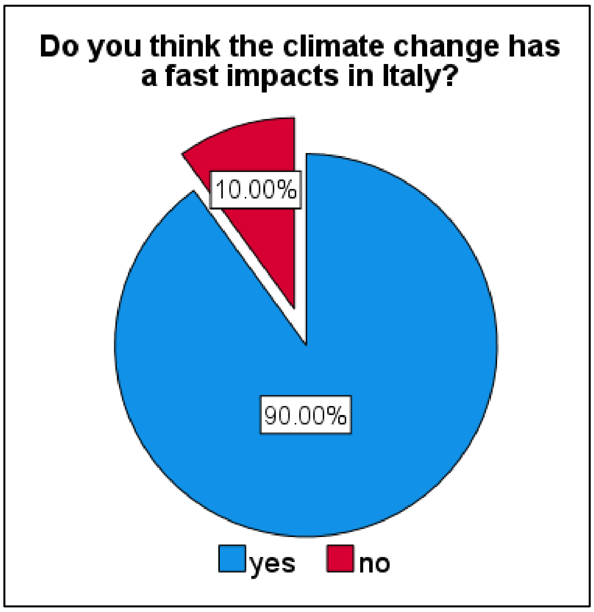


Figure B. 65 Climate change fast impact – Italy community

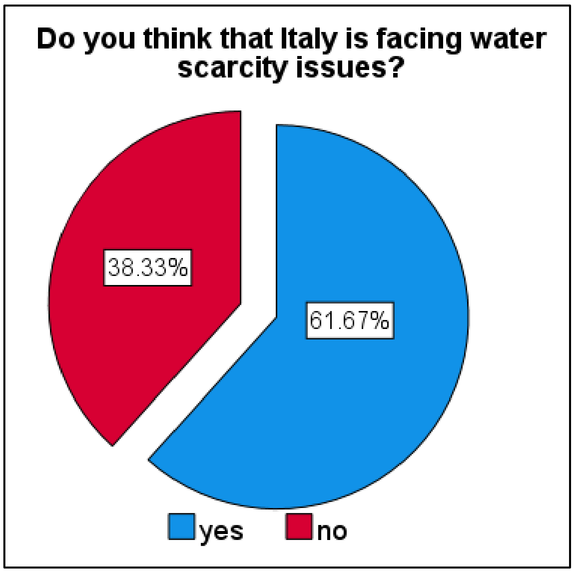


Figure B. 66 Water scarcity – Italy Community

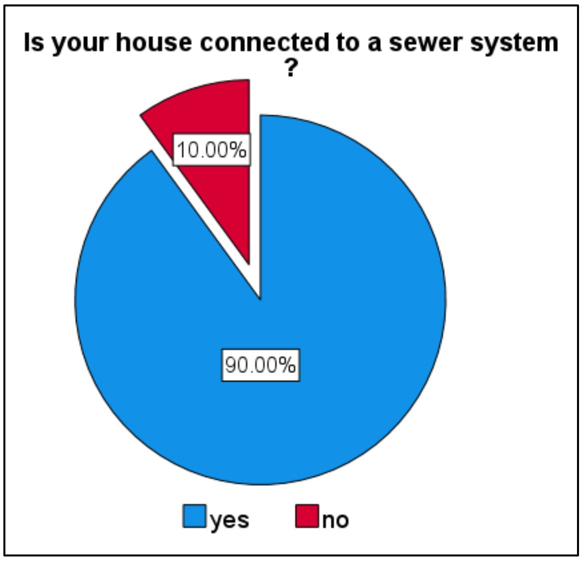


Figure B. 67 Household connection to sewer – Italy Community

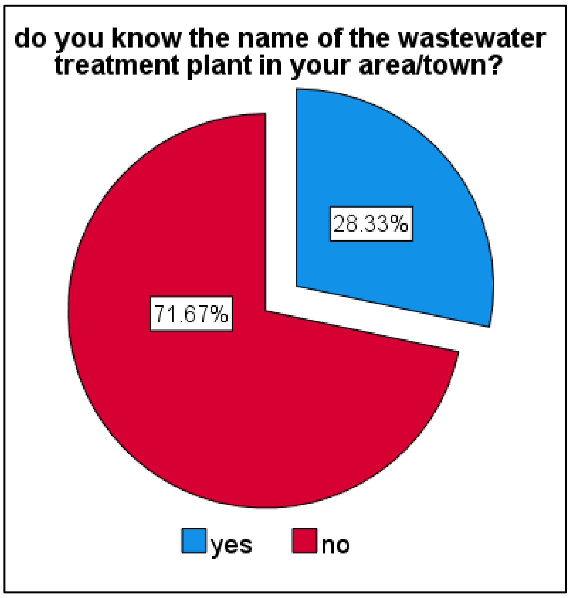


Figure B. 68 Name of WWTP – Italy community

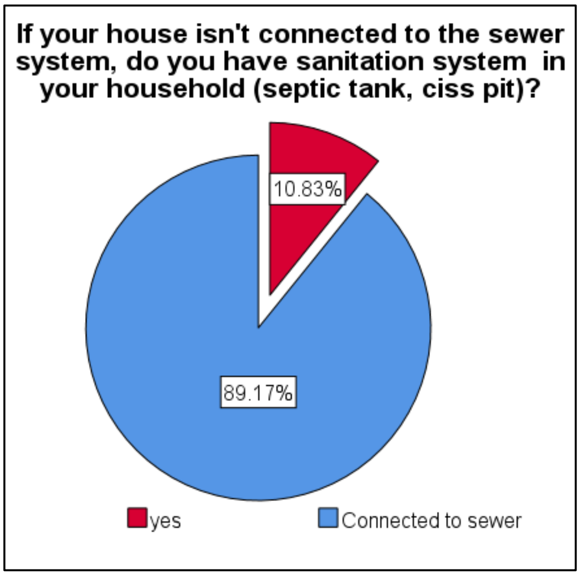


Figure B. 69 Sewer connection vs Septic tank – Italy community

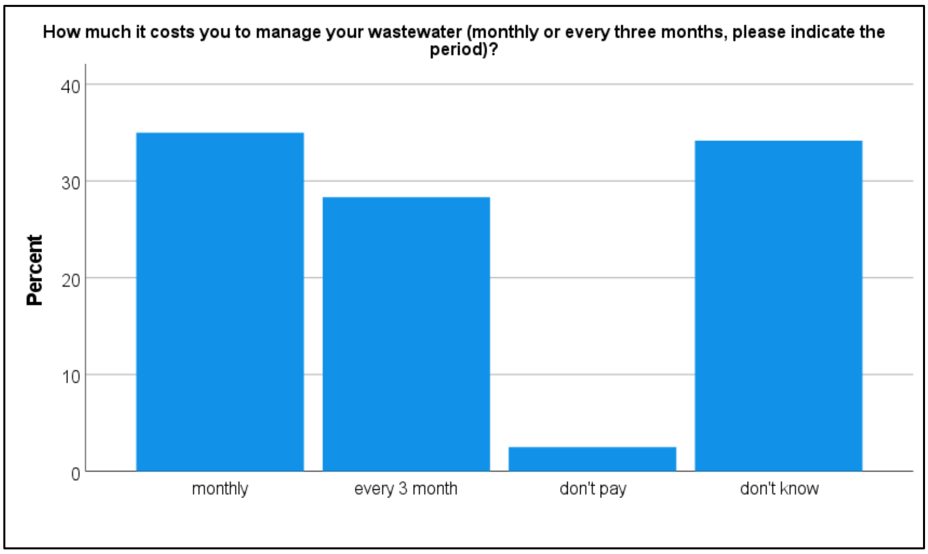


Figure B. 70 Duration for managing wastewater – Italy community

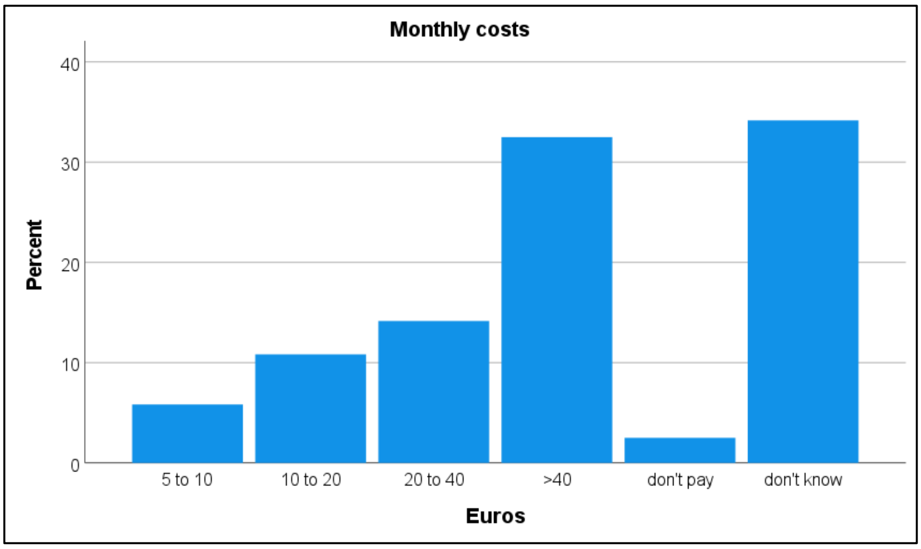


Figure B. 71 Actual costs for managing wastewater – Italy community

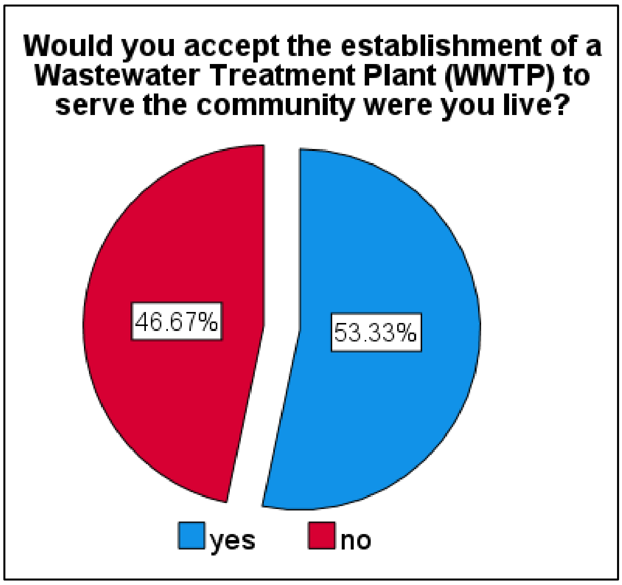


Figure B. 72 WTA of establishing WWTP – Italy community

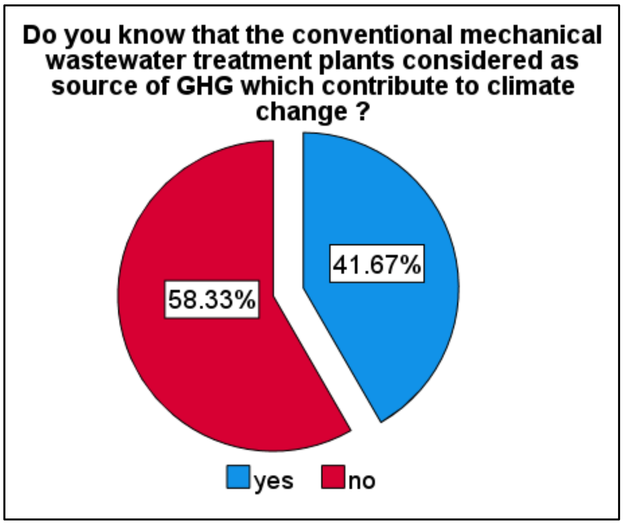


Figure B. 73 WWTP as a source of GHG – Italy community

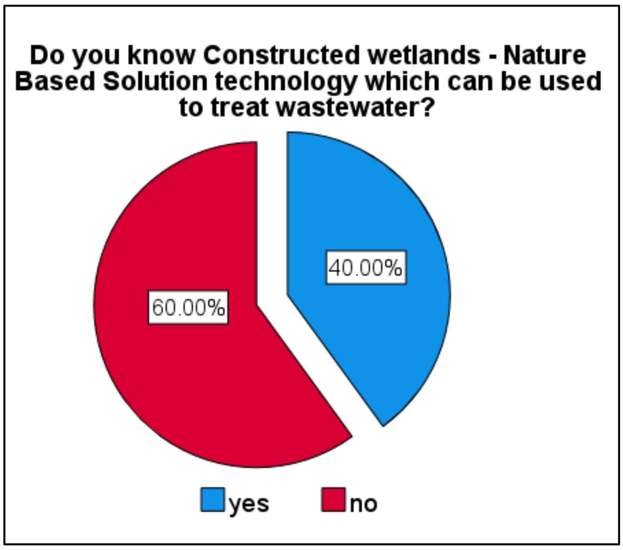


Figure B. 74 Knowledge about NBS - CWs – Italy community

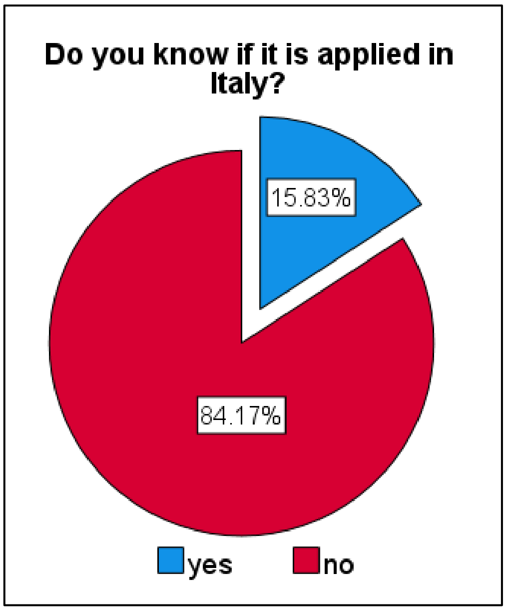


Figure B. 75 Knowledge of applying NBS - CWs – Italy community

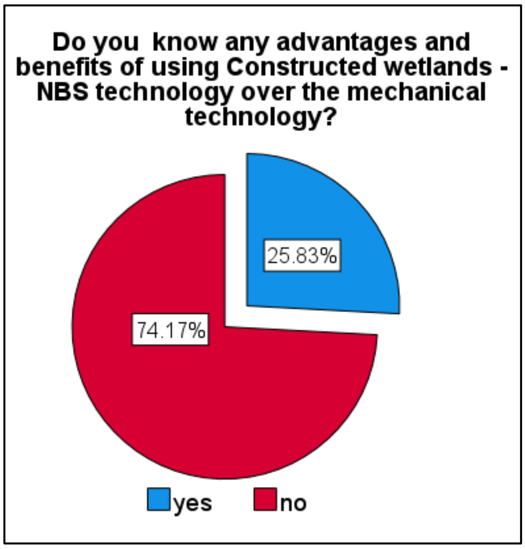


Figure B. 76 Knowledge of advantages of NBS - CWs – Italy community

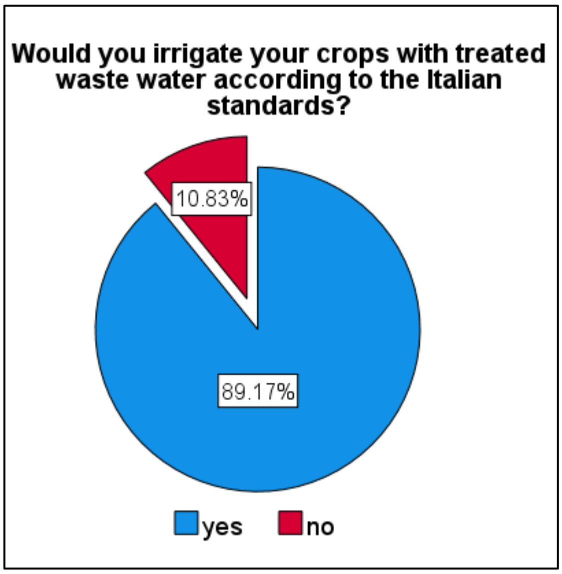


Figure B. 77 Reusing TWW with respondent's crops – Italy community

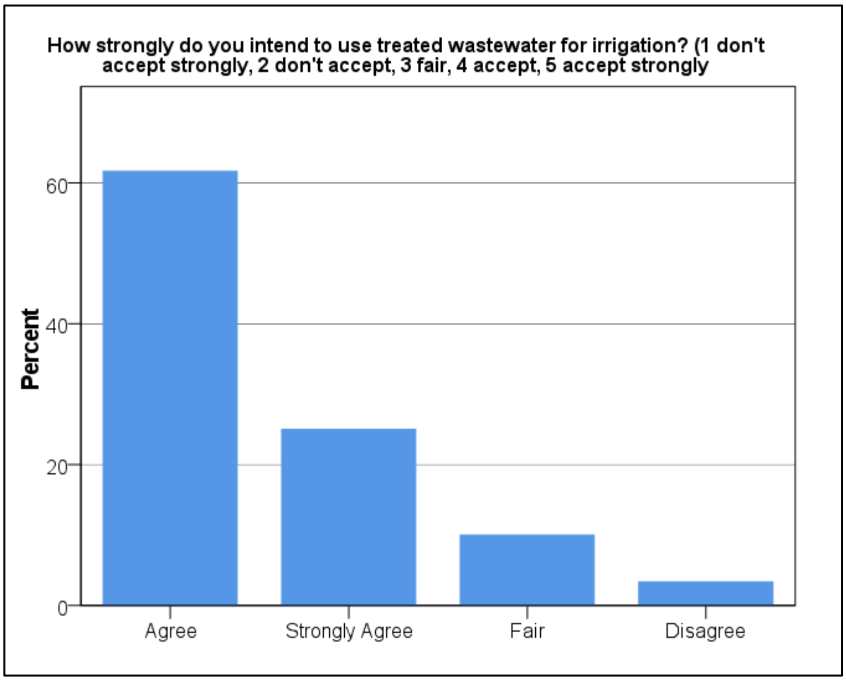


Figure B. 78 How strongly do you intend to use treated wastewater for irrigation General– Italy community

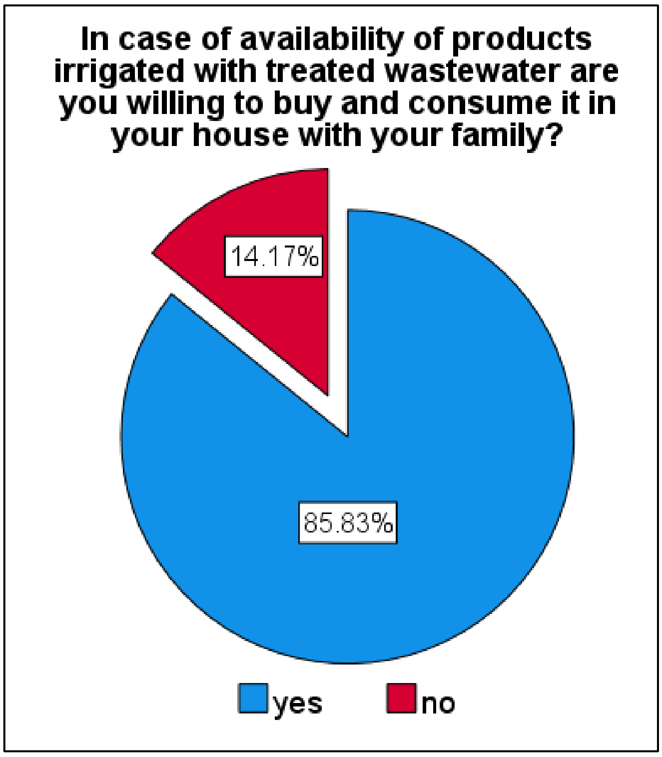


Figure B. 79 Consuming products irrigated with TWW – Italy community

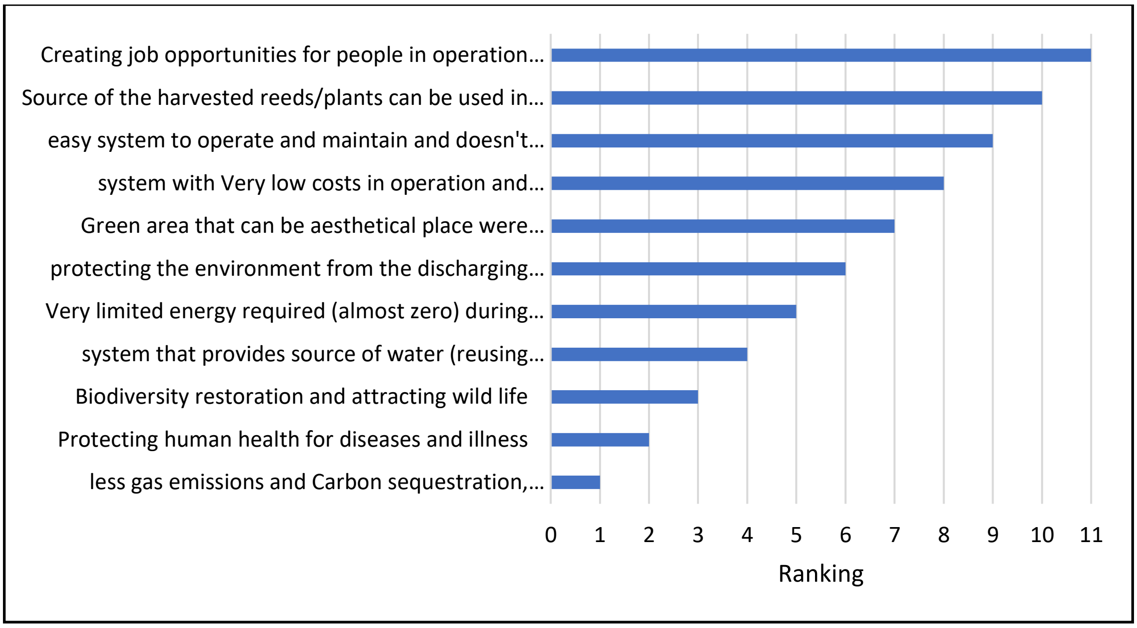


Figure B. 80 Final ranking of CWs benefits according to Italian community

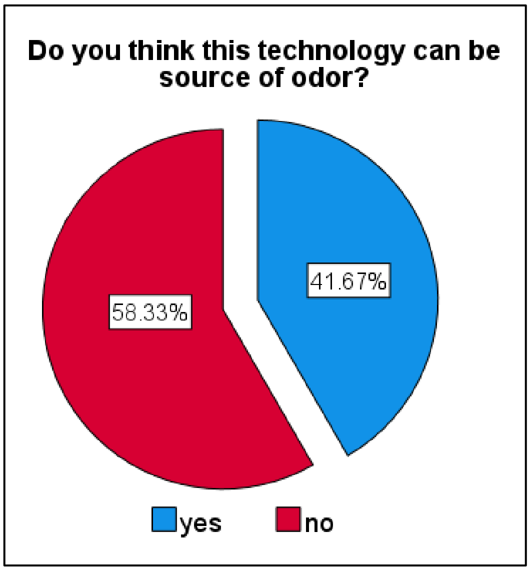


Figure B. 81 Source of odor - Italy community

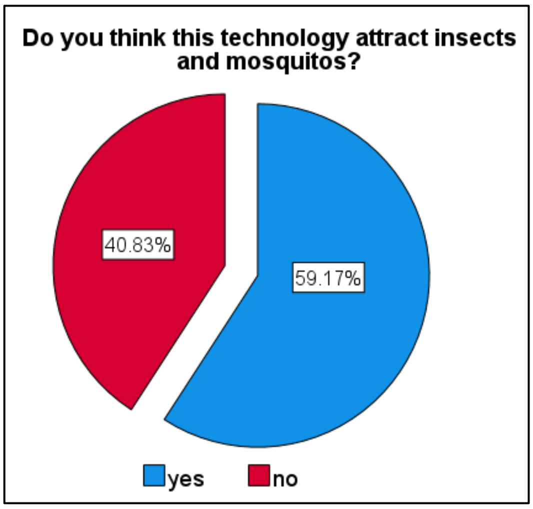


Figure B. 82 Attracting insects - Italy community

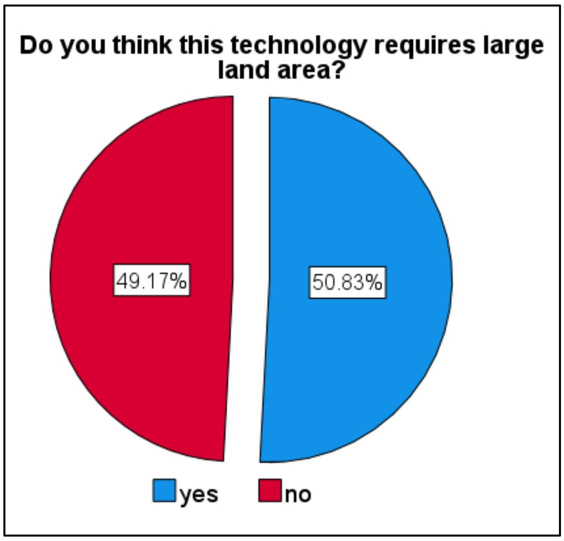


Figure B. 83 Required large area - Italy community

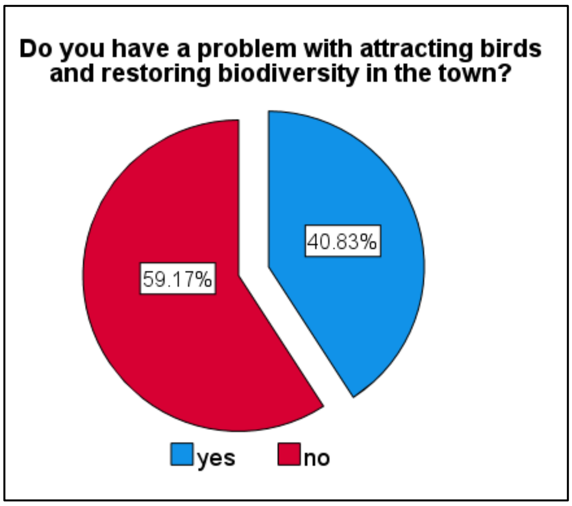


Figure B. 84 Restoring biodiversity - Italy community

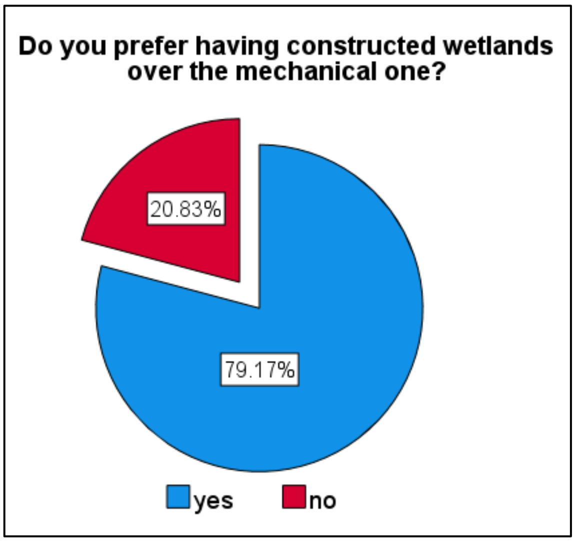


Figure B. 85 CWs vs Mechanical preferences - Italy community

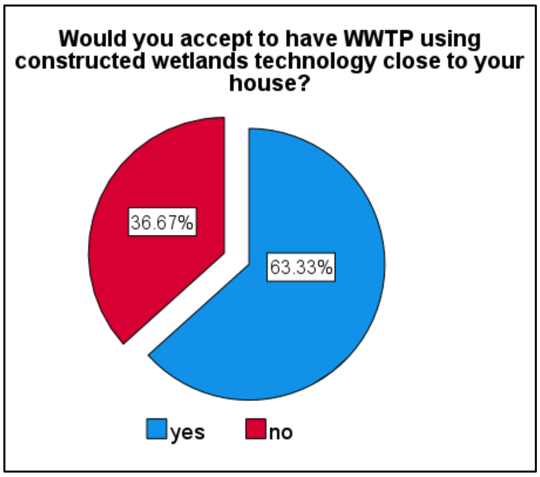


Figure B. 86 WTA of CWs near house - Italy community

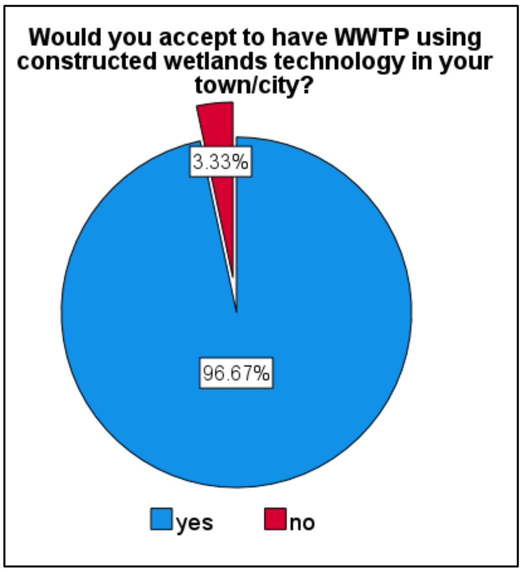


Figure B. 87 WTA of CWs in town/city - Italy community

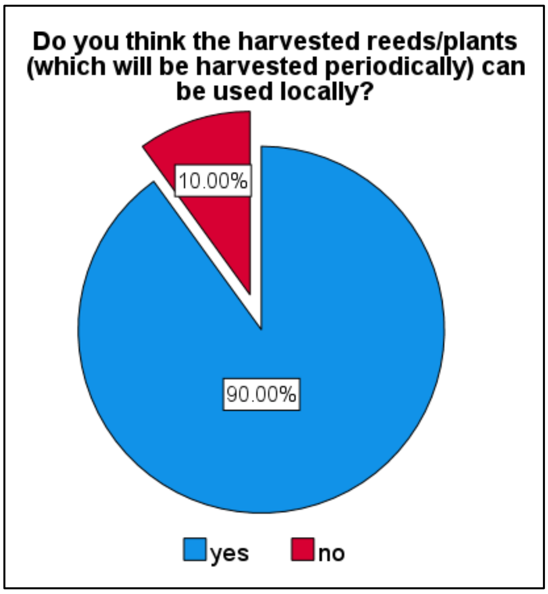


Figure B. 88 Reusing harvested reed locally - Italy community

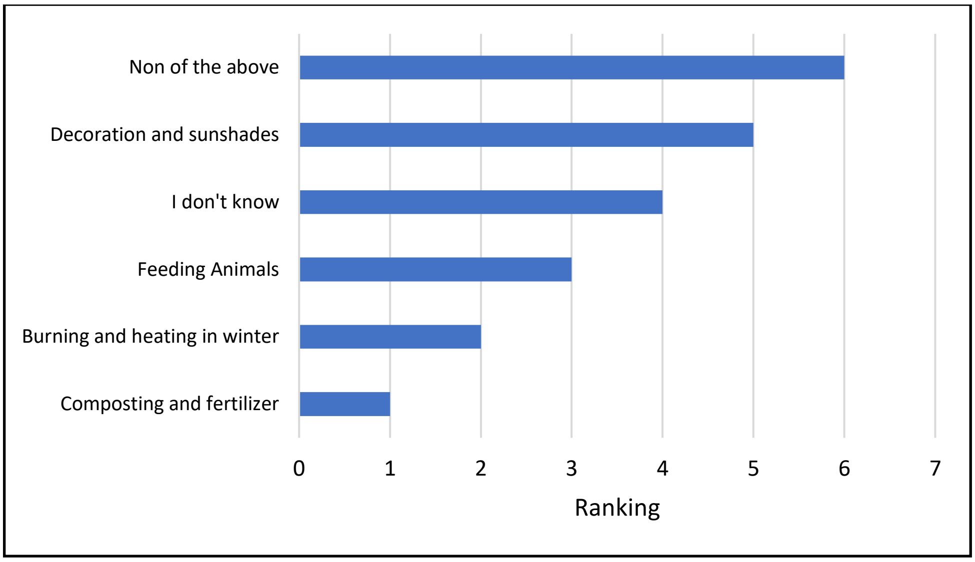


Figure B. 89 Priority of reuse of harvested reeds options - Italy community

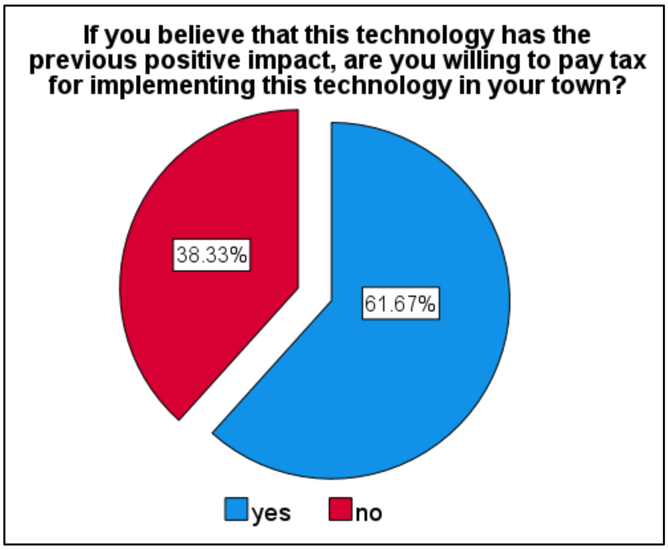


Figure B. 90 WTP for implementing CWs - Italy community

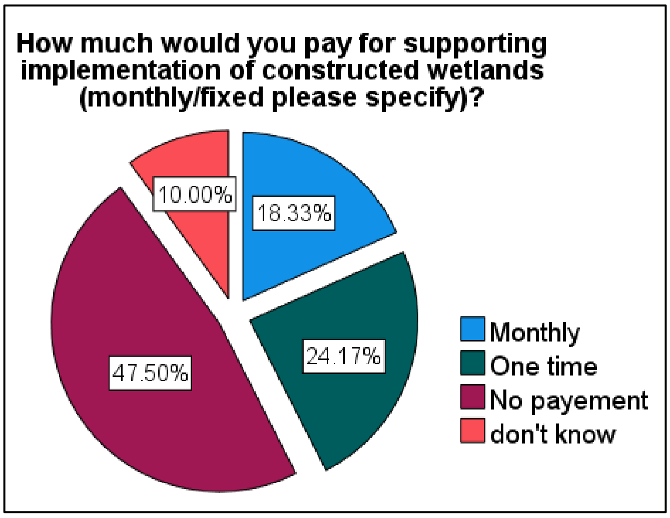


Figure B. 91 WTP for implementing CWs - Italy community

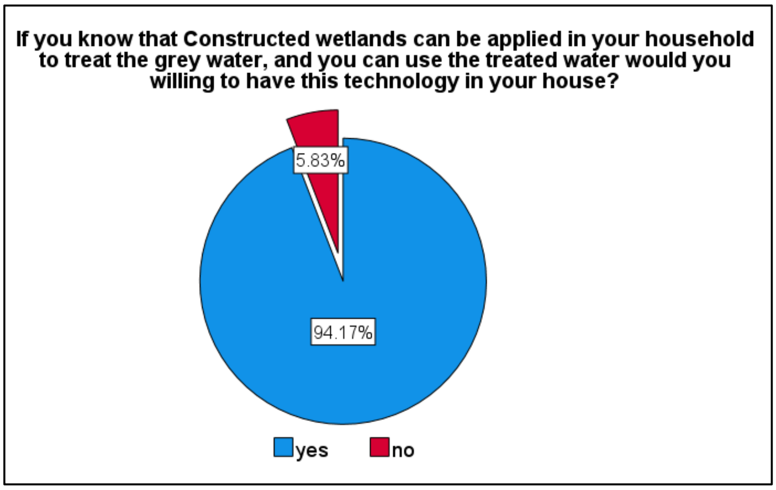


Figure B. 92 WTA for implementing CWs at HH level - Italy community

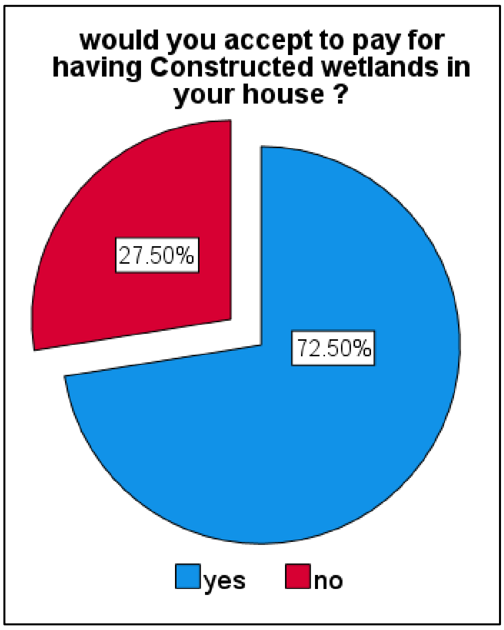


Figure B. 93 WTP for implementing CWs at HH level - Italy community

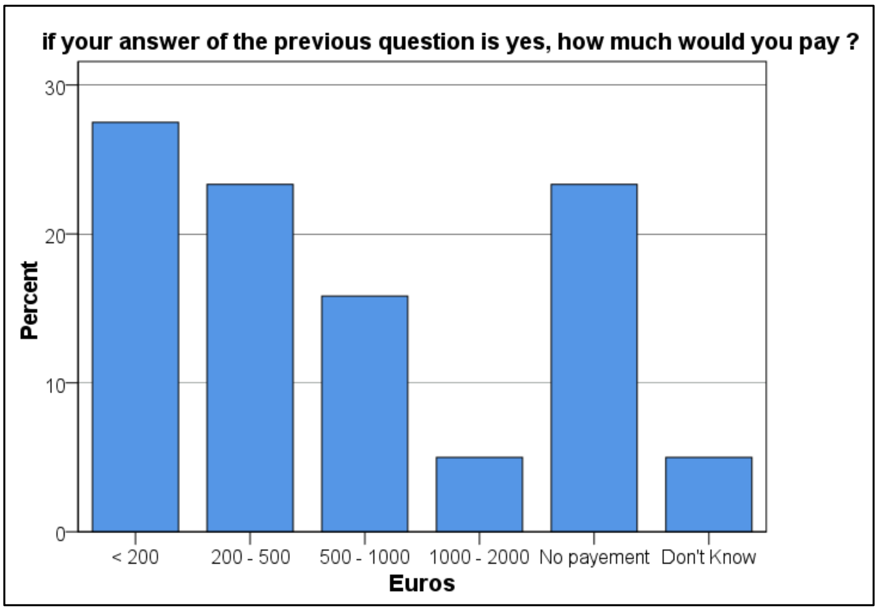


Figure B. 94 Bid values - WTP for implementing CWs at HH level - Italy community

Appendix C. The definitions of indicators used in MCA

The basic definitions of all indicators used for the assessment and the type of indication. Positive indication refers to the preference or desirability increases with the value of that criterion whereas the negative indication refers to the opposite direction of preference

Criteria	Indicator	Definitions	Type of value indication
Technical	Ease of implementation & operation	The ease to implement and design the treatment facilities and the ease to operate the process, which is associated with the manpower resource as well as the level of skills and training required for operators.	Positive
Technical	Climate change resilience	The ability of technology/process to face different climate change impacts and its ability to adjust or upgrade to adapt to climate change while maintaining the treatment efficiency	Positive
Technical	Amount of sludge & by-products (Managing the generated sludge)	The required treatment and disposal/ reuse process related to the produced sludge and other by products such as the harvested plants	Negative
Financial	Capital cost	Capital cost related to the construction and commissioning of the treatment process or technology	Negative
Financial	Operation & maintenance cost	Cost related to materials (consumables), staff cost (operators), power consumption, hired and contracted services (e.g., transport; service contract for specific treatment process)	Negative
Financial	Resource /energy recovery & reuse opportunities	The opportunities to recover resources or energy the system can provide, including the treated wastewater	Positive
Environmental	Total emission	Total of direct and indirect emission associated with the wastewater treatment process	Negative
Environmental	Soil & land contamination	The potential contamination soil and land resulted from the construction and the daily operation process	Negative
Environmental	Biodiversity restoration	The ability of the technology to restore biodiversity, flora and fauna	Positive
Environmental	Carbon Sequestration	The ability of the technology to capture and store atmospheric carbon dioxide in carbon pools such as soil and plant tissues	Positive
Social	Public acceptance	people acceptant to have this technology in their town (considering their perspectives about odor, land costs, etc.)	Positive

Criteria	Indicator	Definitions	Type of value indication
	Provision of aesthetic and green places	The ability of the system to provide green areas and aesthetical places where people can enjoy and visit the treatment plant and its boundaries	Positive
	Willingness to pay	People willingness to pay tariffs or tax to have the treatment plant and enjoy the main benefits and the co-benefits of the technology	Positive
Institutional	Local personnel capabilities and local technical capabilities	How the technology is familiar with the local technical capabilities, skills and experiences	Positive
	Compatibility with national strategies, standards, and common practices	The ability of the technology to meet the national strategies, operation and disposal standards and reuse/disposal practices	Positive
	Organizational effort & financial management required	The required efforts and funds that requested from the responsible institute to operate and maintain the technology	Negative

Appendix D. Mosques assessment details

Site Assessment Report

Jabiha, Amman

City of Amman, Amman Governorate, Jordan

First site assessment day and date: Monday 11th April 2022

Second assessment day and date: Saturday 16th April 2022

First site assessment 08 – 11 April 2022

Second assessment 23 April 2022

Prepared by: Tasnim Al-Harahsheh, Ahmed Masoud, Marika Belotti, Elham ALshurufat

Introduction

This site assessment report has been prepared and summarized the site assessment activities which has been conducted as the first step of "implementing NBS to treat greywater project". Th report summarizes the overall objectives of the assessments, assessment criteria, assessment team, the location of the assessed facilities, summary about the results and the final output.

First: The overall objectives of the assessment can be summarized in the following points

- Assessing WASH conditions in each of the Mosques, to choose one mosque for wetland
- Understand current mosque and individual WASH practices
- Identify any other elements that will help select the mosque for wetland
- Visit the mosques with a group of engineers, and assess key environmental features related to mosques conditions, space related and, WASH infrastructure (pipes, water tanks, water meters). Take photographs of these features (not people)
- Note other key features related to the assessment
- For Mosques site, the activities are carried out for about 6 hours in two days with 1 groups of engineers (3) from both CAN and University of Brescia the studied feature will be as follows:
  - The Mosque location
    - Distance form governorate
    - Distance from Amman City
    - Transportation and Roads Condition
    - Presence of Antiquities and Caves
  - Internal and the Adjoining Spaces to the Institution
    - Institution Area
    - Area of Empty spaces in the Institution
    - Available Roof Space

- Institution Characteristics, Functionality, and Key Staff
  - Number of targeted beneficiaries and types in our case the community
  - Extracurricular Activities, Agricultural, and Professional/ Vocational Activities
  - Working Hours
  - Key Staff / Positions at Institution number is needed

- Institution WASH Infrastructure Status Analysis
  - Type, number, and general conditions of toilets
  - Type of toilets flushing system
  - Number and statues of washing sinks in toilets
  - Evaluation for the Ablution Places
  - The level difference between the Washbasin facilities and toilets in institution
  - Cleaning equipment (bin, water pot, cleaning kits, soap holder, hand drier, etc…)
  - WASH buildings/rooms infrastructure conditions: Tiles, leaking, paints, doors, etc…
  - Piping location (External or Internal Connection) and conditions

Assessment Team

The team which conducted the Assessment consisted of:

- Tanseem Al Harahsheh,
- Anas Dwaimah
- Ahmed Masoud
- Alham AL shurufat
- Marika Belotti

Furthermore, local planning for the assessment was led by the team. Post analysis and quality control of assessment results and generated data was also carried out

Site Assessment: Extent and Length

The Assessment covered eleven mosques in Amman and Zarqa and the surrounding area.

The main focus was to have a mosque that contains i) available space for implementing the system, ii) potential of reuse of the treated greywater, iii) availability of local staff to operate the system in the long term.

Eleven mosques were assessed according to the tables below

Table D.1 Mosque's location

The Institution location	#1 Imam Shafi'i Mosque	#2 University housing mosque	#3 Ayed Al-Lawzi Mosque	#4 Um Zwaitnia Mosque	#5 Al-Khalil Al-Salem Mosque	#6 Zamzam Mosque	#7 Al-Dawaima Mosque	#8 Fatima Mosque	#9 Jubeiha Mosque	#10 Imam Al-Ghazali Mosque
Distance from the CAN	500 m	3000 m	2000 m	1500 m	18000 m	2100 m	19000 m	2800	2000 m	**4100 m**
Transportation and Roads Condition	**Easy to access and all the roads are in good condition**									
Presence of Antiquities and Caves(4 no appearance)	**no appearance of any Antiquities and Caves**									

Table D.2 Internal and the Adjoining Spaces to the Institution

The Institution location	#1 Imam Shafi'i Mosque	#2 University housing mosque	#3 Ayed Al-Lawzi Mosque	#4 Um Zwaitnia Mosque	#5 Al-Khalil Al-Salem Mosque	#6 Zamzam Mosque	#7 Al-Dawaima Mosque	#8 Fatima Mosque	#9 Jubeiha Mosque	#10 Imam Al-Ghazali Mosque
Area of Empty spaces in the Institution	<20 m^2	<10 m^2	750 m^2	0 m^2	Privet mosque	A garden of olive trees nearby, not affiliated with the mosque, with an estimated area of 1 dunum	A nearby tree garden that is not affiliated with the mosque, with an estimated area of more than 1 dunum	< 10 m^2	< 12 m^2	**Empty land (wadi) behind the mosque, estimated at a 500 m^2**
Available Roof Space	5 m^2	0 m^2	20-25 m^2	180 m^2	Privet mosque	0 m^2	40-50 m^2	5 m^2	5 m^2	**5 m^2**
Wall Conditions	all the walls, and roofs are in good condition			Very old mosque, the construction is fair condition	Privet mosque	**all the walls, and roofs are in good condition**				
Roofs Conditions					Privet mosque					
Number of floors	2	3	2	1	Privet mosque	2	2	3	2	**2**

Adjoining Sidewalk Conditions	Sidewalks are in good condition					**Sidewalks are in good condition**				
WASH Facilities Locations: (Floor number, basement, etc…)	Basement	Basement	Basement	Basement		Basement	Basement	Basement	Basement	**Basement**
Location of the Muezzin House (Within the mosque lands, the possibility of adding greywater from the house of the muezzin to the greywater treatment system)	no possibility of adding greywater from the house of the muezzin to the greywater treatment system					**no possibility of adding greywater from the house of the muezzin to the greywater treatment system**				
Possibility of Separate the Greywater Types										

Table D.3 Institution Characteristics, Functionality, and Key Staff

The Institution location	**#1 Imam Shafi'i**	**#2 University housing**	**#3 Ayed Al-Lawzi**	**#4 Um Zwaitnia**	**#5 Al-Khalil Al-Sale**	**#6 Zamzam**	**#7 Al-Dawaima**	**#8 Fatima**	**#9 Jubeiha**	**#10 Imam Al-Ghazali**
Number of targeted Beneficiaries and types in our case the	direct beneficiary: 300 indirect beneficiaries	direct beneficiary: 750 indirect beneficiary	direct beneficiary: 500-750 indirect beneficiary	No available information	Privet mosque	direct beneficiary: 800-900 indirect benefici	Direct beneficiary: 150-200	Direct beneficiary: 400-600	direct beneficiary: 900-1200 indirect benefici	**direct beneficiary: 500- 600 indirect beneficiary**

community						ary			ary	
Extracurricular Activities, Agricultural, and Professional/ Vocational Activities	Non	Non	Agricultural	Non		Non	Non	Non	Non	**Non**
Working Hours	6 hr	6 hr	6 hr	6 hr		6 hr	6 hr	6 hr	6 hr	**6 hr**
Key Staff / Positions at Institution number is needed	**1**	**3**	**2**	**1**		**3**	**0**	**2**	**3**	**3**

Table D.4 Institution WASH Infrastructure Status Analysis

The Institution location	**#1 Imam Shafi'i Mosque**	**#2 University housing mosque**	**#3 Ayed Al-Lawzi Mosque**	**#4 Um Zwaitnia Mosque**	**#5 Al-Khalil Al-Salem Mosque**	**#6 Zamzam Mosque**	**#7 Al-Dawaima Mosque**	**#8 Fatima Mosque**	**#9 Jubeiha Mosque**	**#10 Imam Al-Ghazali Mosque**
Type of toilets	4	10	6	2	Privet mosque	10	4	4	10	**6**
Type of toilets flushing system	6 hr	6 hr	6 hr	6 hr		6 hr	6 hr	6 hr	6 hr	**6 hr**
Number of washing sinks in toilets	2 sinks 4 ablution area	8 sinks 17 ablution area	2 sinks 6 ablution area	1 sinks 3 ablution area		8 sinks 20 ablution area	5 sinks 5 ablution area	2 sinks 6 ablution area	8 sinks 17 ablution area	**4 sinks 6 ablution area**
Status of washing sinks in toilets	all sinks are in good condition			Fair		**all sinks are in good condition**				
Evaluation for the Ablution Places	all ablution area are in good condition			Fair		**all ablution area are in good condition**				
Number of internal toilets in institution	4	10	6	2		10	6	8	10	**6**
Infrastructure status for the toilets in institution	good condition			Fair		**good condition**				
The level difference										

between the Washbasin facilities and toilets in institution				
Cleaning equipment (bin, water pot, cleaning kits, soap holder, hand drier, etc…)	**All the mosques have cleaning equipment**			
Other needed equipment (ladder, etc….)	**No ladder needed; all the mosques have accesses to the roof**			
WASH buildings/rooms infrastructure conditions: Tiles, leaking, paints, doors, etc…	All in good condition	Fair		**All in good condition**
Piping location (External or Internal Connection) and conditions	**Internal piping, in good condition**			**Internal piping, in good condition**

Table D.5 Institution Water Consumption Patterns

The Institution location	**#1 Imam Shafi'i Mosque**	**#2 University housing mosque**	**#3 Ayed Al-Lawzi Mosque**	**#4 Um Zwaitnia Mosque**	**#5 Al-Khalil Al-Salem Mosque**	**#6 Zamzam Mosque**	**#7 Al-Dawaima Mosque**	**#8 Fatima Mosque**	**#9 Jubeiha Mosque**	**#10 Imam Al-Ghazali Mosque**
Water Consumption Amounts in the institution	Information related to water consumption and its bills is available at the Ministry of Awqaf and will be requested after determining the mosque				Privet mosque	**Information related to water consumption and its bills is available at the Ministry of Awqaf and will be requested after determining the mosque**				
Ways by Occupants During Working Hours During the Year's Seasons										
Number of water tanks in	4 m^3	10 m^3	6 m^3	2 m^3		6 m^3	4 m^3	6 m^3	9 m^3	**4 m^3**

the institution										
How Many Time the Water Reaches the Institution , and at What Rate	Information related to water consumption and its bills is available at the Ministry of Awqaf and will be requested after determining the mosque					**Information related to water consumption and its bills is available at the Ministry of Awqaf and will be requested after determining the mosque**				
Water bills over a year to understand the season variation (if any). Can we get a copy?										

Table D.6 Power Supply

The Institution location	**#1 Imam Shafi'i Mosque**	**#2 University housing mosque**	**#3 Ayed Al-Lawzi Mosque**	**#4 Um Zwaitnia Mosque**	**#5 Al-Khalil Al-Salem Mosque**	**#6 Zamzam Mosque**	**#7 Al-Dawaima Mosque**	**#8 Fatima Mosque**	**#9 Jubeiha Mosque**	**#10 Imam Al-Ghazali Mosque**
Energy source (solar system availability)	Solar system				Privet mosque	**Solar system**				
Location for the Solar System (if any) (sketch)	At the roof					**At the roof**				
Area of the Solar System (if any)	Solar panels cover approximately 70-75% of the surface area					**Solar panels cover approximately 70-75% of the surface area**				
Electricity bills (if any)	**Information related to electrical consumption and its bills is available at the Ministry of Awqaf and will be requested after determining the mosque**					**Information related to electrical consumption and its bills is available at the Ministry of Awqaf and will be requested after determining the mosque**				

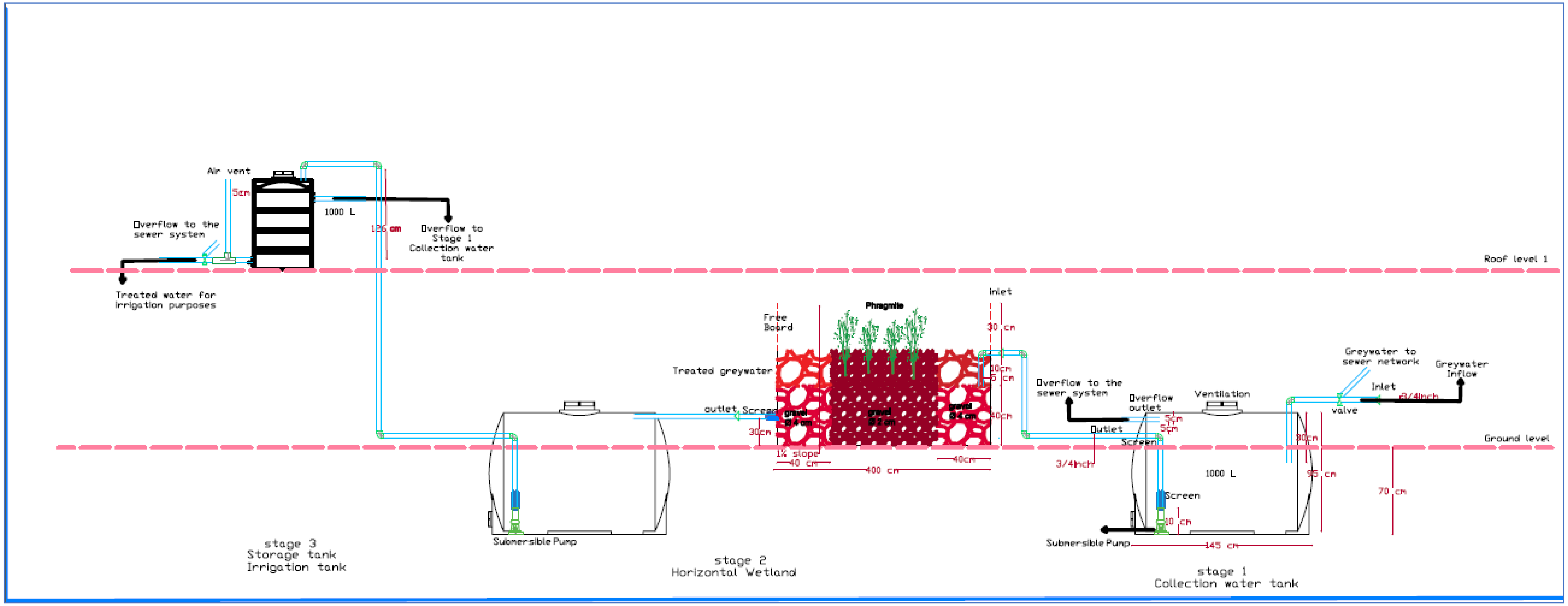
Table D.7 Mosques assessment using scoring method

SCORING: 1 – weak 2 – fair 3 – good 4 – very good

The Institution location	#1 Imam Shafi'i	#2 University housing	#3 Ayed Al-Lawzi	#4 Um Zwaitnia	#5 Al-Khalil Al-Salem	#6 Zamzam	#7 Al-Dawaima	#8 Fatima	#9 Jubeiha	#10 Imam Al-Ghazali
Distance from the CAN	4	3	4	4	Privet mosque	3	1	3	4	**2**
Transportation and Roads Condition	4	4	4	4		4	4	4	4	**4**
Presence of Antiquities and Caves(4 no appearance)	4	4	4	4		4	4	4	4	**4**
Area of Empty spaces in the Institution	2	2	3	1		4	4	1	2	**3**
Available Roof Space	1	1	3	4		1	3	1	1	**1**
Wall Conditions	4	4	4	2		4	4	4	4	**4**
Roofs Conditions	4	4	4			4	4	4	4	**4**
Number of floors	4	4	4	4		4	4	4	4	**4**
Adjoining Sidewalk Conditions	4	4	4	4		4	4	4	4	**4**
WASH Facilities Locations: (Floor number, basement, etc…)	4	4	4	4		4	4	4	4	**4**
Number of targeted Beneficiaries and types in our case the community	3	4	4	No avallabile information		4	3	4	4	**4**
Extracurricular Activities, Agricultural, and Professional/ Vocational Activities	1	1	4	1		1	1	1	1	**1**
Key Staff / Positions at Institution	4	4	4	1		4	1	4	4	**4**

number is needed										
# of toilets	4	4	4	4		4	4	4	4	**4**
Status of washing sinks in toilets	4	4	4	2		4	4	4	4	**4**
Evaluation for the Ablution Places	4	4	4	2		4	4	4	4	**4**
Infrastructure status for the toilets in institution	4	4	4	2		4	4	4	4	**4**
Cleaning equipment (bin, water pot, cleaning kits, soap holder, hand drier, etc…)	4	4	4	4		4	4	4	4	**4**
WASH buildings/rooms infrastructure conditions: Tiles, leaking, paints, doors, etc…	4	4	4	2	Privet mosque	4	4	4	4	**4**
Piping location (External or Internal Connection) and conditions	4	4	4	2		4	4	4	4	**4**
Energy source (solar system availability)	**4**	**4**	**4**	**4**		**4**	**4**	**4**	**4**	**4**

Appendix E. HFCW detailed design



Appendix F. Operation and maintenance manual

Operation and Maintenance Manual

Greywater treatment system using constructedwetland system

first edition

July, 2022

Team

University of Brescia -CeTAmb Italy
PhD. Ahmed Masoud
Eng. Marika Belotti
Jordan Climate Action Association
Eng. Elham Al Shurufat
Eng.Tasneem Harahsheh

Introduction

This guideline explains the procedures necessary to operate and maintain the constructed wetland which is implemented to treat greywater and reuse system which was implemented in Jordan within the activities of the project "Implementing a greywater system in mosques using natural-based solutions in Jordan" within the cooperation agreement between the Jordan Climate Action Society And the Italian University of Brescia - CeTAmb and the Italian non-profit organization Sipec in order to achieve the following specific goals:

1) Providing a new source of water that can be used in the mosque and replace fresh water for irrigation purposes (an example that can be replicated in other mosques in the community)
2) Raising awareness in the community level about accepting of reusing treated greywater, conserving water, and adapting to climate change.

The CW system was established in Abdullah Al-Azab Mosque in Zarqa Governorate, the mosque was provided with a small treatment plant with a hydraulic capacity of one cubic meter per day to be treated using CW technology. The system aims to provide the mosque with treated water according to Jordanian standards for reuse treated greywater for irrigation purposes. .

<u>Main tools and components</u>

1. Pipes to separate greywater from the black water
2. Two valves on the main pipeline that feed the treatment system
3. Plastic collection tank which aims to collect raw greywater, named as (Tank No. 1)
4. Submersible Pump in tank No. 1, named as (Pump No. 1)
5. Electric timer to control pump No. 1
6. Constructed wetland basin planted with reeds
7. Plastic tank for collecting treated greywater from the constructed wetland, name as (Tank No. 2)
8. Submersible Pump in tank No. 2 which pumps water to tank No. 3, named as (pump No. 2)
9. Plastic collection tank elevated on the roof of the toilet to collect the treated water, named as (Tank No. 3)
10. Irrigation network from tank No. 3 to the trees in the mosque's garden

Figure F. 1 Electrical details, 1 for electricity breaker for pump 1, 2 for pump 2, 3 is the timer system

Daily Operation Instructions

- The operation, inspection and maintenance process must be carried out by an adult and technically qualified person.
- The person responsible for the operation, inspection, and maintenance must abide by the procedures and public safety equipment (gloves, masks, protective clothing, etc.)
- The person responsible for the operation, inspection, and maintenance must comply with the operating instructions
- The necessity of checking and cleaning the collection tank No. 1 every three months
- Inspect tanks, connection and irrigation pipes tobe detectted periodically against any damage or leakage from the network.

It is very important to educate people who use the WASH units to not throw solid waste into drains

How the system works

The system operates automatically, the greywater flows through the pipes to the collection tank (Tank No. 1) and when the required level is reached and this corresponds to the timer signal, the automatic pumping is carried out from the tank to the constructed wetland through the submersible pump No. 1 (in the absence of a signal from timer or in case of a pump failure, the greywater will flow out from tank 1 to the nearby manhole through the overflow pipe)

Automatic pumping is carried out from tank No. 1 to the constructed wetland established in the form of dosing and the water flows through the filter materials within the constructed wetland and flow out due to the slope and the level difference in the water and being collected in the tank No. 2

Water is pumped from tank No. 2 through a submersible pump No. 2, which works automatically when the tank reaches a certain level and also stops automatically when the level drops (in the event of any malfunction in pump No. 2, the water automatically flows out of the tank No.2 to the surrounding trees, where The water is treated water.

The treated water is pumped from tank No. 2 to tank No. 3 which is elevated on the roof of the WASH unit

Three drainage options are available from tank No. 3:

1. To the irrigation network
2. Drainage points to the sewage network for the purpose of emptying when not in use
3. The overflow point, which allows the water to flow into tank No. 1 again, to ensure that there is water in the system and to reuse the largest amount of treated water.

Periodic maintenance

- Check the tanks and pipes on a daily basis and make sure that the pumps are working, by noting the continuous flow of water through the system
- Cleaning tank No. 1 through shovel and assembly tools in order to collect and remove any floating materials from the surface of the water, and the process is repeated every three months or less according to the quality of the water, so it is recommended to perform the process on a monthly basis

- Cut and harvest the planted reeds annually in March or April every year, keep 40 cm from the original length of the reeds.
- Please be careful and use the appropriate tools while performing the periodic maintenance of the system

Special maintenance

In case of a malfunction or when major maintenance is needed, such as failure of pumps, the lack of flow or lack of smooth flow of water, or in case of pipe clogging in the system, the operator must disconnect the system by opening valve No. 2 and closing valve No. 1 and immediate communicating with the maintenance team using the contact information provided below

Engineer Elham Al Shurfat 0785075700

Copyright and non-disclosure

Appendix G. Photos of implementation

Figure G. 1 Abduallah Al Azab Mosque

Figure G. 2 Separated WASH unit

Figure G. 3 Primary settling tank – overflow to sewer system

Figure G. 4 Primary settling tank – complete plumbing works

Figure G. 5 Recirculation to primary tank

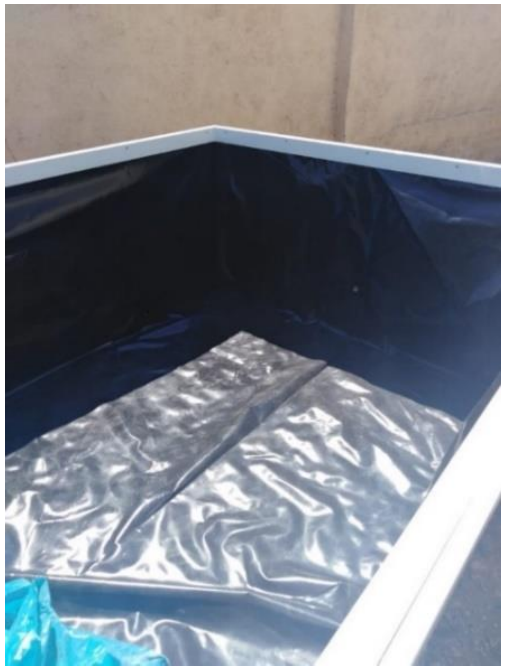


Figure G. 6 HFCW bed

Figure G. 7 Installation of HFCW bed

Figure G. 8 Inflow pipe HFCW

Figure G. 9 Even distribution – inflow pipe

Figure G. 10 Even distribution – outflow pipe (2)

Figure G. 11 Outflow pipe installation

Figure G. 12 Distribution filter materials

Figure G. 13 Flow testing

Figure G. 14 HFCW planted bed

Figure G. 15 Reeds after 30 days of operation

Figure G. 16 Reeds after 30 days of operation (2)

Figure G. 17 TGW Collection tank

Figure G. 18 Elevated irrigation tank

Figure G. 19 TGW disposal and reus connections

Figure G. 20 irrigation network

Figure G. 21 Raw greywater(right) and Treated graywater (left)

MODULO DI EMBARGO DELLA TESI

(da compilare solo se si richiede un periodo di segretazione della tesi)

Il/La sottoscritto/a…Ahmed Mohammad Nafea Masoud……… Nato/a il……19 May 1990……………….

a (indicare anche l'eventuale paese estero)………Jordan……………………………………….

provincia di (ovvero sigla del paese estero)………………Irbid…………………………………….

Dottorato di Ricerca in Civil, Environmental Engineering, International Cooperation and Mathematics

DICHIARA

- che il contenuto della tesi **non può essere immediatamente consultabile per il seguente motivo**

---------Stiamo ancora lavorando so pubblicazione di articoli scientifici a partire dai risultati della tesi------

La motivazione deve essere dettagliata e controfirmata obbligatoriamente dal Tutor e/o Relatore

(Brevetto, segreto industriale, motivi di priorità nella ricerca, motivi editoriali, altro)

- che il testo completo della tesi potrà essere reso consultabile dopo:

X 6 mesi dalla data di conseguimento titolo

□ 12 mesi dalla data di conseguimento titolo

□ 24 mesi dalla data di conseguimento titolo

□ altro periodo ______________________

- che sarà comunque consultabile immediatamente l'abstract della tesi, che viene caricato in Esse3, profilo studente.

Luogo e Data

Firma del Dichiarante

Brescia 13 Mar 2023

Controfirma del Tutor e/o Relatore del Dottorato

per la motivazione di embargo e il periodo.