The role of al-Bīrūnī in the history of hydrology. A modern vision 600 years in advance.

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ABSTRACT

In today's contemporary world, a walk through the epistemology of the hydrological cycle can help us to frame many current problems in a broader framework, reminding us to remain humble. Among all the scientific concepts that are taught in schools of all kinds and levels everywhere on the planet, the water cycle is one of the concepts that remain in the head even after a long time from the end of compulsory school. The ease in remembering this theory can be attributed to its relative simplicity: water evaporates from lakes, seas and oceans; the vapor forms the clouds; from the clouds come the rains and snows that feed the glaciers and Earth's surface and underground waterways, which in turn return to the oceans, and so on. However, the mechanism is only apparently simple. The trained hydrologist knows very well that studying and communicating the complexity hidden behind hydrological science requires patience and dedication. Modern hydrology, in the Western world, can be considered born at the end of the 17th century thanks to two members of the Académie Royale des Sciences: Pierre Perrault (1611-1680) and Edme Mariotte (1620-1684). The treatises of these two scholars – *De l'origine des fontaines* (Perrault 1674) and *Traité du mouvement des eaux et des autres corps fluides* (Mariotte 1686) – can be considered the first attempts to verify the actual ability of precipitation to supply rivers and sources by means of quantitative analyses.

Anyway, it is clear that a modern vision of the hydrological cycle was present in the Islamic world at the time of al-Bīrūnī. Although he did not leave writings dedicated solely to hydrological sciences, al-Bīrūnī's "modern" vision of the hydrological cycle clearly emerges in some extant passages of his works.

In this memoir, we will discuss how al-Bīrūnī's vision of the hydrological cycle mirrors a theoretical framework widespread among the Islamic scholars of his age, and how its fundamental concepts anticipate the modern hydrological vision that took shape in Europe in the mid-1600s.

KEYWORDS: Hydrology, Epistemology of Water Cycle, History of Science.

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As with many other applied sciences, hydrology was not considered in the past a self-consistent discipline. Indeed, the knowledge based on a well-defined and proper classification of disciplines can be considered a modern feature. This epistemological issue was investigated and systematized by Auguste Comte in his works on Positivism [1, 2]. Considering that "applied sciences" is a modern taxonomical category, it is important to observe that al-Bīrūnī was well aware of the difference between the theoretical investigation of physical phenomena and the practical application of science to solve specific problems. Therefore, it is also important to highlight which parts of al-Bīrūnī's knowledge can be considered as something pertaining properly to a theoretical sphere or otherwise to applied problems. For sure, the classification of fields of knowledge transmitted by some passages of al-Bīrūnī's *Chronology* can and must be classified *a posteriori* as hydrological science, according to contemporary taxonomical categories used for scientific disciplines. In order to do so, we must interpret the contribution to applied disciplines according to two tracks: *1)* the contribution that purely theoretical speculation has on applied science and *2)* the direct application of theory to the solution of practical problems.

These considerations on al-Bīrūnī's work are extendable to other authors of the pre-modern Islamic world. For example, being aware of the practical application of the sciences is evident in Abū ʾl-Wafāʾ al-Būzjānī (940-998 CE). This scholar – who is famous for having preserved parts of the *Kitāb al-Majisṭī*, one of the most popular works on mathematics between the 9th and 10th centuries – wrote a treatise on geometrical constructions needed by artisans (*Kitāb fī mā yaḥtājū al-ṣāniʿ min al-ʿamal al-handasiyya*) for planning and raising of buildings [3].
It is noteworthy that one of his pupils, Abū Naṣr Manṣūr ibn ʿAlī ibn ʿIrāq (c. 950- c. 1018 to 1036 CE), "who was himself an outstanding scholar and author of some twenty works on mathematics and astronomy, and an outstanding figure in the intellectual history of medieval Islam, was the mentor of Abū ʾl-Rayḥān al-Bīrūnī." [4]. Then, it is not surprising to find at the same time in al-Bīrūnī an attitude both theoretical and practical. To give an example, al-Bīrūnī in his *Kitāb al-Āthār al-Bāqiya*, addressing the reader, explains to him the system for calculating dates used in astronomical works (*zījāt*), for observations of the sky, and for other purposes such as trade agreements and contracts. He says *verbatim*:

"Next we must turn our attention towards fulfilling our promise of teaching the reader that knowledge by means of which he may compute the eras that are in the Canons, for astronomical observations, and elsewhere, *e.g.* in commercial stipulations and contracts [*al-shurūṭ wa ʾl-muʿāmalāt*]" [5].

In order to understand why it is possible to affirm that the pre-modern Islamic knowledge on hydrology was 600 years in advance with respect to the European ones, we should understand how hydrology, intended in the modern scientific sense, was generated.

1 Comte, A. **(1842).** *Cours de Philosophie Positive*.
2 Comte, A. **(1844).** *Discours sur l'ensemble du positivisme*.
3 Bellosta, H. **(2002).** *Geometria pratica, in Storia della scienza. III*. La civiltà islamica, Roma, (pp. 506-525), pp. 507-509. For the Arabic edition of Abū ʾl-Wafāʾ al-Būzjānī's work see Ṣ.A. ʿAlī (ed.), Mā yuḥtāj ilayhi al-ṣāniʾ min ʿilm al-handasa li-Abū ʾl-Wafāʾ al-Būzjānī, Baghdad (University of Baghdad), 1979.
4 Fedorov, M. **(2000).***The Khwarazmshahs of the Banū ʿIrāq (fourth/tenth century)*. Iran, 38, 71-75.
5 Sachau, C. E. **(1879).** (transl. by), *Al-Bīrūnī, The Chronology of ancient Nations. An English Version of the Arabic Text of the Athâr-ul-bâqiya of Albîrûnî.* London: India Office, 131-132 (= p. 135 of Sachau's ed. of the Arabic text).

Before Mariotte's and Perrault's works [6, 7], in modern Europe, it was difficult for scholars to recognize the Sun as the exclusive engine of the hydrological cycle. Before the first accurate measurements on the amount of precipitation and the drained areas carried on in the 17th century, the common feeling was that simple precipitations were not sufficient to fully feed the rivers' flow. Therefore, scholars believed that the rivers flows deriving from precipitations needed to be "integrated" by additional water generated underground. This idea was based on theories borrowed from Aristotle's *Metaphysics* or from subsequent theories such as those of Renaissance period. Aristotle's theory on the hydrological cycle refers to his well-known theory of the Four Elements, in which they are not stable, but transmute themselves from one into the others. So, he believed that, in addition to the rainfall, there was also water generated by condensation in the underground cavities [8].
On a different level, Reanaissance's theories, built on Galen's and Pliny's works, referred to the correspondence between Microcosm (Man) and Macrocosm (Earth). In this vision, the water plays an analogous role to blood by vivifying the earthly body. Therefore, conceiving the Earth as a living being, the tides behave as a pulsating heart, pumping water into underground "veins" that feed springs, so generating rivers. These two general theories were particularly appealing for the scholars of the Renaissance period and were also taken up by the famous Italian polymath Leonardo da Vinci [8]. Despite showing a very good knowledge of the ancient Aristotelian and Plinian "hydrological" theories, some Islamic scholars of the Abbasid age present a decidedly more modern conception of the hydrological cycle. Among the authors of the Abbasid age dedicating treatises to hydrological science, we can mention al-Baghdādī (c. 1080-1164/5 CE). In the chapter *On Generation and Corruption* of the second book of his *Kitāb al-muʿtabar* a modern view of the hydrological cycle is absolutely clear. Although he knows the Aristotelian theory about the underground generation of water, al-Baghdādī believes that the underground waters derive solely from rain and snow that infiltrate the soil and the Earth's cavities. He states:

"Some of the streams flow when rain falls upon elevated places of the earth and mountains. They cease to flow shortly after the rain has stopped. There are others that flow from snow that melts in the highest places of the mountains. These keep flowing as long as there is snow on the mountain. They increase with the increase of snowmelt and decrease according to its decrease. [...] People say and many ancient and modern philosophers believe that the air trapped inside the mountains cools down and changes into water that flows. Air is further sucked in, cooled down, and changed into water, and this happens continuously and incessantly. The answer to them is that springs dry up, and wells desiccate, and rivers and wadis cease to flow when snow or rain become too little and why they increase when the latter increases, and why they decrease as the latter decreases. The intensity of the cold is not helpful against the lack of rain and snow to increase the water in springs and wells and its persistence." [9]

6 Mariotte, E. **(1686).** *Traité du movement des eaux et des autres corps fluides.*
7 Perrault, P. **(1674).** *De l'origine des fontaines.*
8 Ravelli, F. **(2001).** *Il ciclo idrologico naturale nel pensiero dei classici fino agli albori della moderna idrologia.* Appunti.
9 Yaltakaya. S. **(1939).** *Al-Baghdādī, Abū l-Barakāt, Kitāb al-muʿtabar fī l-ḥikma, Dāʿirat al-Maʿārif al-ʿUthmaniyya.*

To question why in the Islamic world a modern vision of hydrology had developed significantly earlier than in Europe, a simplistic answer may be that this happened because in large part of the Islamic world there is on average less water. However, this would be a hasty conclusion derived from a purely techno-scientific perspective, and it does not really answer the main question, *i.e.* why the Islamic world developed a modern hydrologic theory six centuries in advance. In fact, one could observe that it is difficult to state that the Northern and Southern Mediterranean shores were not in contact... Moreover – and in a much more significant way – to retain that in the past vast regions of Southern Europe, such as parts of Greece or Spain, were not affected by aridity is highly questionable.
In order to suggest a possible investigation line for solving the question about the early development of a correct hydrological theory among the Islamic scholars of the Abbasid age we can think of an influence of Middle Eastern ideas circulating at that time. Among these ideas, not considering the Babylonian conceptions of the water cycle, it is worth recalling some cosmological conceptions in the Zoroastrian tradition, such as those seeing the sea as a water purifying filter aided by the wind, and a water cycle beginning with a great rain when, after the first Ahriman's attack, all the natural beings started moving thanks to the heat of the divine Fire (Ātur). Such ideas can be traced also to the 9th-century cosmological treatise on the Creation (*Bundahišn*), which had been composed in Baghdad by some Zoroastrian priests. This highlights the circulation of pre-scientific elements, constituting the fertile ground on which it was possible to develop an absolutely contemporary conception of the hydrological cycle, albeit pre-scientific and framed within an idea of a cosmic order [10, 11, 12].

Coming back to our time, it is necessary to specify that hydrology is a quite recent discipline. Because of this scholars do not perceive it as a field of research a millenary history as geometry or astronomy. Therefore, the main attitude towards this discipline is to ignore all concepts and ideas not directly developed within the discipline after the Enlightenment Age, so impoverishing it of its broader historical dimension. This attitude is not without consequences on both epistemological and practical levels.
Today, when one looks at researches being carried out on the hydrology of arid areas, the term "*wadī* hydrology" is often used [13]. Such terminology emphasizes hydrological studies in arid areas as a second natural child of the hydrological science born in Europe at the dawn of the Enlightenment Age.
As an applied science in modern terms, hydrology was born and developed in European regions (France, the United Kingdom etc.) particularly generous in water. Despite this last statement seems to mirror the argument mentioned before in order to criticize the simplistic answer on the early development of a correct hydrologic theory in the Islamic world, the logic is here quite different, because modern hydrology has been fully systematized as applied science in a Galileian scientific framework, carrying out measurements and the developments of models and operational tools calibrated on the wet climates and not the arid ones. Therefore, the discipline results shifted towards a "wet bias".

10 Mary, B. **(1982).** ĀB i. The concept of water in ancient Iranian culture. In *Encyclopaedia Iranica*. 27. Brill.
11 Kreyenbroek, P. G. **(1993).** i. in Cosmogony and Cosmology. In *Encyclopaedia Iranica Online.* 303-307. Brill.
12 Malandra W. and Stausberg M. **(2007).** *Iran* in Johnston, S. I. ed. *Ancient religions.* Harvard University Press.
13 Şen, Z. **(2008).** *Wadi hydrology.* Crc Press.

This fact is the harbinger of a series of interpretative and operational tools that, if set in different contexts (*i.e.* those proper to "*wadī* hydrology"), may reverberate wrong.
In this perspective, just to name a few interesting authors worth to be red, a very good one is Nick Cullather [14], who collected the evidence of the results of an epistemological and techno-positivist bias in the hydrological field in an excellent work on the modernization of the Helmand river basin. The author shows very well how the application of this hydrological "wet bias" created many problems in local water ad soil management. Another good paper is the one by Sara B. Pritchard [15], who carried out a similar work dedicated to the hydrological interventions of French technicians in the arid French colonies in North Africa, which from the point of view of water resource management have been a great unsuccess.
It is therefore clear how the deep study of the epistemological development of a discipline – all the more so if it is an applied discipline – it is particularly interesting for reading in a historical key a series of errors and bad habits, that through the discipline itself can easily manifest themselves in present times.
The challenges posed by the future are strongly related to the management of ecosystems and natural resources, and this is even more true since most observers agree on the fact that the wars of the future will be waged for water. Therefore, it becomes interesting to dissect hydrology and natural sciences dealing with water at historical and cultural levels too.
The importance of some passages by al-Bīrūnī's is immediately evident if we take into consideration a short digression in the *Kitāb al-Āṯār al-Bāqiya*, where this author quotes the treaty by Ibn Qurra, titled *Why is the sea water salty?*(*Qawl fī Sabab alladhī Juʿilat lahu Miyāh al-Biḥar Māliḥa*). This treaty is a short *risāla* dealing with the question of sea salinity. Al-Bīrūnī's passage has been recently translated and edited in English by Borroni and Boselli [16], caring due attention to the technical terminology used in it. This passage reveals al-Bīrūnī's understanding of fluvial regimes, water physical behaviour, and a handful of peculiar natural phenomena. Al-Bīrūnī discusses *1)* weather forecasts and seasonal fluvial regimes of some big rivers, *2)* the principle that water moves only downwards in the absence of external forces, *3)* the origin of sea salinity, *4)* the functioning of syphons-related hydraulic machines, and *5)* the peasants' observation of the physical phenomenon known as "hydraulic jump", that he dismisses as result of faulty observations. The passage contains also relevant information on al-Bīrūnī's understanding of the water cycle.
Ibn Qurra's treatise quoted by al-Bīrūnī – also recently translated and edited for the first time by Borroni (in printing) – offers an interesting starting point for pondering on current problems regarding sea salinity, and some contemporary techno-positivist approaches, which undoubtedly have major limitations in their side effects.
For example, especially in the Middle East and North Africa, desalination is thought of as a solution to water scarcity. However, for every liter of fresh water, at least one liter of brine is obtained, which is a highly corrosive and sterilizing waste that must be disposed of in some way.

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14 Cullather, N. **(2002).** *Damming Afghanistan: Modernization in a buffer state.* The Journal of American History, 89(2), 512-537.
15 Pritchard, S. B. **(2012).** *From hydroimperialism to hydrocapitalism: 'French' hydraulics in France, North Africa, and beyond.* Social Studies of Science, 42(4), 591-615.
16 Borroni, M. and Boselli, V. **(2021).** *Hydraulics and hydrology in a passage of the Kitāb al-Āṯār al-Bāqiya by al-Bīrūnī.* Arabic sciences and philosophy, 31(2), 159-182.

When disposing of the brine waste on land, one must be sure that it does not percolate salinating the aquifer, and discharging it into the sea, the risk is sterilizing entire marine stretches due to excess of salinity. Many countries, especially in the Gulf area, today find themselves having to face these technical problems.

In light of what has been discussed so far, the leading role of al-Bīrūnī in reworking and handing down the cornerstones of a discipline, such as hydrology, is clear. At the same time, his argumentations are widespread in various points of his writings, and because of this, these passages obtained minor attention. The importance of studying these passages by al-Bīrūnī and other authors of the pre-modern Islamic world is of particular interest in the context of the history of certain disciplines. We remind that these disciplines appeared as such in the taxonomy of knowledge only during the Modern age, and sometimes – such as in the case of hydrology – it is possible to distinctly grasp a contemporary vision as much as 600 years in advance. This fact can help us put into the correct scientific perspective problems that seem easily solvable with short-term technical solutions. However, it is not given that those contemporary solutions, are good solutions once analysed by placing the problem in a broader framework. We can so conclude saying that, if al-Bīrūnī's historical contribution to the hydrologic science was that of an outstanding messenger of the hydrological vision of the Islamic world during his own era, the current role of the epistemological study of hydrology carried on by al-Bīrūnī's and other authors, can help us to re-frame hydrology a broader context as the applied science studying the relationship between the hydrosphere and human activities. In philosophical terms, the epistemological study of hydrology could be declined also as a *katéchon* [17] for the contemporary discipline.

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17 Cacciari, M. **(2013).** *Il potere che frena*, Adelphi.