3 Al-Bīrūnī's Thought on Water and the Influence of Ṯābit

Summary 3.1 The Scientific Career of al-Bīrūnī. – 3.2 Climatic and Environmental Subjects in al-Bīrūnī's Scientific Production. – 3.3 Al-Bīrūnī and the *'Anwā'*. – 3.4 Hydrology in the *Kitāb al-Āthār al-Bāqiya*. – 3.5 Hydrology in the *Kitāb taḥdīd al-amākin*. – 3.6 The Water Cycle According to al-Bīrūnī, Ṯābit and al-Karaǧī: A Comparison.

3.1 The Scientific Career of al-Bīrūnī

According to his own account, al-Bīrūnī was born in "the city of Khwarazm" on Thursday, 3 Ḏū al-Ḥijja 362/4 September 973. The city of Khwarazm is Kāṭ, and his nisba, *bīrūnī*, derived from the term *bīrūn* for 'outskirts', has led to some speculation. The most common interpretation in modern scholarship is that this nisba indicates that al-Bīrūnī's family lived on the outskirts of Kāṭ, but other possible explanations include that it refers to the rural origin of the family or his status as an outsider in the Banū ʿIrāq family, rulers of Khwarazm, who may have taken him in at a young age or even provided a wet nurse for him, as there are hints, although not conclusive, that al-Bīrūnī may have lost his parents at an early age. Regardless, Abū Naṣr Manṣūr b. ʿAlī (d.b. 427/1035-36), a member of the Banū ʿIrāq family and a mathematician and astronomer, became al-Bīrūnī's teacher and trained him in these fields.[1]

In the late tenth century, the collapse of the Samanid dynasty brought about a change in power in Khwarazm and marked the end of the rule of the Banu ʿIrāq. As a result, al-Bīrūnī, who had a close relationship with the Banu ʿIrāq, was forced to travel between cities for a period of time. In 338/998, he joined the court of the Ziyarid ruler of Tabaristan, Shams al-Maʿāli Qābūs

1 Bosworth, "Bīrūnī, Abū Rayḥān I. Life". On the relationship with Abū Naṣr Manṣūr see Brentjes, "Abu Nasr Mansur".

DOI 10.30687/978-88-6969-790-6/003

b. Wušmagir (r. 366-371/977-81 and 388-403/998-1012-3).[2] During this time, al-Bīrūnī produced several important works on astronomy, benefitting from the Ziyarid's interest in the subject, while also working on his first major work, the *Kitāb al-āṯār al-bāqiya*. Despite his success in these endeavours, al-Bīrūnī was not entirely satisfied with his situation and spent several years at the Ziyarid court.

In 394/1004 the court of Jurjāniyya, Khwarazm new capital under the rule of the Banū Maʾmūn, welcomed back al-Bīrūnī. There, the astronomer and scientist acted as boon companion, advisor and diplomat, at the same time pursuing his scientific interest but not producing much writing. The likely encounter with Ibn Sīnā happened in Jurjāniyya deserves a mention. Ibn Sīnā entered the court of Abū al-Ḥasan ʿAlī b. Maʾmūn (r. 387-399/997-1008-9) before 399/1009 and left in the winter of 403/1012-3 for the Ziyarid court, therefore it is highly likely that the two did in fact meet.

Al-Bīrūnī's years in Khwarazm came to an end, once again, with military and political changes in the region. Starting in 403/1013, tensions began to mount between Abū al-Ḥasan ʿAlī b. Maʾmūn and his brother-in-law the Ghaznavid Sulṭān Maḥmūd. As the latter required his name to be included in the *ḫuṭba* (Friday sermon), a request of recognition of his supremacy that was granted but not really applied, the Abbasid Caliph sent to the Khwarazmshāh an honorific title and robe. Al-Bīrūnī himself was sent to accept the gifts, so that a public investiture, sure to further complicate relations with Ghazna, could be avoided. This move damaged the legitimacy of the Khwarazmshāh, and when he was killed in a military revolt, Sulṭān Maḥmūd intervened on the pretext of vindicate him and installed his own officers in 408/1017.

At this time al-Bīrūnī was completing his *Taḥdīd* (*Determination*), as he testified himself, and was brought to Ghazna with little say in the matter. Although al-Bīrūnī did not leave Khwarazm of his own will, in Ghazna he enjoyed the patronage of Sulṭān Maḥmūd, who supported the study of astronomy and astrology in particular. Al-Bīrūnī also visited the Indian regions of the Ghaznavid empire where he collected the vast corpus of sources and data that allowed him to compose a book on Indian sciences and customs known as *Taḥqīq mā li-l-Hind* (known in English as *Biruni's India*).

After the death of Sulṭān Maḥmūd in 421/1030 the power transitioned to his son Masʿūd, after a brief military confrontation with the other son of the late Ghaznavid ruler. Under Sulṭān Masʿud al-Bīrūnī maintained his position and had the chance of visiting his native Khwarazm for research purposes. He finalised a work on astronomy and astronomical geography, dedicated to the new ruler under the title of *Qanūn masʿudī* (Canon Masudicus), and later treatises on astrology, notwithstanding his lack of love for the discipline, and on mineralogy, the *Kitāb al-ǧamāhir* (*On Jem and Precious Stones*). The latter was in fact dedicated to Sulṭān Mawdūd̠, who succeeded to the throne after Masʿud's death at the hands of his own commanders after a military defeat against the Seljuqs.

During the latter years of his life, al-Biruni devoted himself to writing an encyclopaedic treatise on pharmacology. Unfortunately, his own illness prevented him from completing the work, and he passed away in 440/1048. Throughout his life, al-Bīrūnī is known to have written 183 works, although only a small portion of these have survived to the present day. His contri-

2 Cristoforetti, "Cycles and Circumferences".

butions to the fields of geometry, mathematics, and astronomy, both within the Islamic world and in Europe, have had a lasting impact. In modern times, there has been renewed interest in al-Bīrūnī's life and the breadth of his research, leading to a revitalisation of his legacy.[3] Al-Bīrūnī's esteemed reputation today makes it particularly interesting to examine his views on the natural world, including his thoughts on water, which he studied as both an engineer and a scientist.

3.2 Climatic and Environmental Subjects in al-Bīrūnī's Scientific Production

A considerable part of al-Bīrūnī's writing on climatic and environmental subjects seems to be lost, in particular his meteorological work *Maqāla fī al-baḥṯ ʿan al-āṯār al-ʿulwīya* (Discourse on Research Concerning Meteorology). Nevertheless, a few things can be said about his view of the natural world.[4] Although extant writings do not provide us with a comprehensive definition of nature according to al-Bīrūnī, three aspects emerge from brief digressions in the *Kitāb al-āṯār al-bāqiya* and *Taḥqīq mā li-l-Hind*: Nature as a creative power, its divine design, and, consequently, the avoidance of any "lack or deficiency".[5] A passage from the *Taḥqīq mā li-l-Hind* exemplifies the three points rather clearly:

> Nature […] allows the leaves and fruit of the tree to perish, thus preventing them from fulfilling the ends for which they are intended in its system, [and] removes them to make room for others.[6]

In terms of cosmology, al-Bīrūnī follows Aristotle in distinguishing between the sublunar region and the heavens. Only in the sublunar region we have the world of change, entailing both generation and corruption, in which the creative power of nature plays its role in accordance with the divine design, though it should be noted that in his exchange with Ibn Sīnā, al-Bīrūnī expressed some scepticism about posing that the two realms have essential physical differences.[7] A similar stance of critical adoption of Aristotelian doctrine emerges in other aspects of his cosmology. A further example is his adoption of geocentrism but, at the same time, affirmation that heliocentrism would be mathematically equivalent.[8]

The concept of nature as creative power of change informs his understanding of the environments of the Earth. By merging his knowledge of

3 A few recent titles that may serve as introductions to his work are Malagaris, *Biruni*; Sanagustin, "Abū Rayḥān al-Bīrūnī"; Ataman, "Re-Reading al-Birūnī's India"; Mirza, "Bīrūnī's Thought and Legacy"; Malik, Bīrūnī, "Al-Biruni".

4 For a comparison of the scientific and philosophical divergences between al-Bīrūnī and Ibn Sīnā in the study of natural sciences see Mirza, "Believing is Seeing".

5 The first ambitious and seminal study of the cosmological thought of al-Bīrūnī is part of Hossein Nasr's monograph on natural sciences in the Arabo-Islamic tradition. Nasr, *An Introduction to Islamic Cosmological Doctrines*, 107-74.

6 Bīrūnī, *India*, 1: 400-1; al-Bīrūnī, *Hind*, 200. Cited in Nasr, *An Introduction to Islamic Cosmological Doctrines*, 123.

7 Mirza, "Bīrūnī's Thought and Legacy".

8 Mirza, "Bīrūnī's Thought and Legacy", 612.

the Greek scientific traditions with his own observations and elements of the Indian and Persian geography he argued that geological changes happen over long spans of times:

> This steppe of Arabia was at one time sea which later upturned, and the traces of that sea become evident on digging for wells and springs, because the desert then unfolds various strata of earth, sand, and soft pebbles, intermingled with pieces of pottery, glass, and bones, which could not have been buried there intentionally. Again, a variety of stones is excavated which reveals, on breaking up, definite sea products: shells, cowrie shells, and what are called 'fish ears'. These products will be found either fully preserved, or in a state of complete decay, and in the latter case they will have left their figures completely imprinted in cavities in the stones.[9]

3.3 Al-Bīrūnī and the *ʾAnwāʾ*

Weather forecasting, which should not be confused with the broader field of meteorology, is also a way of gaining insight into the understanding of the environment held by our authors. As mentioned previously, the *Kitāb al-āṯār al-bāqiya* contains some elements of meteorological forecasting. In the chapter on the *rūmī* (Byzantine, i.e. Julian) calendar, al-Bīrūnī explains the differences in weather forecasting between the *rūmīs* and Syrians on the one hand, and the Arabs on the other.

As al-Bīrūnī explains, the *anwāʾ*,[10] or 'weather predictions', of the Arabs are based on the movements of the fixed stars. This means that the weather for a particular day is determined by the positions of the stars. In contrast, those who follow a solar calendar believe that each day of the year has a unique meteorological character, although this does not necessarily mean that a sunny day will always be sunny. These 'solar' *anwāʾ* are based on average weather determined by historical observations, but the actual weather experienced on given day of a certain year will be affected by other factors as well.[11]

Al-Bīrūnī cites the *Kitāb al-anwāʾ* (Book on the anwāʾ), a lost text written by Sinān (d. 331/943), son of Ṯābit, as the source for the solar *anwāʾ* included in his version of the *rūmī* calendar. This text was reportedly commissioned by the Abbasid Caliph al-Muʿtaḍid, which means it was likely produced between 892-902. It is possible to speculate that the creation of this text, which is linked to the solar calendar, may have been related to al-Muʿtaḍid's decision to adopt the solar calendar for financial purposes at the beginning of his caliphate.[12] At the very least, it may signal a broader interest by al-Muʿtaḍid in the use of the *rūmī* calendar for agricultural and fiscal purposes.

As Nallino suggested, and Samso and Rodriguez conclusively argued, the *Kitāb al-anwāʾ* appears overwhelmingly based on Ptolemy's phases.[13] In

9 Al-Bīrūnī, *Taḥdīd*, 44; *Determination*, 18.

10 Varisco, "The Origin of the Anwa' in Arab Tradition"; Varisco, "Anwāʾ".

11 Al-Bīrūnī, *Chronology*, 231-3.

12 Busse, "Das Hofbudget des Chalifen al-Muʿtaḍid billāh (279-892/289-902)"; Borroni, *Il nuovo giorno dell'impero*, 148-62.

13 Nallino, *ʿIlm al-falak*, 154-5; Samsó, Blas Rodríguez, "Las 'pháseis' de Ptolomeo". On Ptolemy's phases see Hall, "Horoscopes of the Moon".

addition to the *anwā'* derived from an Arabic translation of Ptolemy, there a few derived from other Hellenistic sources, and personal observations by both Sinān and al-Bīrūnī.

Fortunately, Sinān's observations are clearly identified in the text by phrases such as "Sinān said", and they are likely to relate to Ṯābit's unfinished work on the same topic. According to al-Bīrūnī, Sinān himself conducted a comprehensive study in which he observed meteorological conditions in ʿIrāq over a period of 30 years in order to refine and adapt the *anwā'* of other countries to his own region. While Ṯābit did not complete his own project on this subject during his lifetime, his approach is still important because it was recognised by al-Bīrūnī, who reported at least some of the results in his work, highlighting the close connection between these two scholars in their understanding and study of nature.

If Sinān's observations in the *K. al-āṯār al-bāqiya* are rather succinct and sparse, al-Bīrūnī devotes more space to his own. These observations are mixed with ample digressions on a variety of scientific subjects at times only loosely related with the presented *anwā'*. The first of these digressions is especially relevant to al-Bīrūnī's understanding of the natural world. On the *naw'* for 7 November, al-Bīrūnī relates that it is the first day of the rainy season, marked by the Sun entering the 21st degree of Scorpio. In this regard, and in accordance to the regional variability of the *anwā'* theorised by Ṯābit, al-Bīrūnī notes that this statement is valid only for Iraq and Syria, which as a side note suggests that it is an original *anwā'* by either Sinān b. Ṯābit or Ṯābit. He provides empirical proof of the geographical limits of applicability of the *anwā'* based on his personal observations in Khwarazm and on the accounts of the third/ninth century geographer Ibn Ḫurdāḏbayh:

> I believe, however, that this is only peculiar to the climate of ʿIrāq and Syria, not to other countries, for very frequently it rains with us in Khwarazm even before this time. ʿAbū al-Qāsim ʿUbaydallāh b. ʿAbdallāh b. Ḫurdāḏbayh relates in his *Kitāb al-masālik wa al-mamālik* that in Hijaz and Yemen it rains during June, July, and part of September. I myself have been dwelling in Ǧurǧān during the summer months, but there never passed ten consecutive days during which the sky was clear and free from clouds, and when it did not rain.[14]

The digression then goes on to describe various local climatic *ʿaǧā'ib*, or 'phenomena' that occur in specific places and are difficult or impossible to explain scientifically.[15] These *ʿaǧā'ib* include mountains in Tabaristan where the air is so humid and thick that the mere crashing of garlic can cause rain by dissolving the vapours,[16] a cave and well that cause rain when their waters become cloudy, and a rock in the land of the Turks that brings heavy, destructive rain if touched by sheep's wool. The chapter on the *rūmī* calendar includes several other similar *ʿaǧā'ib*, and al-Bīrūnī offers his interpretation of these inexplicable phenomena:

14 Al-Bīrūnī, *Kitāb al-āṯār al-bāqiya*, 245-6; al-Bīrūnī, *Chronology*, 234-5.

15 Al-Bīrūnī, *Kitāb al-āṯār al-bāqiya*, 246; al-Bīrūnī, *Chronology*, 235-6.

16 The use of garlic and other acid or pungent plants in apotropaic rites is widely attested in Persian popular culture. Peyman Matin, "Apotropaic Plants".

> These things are natural peculiarities of the created beings, the causes of which are to be traced back to the simple elements and to the beginning of all composition and creation. And it was not possible to come to understand them.[17]

Therefore, the fact that these phenomena are difficult to explain should not be interpreted as a suspension of the rational order that underlies the divine plan. Rather, they serve as a reminder of the limitations of current scientific understanding, which could potentially be overcome if we had access to a more complete understanding of the fundamental building blocks of creation. This perspective is similar to that of Ṯābit, as he presents it in his treatise on seawater salinity, who saw the pursuit of knowledge about the divine wisdom through the study of creation as an endlessly unattainable quest.

Al-Bīrūnī further confirms this perspective in a subsequent paragraph discussing the distinctive climates of larger regions. After discussing some examples of unusual meteorological phenomena on a small scale as *ʿaǧāʾib*, he examines regions with exceptional meteorological characteristics, such as the extremely rainy mountains of Tabaristan and the exceptionally dry region of Fustat. According to al-Bīrūnī, the climatic differences of larger regions can be explained by geographic factors such as distance from mountains and the sea, elevation, and latitude. Al-Bīrūnī suggests that global climate is influenced primarily by the geographic features of an area, and in some cases, by physical differences on a smaller scale.[18]

Of course, al-Bīrūnī's willingness to accept, at least in theory, reports of inexplicable *ʿaǧāʾib* should not be taken as a sign of excessive credulity. In a brief digression around 6 January, al-Bīrūnī mentions the belief that there is an hour on this day when all salty water in the world becomes sweet.[19] He rejects this notion, stating that "the qualities occurring in water depend exclusively on the nature of the soil where it is enclosed, if it is stagnant, or over which it is flowing, in the case of running [water]". He also notes that these qualities are "stable" and can only change gradually. This example illustrates that al-Bīrūnī is willing to consider reports of inexplicable *ʿaǧāʾib* as long as they do not contradict a general scientific principle.[20] In fact, he applies this same criterion to reports in general. This can be seen in his later discussion of hydrology and hydraulics, which will be discussed in conjunction with the continuation of this passage on the properties of salty water.

Continuing on the environmental themes discussed by al-Bīrūnī, it is worth mentioning his views on the origin of heat in the air and Sun rays. This topic is relevant in this context because it is connected to a fundamental point of agreement between al-Bīrūnī and Ṯābit. Al-Bīrūnī presents the theories held at the time on the origin of the heat of the air. He first touches on the subject discussing the coal days. These are three days when an increase in atmospheric heat occurs, due to either a spreading of subterranean heat or a change in the action of Sun according to the competing theories presented by al-Bīrūnī. Here the author does not seem to prefer a the-

17 Al-Bīrūnī, *Kitāb al-āṯār al-bāqiya*, 245; al-Bīrūnī, *Chronology*, 235.

18 On geography, orography, and their respective influence on the Arabo-Islamic reception of the classical climes theory, see Al-Azmeh, "Barbarians in Arab Eyes", 7-8.

19 Al-Bīrūnī, *Chronology*, 240.

20 On *ʿaǧāʾib* literature see Zadeh, "The Wiles of Creation".

ory over the other, and simply notes that according to some atmospheric heat is caused at least in part by heat from the interior of the earth, while others maintain that the only cause is Sun rays.

Al-Bīrūnī takes a position in the debate about atmospheric heat further on, discussing the weather condition of the first day of March:

> People say that [...] the heat of heaven and the heat of earth meet each other. This is a somewhat exaggerated expression for the beginning of heat, its increase and spreading, and for the air adapting to receive it. Because heat is just the rays of the Sun sent from its body towards the Earth or from the warm body touching lunar sphere called Fire.[21]

Thus, he distinguishes between two types of heat: the heat 'inherent' to sun-rays and the heat of the body between the lunar and sublunar sphere, called Fire. The latter, according to al-Bīrūnī is caused by friction due to the rapid movement of the spheres.[22] Al-Bīrūnī prefers this explanation over the Aristotelian doctrine of the natural place, which would place fire above air, precisely because he adopts the view of Ṯābit on the subject:

> This explanation is in conformity with the theory that none of the existing bodies is in its natural place, that all of them are where they are only in consequence of some force being employed, and that force must of necessity have had a beginning.[23]

3.4 Hydrology in the *Kitāb al-Āthār al-Bāqiya*

The longest discussion of water-related topics found in al-Bīrūnī's works is a lengthy digression in the *rūmī* calendar chapter from the *Kitāb al-Āṯār al-Bāqiya*. This hydrological and hydraulic digression is similar those discussed above, and departs from the *naw'* of 28 April, when according to Eudoxus and Sinān there is a tendency towards rainfall and rivers grow in this period.[24] Commenting on the periodicity of fluvial regimes, al-Bīrūnī devotes a few pages to a multifaceted discussion of several hydrological and hydraulic subjects covering:

- Fluvial regime of the Oxus in comparison with the Tigris and Euphrates
- Fluvial regime of the Nile
- Seasonality of water springs
- Role of the mountain in the water cycle
- Upward movement of water

21 Al-Bīrūnī, *Chronology*, 246-8.

22 This debate was also discussed in al-Bīrūnī's correspondence with Ibn Sīnā. Starr, *Lost Enlightenment*, 260. A German translation of this passage is also available in Strohmaier, *In den Gärten der Wissenschaft*, 58-60.

23 Al-Bīrūnī, *Kitāb al-āṯār al-bāqiya*, 257; *Chronology*, 247.

24 The two sources are Eudoxus of Cnidos (ca. 408-355 BC) and of course the aforementioned Sinān b. Ṯābit. The source of the *anwā'* of Eudoxus, who appears often in the chapter and studied the periodicity of weather phenomena, may be an Arabic version of the *Ceimonos Prognostica*, a treatise on bad-weather predictions of Babylonian origin. Frisinger, *The History of Meteorology*, 10-15; Sarton, *A History of Science*, 447.

- Hydraulic machines
- Peculiar customs and places related to water

For the purposes of this discussion, we will focus on the aspects of this passage that pertain to al-Bīrūnī's views on the environment and hydrology.[25]

Al-Bīrūnī discusses fluvial regimes starting with the general statement that rivers and *awdiya* (sing. *wādī*) begin to increase in water output on 28 April. Here *wādī* should be understood as a broad term referring to streams, rather than what is referred to by the term wadi today, e.g. a typical stream in an arid region presenting occasional waterflows for very short timespans. Al-Bīrūnī notes that not all watercourses have the same regime, and he singles out four rivers to illustrate how and why fluvial regimes can vary according to seasonality:

> It is said that the south wind blows on this day, and that the streams and rivers begin to grow. This increase of the water does not happen in all streams and rivers in the same way. On the contrary, they differ a great deal from each other in this respect. For instance, the Oxus has high water when there is little water in the Tigris, Euphrates, and other rivers. This happens because [rivers] that originate from streams in colder places have more water in summer and less in winter.[26]

Al-Bīrūnī notes that the Oxus, also known as the Amu Darya, receives the water that causes its growth during the summer from snowmelt. Thus, he describes here what hydrologists today call a nivo-glacial regime. The Tigris and the Euphrates are characterised by what is today known as a pluvial regime, which al-Bīrūnī describes as a seasonal growth of the rivers caused by an increase in rainfall. The Nile also presents a pluvial regime according to al-Bīrūnī, but its geographical position makes it a peculiar case, which will be discussed in what follows. Here it is important to note how al-Bīrūnī recognises how all of the rivers that he is taking as exemplary cases grow and decrease according to the respective availability of their water sources. All of the water sources mentioned here are part of an exogenous water cycle, and there is no mention whatsoever of water generation or transformation of air into water happening in the depths of the earth. In this regard, it should be noted that al-Bīrūnī expressed his perplexities on the transformation of water into air also in his epistolary exchange with Ibn Sīnā and the latter's pupil al-Masʿūmī. In the tenth question posed to the philosopher, al-Bīrūnī inquires whether "when water transforms into air, does it become air in reality, or is it because its particles spread out until they become invisible to the sight so that one cannot see these separate particles?".[27] Ibn Sīnā's answer negates the second explanation proposed by al-Bīrūnī, referring him to Aristotle's works on the subject, and al-Bīrūnī does not comment on it.[28] Later in life, when he composed the didactic but comprehensive treatise on astronomy and astrology titled *Kitāb al-tafhīm*,

25 For an analysis of the hydraulic aspects of this passage see Borroni, Boselli, "Hydraulics and Hydrology".

26 Borroni, Boselli, "Hydraulics and Hydrology", 177.

27 Berjak, Iqbal, *Ibn Sina – Al Biruni Correspondence*, 17 [42].

28 Brentjes, "Abu Nasr Mansur", 31.

al-Bīrūnī explicated that water "becomes suspended in the air", only to regain its original liquid nature as it falls from the clouds in forms of rain.[29]

Interestingly, al-Bīrūnī appears to be correct for the wrong reason when he states that the sources of the Oxus are frozen around time when the Tigris and Euphrates grow thanks to rainfall because the Oxus originates further north than the Mesopotamian rivers. In fact, both sources are located at about the same latitude. The reason for the discrepancy between the seasonal regimes of the Tigris and the Euphrates, on one side, and the Oxus, on the other is that the sources of the latter lie at much higher altitude. Thus, they are indeed frozen in early spring when the Tigris and the Euphrates receive more rainfall. Al-Bīrūnī's interpretations appears to be linked with his conception of climates, which focused primarily though not exclusively, in latitude.[30]

Lastly, the passage features an expression to designate precipitation. Al-Bīrūnī employs here the term *wuqūʿ al-andiyya*, which is roughly translatable as 'dewfall'. In fact, this was also how Sachau rendered the term in his English version of the *Kitāb al-āṯār al-bāqiya*, but the context makes it clear that al-Bīrūnī also had in mind rain and snow, since he mentions the latter little later on in the text. Thus the terms *wuqūʿ al-andiyya* and *al-andā'* should be understood as referring to all naturally occurring water from atmospheric precipitation, such as rain and snow.

The Nile receives a longer treatment in the digression, since al-Bīrūnī presents two alternative explanations for his peculiar fluvial regime. The first theory assumes that the sources of the Nile are located south of the Equator. Being first and foremost an astronomer, al-Bīrūnī knows that the seasons are reversed in the southern hemisphere. This means, he notes, that the Nile receives more water during the dry season in the northern hemisphere. Alternatively, the author suggests, it could be that the sources of the Nile lie north of the Equator, in which case they would be subject to some regional rainfall regimes, as in the aforementioned case of Yemen:

> As for the Nile, it grows when Tigris and Euphrates shrink. This is because its source lies in the Mons Lunae, as it has been said, beyond Assuan – the city the Abyssians in the southern region – either at the Equator, or beyond it. This is, however, a matter of doubt, because those surroundings are not inhabited, as we said earlier. It is evident that in those regions any freezing of moist substances is impossible. Therefore, it could either be that the growth of the Nile is caused by precipitated water, as it is evident that the water does not stay where it has fallen, but flows off to the Nile at once, or that it is caused by the springs, that have the most water in winter. [In the latter case,] the Nile rises in summer, because when the Sun is near us and at our zenith, it is far away from the zenith of those regions whence the Nile originates, and it is winter there.[31]

Clearly, both theories assume a purely exogenous water cycle. Al-Bīrūnī's reliance on the model outlined by Ṯābit becomes more explicit as he moves to discuss the seasonality of water springs, which directly influence the behaviour of fluvial regimes:

29 English and Arabic text in Bīrūnī, *The Book of Instruction*, 124-5.

30 Antrim, *Routes and Realms*, 90-1.

31 Borroni, Boselli, "Hydraulics and Hydrology", 178.

> Regarding the question why the water of springs is most copious in winter, it is because the all-wise and all-mighty Creator intended to place the mountains [on earth] for a number of beneficial uses, some of them mentioned by Ṯābit in his book on why the mountains were created. This reason [that interests as here] is to fulfil [his] intention of making the water of the seas salty. Clearly, precipitation in winter is higher than in summer, and they are higher in the mountains than in the plains. When [this water] falls, a part of it flows away in the torrents and the remaining part seeps down into the pores in the mountain caves, and there it is stored up. Afterwards, it begins to come out from the holes that are called springs. That is the reason why [this water] is most copious in winter: it is because there is more of its own substance. Moreover, if these mountain caves are clean and pure, the water flows out just as it is, agreeable [to the taste]. If that is not the case, the water acquires different qualities and peculiarities, the causes of which are hidden from us.[32]

Here, al-Birūnī cites Ṯābit's treatise *On the Benefits of the Mountains*. The treatise appears today to be lost and the most detailed account of its content is the aforementioned summary by Miskawayh. The *Kitāb al-āṯār al-bāqiya* features only this reference to Ṯābit's argument that, despite its brevity, is nevertheless useful in confirming two points found in Miskawayh's summary.

First, the role of mountains as collectors of rain. Al-Bīrūnī does not delve into the details of how and why mountains are key in the production of rain, but describes the functioning of a karst system in broad strokes. Second, al-Bīrūnī maintains that precipitation is the only source of water involved in the regulation of fluvial regimes, thus excluding the endogenous model of the water cycle. This is true even though he describes the karst system, which entails subterranean waters that would be easy to explain via water generation in the depths of the earth. More broadly, the short summary provided by al-Bīrūnī confirms the teleological approach of Ṯābit's lost treatise, in agreement with the theses advanced in the treatise *On Why Seawater Was Made Salty* on a natural world functioning towards its own regeneration.

According to al-Bīrūnī, mountains and the karst systems he describes play a role in defining the characteristics of water. While he does not delve into the relation between soil and the characteristics of the water it contains in depth, this concept had already been expounded upon in his commentary to the *naw'* of 6 January. There, the author relates that some people – it would seem that these are common people rather than men of science – maintain that on this day there is an hour when all the salty water of the world turns sweet for an instant. Al-Bīrūnī dismisses this belief:

> All the qualities occurring in the water depend exclusively upon the nature of that soil by which the water is enclosed, if it be standing, or over which the water flows, if it be running. Those qualities are of a stable nature, not to be altered except by a process of transformation from degree to degree.[33]

Al-Bīrūnī further elaborates on the assertion that water can only change its qualities gradually by describing the behaviour of the lake of Tinnis, a brack-

32 Borroni, Boselli, "Hydraulics and Hydrology", 178.

33 Al-Bīrūnī, *Kitāb al-āṯār al-bāqiya*, 230; *Chronology*, 240.

ish deltaic lake in north-eastern Egypt which is today known as the lake of Manzala. He relates that the lake is sweet in autumn and winter and salty for the remainder of the year because, given the seasonality of the Nilotic fluvial regimes, the lake receives different amounts of sweet water from the river and salty water from sea according to the season.

3.5 Hydrology in the *Kitāb taḥdīd al-amākin*

The *Kitāb taḥdīd al-amākin li-taṣḥīḥ masāfāt al-masākin* is of special importance to the study of the connections between al-Bīrūnī's and Ṯābit's view of the environmental role of water. Al-Bīrūnī devoted this book to mathematical geography and expounds on it in great detail, calculating the coordinates of the city of Ghazna, where he had been brought, not entirely willingly, by Sulṭān Maḥmūd in 409/1018. Seven years after his arrival in Ghazna, in 416/1025, he completed the *Kitāb taḥdīd* as a praise of Ṣultān Maḥmūd himself. As with the *Kitāb al-āṯār al-bāqiya*, it is impossible to do justice to the wide range of subjects covered by al-Bīrūnī here.[34] Instead, we will focus on his paraphrase of Ṯābit's treatise *On Why Seawater Was Made Salty*.[35]

Al-Bīrūnī approaches the subject in the introductory chapter, where he defends the merits of knowledge in general and mathematical geography in particular. The latter, as noted by al-Bīrūnī, is essential to Islam as a tool for calculating the direction of the *qibla* for the ritual prayer. The former is first and foremost a natural need of every mind, and moreover it forms the basis for any materially beneficial activity that is morally sound. From these premises, al-Bīrūnī moves on to discuss the origin of the world and its perpetual state of change. In these pages, he relates several historical instances of the natural landscape and human civilisation influencing each other. Al-Bīrūnī reports a variety of cases from various sources in which either natural catastrophes or destructive or constructive human activities dramatically changed different waterscapes. These changes, in turn, affected the lives of cities and peoples, leading al-Bīrūnī to state that "civilisation demands water, and it shifts in pursuit of it, because the former is dependent on the latter".[36]

The reasoned recognition of the importance of water for all human civilisation serves al-Bīrūnī a basis to discuss the natural history of water and its role in the divine plan. Al-Bīrūnī draws on Aristotle, the Torah, and the Quran to explain that God changed an originally perfectly spherical, but desolate Earth by elevating and thus drying some of its parts, while water accumulated in the sea. To explain the salinity of the sea, al-Bīrūnī first turns to Ṯābit:

> He called the water that gathered in a depression a sea, and gave it the taste of salinity. This salinity, according to Ṯābit, prevents the water from getting foul, and eliminates putrefaction which would be disastrous to His intended creatures. The sea was also intended to be a reservoir of water for man's special needs, and as the lives of both man and animal, which is put in man's service, are dependent on fresh water, and as his habitation

34 For a discussion of the astronomical, mathematical, and geographical aspects of the *Taḥdīd*, see Kennedy, *A Commentary upon Biruni's Kitab Tahdid Al-Amakin*.

35 The English versions of the passages from the *K. Taḥdīd* quoted here are from Jamal Ali's translation of the book. Al-Bīrūnī, *Determination*.

36 Al-Bīrūnī, *Taḥdīd*, 52; *Determination*, 24-5.

> is far away from reservoirs, so God Almighty has designed the continuous motion of the Sun and the Moon, and commanded them both to produce motion in the water, to evaporate it, and to lift its vapour upwards.

This short summary of the central thesis of Ṯābit's treatise on seawater further confirms what has been conveyed by Miskawayh and the content of the only extant manuscripts. Interestingly, here al-Bīrūnī slightly corrects Ṯābit's biocentric approach by noting that, while the divine plan for the natural world ensures the lives of all animals, the latter are in "man's service". This slight change in outlook may suggest that Ṯābit's biocentric vision of the environment somewhat discorded with al-Bīrūnī's more anthropocentric one as a mainstream Muslim.[37]

The passage continues briefly addressing the role of heat and winds as the main forces behind the continuous cycle of waters, leading to a description of what we today call the water cycle in purely exogenous terms:

> Then He commanded the winds to drive water vapour, in the form of clouds, to desolate and waterless lands so that its rain in those lands will refresh and sustain the lives of animals and plants over there, and its rain on the mountains will penetrate and accumulate deep inside them, or will remain on their tops in the form of snow. Further, the accumulated water will form rivers which will carry it back to the seas, but their courses will run by the dwelling places of peoples and animals, who will use the water for drinking and other utilities.[38]

This paragraph is likely the clearest depiction of a purely exogenous water cycle in Arabic sources of the period. Al-Bīrūnī does not credit Ṯābit with this idea, since this paragraph does not seem to be intended as part of the summary of the Sabian's treatise. Nevertheless, it seems abundantly clear that the main source of reference for al-Bīrūnī on the matter is precisely the treatise *On Why Seawater Was Made Salty*, since he chooses to complete his discussion on seawater salinity with a dismissal of other possible tastes that clearly echoes Ṯābit's own longer discussion of the same subject:

> These benefits could not have been possible, if the solute in sea water were other than salt, because vapours of solvents, except the vapours of solvents carry the tastes of solutes dissolved in them. For example, bitter water is injurious to animals; sweet water is more readily fouled than

37 The anthropocentric character of most of the Arabo-Islamic tradition has been explained both as a response to the text of the Revelation to Muḥammad, and as a result of the adoption of the Aristotelian and Ptolemaic cosmology. It should be noted that several modern thinkers reject the idea that the Islamic Revelation expresses an anthropocentric point of view, arguing, rather, that it is theocentric and that humans only have a peculiar set of duties and rights in the Creation (*ḫilāfa*) At the same time, There is no mention of the *ḫilāfa* of humans in creation in Ṯābit's work. This concept is the cornerstone of a broader framework of Islamic discourse on ecology. Proponents of this approach understand the natural world as necessarily Muslim, that is, submitted to God's will, and humans as *ḫalīfa*, meaning stewards or viceroys. This approach is not without opposition. In the late 1990s, for instance, Kaveh L. Afrasiabi argued that this hierarchical, utilitarian, and anthropocentric interpretation should be left behind. Bagir, Martiam, "Islam: Norms and Practices"; Afrasiabi, "Toward an Islamic Ecotheology". Özdemir, "Towards and Understanding of Environmental Ethics"; Rizvi, "Islamic Environmental Ethics"; Sessions, "Anthropocentrism and the Environmental Crisis", 74.

38 Al-Bīrūnī, *Taḥdīd*, 54; al-Bīrūnī, *Determination*, 24-5.

> fresh water; acid water is repugnant, makes surfaces hard and rough, and reacts so vigorously that it changes whatever comes into contact with it, and it is sufficient to mention its action on iron and similar metals. Glory be to God, Most Omnipotent, Most Wise![39]

These passages from the introductory chapters of the *K. Taḥdīd* show a clear influence of the work of Ṯābit on al-Bīrūnī's thought on the environment and the role played by water in it. As is well-known, this relationship between the two scientists is not limited to this only subject,[40] but in this case, as we hope to have shown, it puts their views at odds with a wider tradition that was closely aligned with the Arabo-Islamic Aristotelian doctrine. It may be possible to envision a link connecting the two through the Baghdadi-based astronomer al-Buzǧānī (d. 387/997-8), who was the main teacher of al-Bīrūnī's own teacher Abū Naṣr Manṣūr.

In any case, one should not assume that al-Bīrūnī distances himself in any manner from the theses he reports, citing the authority of Ṯābit. Although it is true that in the passages mentioned, the wise Sabean is always duly cited, in al-Bīrūnī's *Kitāb al-jamāhir fī maʿrifat al-jawāhir*, he presents his own synthesis of the water cycle. He does this specifically at the beginning of the text, which is none other than an erudite treatise on the properties and origins of various precious stones and metals, complemented by a treasury of anecdotes and historical titbits related to each of these.

The introduction to the *Kitāb al-jamāhir*, however, covers a much broader range of topics, and there al-Biruni, while always relying on legends, anecdotes, historical facts, and his own reflections and personal experiences, ranges from advice for married life to political doctrine, from the foundations of economic theory (the value of gold is purely conventional) to the fundamental aspects of creation, that is, the natural world.[41] This engaging tour de force, which prepares the reader for the subsequent mineralogical discussion, begins precisely with the following words:

> All praise is for the Sustainer of the world, Who from the beginning to the end is Unique, Who has ordained the survival of *islām* which destructs ills and misfortunes, and [brings about] health and tranquillity, Who has distributed food and fixed morality, Who has made struggle the source for food in the same way in which he has made the Sun and the Moon as the actors that uplift water towards the heaven. So, when the clouds are filled and laden with rain, winds drive them towards dry land and flood it with the blessing of water. Then, the earth generates plenty which for man is wealth and for animals sustenance. Moreover, this very same water returns to the slopes and [then] the oceans. He knows what comes to the earth, what comes out of it, and what comes down from the heavens and ascends towards them. Verily, he is the Knower, and He has issued commands out of his infinite wisdom.[42]

39 Al-Bīrūnī, *Taḥdīd*, 54; al-Bīrūnī, *Determination*, 24-5.

40 See for instance their respective work on the Sun's mean position on its ecliptic and its actual position.

41 Nadvi, "Al-Birūnī and His Kitāb al-Jamāhir".

42 Al-Bīrūnī, *Kitāb al-jamāhir fī maʿrifat al-jawāhir*, 3. This English translation is a slightly edited version of H.M. Said published in Al-Beruni, *The Book Most Comprehensive in Knowledge*, 3.

Therefore, at the opening of the *Kitāb al-jamāhir*, al-Bīrūnī praises God for the wisdom expressed in the mechanism of the water cycle, which al-Bīrūnī describes once again and in his own terms as purely exogenous.

3.6 The Water Cycle According to al-Bīrūnī, Ṯābit and al-Karaǧī: A Comparison

Any treatment of hydrologic or hydraulic knowledge in premodern Islam is bound to find fruitful material in the eleventh-century treatise on the construction of *qanāt* entitled *Kitāb inbāṭ al-miyyāh al-ḫafīyya*. Its author, Muḥammad al-Karaǧī (d. after 410/1019),[43] hailed from the city of Karaj in the Iranian Jibal,[44] early in his career, moved to Baghdad. There, he entered the entourage of vizier Faǧr al-Mulk as renowned mathematicians and held several important positions working on the construction and maintenance of roads, bridges, canals, and *qanāts.* He returned later in life to Jabal and it is there that he composed the *Kitāb Inbāṭ al-miyāh al-ḫafīya* in honour of vizier Abū Ġānim Muḥammad b. Ḫalaf (deposed in 420/1029).

Al-Karaǧī wrote mostly on mathematics, geometry and algebra. Only a few of his works have come down to us, and the *Inbāṭ* is among what we have of his production, and it has received some attention as a technical treatise. In addition to the Arabic editions, of which the 1997 critical edition provided by ʿAbd al-Munʿim is the most valuable,[45] there is a French translation by Aly Mazaheri based on the 1941 edition in Hyderabad.[46] The *Inbāṭ* is devoted to illustrating in detail the construction and upkeep of the *qanāt*. These underground channels of Iranian origin are a key feature of the irrigated landscape and urban water-provisioning of the Islamic world from Central Asia to the Western Mediterranean. Al-Karaǧī introduces his treatment of the technical knowledge involved in infrastructure building and maintenance with a concise but meaningful discussion of the general hydrological principles that govern the natural world. The description of the water cycle and the role of water in the ecosystem that emerges from the introductory chapters of the *Inbāṭ* bears interesting comparisons with the theses expounded by al-Bīrūnī and Ṯābit before him. Al-Karaǧī meant to provide the reader with a general idea of the scientific consensus on the hydrology of the natural world, on which *qanāt* technology is obviously based. Doing so, he also conveys a clue on why it appears that scholars who affirmed the endogenous and exogenous models of the water cycle did not actually debate each other.

Al-Karaǧī adopts a purely Aristotelian starting point, stating both the impossibility of void and the doctrine of the natural place, rejected by both al-Bīrūnī and Ṯābit, as we have seen:

> And God, who is blessed and glorified, created the universe as solid, with no voids, and He established for everything, meaning the celestial orb,

43 Vernet, "Al-Karadjī".

44 Until the 1930s he was considered to be born in the Baghdadi suburb of Karḫ, and for this reason modern scholarship knows him also under the incorrect name of al-Karḫī; Solignac, "Mohamed Al-Karagi, ingénieur hydrologue (m. 410/1019)". On his life and work see also Solignac, *Mohamed Al-Karagi, ingénieur hydrologue*; Ferriello, "Problemi di storia della scienza".

45 Al-Karaǧī, *Inbāṭ*.

46 Al-Karajī, *Eaux cachées*.

> the stars, fire, air, water, and earth, a specific location for each; a location that it seeks through its motion, if it becomes separated from it. Therefore, dense bodies such as water and earth seek the centre, and the denser body precedes the other.[47]

Al-Karaǧī, who is only interested in water, explains that the irregular shape of the Earth enables water to flow. Both earth and water strive to move towards the centre of the universe, thereby attempting to achieve a spherical shape. As a result, water placed in higher reservoirs will eventually flow:

> When God, may He be glorified, decreed that water flowed and that it would be moved from one place to the other, and that the Earth had both dryland and sea, and that both dryland and sea had animals, seeds, fruits and the various plants, minerals and other things that are necessary to the prosperity of the earth and the life of the creatures upon it; together with the food, drink, clothing, and the many gems and medicines that they need, He created the earth with mountains, valleys, alluvial flans, peaks, gullies, highlands, and chasms; all of these from many different types of stone and soil, so that the distance between the centre of the earth and its surface would have been unequal and that water flows from locations distant from the centre of the earth to locations close to it.[48]

Here, we can appreciate a subtle echo of the biocentric principle that upholds Ṯābit's thesis in both the *Treatise on Why Is Seawater Salty* and the *Treatise on the Usefulness of Mountains*. More importantly, this passage brings al-Karaǧī to deal with the all-important question of how water in high elevations is replenished:

> Water flows continuously from [higher] places to areas closer to the centre of the Earth, with the transformation of air to water during cold periods and in cold locations, and the transformation of water to air when it becomes rarified during warm periods and in warm places.

This picture offers a partial and simplified version of the Aristotelian doctrine envisioning the transformation of water into air and vice versa, although it would seem to ignore the subterranean generation of water and describe an overall exogenous water cycle. However, in two further passages al-Karaǧī describe this component of the endogenous model.

The first time he does so in a dubious fashion, presenting the generation of water in the depths of the earth as a real possibility but with limited impact on the overall cycle of water:

> A philosopher has expressed the opinion that in the bowels of the air (sic) which is transformed into water – on condition that the soil is very cold – which gives rise to springs flowing along natural underground channels and forming stagnant pools.[49]

47 Al-Karaǧī, *Inbāṭ*, 29.

48 Al-Karaǧī, *Inbāṭ*, 30.

49 Al-Karaǧī, *Inbāṭ*, 32.

In the second passage dealing with subterranean water generation, al-Karaǧī resorts to it as a possible explanation the reports of lakes and springs on mountaintops. Here the author is dealing with same question that preoccupied Ibn al-ʿAmīd, the presence of sources on mountain islands. Al-Karaǧī first argues that such sources rely on a subterranean connection with a faraway reservoir that lies higher the source on the island. Then, he completes the picture by mentioning a different opinion:

> Scientists have said: It is possible that the substance of springs on mountaintops is from the penetration of a great deal of vapour in the interior of the mountain, which rises to the top and transforms into water, which in turn appears on the summits.[50]

This explanation is not intended to be fully contrarian to the circulation of water through long-distance subterranean networks. Instead, al-Karaǧī strives to provide a general but complete picture of the scientific understanding of his time. In this broader context the split between endogenous and exogenous models blurs. In fact, in accordance with the customs of *adab* literature, the text presents the original opinions of al-Karaǧī and all others that are deemed valuable and authoritative by the author.[51]

The broad picture provided by al-Karaǧī suggests that a debate about the endogenous and exogenous models did not actually occur scholars could easily find ample middle ground between the two models. Among the texts at our disposal, this happens most clearly in the introductory chapters of the *Inbāṭ*, where al-Karaǧī espouses a substantially exogenous model, while allowing a complementary place to the hallmark of the endogenous model that is the subterranean generation of water. In doing so, al-Karaǧī shows both a partial departure from the Aristotelian doctrine, in which subterranean generation of water plays a very important role in the workings of the natural world, and a hybridisation of the ideas on the water cycle put forth by Ṯābit and later by al-Bīrūnī.

Ṯābit and al-Bīrūnī are at the extreme of this spectrum, as they do not consider the contribution of subterranean water generation even in limited cases. The divergence between al-Karaǧī and al-Bīrūnī becomes clear if we compare al-Karaǧī's discussion of sources on island mountain-tops, which we just analysed, and al-Bīrūnī's discussion of the lake of Sabzarūd, today known as *Chasmeh Su*. Al-Bīrūnī mentions this small lake, located on a mountain top not far from Ṭūs, in his digression on water from the *Kitāb al-Āthār al-Bāqiya*. After discussing that water may only flow downwards, al-of this lake, or indeed any lake, on a mountaintop, by agreeing with the "distant reservoir" hypothesis that we find in al-Karaǧī. Al-Bīrūnī envisions three possible explanations for the presence of this lake, all relying on the same principle of the communicating vessels: water may come from a distant "reservoir higher than the lake itself", or from a reservoir "which lies on the same level with the lake", or from a natural mechanism similar to self-feeding lamps.[52]

50 Al-Karaǧī, *Inbāṭ*, 141.

51 Ghersetti, *La letteratura d'adab*; Salvatore, "The Islamicate Adab Tradition".

52 Borroni, Boselli, "Hydraulics and Hydrology", 174-5.

Al-Bīrūnī further mentions two lakes on mountaintops, which suggests that he extended his description of the possible origin of the water of the Sabzarūd to be generally applicable to all similar cases. Now, while he's opinion on the matter is clearly in agreement with the main discourse by the coeval al-Karaǧī, he does not mention the possibility of subterranean water generation. This further confirms that he did not take it into consideration, showing how different opinions on the water cycle existed on a continuum.

For instance, the Buwayhid vizier Ibn al-ʿAmīd, whom we cited earlier in reference to his *risāla* on the presence of sweet water sources on islands, held beliefs closer to the Aristotelian doctrine than al-Karaǧī, as he identifies the most important source for water on islands in the process of subterranean generation of water from air. Nevertheless, he provides two other possible explanations. In some cases, water may simply be caused by precipitations stored in the mountains, or, he argues, sweet water could be seawater filtered by the particular soil of some islands which does not allow the salty part percolate. In Ibn al-ʿAmīd's thought, these two possibilities appear as only complementary to the more important generation of water that takes place in the depths of the earth.