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Mapping ancestral irrigation techniques in the Mediterranean basin and Central Asia for a climate-based analysis

Keywords: Ptolemaic Ecumene, Bonne sphere—based projection, Köppen–Geiger climate classification, De Martonne aridity index, Johansson continentality index.

Summary: As a cartographic base for the analysis of an extensive literature review on the ancestral irrigation and water management techniques in the Mediterranean basin and Central Asia, we propose some thematic maps that presents a classification of the ancestral irrigation techniques and some climatic indices, i.e. the Köppen–Geiger climate classification, the De Martonne aridity index, and the Johansson continentality index. In view of underlining the deep cultural role of the ancestral techniques into relationship with the development of the agriculture and settlements in the Ancient World and their relationship with the local climate, the maps are projected on a cartographic base which mimics the Ptolemaic Ecumene, thus stressing the fact that these techniques were diffused in almost all the considered—livable lands of the ancient Geography.

An Ecumene perspective on ancestral irrigation techniques

According to the economic historian Malanima (1995), three main paradigms characterized the origin and the development of agriculture: they are the *discontinuous agriculture,* the *arid agriculture* and the *irrigated agriculture*, depending on how Humans refurbished the soil fertility. In the case of the discontinuous agriculture, indeed, the slash—and—burn practice was sufficient at restoring the soil fertility, whereas in the arid agriculture the agricultural rotations were (and are) effective at doing so. Another is the case of the irrigated agriculture, also called *intensive agricultural system*, for which the soil fertility is restored via the irrigation, with particular reference to the complex system of simultaneous irrigation and fertilization performed in ancient times along the great rivers as the Nile. Between these three paradigms, many intermediate cases can be found. The qualification *intensive* attributed to irrigated agriculture not only refers to the crop yield but also to the human's activity required to manage the irrigation agroecosystem so that the resulting landscapes are often referred to as labor—intensive landscapes. It has been pointed out (Liverani, 1996) that irrigation, or more generally the system composed of drainage and irrigation, played a key role in the birth of ancient cities. Indeed in the Fertile Crescent, during the Ancient—Uruk Era, not only the shift from the basin irrigation to the farrow irrigation contributed – together with the use of the sowing plow – to the production of the agricultural surplus, and it therefore allowed the formation of social classes not directly involved in the agricultural works, but it also required the formation of groups of engineers, land surveyors, and skilled workers almost fully devoted to the maintenance of the complex channelization of the low course of the Tigris and Euphrates rivers. The irrigation was later an axle for the development of the oases civilization in

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Central Asia (Starr, 2015), and the techniques that allowed to cultivate otherwise barren soils, mostly in water scarcity conditions, diffused to almost all the Ancient World.

In this work, we will particularly focus on this variegated complex of systems, typical of semiarid or arid climates, that is composed of many strategies mainly devoted to drain, collect, store, protect (principally from evaporation) and distribute the water in scarcity conditions. In the following text, we will detail some of these techniques. Here it is important to stress the fact that most of them not only are rooted in ancient times, but also, they became traditional, in the sense that they became a heritage of the populations that practiced them and that they are still in use, at some extent. Therefore, in order to overcome the shift from *ancient* to *traditional* irrigation, we will refer to them as to *ancestral* irrigation, thus stressing the link between past and present, in agreement with the UNESCO definition adopted in the main conclusions of the 2023 International Conference on Ancestral Hydrotechnologies (UNESCO, 2023). The important role historically played by these techniques at shaping the landscape and the settlements, at mitigating the water scarcity and at allowing the irrigated agriculture in labor—intensive landscapes, is such that they became a cultural heritage for the populations and an important link between Humans and Nature.

What can be, at present, the interest in these techniques and practices? According to the recalled UNESCO statement (but see also UNCCD, 2005 and Laureano, 2013), most of these practices are structurally sustainable and resilient. In fact, they are based on the adequacy of agriculture to the water cyclical availability, even considering different temporal scales, and they proved of being able to react to extreme climatic conditions, as it happens in the desert. Moreover, being traditional, that also means that they can be easily orally transferred, they are dynamic, flexible and coevolutive with the surrounding environment (see again UNCCD 2005, on the zaï pit). They can therefore be regarded as an effective strategy to face climatic changes and water scarcity conditions.

Now these techniques stand at a crossroads of their history, between the rediscovery and the acknowledgment of their importance as a climate regulating agent, on one side, and the abandonment in favor of modern ones, on the other side. The loss inherent in their forgetfulness goes beyond accidental damage, because the deep roots in the landscape which they boast and the mostly oral transmission made them complex techniques. Indeed, they are mostly based on a range of principal and ancillary water resources (as it is the case of the qanats and of the Pantelleria gardens) and they are therefore hardly designable according to modern technical attitudes, based on the functional separation of the technical systems. Whereas some of them have been rediscovered in the last decades, as it is the zaï pit, others suffer the risk of being abandoned and hardly reactivated, as the water regulating practices of the bailiffs of Algerian and Omani oases (UNESCO, 2023; Nash, 2007).

In a previous brief contribution (Barontini and Bettoni, 2020) we made eight conjectures on why studying traditional irrigation focused on their cultural, climatic and environmental role, and we guessed that, given those conjectures and the different and contrasting present attitudes with regard to these techniques, the future of traditional (ancestral) irrigation is yet to be written. In this work, as a cartographic frame for an extensive literature review (Barontini et al., in preparation), which aims at assessing the state of the art regarding the present interest of the scientific community on these practices in the frame of the eight cited conjectures, we propose a thematic map of the techniques classification and distribution in the Mediterranean basin – which is a hotspot for the climate change – and Central Asia. The investigated area covers most of the Ptolemaic Ecumene (Figure 1).

The comparison between the investigated area and the Ptolemaic Ecumene not only is suggestive and fascinating, but it also has a deep cultural meaning. As a first point, indeed, the Ecumene –

which is the ensemble of the known livable lands – has a strong climatic characterization (Sanderson, 1998), being the climata, i.e. the slope of the Earth from the Equator to the pole (that is an indicator of the solar irradiation), considered a major factor of livability of a land. Then, one of the ages of major diffusion and effectiveness of these techniques in the Mediterranean basin and Central Asia was that of the late Medieval flourishing of the oases civilization (Starr, 2015) and of the diffusion of the Arabian agriculture to the Northern Mediterranean basin, and it corresponds to the apogee of the Ptolemaic based geography of al—Idrisi and al—Fida (Frolov and Konovalova, 2018), just before that the geographical explorations changed the knowledge and the perception of the World. Therefore, although limiting the analysis at this restricted area, and despite some of these techniques crossed the boundaries of the Ancient World and arrived also into the New World (it is e.g. the case of the qanats), by underlying this particular aspect we mean to stress the cultural importance of these practices which goes beyond their local usage. They were in fact spread by skilled workers migration and, anywhere they arrived, they were mostly assimilated as an exogenous tradition. They are therefore ecumenic in both the literal and wide sense.

Figure 1 The Ptolemaic Ecumene engraved by the woodcutter Johannes Schnitzer (sive Johannes of Armsheim), for Leinhart Holle's 1482 edition of Nicolaus Germanus' emendations of Ptolemy's *Geography* (Source: Wikimedia Commons, accessed 30 April 2023).

Despite the known difficulties and approximations inherent the representation of the Ptolemaic Ecumene in the modern cartographic projections (Livieratos, 2006; Gusev and Stafeyev, 2022), in order to underline the cultural link between the Ptolemaic geography and the diffusion of the ancestral irrigation and water management techniques, we proposed to represent the techniques on a Bonne sphere—based projection, as a modern evolution of a Ptolemaic projection.

The dichotomy, between arid and intermittent agriculture on one side and irrigated agriculture on the other side, evidences the important role played by the climate at shaping civilizations, settlements and landscapes. Therefore, in view of investigating the relationship between the presence of the techniques and the local climate, the thematic map was superimposed to classical climatic descriptors, i.e. the Köppen–Geiger climate classification, the De Martonne aridity index, and the Johansson continentality index. In the following, after presenting a brief description of the classification of the techniques, and the performed mapping choices, we discuss the climate clustering of the technique according to the recalled climatic indices.

Classification of the techniques

Ancestral irrigation or water management techniques are often multidimensional and multifunctional. The same channel might work as an irrigation or drainage channel depending on the working conditions, and the origin itself of the water supply might be complex and shared between many sources. As a consequence, it is difficult to propose a univocal classification of the techniques. Here we summarize a proposal of classification, rooted in and elaborated from a preliminary form given by Barontini et al. (2017). The proposed classification, based on the analysis of more than 160 literature cases, is founded on the identification of the main feature of the technique and implies three levels. The first level is the *System*, that is *Water harvesting, Water storage,* Water *management* and *Complex systems*. The second level is the *Subsystem*, as presented in Table 1. The third level is the classification of the *Technique* (not reported here). The key to identify the subsystems is different for the considered system. For the water harvesting system, the key is the main source of the water supply. For the water storage system, it is the structure of the storage, and for the management system, it is the main segment of the management process at which the technique is operative. Finally for the complex systems, i.e. systems that are not cataloged for a particular technique, but as a whole, the key is the spatial scale and the degree of complexity of the system. In this case the subsystems are identified as garden, oasis, and mosaic landscape.

Table 1 Preliminary classification of the ancestral water techniques (after Barontini et al., 2017; see Barontini et al., in preparation, for a more exhaustive classification).

System	*Key for the definition of the subsystem*	*Subsystem*
Water harvesting	Main origin of the water supply	Precipitation and surface water; Groundwater; Atmospheric water
Water storage	Structure of the storage	Cistern; Reservoir
Water management	Segment of the management process	Lifting; Transport; Distribution; Drainage
Complex systems	Spatial scale	Garden; Oasis; Mosaic landscape

The widest classes of subsystems, in terms of variety, are the Water harvesting / Precipitation and surface water, and the Water management / Distribution. The first one collects an ample class of techniques, at various spatial scales, that are oriented to slow down the water course in view of harvesting water in the soil or in some storage system. They span e.g. from the zaï pit and from the microbasins to the terraces, to the wadi—and—barrage systems, and to jessour—like systems. The subsystem Water management / Distribution accounts for all the techniques, which are mostly important for the irrigation in scarcity conditions, to manage the water distribution from the storage (or from the main channel) to the cultivation. Most of these techniques are characterized by a great detail in the distribution, ranging from pitcher or pot irrigation to the typical Mediterranean flumes that convey the water plant by plant, but in some cases, as that of the spate or basin irrigation, the distribution plays an active role as managed aquifer recharge as well. An important subsystem is the Water harvesting / Groundwater, because it collects all the vast family of the qanats. These are free—surface galleries that collect the water from an upstream—located groundwater table and convey it to the oasis and to the garden, which can be several kilometers far away. The qanats, originated in Central Asia and later diffused in almost all the Ancient (and New) World, are emblematic of the capability of these techniques to adapt to local climate and geomorphological context and to provide long lasting water supply (see Goblot, 1979, for a general classical introduction to the qanats).

Climate mapping and maps design

After populating the ancestral water techniques classification database described in the previous section, the subsystems of the techniques were plotted on thematic maps together with the Köppen–Geiger climate classification, the De Martonne aridity index and the Johansson continentality index. The maps extend from the Equator to 60°N and from 30°W to 130°E, thus covering all the Ptolemaic Ecumene. A sphere—based Bonne projection with central meridian at 50°E and standard parallel at 40°N, was used as a modern evolution of traditional Ptolemy's projection (Snyder, 1987; see e.g. Figure 1 for a qualitative comparison). The Köppen–Geiger climate classification was simplified from the map made available by Peel et al. (2007). Particularly we maintained the second letter for the classes A, B and C, and only the first letter for classes D and E, which were scarcely represented in the area and not representative for the investigated irrigation techniques. In the following the procedure to obtain the map of the other indices is briefly recalled.

Map of the De Martonne aridity index

The De Martonne aridity index (De Martonne, 1923) characterizes the aridity (in reality the wetness) of an area as a ratio between the annual precipitation *P* (mm) and the mean annual temperature *T* (°C), biased by 10°C. The index is calculated as:

$$I_{DM} = \frac{P}{T+10}.$$

According to the De Martonne aridity index, the climate classification is as reported in Table 2 (Baltas, 2007). Raw data obtained from Peel et al. (2007) provided information on 12,396 rainfall stations and 4,844 temperature stations, which were then analyzed to determine I_{DM}. Because the De Martonne Index uses both temperature and rainfall data, we shortlisted 4,279 stations that had both datasets. The stations with negative temperature were omitted from the analysis to simplify the process, so that at the end a total of 2,608 stations were selected for the calculation of the index. Ordinary Kriging interpolation was used to map the index, with a spherical semivariogram model and the range of 54.9°. The obtained maps are represented in Figures 5 and 6 together with the subsystem classification of the ancestral irrigation techniques.

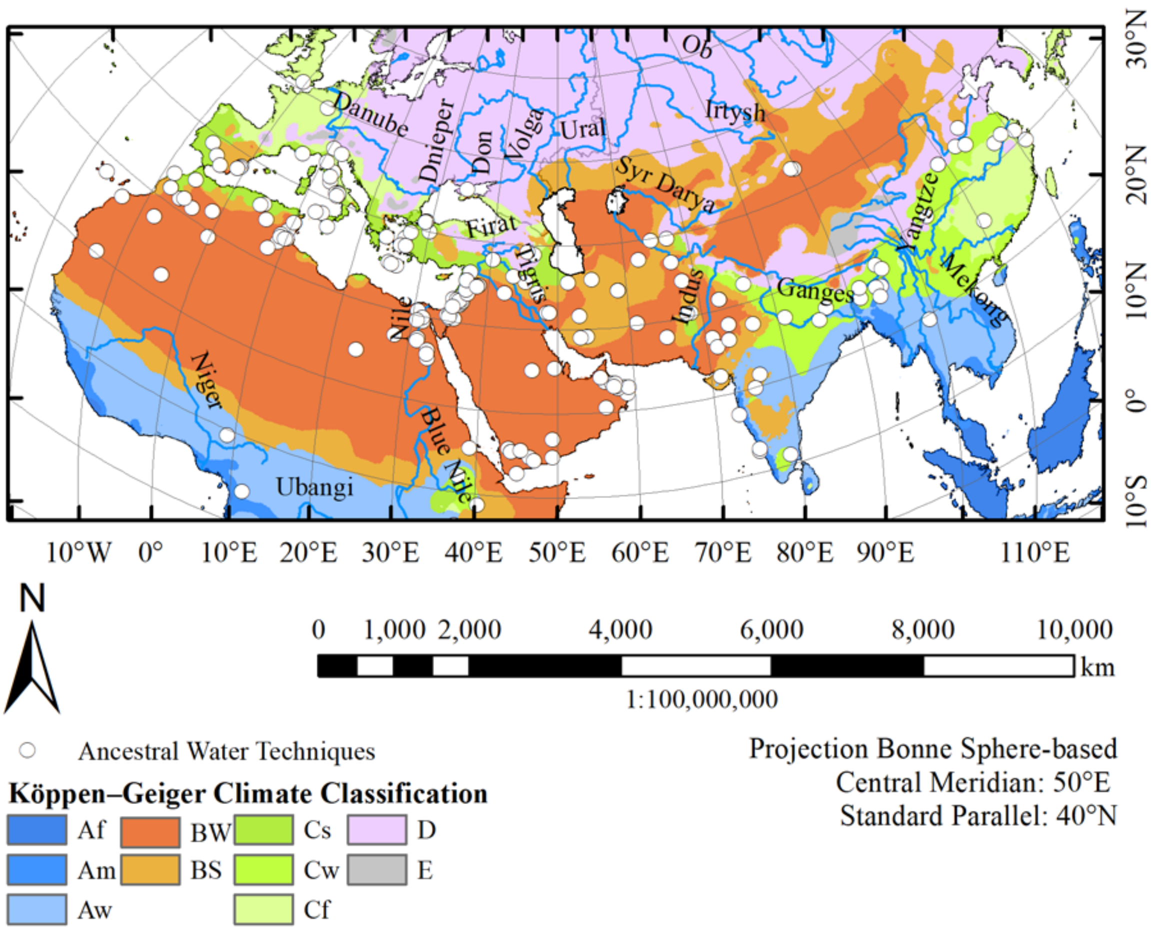

Figure 2 Position of the ancestral irrigation techniques superimposed to the Köppen—Geiger climate classification. The climatic classification is simplified from Peel et al. (2007).

Table 2 Climate classification according to the De Martonne aridity index (Baltas, 2007).

Climate	I_{DM}	P
Dry	$I_{DM} < 10$	P < 200
Semi-dry	$10 \leq I_{DM} < 20$	200 ≤ P < 400
Mediterranean	$20 \leq I_{DM} < 24$	400 ≤ P < 500
Semi-humid	$24 \leq I_{DM} < 28$	500 ≤ P < 600
Humid	$28 \leq I_{DM} < 35$	600 ≤ P < 700
Very humid	a. $35 \leq I_{DM} \leq 55$	a. 700 ≤ P ≤ 800
	b. $I_{DM} > 55$	b. P > 800

Map of the Johansson continentality index

The Johansson continentality index (Gorczynski, 1920) is used to characterize the degree of continentality as a function of the amplitude A (°C) of the yearly temperature regime and of the geographical latitude φ by means of the formula:

$$I_J = 1.7\frac{A}{sin\varphi} - 20.4.$$

According to this index, the climate is marine when I_J is between 0 and 33, continental when I_J is between 34 and 66, and exceptionally continental when I_J is between 67 and 100. The map was obtained after the raw data provided by Peel et al. (2007), excluding the stations with negative temperature values and restricting the area to a latitude above 5°N. Ordinary Kriging interpolation was used to map the index, with a Gaussian semivariogram model with the range of 32.7°. The obtained maps are represented in Figures 7 and 8 together with the subsystem classification of the ancestral irrigation techniques.

Discussion

In Figure 2 the location of the classified ancestral irrigation techniques is represented on the Köppen—Geiger climate classification. It clearly emerges that most of the collected information refers to the arid climate BW (desert) and to the temperate climate with dry summer, the latter being the typical Mediterranean climate, with winter rainy season. The De Martonne aridity index (Figures 5 and 6) provides similar information, being most of the cataloged techniques located in the dry, semi—dry and Mediterranean areas. It is worth noting that the De Martonne index has also a geomorphological meaning, as those areas with $I_{DM} < 5$ are typically areic, areas with $5 < I_{DM} < 20$ are typically endoreic and Mediterranean areas might be endoreic or esoreic, depending on the local relief. In these areas they are indeed very common the wadis, that are rivers with intermittent discharge.

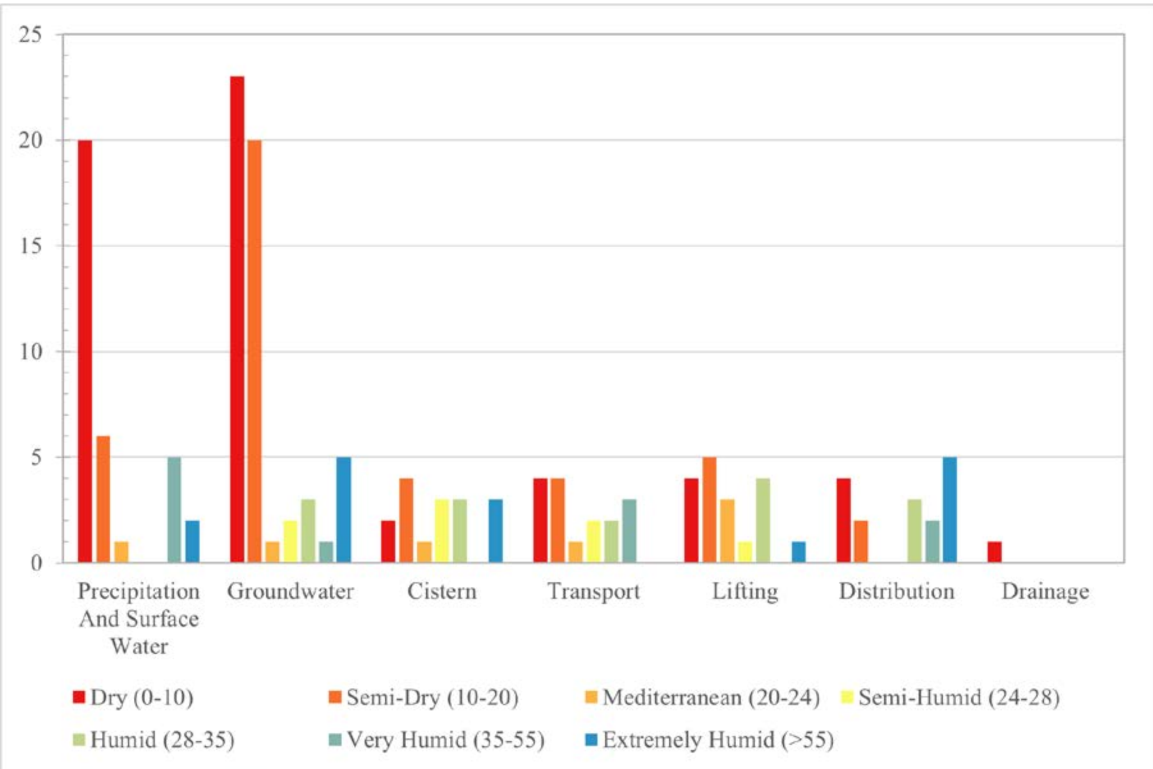

Figure 3 Distribution of ancestral irrigation and water management techniques according to the climatic types identified by the De Martonne aridity index.

By looking at the histograms reported in Figure 3, which represent the subsystem of the ancestral irrigation techniques with respect to the De Martonne aridity index, it emerges that most of the classified techniques, which are mainly those based on precipitation and surface water and on the groundwater, i.e. the wadi—and—barrage system and the qanats, are present in dry and semidry areas. It also emerges that a non—negligible number of cases was found in semi—humid and humid areas. This cases deserve of being investigated in detail, as long as the necessity of using typical arid—areas irrigation techniques also in humid areas might be induced by the local orography, by steep slopes or by the particular cultivation performed, as it was in the emblematic case of the Lake Garda lemon houses in Northern Italy (Cazzani and Barontini, 2020; Cazzani et al., 2022). Finally, according to the classification of the Johansson continentality index (Figures 7 and 8, and histograms in Figure 4) it clearly emerges how most of the investigated techniques fall within the range of weakly maritime climate and of continental climate, with a meaningful majority for the continental climate, but avoiding the degrees of extreme contintentality. It therefore clusters all the so far investigated techniques in only four climatic types.

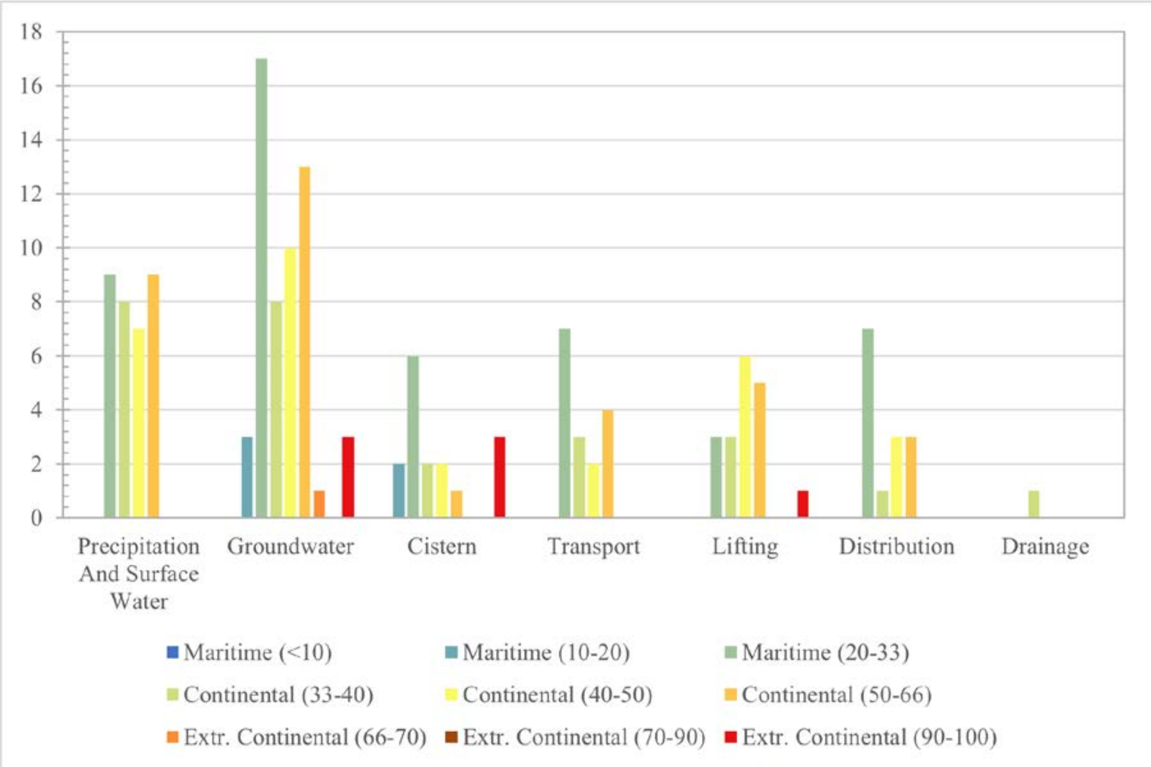

Figure 4 Distribution of ancestral irrigation and water management techniques according to the climatic types identified by the Johansson continentality index.

Conclusions

In this work we presented a cartographic frame that will serve as basis for the analyses of an extensive literature review on ancestral irrigation techniques, which aims at assessing the state of the art regarding the present interest of the scientific community on these practices. The database of the techniques, classified according to their main characteristic within a functional system classification, was represented on a map focused on the North Africa and Eurasia continents, which mimics the Ptolemy Ecumene. This choice aims to suggest the idea that these techniques are ecumenical both in the sense that they have been applied all over the ancient Ecumene, and in the sense that they were able to migrate and to be assimilated by the populations which received them. According to the classical subdivision of the agriculture in arid, intermittent and irrigated one, these techniques are mainly typical of the irrigated agriculture, and they are therefore present in arid, semiarid and Mediterranean conditions, where the precipitation is not enough to compensate for the evapotranspirative demand, and irrigation is therefore needed. This feature clearly emerges from the analysis of the map of De Martonne aridity index and of the map of the Johansson continentality index. According to these maps, indeed, most of the techniques fall within the range of the arid / semiarid / Mediterranean climate (according to the De Martonne aridity index) and within the range of the weakly maritime and continenental climate (according to the Johansson continentality index).

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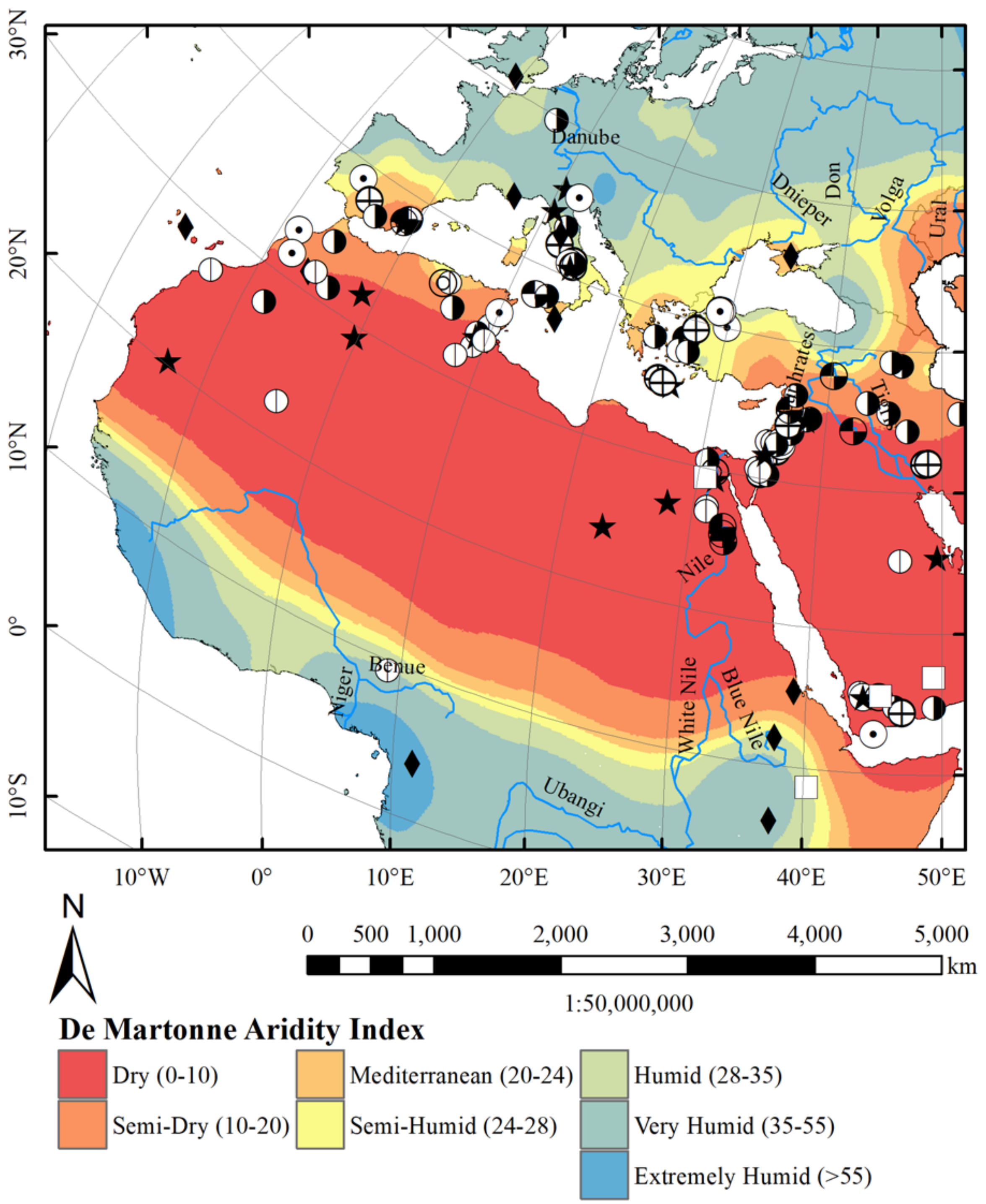

Figure 5 Position of the subsystems of the ancestral irrigation and water management techniques superimposed to the De Martonne aridity index (West side).

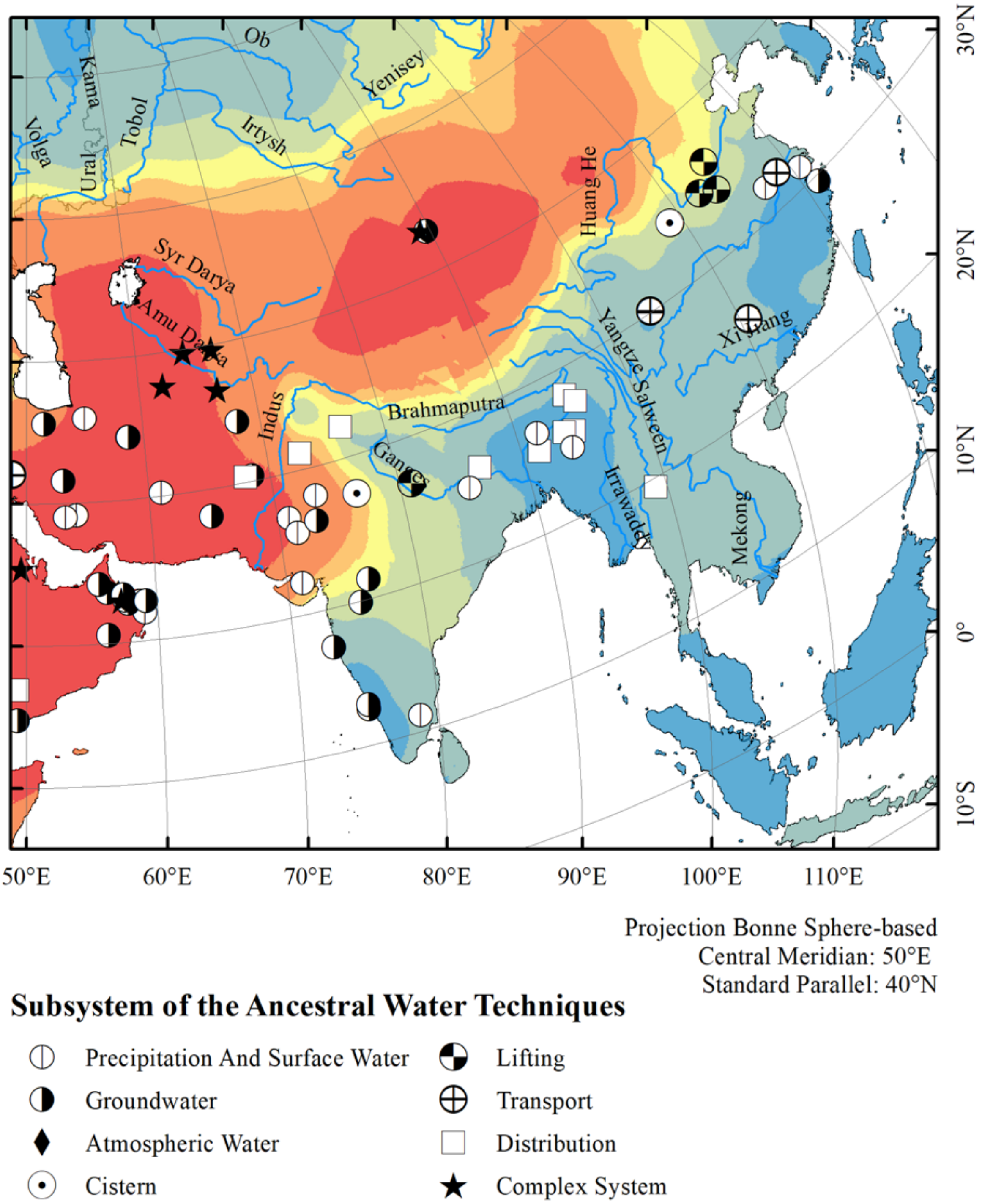

Figure 6 Position of the subsystems of the ancestral irrigation and water management techniques superimposed to the De Martonne aridity index (East side).

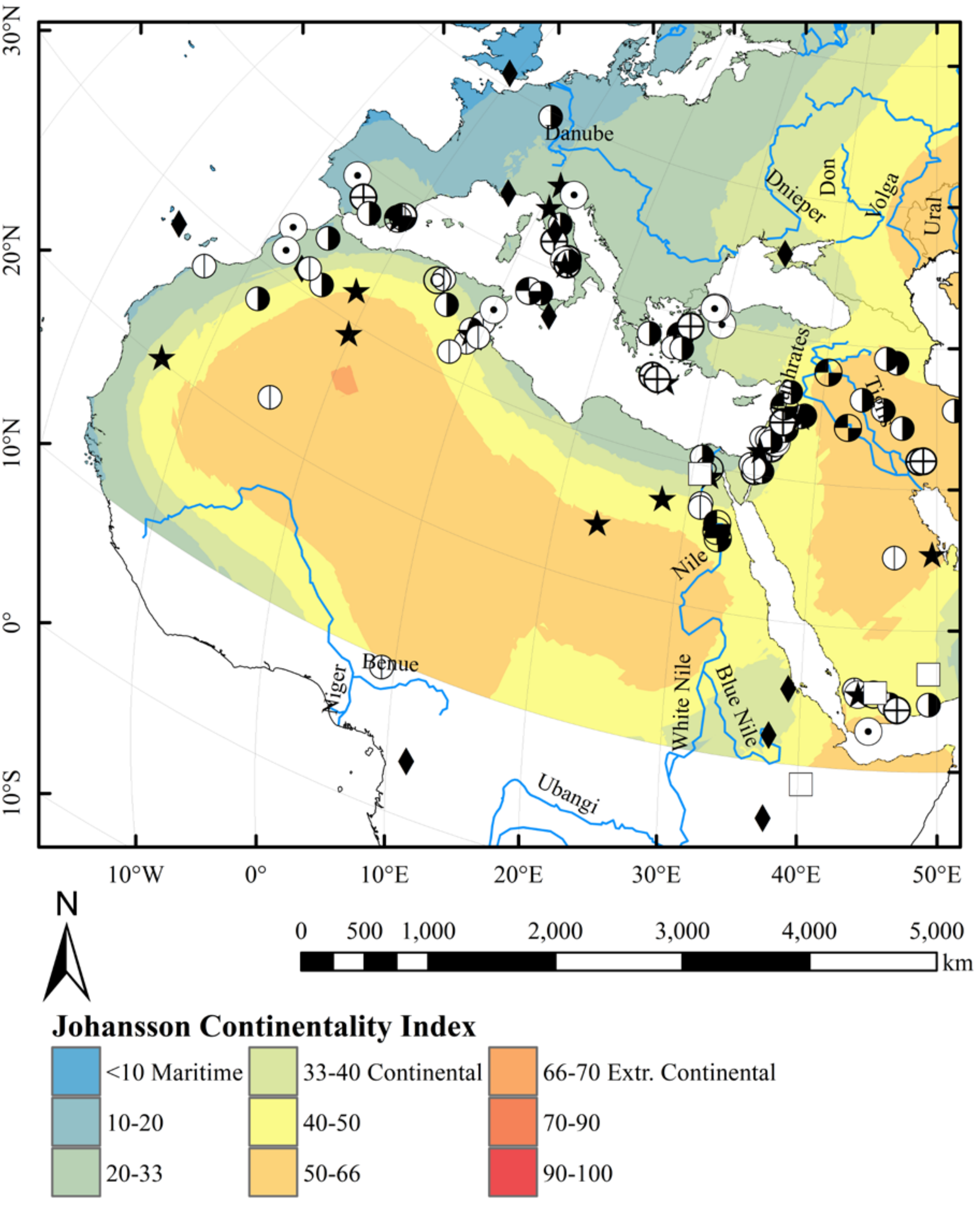

Figure 7 Position of the subsystems of the ancestral irrigation and water management techniques superimposed to the Johansson continentality index (West side).

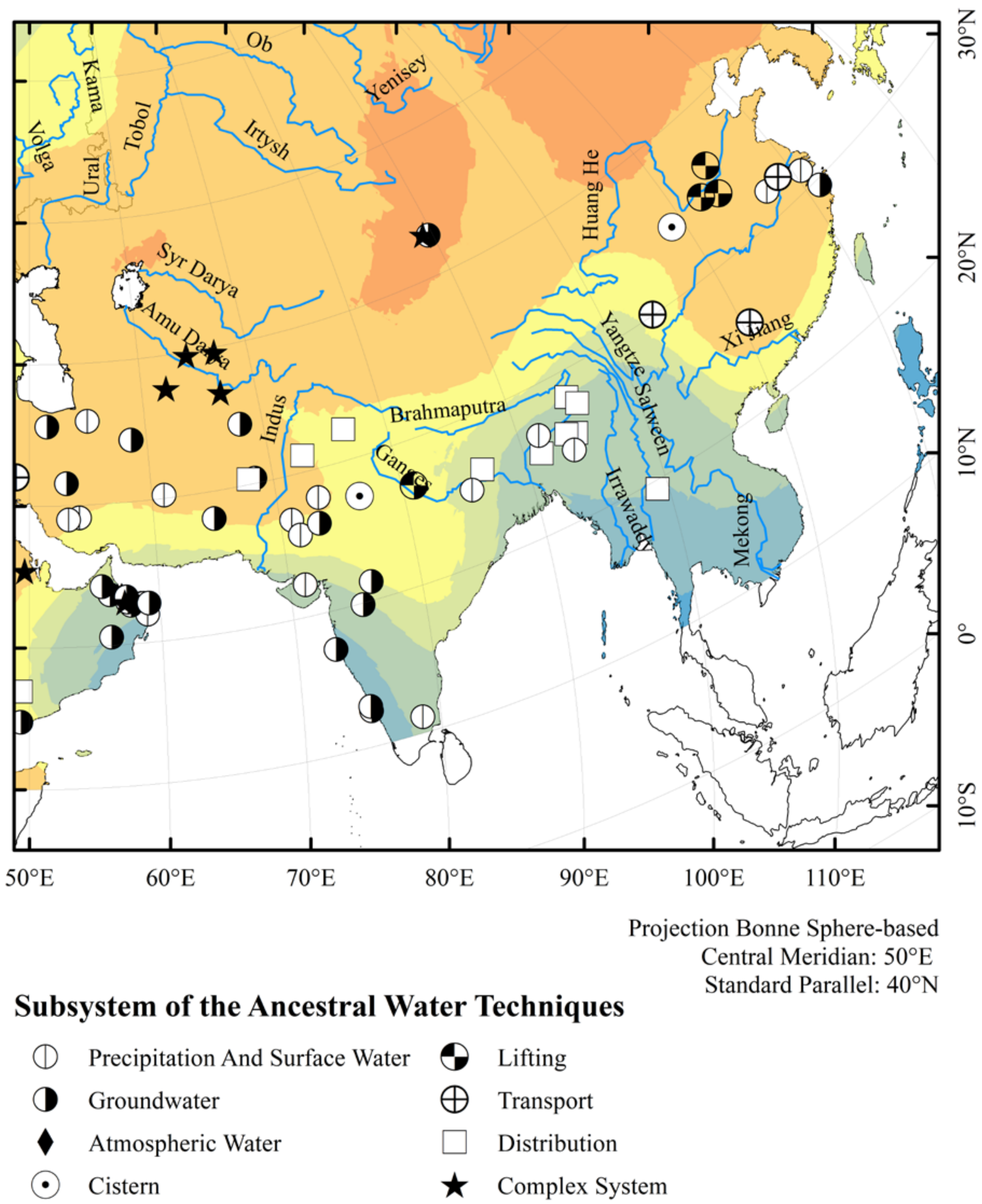

Figure 8 Position of the subsystems of the ancestral irrigation and water management techniques superimposed to the Johansson continentality index (East side).