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RESEARCH ARTICLE

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Human affinity for rivers

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Abstract

Human civilization prospers along rivers worldwide. Here, we investigated human–river relations by revealing the linkage between water and habitability for human settlements, and socioeconomic and cultural development across China. We found that human–water co-occurrence relationships are self-similar over sub-basins for different scales of stream-order in the river networks. According to the earlier complete demographic census conducted during the reign of the Qing Dynasty (1776), there has been a general tendency for inhabitants to live close to rivers, characterized by population density associated with habitability cored by water under a near-natural state, which still remains to date (2019) even after long-term population growth and human interventions. Throughout history, we have extended the linkage of human settlements to humanistic attributes with river networks, derived four different modes of human aggregation towards rivers, and elucidated the geographical diversity of river density, population density, cultural prosperity, and clusters of ethnicity, particularly the Western and the Northeast culture established in the arid (desert) areas, the Huaxia culture in the alluvial plains, the Loess/Nomadic/Southwestern Ethnic culture in the plateaus, and the Qi-Lu/Wu-Yue/Linnan culture in coastlands across the whole country. This work is also of significance to understanding long-term human–water relationships at a global scale.

KEYWORDS

cultural prosperity, geographical diversity, habitability, human settlement, population density, river density, river network

1 | INTRODUCTION

Throughout history, humans have chosen to live close to rivers due to the availability of agricultural and domestic water supply, natural resources, navigation, and trade (Kummu et al., 2011). Records on human affinity for rivers can be traced early to the *Classic of Mountains and Rivers* (Yuan, 2014) during the Pre-Qin Period (Paleolithic Period—221 BC). Alongside the world's great rivers, people have extended a new dimension of social progress, established settlements, developed riverine economic activities, and explored the intellectual and artistic domains of the human mind (Best, 2019; Hasan, 1997).

River networks are hierarchical systems with both natural and human dimensions. Statistically, rivers with different stream-orders follow certain geometric laws, notably identified by different schemes such as the Horton (1945) and Strahler (1952, 1957) stream-order rules, along which self-similarity in natural river networks has been confirmed (Y. C. Wang et al., 2018; Zanardo et al., 2013). Moreover, river density, defined as the ratio of the total stream number or channel length in a catchment to the total catchment area, is also an effective factor characterizing the degree of development of river networks, which usually corresponds to plentiful precipitation and high vegetation coverage (X. B. Chen et al., 2019). Compared with the perceived physical characteristics of river networks, there exists a gap in understanding river systems from the human perspective, for example, human settlements and behaviors. Globally, preferential downstream clustering of human settlements has been observed

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across continents (Fang et al., 2018). In particular, the outlets of great rivers are more attractive for human settlements compared to other coastal areas because of favorable opportunities for nature resources, geographic advantages, and ecological assets, even though humans would be more vulnerable to flood risk (Tellman et al., 2021).

The geospatial pattern of human settlements could be regarded as a symbol of the complex human–nature relationship influenced by an interplay of varying factors. Besides proximity to the river, the local land elevation and latitude are also important geographical considerations for human settlements (Kummu et al., 2016; Viviroli et al., 2020). It has been reported that around 50% of the population dwells within the area between 20°N and 40°N, where most of the world's development and poverty-related problems also co-exist (Kummu & Varis, 2011). Moreover, human settlers have made continuous strides towards socioeconomic and cultural development, mirrored by lifestyle, production, architecture, ethnic, and other social characteristics (Hasan, 1997; Singh et al., 2017). For example, human behavior has even stretched to a cultural perspective of river networks through colorful river naming practices (Y. J. Liu et al., 2010; Y. C. Wang et al., 2019), while relations between rivers and the origin of language and expansion were phylogenetically evidenced with historic human populations and their cultures (M. H. Zhang et al., 2019).

Over the centuries, the relationship between people and rivers has become more complicated due to increasing anthropogenic interference and climate change (L. Li et al., 2020; Maavara et al., 2020; Ni et al., 2022; Y. C. Wang et al., 2020; Wu et al., 2021). On the other hand, the reliance of humans on direct proximity to rivers has been buffered due to enhanced capability of water diversion and exploitation of alternative sources (Scanlon et al., 2012). Hence, population density seemed not so closely coupled with croplands spreading towards inland zones (Kummu et al., 2016). These raised widespread concerns about the diverse trajectories of settlement proximity to major rivers induced by heterogeneities of climate, urbanization, and economic development at regional and global scales (Ceola et al., 2015; Fang & Jawitz, 2019; Veldkamp et al., 2017).

In the present paper, we investigated human–river relationships through the linkage between water and habitability for human settlement, and socioeconomic and cultural development across China. Based on the earlier complete demographic census conducted during the reign of the Qing Dynasty (1776), we interpreted the preferential orientation of people toward rivers in a near-natural state. By revealing the geographical diversity of river density, population density, cultural prosperity, and clusters of ethnicities, the human–nature harmony is elucidated in conjunction with the representative modes of human aggregation through long-term development, which is also helpful for understanding human–water interactions in the rest of the world.

2 | MATERIALS AND METHODS

2.1 | Data sources

Digital elevation modes (DEMs) at 30 m × 30 m resolution for extraction of river networks and basin boundaries were available at https://search.earthdata.nasa.gov/search. The referenced river network data for validation and Gridded population data at 1 km × 1 km resolution for China were derived from http://www.resdc.cn/. Both the annual mean precipitation map and the climatic regionalization map of China were obtained from the Atlas of Physical Geography of China (Department of Geography Northwest Normal University, 1984). The annual average aridity index data for 1970–2000 were available at https://doi.org/10.6084/m9.figshare.7504448.v3. Terrain slope was calculated based on the 90 m × 90 m resolution DEMs available at http://www.gscloud.cn/. Population data for the Qing Dynasty (1776) at the prefecture scale were obtained from the History of Population in China, Qing Dynasty (Ge, 2001). Global population gridded data sets were assessed via https://sedac.ciesin.columbia.edu/data/set/gpw-v4-population-count-rev11. Dynastic litterateur data for China from the Zhou Dynasty to the Qing Dynasty were collected from historic classics of China (Mei, 2004). Prefecture unit boundary polygon files of China in the Qing Dynasty were derived from CHGIS (2003). The polygon file was further clipped using the present China boundary map for better comparison. Chinese provincial administrative boundary data were obtained from http://www.resdc.cn/.

2.2 | Extraction of river networks

Drainage networks and the corresponding basin boundaries for China were extracted using a high-efficiency algorithm based on a size-balanced binary search tree (Bai et al., 2015). The extraction system involves five steps: (1) filling local depressions; (2) determining flow directions; (3) accumulating upslope areas; (4) identifying river channels in terms of threshold values of critical source area and local slope; and (5) vectorizing geographic features. In this study, the threshold values of critical source area (number of grid cells) and local slope were determined to be 20 and 0.01, respectively. For endorheic rivers in the Northwest China and the Tibetan Plateau, pretreatment on DEMs was undertaken (Y. C. Wang et al., 2019).

2.3 | River system hierarchy

Rivers were defined using the Strahler stream-ordering scheme (Strahler, 1952, 1957), in which the first-order rivers were headwaters without bifurcation. At a confluence, the stream-order of the downstream river followed the rules:

$$n_d = \begin{cases} n_1 + 1, & \text{for } n_1 = n_2 \\ \max(n_1, n_2), & \text{for } n_1 \neq n_2 \end{cases}, \quad (1)$$

where n_d is the stream order of the downstream river, and n_1 and n_2 are the respective stream orders of the upstream rivers at the confluence.

2.4 | Quantification of natural and humanistic factors

Natural river density (F_R, 10^{-3} km^{-2}) was expressed as

$$F_R = N/A, \quad (2)$$

where N is the number of rivers estimated using the Strahler scheme, and A is the catchment area of the corresponding basin (km^2).

Habitability for human settlement was measured by the index (HI):

$$\text{HI} = \text{MCTI} \times T, \quad (3)$$

where T is the weight factor at different climatic zones, assigned to 1 for tropics, subtropics, and warm temperate climatic zones, to 0.4 for middle temperate and cold temperate climatic zones, and to 0.6 for the plateau climatic zone. MCTI is a modified compound topographic index, derived from CTI (Moore et al., 1991), which is a function of slope and upstream flow accumulation, and defined as

$$\text{MCTI} = \ln(\text{AI}/\tan(\pi S/180)), \quad (4)$$

where AI is the annual average aridity index defined as the ratio of precipitation (Sun et al., 2018) to potential evaporation and S is the slope (°).

Finally, cultural prosperity in a particular dynasty was represented by the number of litterateurs per province (N_L, Person) recorded in the historic classics of China (Mei, 2004).

2.5 | Correlation analysis

Relationships between factors characterizing geographic conditions, human settlements, and cultural development were identified by Pearson or Spearman correlation analysis. For all statistical analyses, a value of $p < 0.01$ (99% confidence level) was considered significant. IBM SPSS 19.0 statistical software was used in the relevant analysis.

3 | RESULTS AND DISCUSSION

3.1 | Habitability of human settlements

Human habitability generally depends on geographic and climatic conditions. Figure 1a shows the mean annual precipitation (MAP) across China. North-west China, with MAP < 400 mm, is a nomadic region where animal husbandry dominates. Much of the remainder of China is farmland due to substantial rainfall. The farming region can be separated about the 800 mm isohyet into dry and rice farming areas in northern and southern China. Figure 1b shows the spatial distribution of a modified compound topographic index (MCTI, Methods) based on the ratio of aridity to topographic slope. The index is higher in east China, which comprises hills and plains (MCTI > 1.7), especially in coastal and estuarine areas, but lower in west China, which contains plateau and steeply sloping mountainous regions (0.5 < MCTI < 1.7) and arid desert regions (MCTI < 0.5). Latitude, which in turn affects ambient temperature, is of the utmost importance to human well-being, productivity, and cultural development (James, 1972). Figure 1c shows the climatic zones of China, where tropical, subtropical, and warm-temperature zones lie within latitudes 20°N–40°N and are optimal for human residence and development (Kummu & Varis, 2011). Attractiveness for human settlement is quantified in terms of the habitability index (HI), which combines MCTI and latitude. As shown in Figure 1d, coastal areas (HI > 2.5) and alluvial plain areas (1.5 < HI < 2.5) of the Yangtze and the Yellow rivers are more preferable for human settlements, compared with plateau regions (0.55 < HI < 1.5) and high-latitude regions (arid desert or cold northeast China, HI < 0.55).

3.2 | Human–water co-occurrence relationships at varying scales

To eliminate uncertainty arising from increased human mobility in recent centuries, the near-natural population density is determined from the census information conducted in the year 1776 during the Qing Dynasty (D_{1776}), when complete provincial demographic statistics (Ge, 2001) became commonly established and the tendency for inhabitants to live close to rivers was still strong. Then, human–water relationships in river networks could be analyzed through the linkage between natural river frequency (F_R, 10^{-2}km^{-2}), habitability index (HI), and population density in the Qing Dynasty (D_{1776}, Person km^{-2}) for 9834, 2252, 508, and 112 sub-basins at different stream-orders (5–8) in China. The positive feedback of HI to increased F_R reveals that conditions suitable for human aggregation occur more frequently in areas of higher river density (Figure 2i). D_{1776} also shows a significant positive correlation with HI, confirming that HI is an effective indicator of the scale of human aggregation (Figure 2ii). The consistency of results across different scales demonstrates a robust fractal structure of human–water co-occurrence relations in hierarchical river networks despite the spatial heterogeneity of geographical environments and diversity of human aggregation patterns and lifestyles.

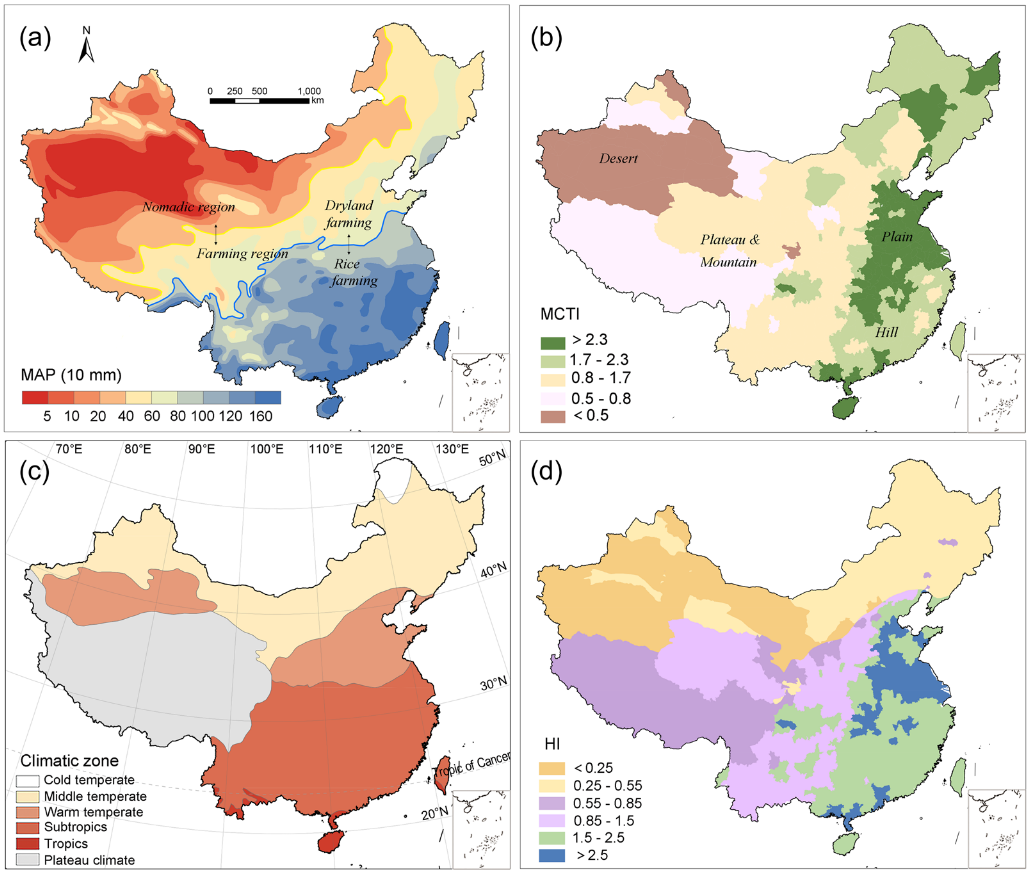

FIGURE 1 Geographic and climatic conditions for human settlement in China. Distribution of (a) mean annual precipitation (MAP, 10mm). (b) Modified compound topographic index (MCTI). (c) Climatic zones of China divided according to latitude. (d) Habitability index (HI). The nomadic and farming regions are divided by the 400 mm isohyet (in yellow), and the dryland and rice farming regions are divided by the 800 mm isohyet (in blue)

3.3 | Preferential orientation of inhabitants towards rivers

The general tendency for inhabitants to live close to rivers since ancient times is fairly identified by the so-called Hu Line (W. Qi et al., 2016), which divides China into two regions (Figure 3a,b). The southeast region of China (below the Hu Line) is more attractive for human settlement due to its natural advantages of abundant water resources in addition to fertile soil and plentiful sunlight. The number of rivers with catchment areas greater than 100 km^2 per unit area (F_R) in the regions below the Hu Line is $4.37 \times 10^{-3}\ \mathrm{km}^{-2}$, which is 21% higher than that in regions above the Hu Line. The mean value of HI in the regions below the Hu Line (1.87) is fourfold higher than that above the Hu Line (0.45). From the census information, the mean D_{1776} in the region below the Hu Line (101 Person km^{-2}) is significantly greater than that above the Hu Line (15 Person km^{-2}). A higher correlation between F_R and HI (Figure 3c,d), as well as F_R and D_{1776} was observed in areas below the Hu Line, suggesting an essential role of rivers in human aggregation in areas with dense river networks. The mean D_{1776} increased with F_R below the Hu line (Figure 3e), but remained unchanged above the Hu line (Figure 3f), suggesting a diversity of human aggregation patterns and lifestyles across the whole country. Interestingly, the distributions of population density in 1776 (Figure 3a) and 2019 (Figure 3b) are generally similar from the perspective of the Hu Line, even though China has experienced rapid population growth and urbanization. Meanwhile, the dependence of D_{1776} and D_{2019} on HI is also at a similar level, particularly in the regions below the Hu Line (Figure 3e,f). It is expected that river networks would continue to play key roles in shaping spatial patterns of human settlements and clusters of economic entities in the absence of dramatic climate change.

3.4 | Characteristics of typical human aggregation modes

By considering the geographical environment, it is possible to map four main human aggregation characteristics (Figure 4). Each set of characteristics has a corresponding range of habitability and population densities. In arid (desert) areas, people tend to live at oases or migrate upstream along the river network, driven by drought events exacerbated by severe evaporation and the drying out of downstream reaches (Ling et al., 2013; Xie et al., 2017). In the northeast plains, several water

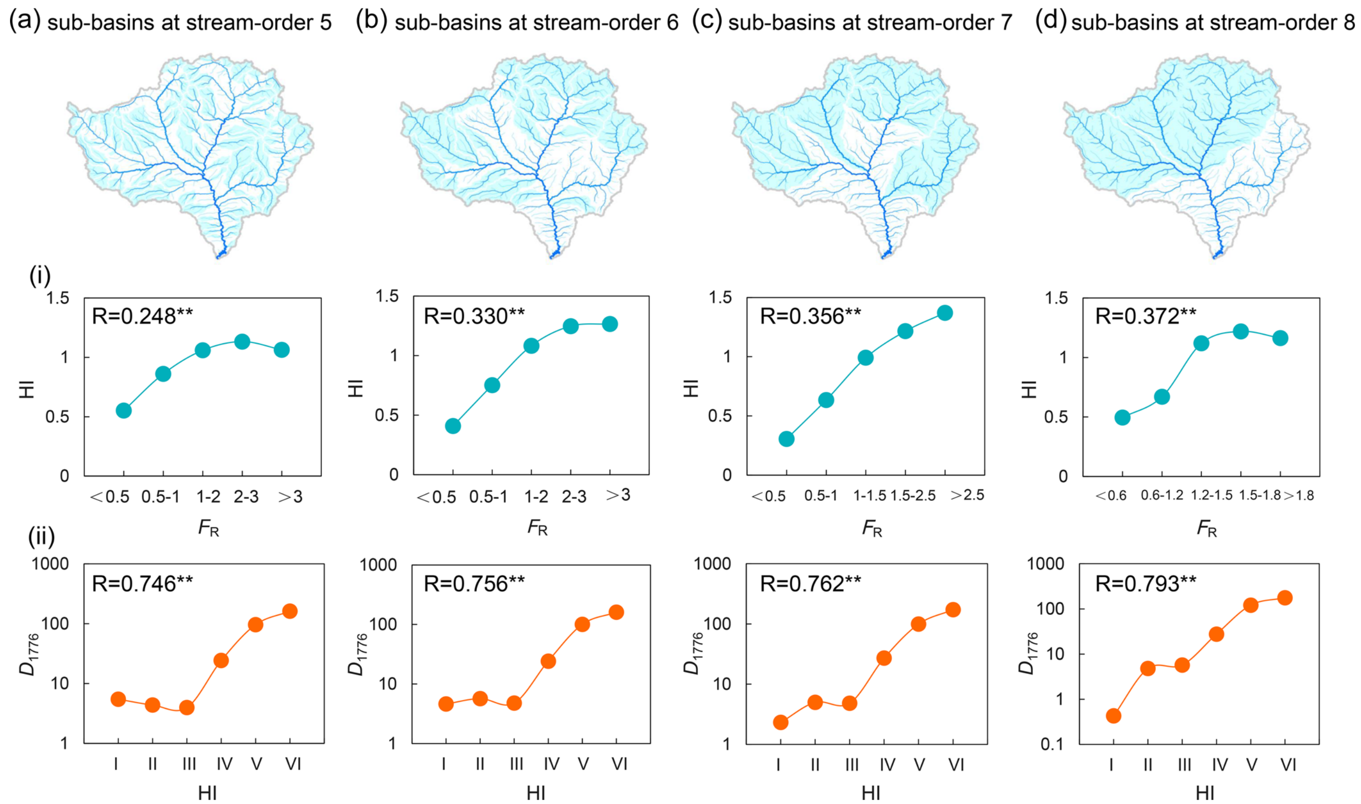

FIGURE 2 Human–water co-occurrence relationships in China at varying scales, shown over sub-basins at (a), stream-order 5, (b) stream-order 6, (c) stream-order 7, and (d), stream-order 8. Human–water relations are characterized by two links, that is, (i) linkage between the natural river frequency (F_R, 10^{-2}km^{-2}) and the mean values of the habitability index (HI) and (ii) linkage between HI and the mean values of population density in the Qing Dynasty (D_{1776}, Person km^{-2}). I, II, III, IV, V, and VI correspond to HI ranges of 0–0.25, 0.25–0.5, 0.5–0.75, 0.75–1.5, 1.5–2.5, and >2.5, respectively. The correlation coefficient (R) was determined based on the Spearman correlation analysis at the 99% confidence level

resources and fertile black soil provide suitable agricultural conditions, but the higher latitude and cold temperatures result in lower population density due to insufficient natural heat energy (Gao, 2012). Sunlight is therefore a primary factor for settlement aggregation in northeast China, where human settlements preferentially cluster on southern slopes (Mode I with a mean $D_{1776} = 4.59$ Person km^{-2}, Figure 4a). Fluvial plains are important for human settlement because of their natural advantages of water, cultivated land, and heat resources; such plains supported the greatest advances in ancient China (Macklin & Lewin, 2015). In the extensive fluvial plains of the North and the South of China, abundant water supply, fertile soil, and a warm, humid climate provide ideal conditions for dry-land agriculture and rice production, thus feeding the majority of China's population (Mode II with mean $D_{1776} = 128.27$ Person km^{-2}, Figure 4b). Three Mode III subtypes are prevalent in plateau areas, where the local geomorphology also influences human aggregation (Mode III with mean $D_{1776} = 17.50$ Person km^{-2}, Figure 4c): Mode III-1 in the Loess Plateau characterized by loess landforms (J. C. Li et al., 2017); Mode III-2 in the Yunnan-Guizhou Plateau dominated by karst landforms (M. X. Liu et al., 2016); and Mode III-3 in the Qinghai-Tibetan Plateau composed of glacial permafrost landforms (F. H. Chen et al., 2015). In the Loess Plateau, the scale of human settlements is constrained by the fragmented loess landform with interlaced gullies, a semiarid climate, very severe soil erosion, and a fragile eco-environment. Human settlements mostly aggregate at the base of loess ridges and hillocks. In the Yunnan-Guizhou Plateau, the karst landform scarcely contains any cultivatable land and undergoes severe soil erosion, leading to high flood risk and a low degree of habitability, therefore resulting in low population density. Here, people preferentially build settlements on hillside terraces close to rivers to enable the abstraction of water at minimum flood risk. Climatic gradients and geographic constraints of the Qinghai-Tibetan Plateau have led to a vertical distribution in human settlements, which preferentially cluster either at the foot of mountains, where the climate is relatively mild, or near the mountain summits, where glacial meltwater can be accessed. Mode IV occurs in coastal areas, where the scale of aggregation is the highest due to the availability of better water resources, low-sloped flatlands, shipping, and trading opportunities (Bianchi, 2016) (mean $D_{1776} = 202.83$ Person km^{-2}, Figure 4d). Mode IV can be further divided into three subtypes according to their tidal characteristics (Z. Y. Wang et al., 2012): Mode IV-1 related to the Yellow River Delta, Mode IV-2 related to the Yangtze River Delta, and Mode IV-3 related to the Pearl River Delta.

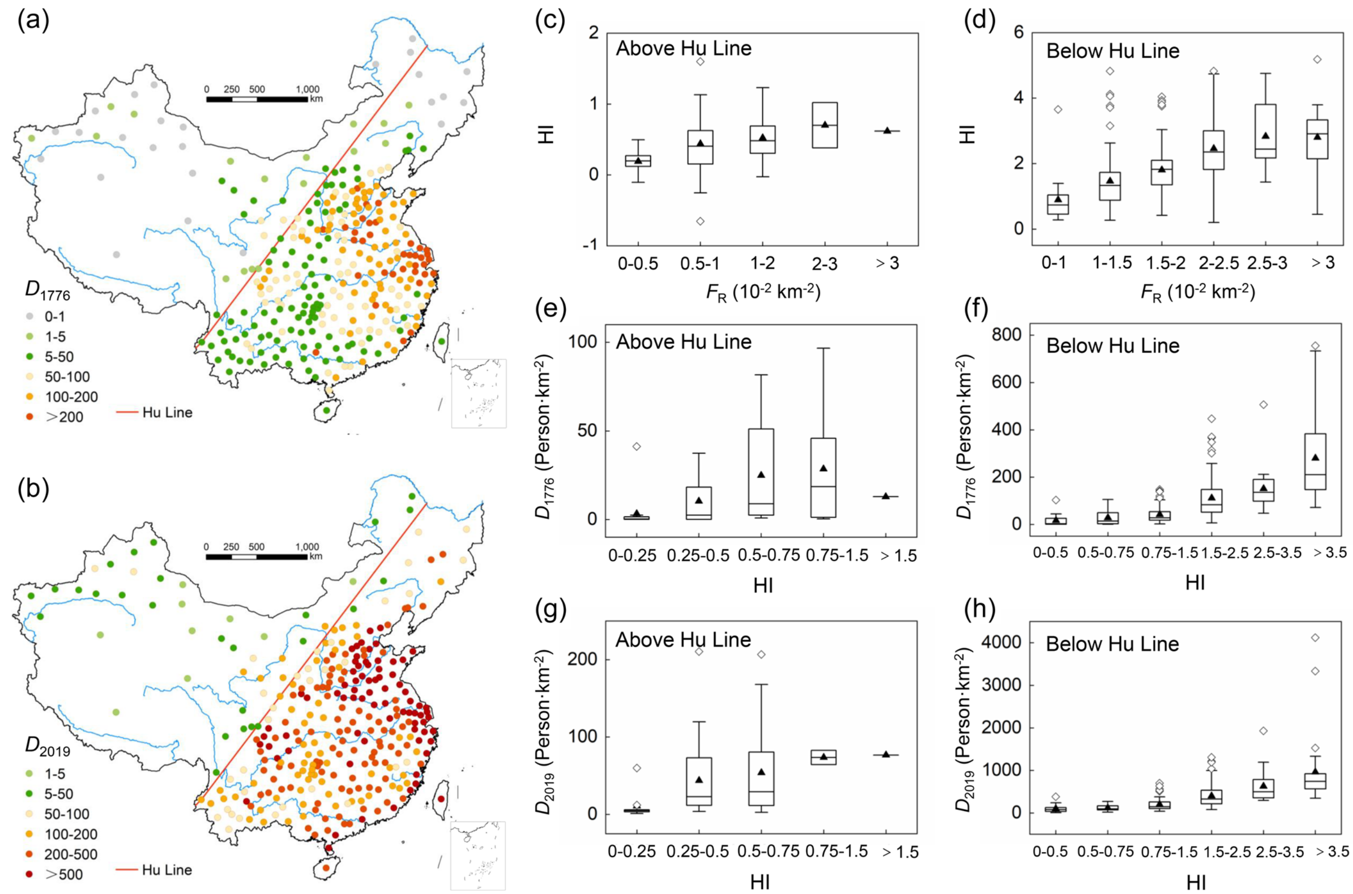

FIGURE 3 Inhabitants' affinity for waters reflected by earlier near-natural distribution (Qing Dynasty) and modern distribution. Panels (a) and (b) show the distributions of major rivers and population density, demarcated by the "Hu Line", in 1776 during the Qing dynasty (D_{1776}, Person km^{-1}) and in 2019 (D_{2019}, Person km^{-1}) throughout China. Panels (c) and (d) show the relations between river density (F_{R}, 10^{-2} km^{-2}) and the habitability index (HI) in the regions above and below the Hu Line. Panels (e) and (f) show the relations between F_{R} and D_{1776} in the regions above and below the Hu Line. Panels (g) and (h) show the relations between HI and D_{2019} in the regions above and below the Hu Line

The different modes of population aggregation towards water bodies in particular areas lead to geographical diversity in not only ethnicity and language but also local culture. For example, Mode I is associated with the Western Regions Culture (Yu, 1981) and the Northeast Culture (Gao, 2012) (Figure 4a). Mode II relates to the dominant Chinese culture (Qian, 1994) (Figure 4b), the Huaxia Culture, introduced before the Zhou Dynasty (1046 BC–256 BC) by the Han ethnic group. Mode III is characterized by the Guan-Shan Culture (Loess Plateau), the Southwestern Ethnic Culture (Yunnan-Guizhou Plateau), and the Nomadic Culture (Tibet Plateau) (Figure 4c). The Guan-Shan Culture (J. C. Li et al., 2017) experienced its first golden age during the Zhou Dynasty. The Southwestern Ethnic Culture (Z. Q. Zhang, 2004) peaked during the Qin–Han Dynasties (221 BC–220). Meanwhile, the Nomadic Culture (J. F. Chen, 2014) experienced great prosperity during the Ming and Qing Dynasties (1368–1912). Mode IV is marked by the Qi-Lu Culture (Wang & Wang, 2008) (Yellow River Delta), the Wu-Yue Culture (Zhang, 1991) (Yangtze River Delta), and the Linnan Culture (Tan, 2002) (Pearl River Delta) (Figure 4d), the former being most prominent in the Han Dynasty and the latter two being the most prominent in the Tang-Song Dynasties (618–1279).

3.5 | Evolution of cultural prosperity from the riverine perspective

As a consequence of human aggregation toward water, the populated areas with high habitability also achieve cultural prosperity. Here, we introduce a cultural prosperity index, given by the recorded number of litterateurs in a particular dynasty (D_{L}, Method). Figure 5a shows the dynamic changes that occurred in the distribution of cultural centers in China over the past 2000 years. From the Zhou dynasty to the Tang dynasty (618–907), the majority of litterateurs resided in the most prosperous provinces of North China, primarily along the middle and lower reaches of the Yellow River. In the South Song Dynasty (1127–1279), the cultural center of China had transferred to South China, with litterateurs attracted towards the middle and lower reaches of the Yangtze River, and rivers in Zhejiang and Fujian provinces. In the Qing dynasty, culture throughout China approached maturity, with the cultural prosperity index D_{L}

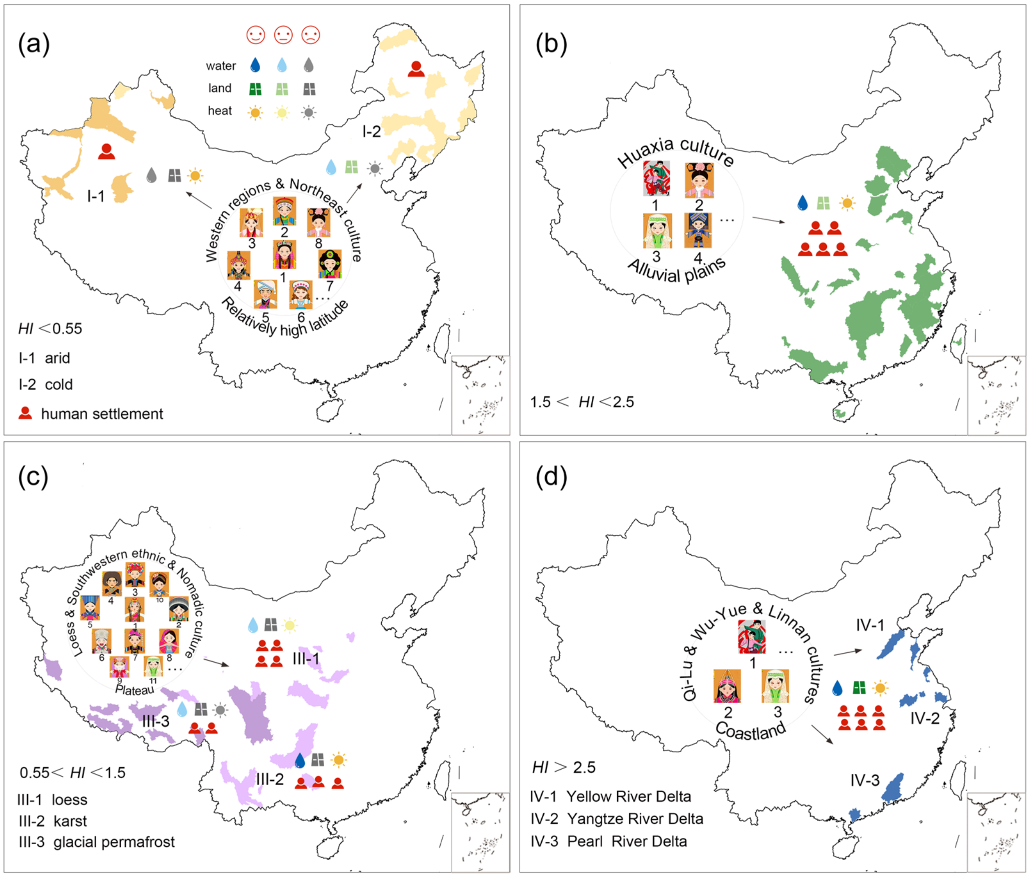

FIGURE 4 Characterization of four typical modes of population aggregation in China in terms of location, geographical environment, ethnic group, and local culture (each mode or sub-mode corresponds to a specific range of HI). (a) Mode I: Relatively high latitude, numbers 1–8 correspond to Uyghur, Daur, Kazak, Mongol, Xibe, Russian, Korean, and Man ethnic groups. (b) Mode II: Alluvial plains, numbers 1–4 correspond to Han, Man, Hui, and Zhuang. (c) Mode III: Plateau, numbers 1–11 correspond to Tibetan, Yi, Moinba, Lhoba, Bouyei, Miao, Dong, Dai, Salar, Qiang, and Hui. (d) Mode IV: Coastland, numbers 1–3 correspond to Han, She, and Hui.

progressively increasing from the inland to the east coastal areas, peaking in Jiangsu (481 Persons), Zhejiang (411 Persons), and Jiangxi (116 Persons) Province.

Benefiting from cultural prosperity, numerous rivers were named accordingly in terms of the geographic environment of regions flowing through, as well as local cultural characteristics and language habits. The cultural brand of human–river relations has been partially condensed in the river chorography through a series of milestone works (Figure 5b): *The Chinese Classics* (*Yugong*) (Legge, 2000) during the Warring States Period (475 BC–221 BC), *Geographical Records in the History of the Han Dynasty* (Dubs, 1938) in the Han Dynasty (202–220), *Commentary on the Waterways Classics* (D. Y. Li, 1894) in the Northern Wei Dynasty (515–527), *Yuanhe Records of Prefectures and Counties* (J. P. Li, 1983) in the Tang Dynasty (813), *An Outline of Waterways* (Z. N. Qi, 1878) in the Qing dynasty, and more recently, the *Encyclopedia of Rivers and Lakes* (Editorial Committee of Encyclopedia of Rivers and Lakes in China, 2014). In addition, historic river regulation strategies and grand hydraulic engineering works (e.g., the Lingqu Canal and Dujiangyan irrigation system) are also great legacy of Chinese human–river culture over the past 2000 years.

The human affinity for rivers and cultural prosperity along rivers is not limited to the national scales. On the global scale, a great number of rural settlements are clustered near the tributaries, and middle-large sized cities (each of population >0.5 million Persons) are distributed along the mainstream rivers stretching to estuarine areas (Figure 6). It seems that population density (D_{2015}, Person km^{-2}) increases with increasing HI in most great river basins worldwide (Figure 6), though exceptions do exist in high-latitude or arid regions. Areas with higher habitability (HI> 5) are frequently found in East Asia, South Asia, Western Europe, the eastern region of North America, and the southeastern region of South America, where the majority of the world's total population is settled (Zhang, 2013). Similarly, human aggregation catalyzed cultural prosperity in a variety of realms represented worldwide by Occidental Culture, Islamic Culture, Indian Culture, East Asian Culture, South-East Asian Culture, and Meso-African Culture (Deng, 2012).

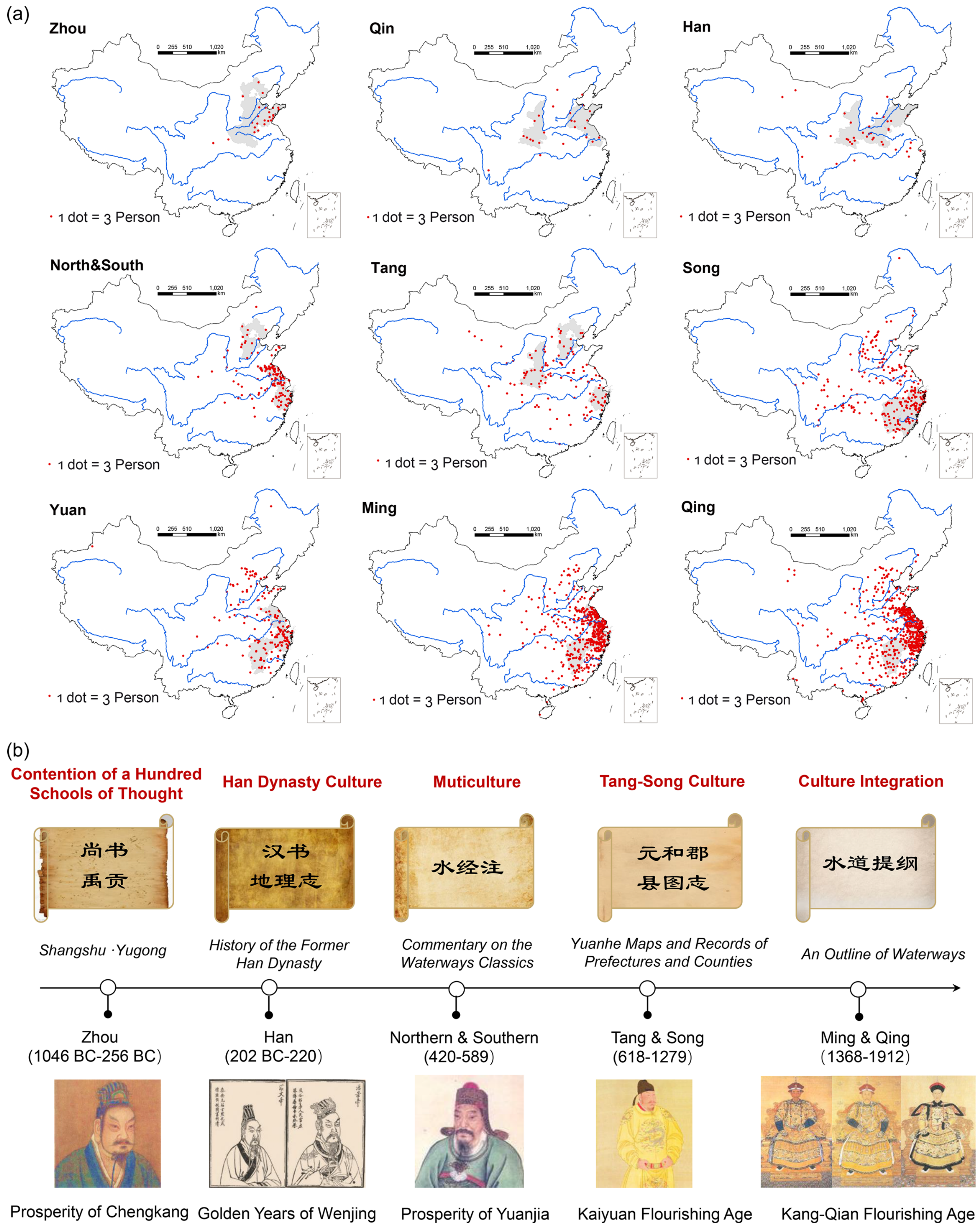

FIGURE 5 Evolution of cultural prosperity from the perspective of human–river relations partially determined by (a), distribution of recorded number of litterateurs (D_L, Person), and (b), growing perfection of river chorography with cultural development throughout history

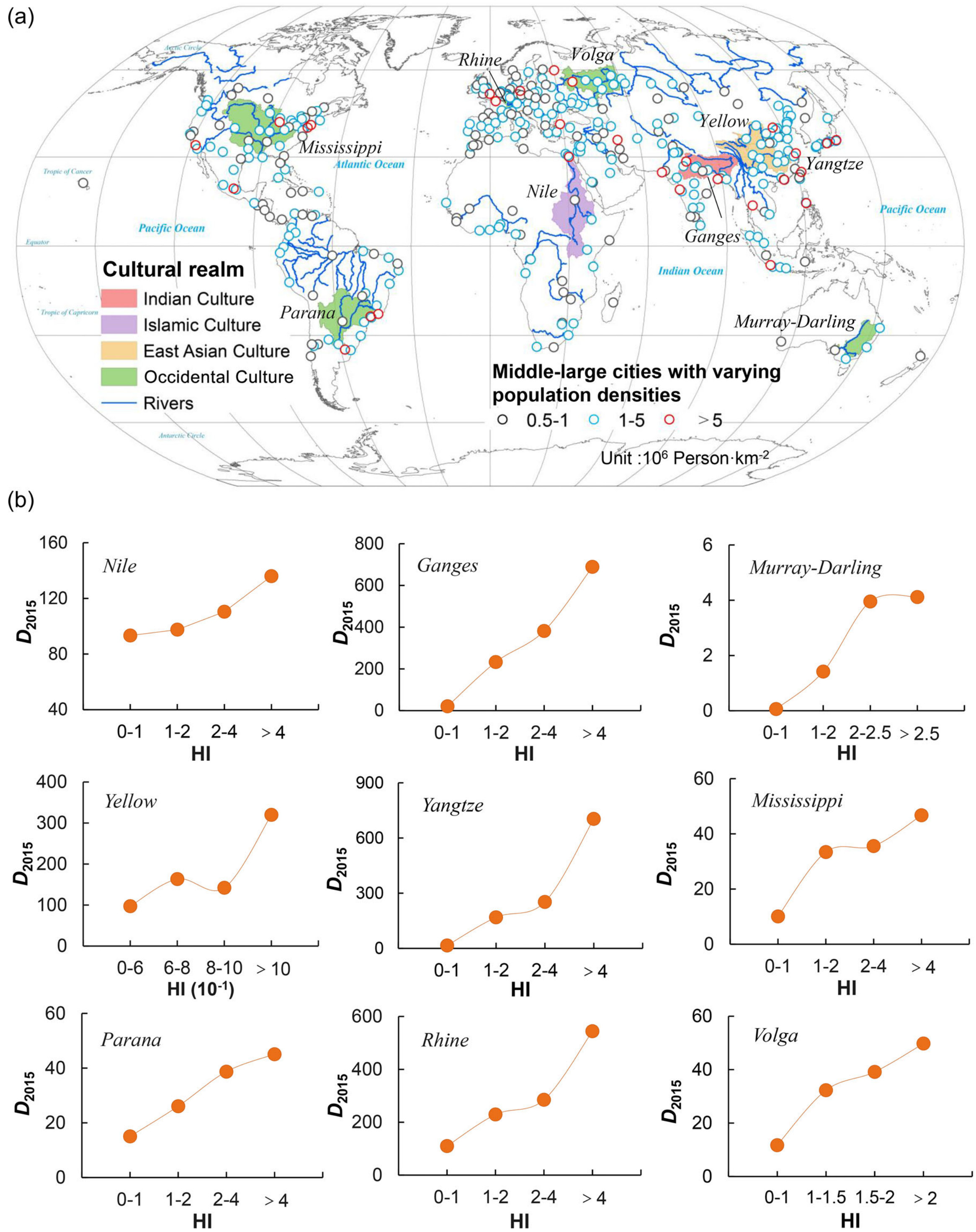

FIGURE 6 Human affinity for rivers and cultural prosperity worldwide. (a) Global distribution of cultures near large rivers and (b) relations between habitability (HI) and population density (D_{2015}, Person km^{-2}) in representative large river basins.

4 | CONCLUSIONS

We confirm the preferential orientation of human affinity for rivers through the linkage between natural river density, human livability, population density, and cultural prosperity in China. Compared with the distribution of population density derived from the demographic census in the Qing Dynasty (1776) under a near-natural state, we find that the relationship between population density and habitability, demarcated by the so-called "Hu Line", generally holds to date (2019) despite long-term natural and anthropogenic changes in the past centuries. Moreover, self-similarity of the human–water co-occurrence relationship exists over sub-basins at varying stream-orders in river networks. We further extend human-water linkage to humanistic perspectives and interpret cultural prosperity and clusters of ethnicity under four representative modes of human aggregation towards rivers, including the splendid Chinese cultures developed in the arid (desert) areas, the alluvial plains, the plateaus, and the coastlands across the whole country. This study also highlights the importance of human–water harmony for historical, socioeconomic and cultural developments in global river ecosystems.

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DATA AVAILABILITY STATEMENT

The data included in this study are available upon request from the corresponding author.

ETHICS STATEMENT

The authors confirm that this article does not contain any studies with animal or human subjects.

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REFERENCES

Bai, R., Li, T. J., Huang, Y. F., Li, J. Y., & Wang, G. Q. (2015). An efficient and comprehensive method for drainage network extraction from DEM with billions of pixels using a size-balanced binary search tree. *Geomorphology*, *238*, 56–67. https://doi.org/10.1016/j.geomorph.2015.02.028

Best, J. L. (2019). Anthropogenic stresses on the world's big rivers. *Nature Geoscience*, *12*, 7–21. https://doi.org/10.1038/s41561-018-0262-x

Bianchi, T. S. (2016). *Deltas and humans: A long relationship now threatened by global change*. Oxford University Press.

Ceola, S., Laio, F., & Montanari, A. (2015). Human-impacted waters: New perspectives from global high-resolution monitoring. *Water Resources Research*, *51*, 7064–7079. https://doi.org/10.1002/2015WR017482.

Chen, F. H., Dong, G. H., Zhang, D. J., Liu, X. Y., Jia, X., An, C. B., Ma, M. M., Xie, Y. W., Barton, L., Ren, X. Y., Zhao, Z. J., Wu, X. H., & Jone, M. K. (2015). Agriculture facilitated permanent human occupation of the Tibetan plateau after 3600 B.P. *Science*, *347*, 248–250. https://doi.org/10.1126/science.1259172

Chen, J. F. (2014). *Nomadic culture of the Qinghai-Tibetan Plateau*. China Social Science Press (in Chinese).

Chen, X. B., Wang, Y. C., & Ni, J. R. (2019). Structural characteristics of river networks and their relations to basin factors in the Yangtze and Yellow River basins. *Science China: Technological Sciences*, *62*, 1885–1895. https://doi.org/10.1007/s11431-019-9531-0

CHGIS. (2003). *CHGIS, Version: 2.0*. Harvard Yenching Institute.

Deng, H. (2012). *Geography of world cultures* (2nd ed.). Peking University Press (in Chinese).

Department of Geography, Northwest Normal University. (1984). *Atlas of physical geography of China*. SinoMaps Press (in Chinese).

Dubs, H. H. (1938). *Geographical records. The history of the Han Dynasty: A critical translation with annotations*. Waverley Press.

Editorial Committee of Encyclopedia of Rivers and Lakes in China. (2014). *Encyclopedia of rivers and lakes in China*. China Water Power Press (in Chinese).

Fang, Y., Ceola, S., Paik, K., McGrath, G., Rao, P. S. C., Montanari, A., & Jawitz, J. W. (2018). Globally universal fractal pattern of human settlements in river networks. *Earth Future*, *6*, 1134–1145. https://doi.org/10.1029/2017EF000746

Fang, Y., & Jawitz, J. W. (2019). The evolution of human population distance to water in the USA from 1790 to 2010. *Nature Communications*, *10*, 430. https://doi.org/10.1038/s41467-019-08366-z

Gao, Y. (2012). *A research on the new deal in northeast at the end of the Qing dynasty*. Heilongjiang Education Press (in Chinese).

Ge, J. X. (2001). *History of population in China*. Fudan University Press (in Chinese).

Hasan, F. A. (1997). The dynamics of a riverine civilisation: A geoarchaeological perspective on the Nile valley, Egypt. *World Archaeology*, *29*, 51–74. https://doi.org/10.1080/00438243.1997.9980363

Horton, R. E. (1945). Erosional development of streams and their drainage basins: Hydro-physical approach to quantitative morphology. *Bulletin of the Geological Society of America*, *56*, 275–370. https://doi.org/10.1177/030913339501900406

James, P. E. (1972). *All possible worlds: A history of geographical ideas*. The Bobbs-Merrill Company.

Kummu, M., de Moel, H., Salvucci, G., Viviroli, D., Ward, P. J., & Varis, O. (2016). Over the hills and further away from coast: Global geospatial patterns of human and environment over the 20th–21st centuries. *Environmental Research Letters*, *11*, 034010. https://doi.org/10.1088/1748-9326/11/3/034010

Kummu, M., de Moel, H., Ward, P. J., & Varis, O. (2011). How close do we live to water? A global analysis of population distance to freshwater bodies. *PLoS One*, *6*, e20578. https://doi.org/10.1371/journal.pone.0020578

Kummu, M., & Varis, O. (2011). The world by latitudes: a global analysis of human population, development level and environment across the north–south axis over the past half century. *Applied Geography*, *31*, 495–507. https://doi.org/10.1016/j.apgeog.2010.10.009

Legge, J. (2000). *The Chinese classics (Yugong), Vol III, The Shoo king, or the book of historic documents*. SMC Publishing Inc. (English translation of Chinese book).

Li, D. Y. (1894). *Commentary on the waterways classics*. Baohua Press. (in Chinese).

Li, J. C., Han, L. Y., Zhang, G. M., Su, Z. Z., & Zhao, Y. F. (2017). Temporal-spatial variations of human settlements in relation to environment change during the Longshan culture and Xia-Shang periods in Shanxi Province, China. *Quaternary International*, *436*, 129–137. https://doi.org/10.1016/j.quaint.2016.11.048

Li, J. P. (1983). *Yuanhe records of prefectures and counties*. Zhonghua Book Company (in Chinese).

Li, L., Ni, J. R., Chang, F., Yue, Y., Frolova, N., Magritsky, D., Borthwick, A. G. L., Ciais, P., Wang, Y. C., Zheng, C. M., & Walling, D. E. (2020). Global trends in water and sediment fluxes of the world's large rivers. *Science Bulletin*, *65*, 62–69. https://doi.org/10.1016/j.scib.2019.09.012

Ling, H. B., Xu, H. L., Fu, J. Y., Fan, Z. L., & Xu, X. W. (2013). Suitable oasis scale in a typical continental river basin in an arid region of China: A case study of the Manas River Basin. *Quaternary International*, *286*, 116–125. https://doi.org/10.1016/j.quaint.2012.07.027

Liu, M. X., Xu, X. L., Wang, D. B., Sun, A. Y., & Wang, K. (2016). Karst catchments exhibited higher degradation stress from climate change than the non-karst catchments in southwest China: An ecohydrological perspective. *Journal of Hydrology*, *535*, 173–180. https://doi.org/10.1016/j.jhydrol.2016.01.033

Liu, Y. J., Zhu, H. B., & Wang, R. (2010). The opinions of the names' formation causes of rivers in the Northern areas of China. *Chinese Agricultural Science Bulletin*, *26*, 347–350(in Chinese).

Maavara, T., Chen, Q. W., Meter, K. V., Brown, L. E., Zhang, J. Y., Ni, J. R., & Zarfl, C. (2020). River dam impacts on biogeochemical cycling. *Nature Reviews Earth & Environment*, *1*, 103–116. https://doi.org/10.1038/s43017-019-0019-0

Macklin, M. G., & Lewin, J. (2015). The rivers of civilization. *Quaternary Science Reviews*, *114*(15), 228–244. https://doi.org/10.1016/j.quascirev.2015.02.004

Mei, X. L. (2004). Manifestation and rules of transmutation of the ancient Chinese literature geography (Doctoral dissertation). Shanghai Normal University. Retrieved from CNKI. http://cdmd.cnki.com.cn/Article/CDMD-10270-2004060855.htm.

Moore, I. D., Grayson, R. B., & Ladson, A. R. (1991). Digital terrain modelling: A review of hydrological, geomorphological, and biological applications. *Hydrological Processes*, *5*, 3–30. https://doi.org/10.1002/hyp.3360050103

Ni, J. R., Wang, H. Z., Ma, T., Huang, R., Ciais, P., Li, Z., Yue, Y., Chen, J. F., Li, B., Wang, Y. C., Zheng, M. S., Wang, T., & Borthwick, A. G. L. (2022). Three Gorges Dam: Friend or foe of Riverine Greenhouse Gases? *National Science Review*, *6*, nwac013. https://doi.org/10.1093/nsr/nwac013

Qi, W., Liu, S. H., Zhao, M. F., & Liu, Z. (2016). China's different spatial patterns of population growth based on the "Hu Line". *Journal of Geographical Sciences*, *26*, 1611–1625. https://doi.org/10.1007/s11442-016-1347-3

Qi, Z. N. (1878). *An outline of waterways*. Shanghai Wenruilou Press (in Chinese).

Qian, M. (1994). *An introduction to the cultural history of China, revised version*. Beijing: The Commercial Press (in Chinese).

Scanlon, B. R., Faunt, C. C., Longuevergne, L., Reedy, R. C., Alley, W. M., McGuire, V. L., & McMahon, P. B. (2012). Groundwater depletion and sustainability of irrigation in the US High Plains and Central Valley. *Proceedings of the National Academy of Sciences*, *109*, 9320–9325. https://doi.org/10.1073/pnas.1200311109

Singh, A., Thomsen, K. J., Sinha, R., Buylaert, J. P., Carter, A., Mark, D. F., Mason, P. J., Densmore, A. L., Murray, A. S., Jain, M., Paul, D., & Gupta, S. (2017). Counter-intuitive influence of Himalayan river morphodynamics on Indus Civilization urban settlements. *Nature Communications*, *8*, 1617. https://doi.org/10.1038/s41467-017-01643-9

Strahler, A. N. (1952). Hypsometric (area-altitude) analysis of erosional topography. *Bulletin of the Geological Society of America*, *63*, 1117–1142. https://doi.org/10.1130/0016-7606(1952)63[1117:HAAOET]2.0.CO;2

Strahler, A. N. (1957). Quantitative analysis of watershed geomorphology. *Eos, Transactions, American Geophysical Union*, *38*, 913–920. https://doi.org/10.1029/TR038i006p00913

Tan, Y. H. (2002). *Lingnan culture and art*. South China University of Technology Press (in Chinese)

Tellman, B., Sullivan, J. A., Kuhn, C., Kettner, A. J., Doyle, C. S., Brakenridge, G. R., Erickson, T. A., & Slayback, D. A. (2021). Satellite imaging reveals increased proportion of population exposed to floods. *Nature*, *596*, 80–86. https://doi.org/10.1038/s41586-021-03695-w

Veldkamp, T. I. E., Wada, Y., Aerts, J. C. J. H., Doll, P., Gosling, S. N., & Liu, J., et al (2017). Water scarcity hotspots travel downstream due to human interventions in the 20th and 21st century. *Nature Communications*, *8*, 15697. https://doi.org/10.1038/ncomms15697

Viviroli, D., Kummu, M., Meybeck, M., Kallio, M., & Wada, Y. (2020). Increasing dependence of lowland populations on mountain water resources. *Nature Sustainability*, *3*, 917–928. https://doi.org/10.1038/s41893-020-0559-9

Wang, Y., & Wang, Q. C. (2008). *Qi-Lu Culture*. Current Affairs Press (in Chinese).

Wang, Y. C., Chen, X. B., Borthwick, A. G. L., Li, T. H., Liu, H. H., Yang, S. F., Zheng, C. M., Xu, J. H., & Ni, J. R. (2020). Sustainability of global Golden Inland Waterways. *Nature Communications*, *11*, 1553. https://doi.org/10.1038/s41467-020-15354-1

Wang, Y. C., Gao, X. W., Li, T. J., Yue, Y., Fang, H. Q., & Ni, J. R. (2018). Geocode-based aquatic habitats in hierarchical system of the Yellow River basin. *Journal of Environmental Informatics*, *32*, 69–81. https://doi.org/10.3808/jei.201800386

Wang, Y. C., Ni, J. R., Yue, Y., Li, J. Y., Borthwick, A. G. L., Cai, X. M., et al. (2019). Solving the mystery of vanishing rivers in China. *National Science Review*, *6*, 1239–1246. https://doi.org/10.1093/nsr/nwz022

Wang, Z. Y., Yu, G. A., Huang, H. Q., & Wang, R. Y. (2012). Gender of large river deltas and parasitizing rivers. *International Journal of Sediment Research*, *27*, 18–36. https://doi.org/10.1016/S1001-6279(12)60013-4

Wu, J., Nan Xu, N., Wang, Y. C., Zhang, W., Borthwick, A. G. L., & Ni, J. R. (2021). Global syndromes induced by variations of dissolved solids in world's large rivers. *Nature Communications*, *12*, 5940. https://doi.org/10.1038/s41467-021-26231-w

Xie, Y. W., Bie, Q., & He, C. S. (2017). Human settlement and changes in the distribution of river systems in the Minqin Basin over the past 2000 years in Northwest China. *Ecosystem Health and Sustainability*, *3*, 1401011. https://doi.org/10.1080/20964129.2017.1401011

Yu, T. X. (1981). *History of western regions culture*, Wulumuqi: Volksverlag Xinjiang (in Chinese)

Yuan, K. (2014). *Annotations to classic of mountains and rivers*. Beijing United Publishing Company (in Chinese).

Zanardo, S., Zaliapin, I., & Foufoula-Georgiou, E. (2013). Are American rivers Tokunaga self-similar? New results on fluvial network topology and its climatic dependence. *Journal of Geophysical Research—earth Surface*, *118*, 166–183. https://doi.org/10.1029/2012JF002392

Zhang, H. (1991). *Wu-Yue culture*. Liaoning Education Press (in Chinese).

Zhang, M. H., Yan, S., Pan, W. Y., & Jin, L. (2019). Phylogenetic evidence for Sino-Tibetan origin in northern China in the Late Neolithic. *Nature*, *569*, 112–115. https://doi.org/10.1038/s41586-019-1153-z

Zhang, S. Y. (2013). *Introduction to population geography* (3rd ed.). East China Normal University Press (in Chinese).

Zhang, Z. Q. (2004). *Southwest ethnics culture of the Yunnan-Guizhou Plateau*. Hubei Education (in Chinese)

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