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A Socio-Hydrological Unit Division and Confluence Relationship Generation Method for Human–Water Systems

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Abstract: Studies on human activities and the natural water cycle as a coupled system are essential for effective water resource management in river basins. However, existing calculation methods based solely on the natural water cycle do not meet the accuracy requirements of natural society dualistic water cycle simulations. Therefore, it is necessary to establish a more scientific and reasonable calculation unit division method and river confluence relationship determination method. This paper presents a socio-hydrological unit with natural society dual characteristics based on both the hydrological characteristics and the social administrative characteristics of the river basin. According to the elevation of the river buffer zone, river confluence relationships among socio-hydrological units are determined, and upstream and downstream confluence of the human–water system is obtained. Finally, a case study of the Jing-Jin-Ji region in China, an area of intensive human activities, was performed. A reliability of 94.3% was reached using the proposed socio-hydrological unit division and river confluence calculation method, suggesting that the approach is highly applicable. Thus, the proposed method for generating socio-hydrological units and determining river confluence relationships can be applied to study the mutual influence and spatial distribution characteristics of natural society dualistic water cycles. The data requirement is minimal, and the approach can provide benefits in research on human water systems.

Keywords: natural society dualistic water cycles; socio-hydrological unit; confluence relationship; elevation of river buffer zone; human–water system

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1. Introduction

With the intensification of human activities, the natural water cycle process has shown significant natural society dualistic water cycle characteristics, and rivers unaffected by human activities are difficult to find in areas with permanent human settlements [1–4]. River runoff is affected by water intake and drainage systems of human societies [5,6]. In addition, artificially constructed canal systems partially change the flow direction of rivers [7]. For these reasons, the study of human activities and the natural water cycle as a coupled human–water system is crucial for effective water resources management and sustainable economic and social development of river basins [8,9]. Furthermore, a more scientific and reasonable method of socio-hydrology unit division and confluence relationship determination should be established and would be of great significance in the construction of simulation models of coupled human–water systems for the management and regulation of water resources.

Hydrological models are important tools for quantitatively studying coupled human–water systems [10]. The construction of accurate hydrological models relies on the appropriately dividing the study area into suitable calculation units (such as sub-watershed units) and determining their river confluence relationships [11]. However, calculation units determined by the natural water cycle alone do not meet the accuracy requirements of natural society dualistic water cycle simulations. At present, the most commonly used methods for dividing hydrological models into calculation units are the grid method and the natural watershed method. The grid method divides the research area into rectangular grids of the same size according to the accuracy requirements of the specific research problem. Owing to its simplicity, the grid method has been applied in the Système Hydrologique Europeen (MIKE SHE) model [12,13], variable infiltration capacity (VIC) model [14,15], and other hydrological models. However, to achieve high accuracy, the number of grids will increase exponentially, leading to the dimensional disaster problem. Conversely, when the accuracy is too low, the model will not properly reflect regional topographic features. The natural watershed method is based on a digital elevation model (DEM), which can extract and divide the river network and sub-watershed; it not only reflects the confluence relationship between the sub-watershed, but can also refine the sub-watershed according to the research requirements for accuracy. This approach has been used with the Soil and Water Assessment Tool (SWAT) model [16–18], water and energy transfer process (WEP) [11,19], and other hydrological models.

The above unit division methods and corresponding hydrological models have been widely used in the fields of hydrological analysis, flood forecasting, and runoff simulation [20–24]. Modifications are typically made to the division of units and determination of confluence relations according to the characteristics of the river basin or study area [25–28]. For example, the WEP model considers the influence of contour zones in dividing the sub-watershed [29]; Jeong and Adamowski [30] introduced a socio-hydrology model using system dynamics in SWAT, presenting a useful approach for process socio-hydrology; Essenfelder et al. [31] created hydrologic–economic representative units in SWAT by combining the boundary of policy decision-making entity and hydrologic responsive units; Farjad et al. [32] analyzed the interaction between human and natural systems by changing land use in MIKE SHE.

Although the methods for unit division and determination of confluence relationships have been improved, these methods cannot be sufficiently applied to research on coupled human–water systems. Previous studies on coupled human water systems based on hydrological models were mostly conducted by adding a water intake process into the water cycle model to reflect the mechanism of mutual feedback between the human activities and the natural water cycle [33–35]. However, since most calculation units are based on grid division or sub-watershed division, a calculation unit often spans two or more administrative boundaries and cannot respond to the different water intake and drainage management policies of different administrative divisions.

In addition to constructing socio-hydrological units based on hydrological models, many scholars have constructed different socio-hydrological units on the basis of local characteristics [36–39]. For example, in order to analyze the co-evolution law of a human and water system in the flooded area of Mekong Delta, Luu et al. [40] constructed four research units considering low dike, high dike, and communes. York et al. [41] considered that it was difficult to establish clear governance boundaries due to regional and international telecoupling on water resource management in the western US. Therefore, they proposed implementing cross-scale and multilevel management of regional water resources using the socio-hydrological system. For the Murray–Darling basin in Australia, as it is composed of sub-basins of different sizes and different states have their own management requirements for rivers, different watershed scales and corresponding management requirements should be taken into account when dividing basin management units [42]. Coelho et al. [43] proposed that hydrographic, physical–environmental, socioeconomic, and political–administrative elements should be considered simultaneously when dividing water resource planning and management units.

At the same time, many water resource management projects also need to consider the natural and social characteristics of the units in the study area. For example, in inter-basin water transfer projects, there will be some social, environmental, and economic impacts on the water source areas and water receiving areas; therefore, multiple natural and social attributes need to be considered in unit division. For example, in Iran's water diversion project from the western basin to Rafsanjan Plain, social policies and natural factors such as local groundwater changes were considered in the water receiving area [44]; this was also the case for Iran's water diversion project from the Great Karoon Basin to the Central Iranian Platea [45]. The construction of a hydropower project will affect the hydrology, morphology, and social economy of the whole basin. By combining the hydrological characteristics of the watershed with the social administrative and ecological characteristics, it is of great significance to study the impact of dam construction. For example, different scholars have studied the impacts of the Ranganadi Hydel project in India [46] and Patuca III Hydropower Project in Honduras [47] on downstream agriculture, fisheries and ecology. In addition, in 2009, the United States and Mexico signed a joint report on the management of transboundary aquifers, which not only divided aquifers according to different hydraulic connections, but also considered the influence of different institutional, economic, social, and political factors in the two countries, providing new insights for transboundary aquifer management and evaluation [48].

It is worth noting that the above studies divided the socio-hydrological units mainly from the perspective of watershed management; however, in research on coupled human–water systems, the relationship between the upstream and downstream confluence of calculation units must be determined to obtain the dynamic response relationship between the downstream water intake and upstream drainage. For example, the water intake, consumption, and drainage of the social water cycle have a huge impact on the water balance of China's Yellow River Basin [49]; upstream drainage water can be used downstream, which significantly increases the total regional water withdrawal. Similarly, in other river basins around the world, such as Saskatchewan River basin [50], transboundary Indus Basin [51], transboundary Lancang–Mekong River [52], and Syr Darya river basin [53], there are also complex relationship between the downstream water intake and upstream drainage. Therefore, in a coupled human–water system, the hydrological characteristics and social administrative characteristics of the river basin should be combined to establish a socio-hydrological unit and to determine the upstream and downstream confluence relationship. This would be of great significance in studying the mutual influence and spatial distribution characteristics of natural society dualistic water cycles.

The main research objectives of this work were as follows: (1) to generate a socio-hydrological unit with natural society dualistic water cycle characteristics on the basis of the hydrological characteristics and social administrative characteristics of the river basin; (2) to determine the confluence relationships among the socio-hydrological units and determine the upstream and downstream confluence of the human–water system; (3) to verify the effectiveness and applicability of the proposed method. By dividing calculation units according to natural society dualistic features in areas with intensive human activities, extracting generalized river networks, and forming confluence relationships, a natural society dualistic water cycle simulation based on socio-hydrological units can be realized. This approach can be applied to water cycle and water balance analyses and research at different scales such as irrigation districts, cities, provinces, and river basins.

2. Methodology

2.1. Division into Socio-Hydrological Units

The socio-hydrological units were generated by superimposing social administrative districts on the basis of water resource zones with characteristics of natural watersheds. The water resource zone can be generated for a sub-watershed by using either the DEM or hydrological zoning boundaries provided by local watershed management agencies. For administrative districts, the administrative boundary is determined by the local government. Moreover, the scope of the study area determines which administrative level of government is appropriate.

Since human activities and water resource policies are managed by different administrative districts, the water resource zone and administrative district are superimposed to form a socio-hydrological unit, which not only conforms to the characteristics of natural watersheds, but also reflects the impacts of different water resources management policies in different administrative districts. As shown in Figure 1, the water resource zone and the administrative district can be divided and grouped into seven socio-hydrological units.

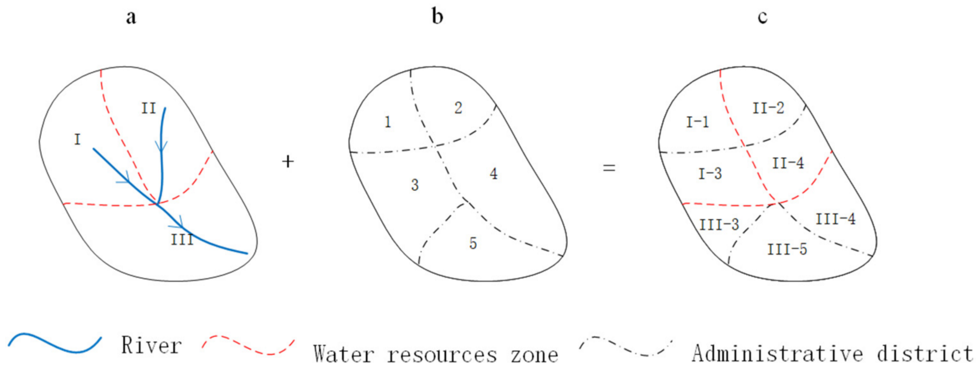

Figure 1. Division of water resource zone (**a**) and administrative district (**b**) into socio-hydrological units (**c**).

2.2. Determination of Confluence Relationship between Water Resource Zones

Water resource zones include sub-watersheds generated using the DEM and hydrological zones based on local watershed management agencies. For study areas with existing hydrological zones, existing river data can be directly used to determine the confluence relationships between hydrological zones; for study areas in which no hydrological zones exist or hydrological zones are too large to meet the research requirements, new hydrological zones can be determined using the DEM, and the confluence relationships between hydrological zones can be determined.

Before the sub-watershed division, the DEM should be corrected by filling depressions according to the actual river network, such as the AGREE algorithm [54]. For the corrected DEM, the flow direction and flow accumulation of each DEM grid can be calculated using the D8 algorithm [55]. Then, the outlet of the basin and basin boundary can be determined. By setting a threshold of accumulation, a digital river network can be generated, and different sub-watersheds are sequentially generated according to the intersections in the river network. The topology of the river network can then be used to establish the confluence relationships between the sub-watersheds. The sub-watershed division and confluence calculation process are illustrated in Figure 2.

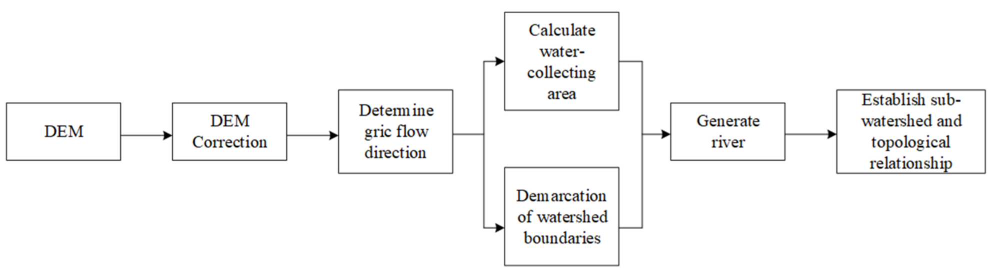

Figure 2. Schematic diagram of sub-watershed division process and establishment of confluence relationships.

2.3. Determination of Confluence Relationship between Socio-Hydrological Units

The confluence relationships of the water resource zones obtained in Section 2.2 conform to the actual river directions. However, after superposing the water resource zones and administrative districts to generate socio-hydrological units, it is difficult to use traditional DEM-based methods to determine the confluence relationships since the administrative boundaries and water resource boundaries are not coincident.

To ensure the rationality of the confluence relationship, this study assumes there is still one and only one drainage basin outlet in the water resource zone after superimposing the water resource zones to generate several socio-hydrological units. The specific process for determining the confluence relationship is described below.

1. Calculation of elevation of river buffer zone

A river buffer zone is proposed, defined as a buffer zone that surrounds the river channels that forms as a result of any river channel within the socio-hydrological unit extending a certain distance in the vertical flow direction of the river. The average elevation within the river buffer zone is the elevation of the river buffer zone in this socio-hydrological unit. The elevation of the river buffer zone is calculated as follows:

$$h = \frac{\sum_i^{n_1} h_{i,\ river} + \sum_j^{n_2} h_{j,\ river\_buffer}}{n_1 + n_2}, \quad (1)$$

where h is the elevation of the river buffer zone, n_1 is the number of raster units in the river channel, n_2 is the number of raster units in the river buffer zone, $h_{i,\ river}$ is the grid elevation of the i-th raster unit in the river channel, and $h_{j,\ river\_buffer}$ is the grid elevation of the j-th raster unit in the river buffer zone.

A schematic diagram of the river buffer zone is presented in Figure 3. The river buffer zone includes not only the elevation of the river channel, but also the slope on both sides of the river channel, which can comprehensively reflect the elevation of the area in which the river is located. Compared with the average elevation of an area, the elevation of the river buffer zone is not affected by hills, mountains, and depressions in that area. For adjacent socio-hydrological units with rivers flowing through them, the elevation of the river buffer zone can reflect the characteristics of the river flowing from a unit with a higher riverbed to one with a lower riverbed.

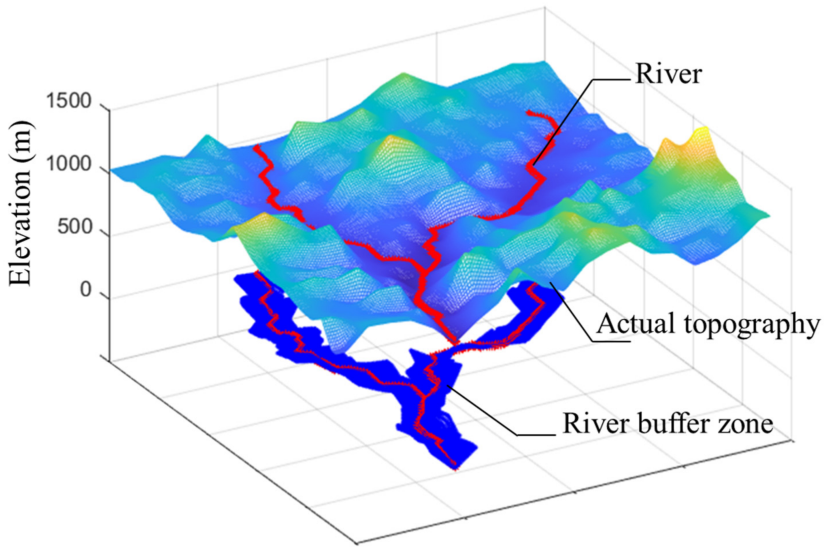

Figure 3. Schematic diagram of river buffer zone.

2. Determination of neighborhoods between socio-hydrological units

The neighborhood relationship of socio-hydrological units can be classified as nonadjacent, adjacent within the same watershed, and adjacent between different watersheds. As shown in Figure 1c, a total of seven socio-hydrological units were generated. Taking the III-3 socio-hydrological unit as an example, the unit is not adjacent to the I-1 and II-2 socio-hydrological units but is adjacent to I-3 in a different watershed and III-5 in the same watershed.

3. Determination of outlet of water resource zone

Since each water resource zone has only one outlet unit, it is necessary to determine the outlet unit of each water resource zone before calculating its confluence. For water resource zone A, if water resource zone A has no downstream basin, the socio-hydrological unit with the lowest elevation in the river buffer zone is selected as the outlet unit of the water resource zone; otherwise, if A has a downstream basin B, all units in water resource zone A that are adjacent to water resource zone B are first determined, and then the lowest elevation of the river buffer zone among these units is select as the outlet unit of A.

4. Confluence of socio-hydrological units and generation of generalized river networks

A set of specific socio-hydrological unit confluence rules can be defined. For socio-hydrological unit A in the water resource zone, the set of all other units adjacent to Q_A should be obtained, and then filtered to obtain $Q_{A'}$, which belongs to the same water resource zone as A. Finally, unit B is obtained as the unit in set $Q_{A'}$ with the lowest elevation of the river buffer zone, and unit A will converge to unit B. According to the above rules, all socio-hydrological units in the water resource zone are calculated until the confluence directions of all socio-hydrological units in the different water resource zones of the study area are determined.

As shown in Figure 4, the confluence relationship (Figure 4b) between different water resources zones is determined on the basis of the river relationship between water resource zones (Figure 4a). Then, on the basis of the elevation of the river buffer zone of the socio-hydrological unit (Figure 4c) and the adjacent relationship between the units, the confluence relationship between the socio-hydrological units in the same water resource zone can be determined (Figure 4d). Finally, a generalized river network of the entire study area is obtained according to the confluence relationships between all socio-hydrological units (Figure 4e).

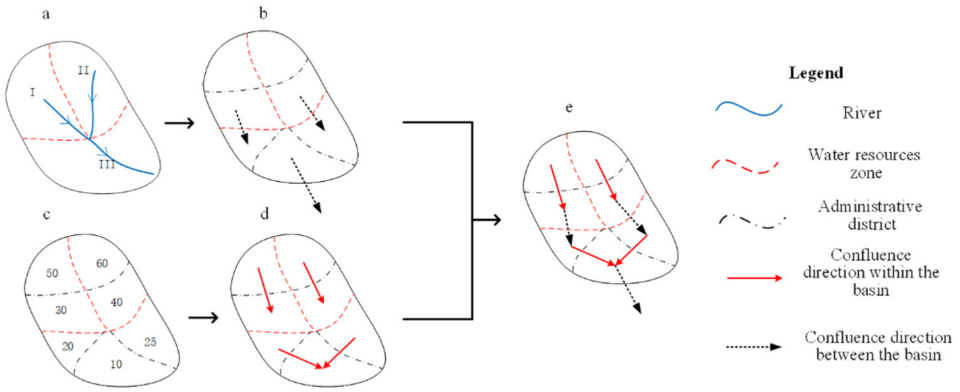

Figure 4. Confluence of socio-hydrological units and generation of generalized river network, (**a**) the water resource zones, (**b**) the confluence relationship between different water resources zones, (**c**) the elevation of the river buffer zone of the socio-hydrological unit, (**d**) the confluence relationship between the socio-hydrological units in the same water re-source zone, (**e**) the confluence relationships between all socio-hydrological units.

3. Study Area

The Jing-Jin-Ji region was used as a case study to test the proposed method of social-hydrological unit division and confluence relationship calculation. The Jing-Jin-Ji region is the largest economic area in northern China, covering an area of 218,000 km^2. The region includes the three provinces of Beijing, Tianjin, and Hebei, as well as the Luanhe river basin, Liaohe river basin, Haihe north river basin, Haihe south river basin, and other various water resource zones. There are many rivers, and the relationship between these rivers is complicated. The DEM data of the study area were obtained from the geographic national conditions monitoring platform (http://www.dsac.cn/DataProduct/Index/20

0820, accessed on 29 July 2021), with a resolution of 90 m × 90 m. As shown in Figure 5, the topography of the study area is high in the west and low in the east, with an average elevation of 503 m. At the 100 m contour (red line in Figure 5), the area can be divided into mountainous areas and plain areas, with the mountainous areas accounting for 58% of the total area.

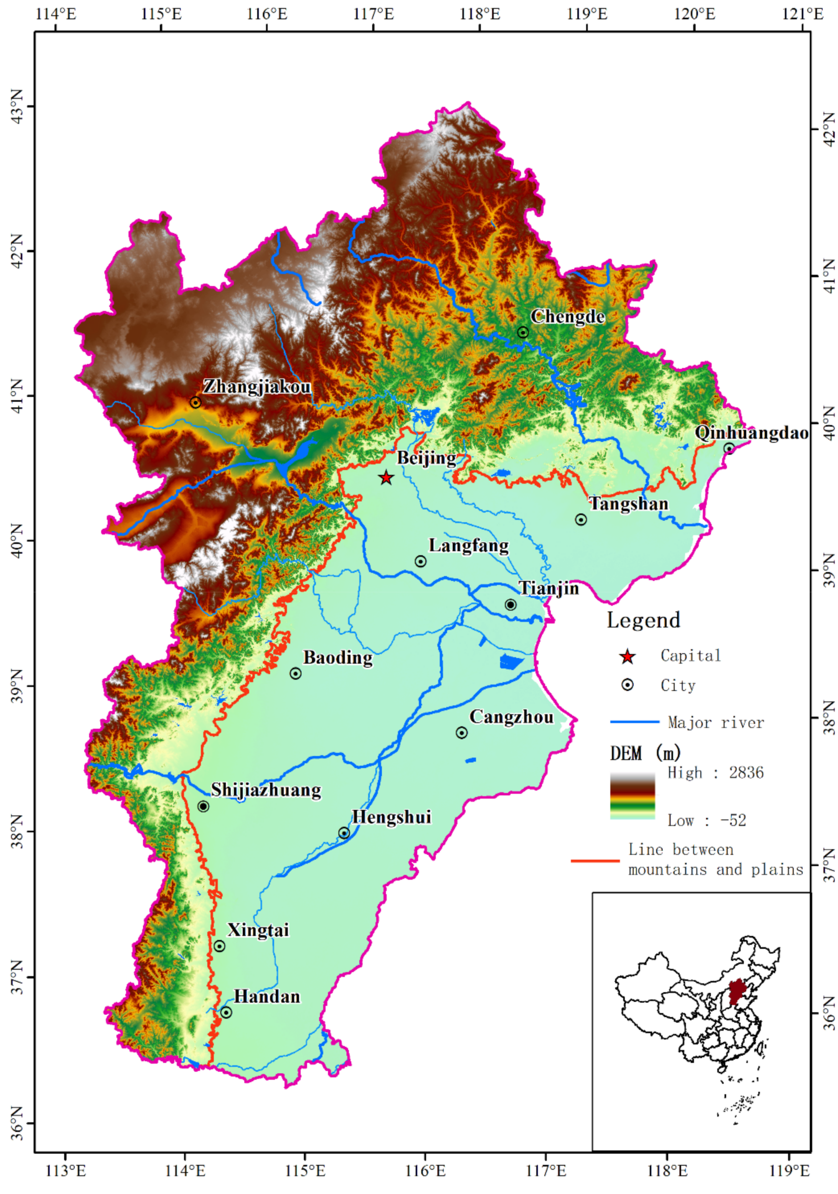

Figure 5. Overview of Jing-Jin-Ji region.

The water resources and social characteristics of Jing-Jin-Ji Region are shown in Figure 6. It can be seen that the region is seriously short of water resources. From 2014 to 2018, the average water resources in the region constituted 19.5 billion m^3, and the water consumption was 25.1 billion m^3. The utilization rate of water resources was more than 129%, and agricultural water accounted for more than 59%. Meanwhile, the region is economically and socially developed. In 2018, the total GDP (gross domestic product) exceeded 8441 billion CNY (about 1266 billion USD, accounting for about 9% of China's total GDP), of which Beijing, Tianjin, and Hebei accounted for 39%, 22%, and 38% respectively, and the proportion of the tertiary sector is the largest, accounting for more than 65%. At the same time, the total population of the region is 112.7 million, and the urbanization rate exceeds 66%.

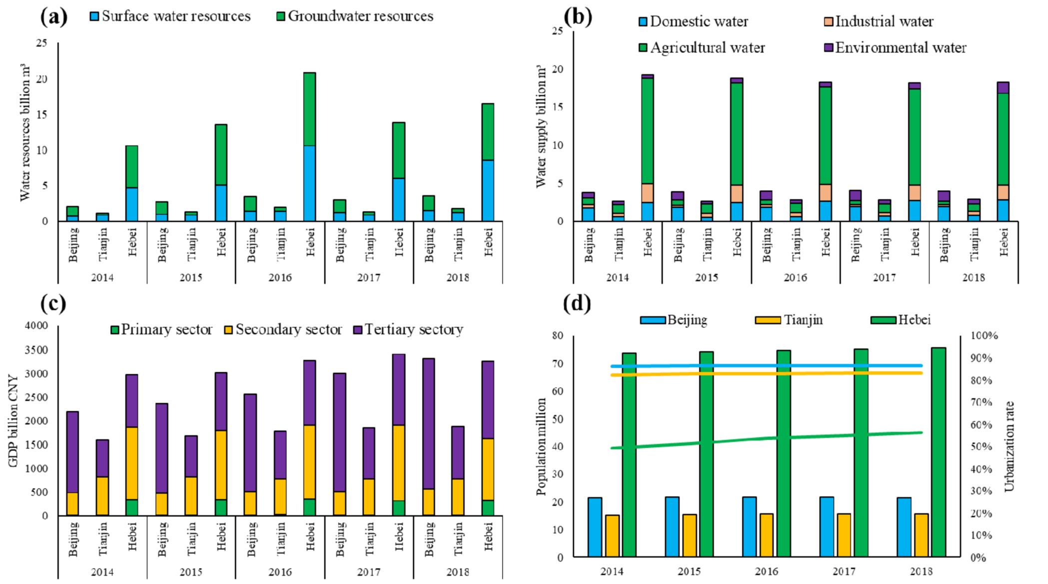

Figure 6. The water resources and socio-economic characteristics of Jing-Jin-Ji Region: (**a**) water resources; (**b**) water supply; (**c**) GDP; (**d**) population.

4. Results

4.1. Generation of Socio-Hydrological Units

First, a division of the study area into socio-hydrological units based on the administrative districts and water resource zones of the Jing-Jin-Ji region was carried out. The administrative division was based on counties, of which there are a total of 172 district/county units, as shown in Figure 7a. The study area contains a total of six water resource zones (as seen in Figure 7b). The scale of the water resource zone is too large, and it was, therefore, refined using the DEM. According to the method in Section 2.2, on the basis of the six original water resource zones, 48 new water resource zones and a river network with a river network density (total length of the river/area of the study area) of 0.089 were generated. The confluence of each water resource zone was obtained. The confluence relationships between the water resource zones are shown in Figure 7b.

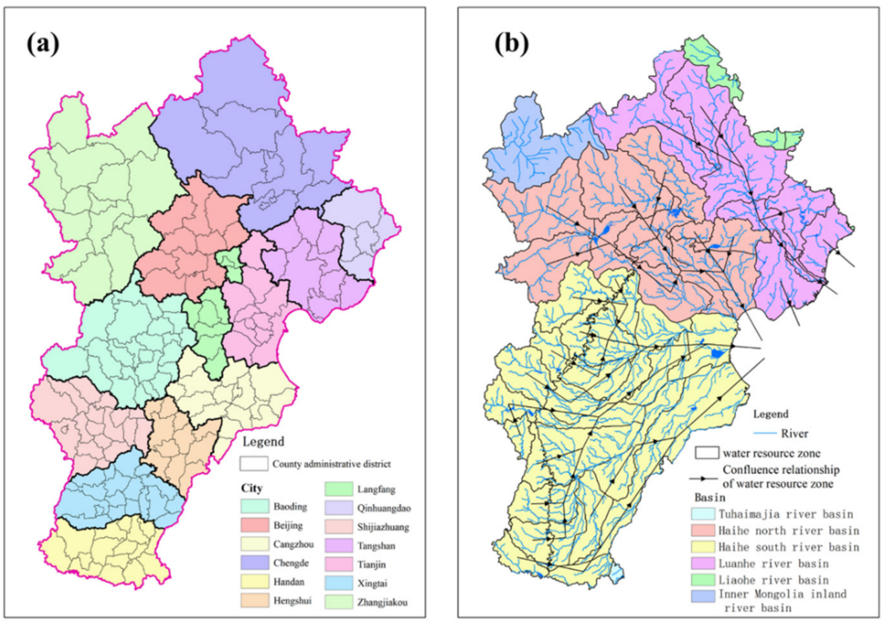

Figure 7. (**a**) Administrative district and (**b**) water resource zones of study area.

As shown in Figure 7, the boundaries of administrative districts and water resource zones do not overlap. With the water resource zones as the bottom layer, the superimposed administrative districts generated socio-hydrological units. Newly generated units with a total area of less than 5% of the original unit area were merged with surrounding units. A total of 283 socio-hydrological units were generated, as shown in Figure 8.

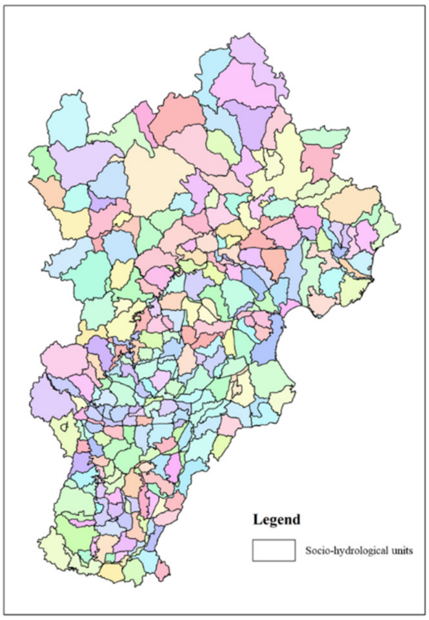

Figure 8. Socio-hydrological units of the study area.

4.2. Calculation of Elevation of River Buffer Zone

The elevation of the river buffer zone based on 3 km river buffer length (the impact of different buffer lengths on the confluence results is discussed in Section 5) was calculated for all socio-hydrological units, and the results are illustrated in Figure 9. It can be seen that the elevation of the river buffer zone decreased from northwest to southeast. At the same time, the average elevation of the socio-hydrological unit was calculated as a comparison, and the comparison results are shown in Table 1. It is worth noting that, because of the large topographical difference between mountainous and plain areas, the land contour also had some impact on the results. An average elevation of 100 m was adopted as the dividing line in this study, and the results were divided into plain and mountainous areas for analysis.

Table 1. The comparison of average elevation and elevation of river buffer zone (m).

Area	Average Elevation	Elevation of River Buffer Zone
Mountain	850	742
Plain	28	26
Jing-Jin-Ji	503	440

As shown in Table 1, the elevation result was significantly higher when the unit average elevation was used instead of the river buffer zone. The average elevation of the study area is 503 m, which is 14% higher than that of the river buffer zone of 3 km, suggesting that higher terrain around the valley was also included in the calculation, leading to an increase in elevation.

The elevation of all socio-hydrological units was compared between river buffer zone and average, as shown in Figure 10. In mountainous areas, the elevation of the river buffer zone for more than 91% of units was lower than the regional average elevation; with the increase in average elevation, the gap between river buffer elevation and average elevation tended to increase. This is because, in mountainous areas, hills, and other areas of higher elevation, rivers flow between canyons, and the average elevation of the unit is significantly higher than the elevation of the river buffer zone. The average elevation can represent the average elevation of the hills and valleys inside the unit, but cannot reflect the characteristics of the river flowing down the valley.

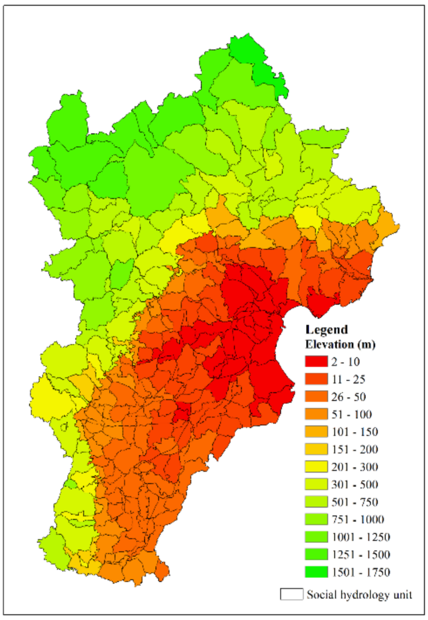

Figure 9. The elevation of river buffer zone in each socio-hydrological unit.

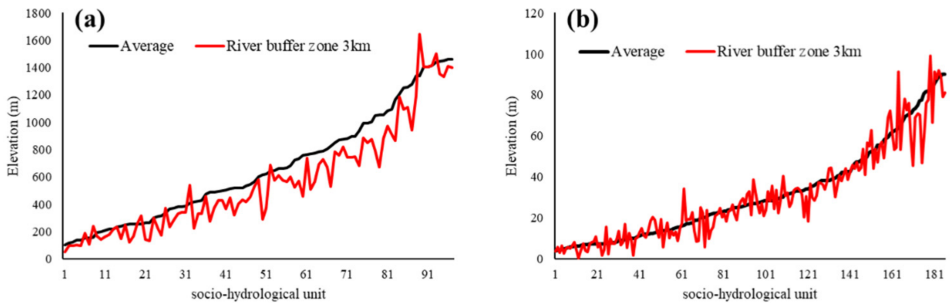

Figure 10. Comparison of river buffer elevation and average elevation of all socio-hydrological units: (**a**) mountain area; (**b**) plain area.

In plain areas, the elevation of the river buffer zone of more than 59% of units was lower than the regional average elevation; the difference between the two elevations was within 7%, and there was no obvious trend with average elevation change. This is because, in the plain area, depressions, ponds, etc. directly affect the average elevation, which may lead to fluctuation differences between the average elevation and the elevation of the river buffer zone. Overall, the elevation of the river buffer zone can better reflect the true characteristics of the confluence of the socio-hydrological unit than the average elevation of the unit.

4.3. Determination of Confluence Relationship of Jing-Jin-Ji Region and Reliability Analysis

The generalized river network of the social hydrological unit in the study area was obtained as shown in Figure 11. Comparing the relationship between the generalized river network and the actual river network, the generalized river network clearly reflects the confluence relationships between the socio-hydrological units in the Jing-Jin-Ji region.

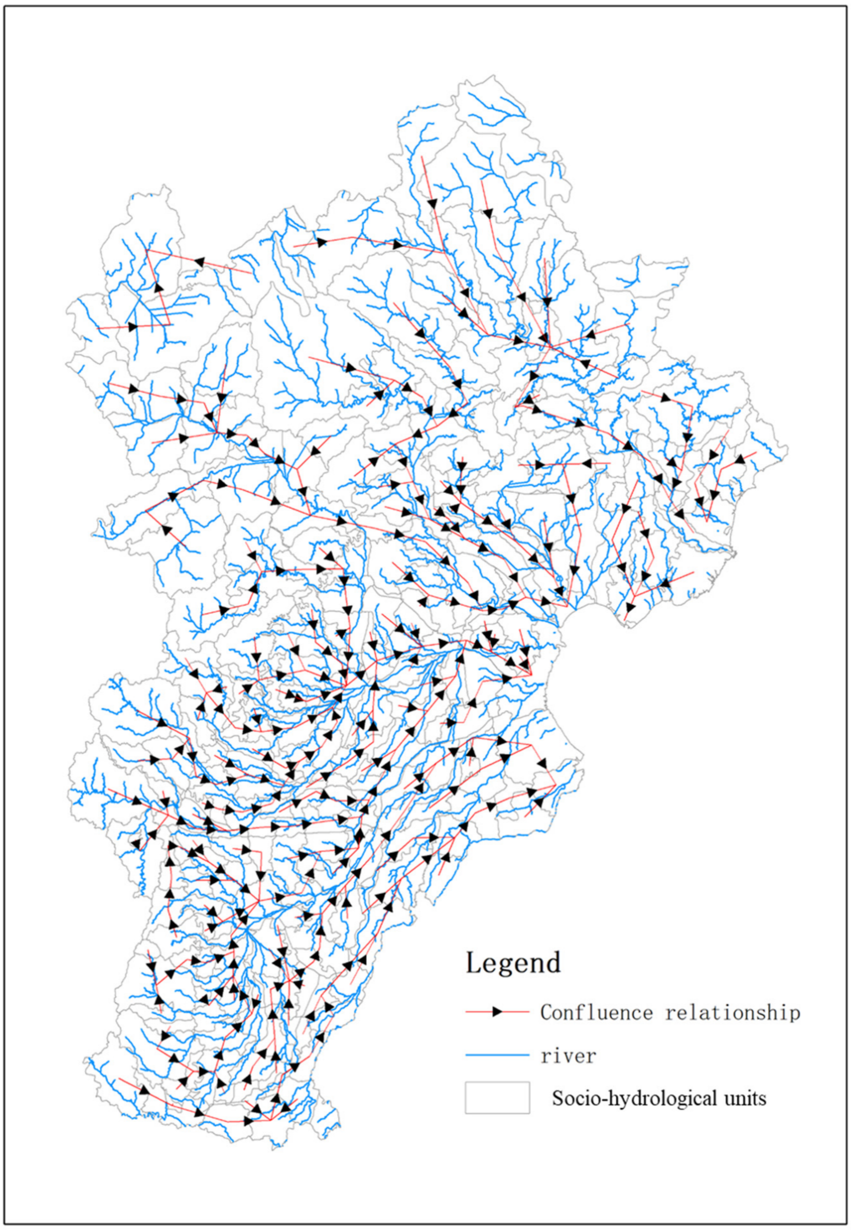

Figure 11. Generalized river network of study area.

On the basis of generalized river network of study area, Google Earth, digital river data, and encyclopedia of rivers and lakes in China, the confluent relationship of each socio-hydrological unit was manually identified and corrected. The corrected confluence relationship is shown in Figure 12.

Reliability analysis is a statistical method to evaluate the consistency of results, and it was used to determine whether the proposed method in this study achieved a permissible level of performance. According to relevant references [56,57], the calculation formula of reliability analysis is

$$Rel = \left(\frac{100\%}{n}\right) \sum_{i=1}^{n} k_i. \tag{2}$$

When the i-th socio-hydrological unit confluence relationship is consistent with the corrected confluence relationship, k_i = 1; otherwise, k_i = 0.

The calculated results show that the Rel of the confluence relationship obtained by the river buffer was 94.3%, while the Rel of the average elevation was 81.6%. The socio-hydrological units with errors in river buffer and average elevation are shown in Figure 13. It can be seen that there were a few units with problems in river buffer zone, which were mainly distributed in the upstream units of mountainous areas and had little influence on the water balance of downstream units. Overall, the method is highly reliable, which suggests it is widely applicable.

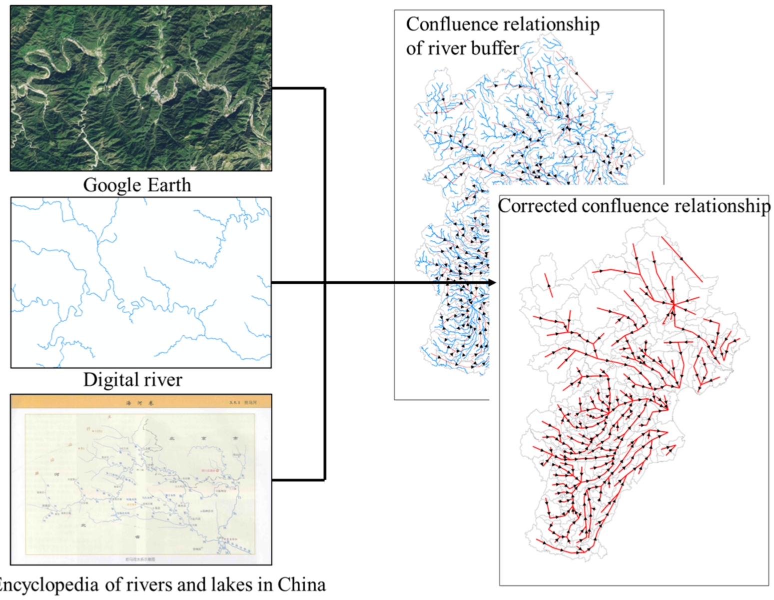

Figure 12. The corrected confluence relationship of Jing-Jin-Ji region.

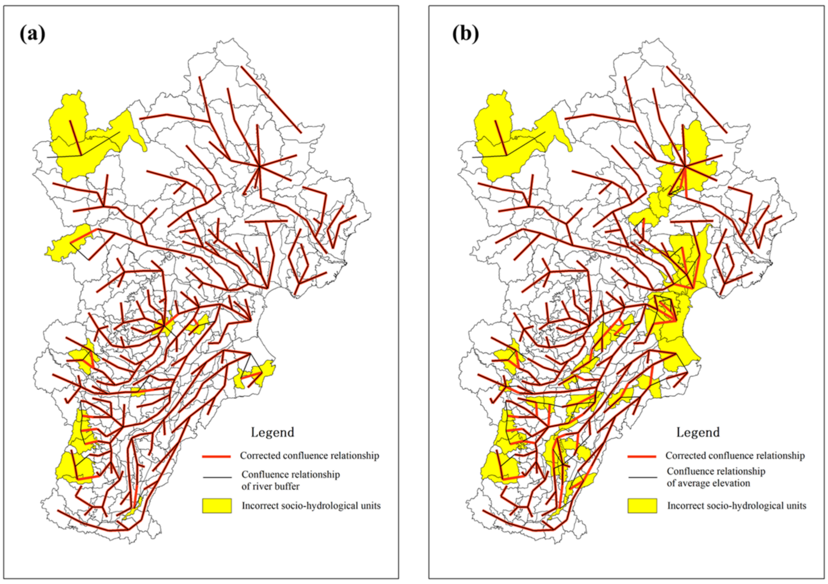

Figure 13. The difference between corrected confluence relationship and (**a**) confluence relationship of river buffer, and (**b**) confluence relationship of average elevation.

5. Sensitivity Analysis of Length of the River Buffer Zone and River Channel Density

The river buffer length directly affects the elevation of the river buffer zone of the units, which has an impact on the final generalized river network. Therefore, a sensitivity analysis was conducted. On the basis of the resolution of the DEM data and the actual distribution of the river, a total of seven different river buffer lengths were selected: 0.2 km, 0.5 km, 1 km, 2 km, 3 km, 4 km, and 5 km.

Figure 14a shows the reliability of the different buffer lengths. The results show that the Rel of all seven river buffer lengths exceeded 92%, indicating that the method itself has strong stability. When the buffer length was 3 km, the Rel of the confluence results was highest, and the results were the most stable. The Rel increased as the length of the buffer zone increased, but tended to worsen above 3 km. Although, in this study, the results were best when a 3 km buffer length was adopted, the results were also highly consistent with different river buffer lengths. Therefore, in practice, the buffer length can be adapted to local conditions including the size of the study area and the DEM resolution.

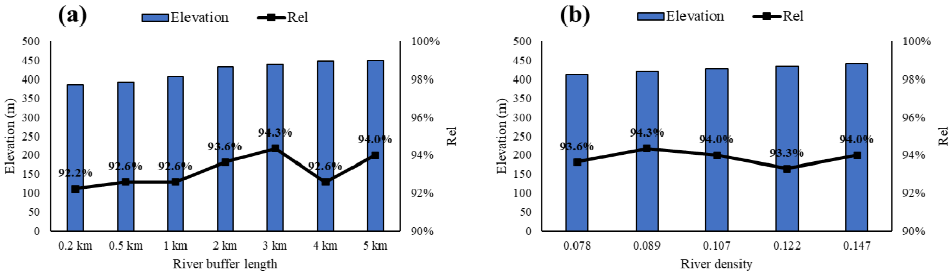

Figure 14. The reliability of (**a**) different river buffer lengths, and (**b**) different river densities.

In addition to the length of the river buffer zone, the density of the river network (total river length/area) will also affect the final confluence result. Therefore, five river networks with different densities were generated using the hydrological analysis toolbox in ArcGIS 10.2: 0.078, 0.089 (the same river network used in Section 4), 0.107, 0.122, and 0.147. According to the results presented above, a 3 km buffer length was adopted. The results are shown in Figure 14b.

As the density of the river network increased, the elevation of the river buffer zone also increased; however, the differences between the elevations were small. Comparing the confluence results under different river network densities, the Rel of all river densities exceeded 93%, indicating that only a small part of the unit flow relationship was inconsistent.

Although the river network density had some impact on the confluence results, the influence was small. The river network density and the length of the river buffer zone both affected the confluence results by affecting the elevation of the river buffer zone. For a single unit, the entire range of the river buffer zone of the unit would increase as the density of the river network increases or the length of the river buffer zone increases. Therefore, both factors, the density of the river network and the length of the river buffer zone, have similar effects on the confluence results. For practical use, when the river density satisfies the existing river network in each socio-hydrological unit, only the influence of the length of the river buffer zone should be considered to simplify the calculations.

6. Conclusions

To address the characteristics and needs of coupled human–water system simulations, this paper proposed a novel method for generating socio-hydrological units and to determine of the confluence relationship among units. The Jing-Jin-Ji region was used as a case study to test the proposed method of socio-hydrological unit division and confluence relationship calculation. The results showed that the Rel of the method reached 94.3%, suggesting that the method is highly applicable, and Rel increased by more than 12% compared with average elevation. Meanwhile, the influence of river buffer length and river network density on the confluence relationship was calculated, and the results showed that the variation of river length and river network density had little influence on the Rel. Thus, for practical use, only the influence of the length of the river buffer zone should be considered to simplify the calculations.

Overall, the method can be used to study the mutual influence and spatial distribution characteristics of natural society dualistic water cycles. For example, when using SWAT, WEP, and other hydrological models to conduct socio-hydrology research, the method can be used to realize the division of socio-hydrological units and the determination of confluence relations, so as to solve the problem of inconsistency between watershed units and administrative boundaries in traditional hydrological models. When conducting water resource management studies in large river basins, such as China's Yangtze River and Yellow River, Lancang–Mekong River, and Saskatchewan River, by using the method to determine the confluence relationship of upstream and downstream socio- hydrological units, the problem of water dynamic balance caused by downstream water intake and upstream drainage can be solved. Furthermore, it can also be widely used in water transfer projects, hydropower projects, transboundary water resource management, and other engineering practices.

In addition, only data on the water resource zone, administrative district, and DEM are required, which are convenient and highly attainable. Therefore, we hope that this new method can provide benefits in future research on human–water systems.

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