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Review Article

Critical issues in the characteristics and assessment of China's water resources

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Abstract: This study provides a comprehensive analysis of the concepts and assessment processes of water resources in China, focusing on the characteristics of water resources and variations in water cycle fluxes. It reveals that the distribution of water resources in China is uneven, with more south and less north, and human activities have led to a decline in water resources, particularly in northern arid and semi-arid regions. Further analysis shows that duplicated measurements of surface water and groundwater significantly affect water balance calculation and water resource assessments, serving as a crucial factor guiding water resource development and utilization. The study also finds that consistency correction of runoff series is insufficient to meet the requirements of accurate water resource assessment. It is urgent to strengthen fundamental research in hydrology and hydrogeology, and to establish a dynamic assessment system for the efficient management and rational use of surface water and groundwater in the current changing environment.

Keywords: Surface water resources; Groundwater resources; Assessment concepts; Duplicated measurement; Restoration measurement

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Introduction

Water resources refer to the annually renewable amount of water in the water cycle (Chen et al. 2002; Liu and Chen, 2001). They are part of natural resources generated through the water cycle that includes precipitation, surface runoff, groundwater flow, and evaporation, all undergoing annual renewal. Influenced by precipitation, water resources exhibit both interannual and seasonal dry-wet variations. Human activities, such as river regulation projects, reservoir construction, and well drilling for water extraction, affect the natural convergence of the water cycle and alter the state of surface runoffs and groundwater flows. This leads to the spatial and temporal redistribution of water resources. Water resources encompass surface water and groundwater, which interact through recharge and discharge.

In the late 1960s, many countries began to pay attention to water resources and conducted national-level assessments. For example, the United States completed two National Water Resources Assessments in 1968 and 1978, respectively, establishing the initial methods and technologies for Water Resource Assessment (WRA) based on hydrological and statistical theories. In 1988, the United Nations Educational, Scientific and Cultural Organization (UNESCO) and World Meteorological Organization (WMO) jointly developed *Water Resources Assessment – Handbook for Review of*

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National Capabilities, which was later revised in 1997. This handbook defined WRA as "the determination of the sources, extent, dependability, and quality of water resources to assess the possibility for utilization and control". It also promoted the convergence of WRA methods among different countries and significantly advanced the process of WRA. During the International Hydrological Decade (IHD) in the 1980s, water resources research was a primary focus, evolving in subsequent phases to address sustainable water resources development in a changing environment. The IHD also emphasized hydrology and water resources development in a vulnerable environment, water interactions, systems at risk, and social challenges. These established research themes, led by UNESCO and involving countries worldwide, reflect the evolving trends in international water resources research (UNESCO, 2022).

Water Resource Assessment (WRA) encompasses the evaluation of the quantity, quality, and utilization of water resources. This paper specially focuses on the assessments of quantity. WRA relies on statistics, hydrology, and water balance theory. Methods for surface water resources assessment include contour line mapping, gauging station representation, neighboring station comparison, and precipitation-runoff correlation techniques. The assessment of groundwater resources involves establishing water balance equations based on groundwater recharge and discharge to calculate regional groundwater resources (Zuo et al. 2008). As socio-economic development progresses, there is increasing demand for more accurate and timelier WRAs. New technologies and methods, such as numerical simulations, artificial neural networks, isotope hydrology, GIS, and RS are widely applied in WRA. For example, a GIS platform based on ArcGIS was developed for the Ningxia Water Resources Quantity Assessment System (Chen et al. 2022). Additionally, RS and DEM were used to automate contour lines generation, overcoming the problem of low accuracy in WRA in the complex terrains of Qinghai Province (Sun and Li, 2022). Based on the big data platform of Ministry of Water Resources of China (MWR), a dynamic WRA framework was established, incorporating data collection, standardization, data warehouse, and algorithm model interfaces to support complex WRA tasks (Zhang and Zhan, 2021). Distributed hydrological models provide a new method for WRA during sub-rainfall events (Xu et al. 2023).

In June 1979, China initiated the "National Comprehensive Survey and Assessment of Water Resources and Research on Rational Utilization" as part of the "Agricultural Natural Resources Survey and Agricultural Zoning" (Lin, 1980). Special research on water resources in North China was also launched during the national Sixth Five-Year and Seventh Five-Year Science and Technology Breakthrough Program. These research achievements laid the foundation for WRA concepts and established assessment methods. China has conducted three systematic WRAs: The first using data series from 1956 to 1979, the second from 1956 to 2000, and the third from 1956 to 2016. The first two assessments were jointly completed by the MWR and the Ministry of Natural Resources (previous Ministry of Geology and Mineral Resources). The latter focused on conducting aquifer system surveys and proposed plans for groundwater development and utilization, while the MWR primarily monitored, investigated, and assessed surface water resources. This included analyzing the relationships between surface water and groundwater recharge and discharge, ultimately leading to water resources planning recommendations. Since 1997, the MWR has annually compiled *China Water Resources Bulletin* to assess water resources for the current year. With recent institutional reforms, responsibilities for water resources surveys and rights confirmation, registration, and management have been transferred to the Ministry of Natural Resources. In recent years, the department has explored and implemented water resources survey and monitoring practices, establishing a preliminary system for water resources survey and monitoring (Li et al. 2022).

In conclusion, China has made significant progress in WRA and utilization. This paper provides a comprehensive analysis of different methods and processes of WRA across different periods. It reveals that assessing only the total water resources may overlook the potential of groundwater resources. Moreover, consistency correction of runoff series in changing environments poses challenges to ensuring the accuracy of the results, ultimately affecting water resources development and utilization. This article discusses these two key issues, which hold significant implications for national natural resources planning and efficient water resource utilization.

1 Characteristics of water resources development and utilization

In China, water resource development has evolved from demand-driven approach to one that emphasizes research and establishment of WRA concepts, employing advanced scientific technologies and methods for water resource management and utilization.

(1) Dominance of water supply: Integrated water resources development system combining reservoir, diversion, and extraction

After the founding of the People's Republic of China in 1949, large-scale construction of reservoirs, river channel improvements, and the development of water supply systems began. It is estimated that from 1949 to 1978, the number of dams over 30 meters in height increased from 21 to 3,651, with a total storage capacity reaching approximately 2,989×10^8 m^3. From 1978 to 2000, the construction of water supply projects significantly accelerated. By 2020, China had built 98,566 reservoirs with a total capacity of 930.6×10^9 m^3, capable of controlling 29.4% of the annual river runoff in the country. The effective irrigated area reached 691.61×10^9 m^2 (Ministry of Water Resources, 2021). The development of water regulation projects also led to substantial growth in the number of wells. The peak period for groundwater wells lasted from the late 1960s to the early 1980s, with 114,400 mechanical and electric irrigation wells in 1961, 2.691 million wells in 1980 (Ministry of Water Resources, China, 2009), 4.37 million wells in 2006 (Ministry of Water Resources, 2007), and 5.173 million wells in 2020 (Ministry of Water Resources, 2020).

China's water resource utilization[1] increased from 103.1×10^9 m^3/a in 1949 (Ministry of Water Resources, 2009) to 443.7×10^9 m^3/a in 1980 (Hu and Wang, 2016), reaching 618.34×10^9 m^3/a in 2013 and relatively stabilizing to 599.82×10^9 m^3/a in 2022. Agriculture accounts for the largest proportion of water resource utilization. Before 1980, agricultural water use made up 92.5% of total water consumption, which later decreased to 77.0% between 1980 and 2000, and furthered to 63.3% from 2000 to 2022 (Fig. 1) (Ministry of Water Resources, 1997–2022). Groundwater extraction is the primary water supply source in northern China. With more and more mechanical wells installed in the area, extracted groundwater has significantly increased. For example, groundwater extraction in the Beijing-Tianjin-Hebei Plain was 11.283×10^9 m^3/a in the 1970s (Zhang et al. 2009), increasing to 15.922×10^9 m^3/a from 2000 to 2010 (Yang et al. 2021). However, with the implementation of groundwater over-exploitation controls and the South-to-North Water Diversion Central Route Project, groundwater extraction has significantly decreased, dropping to 9.697×10^9 m^3/a in 2019. As a result, shallow groundwater levels in urban areas in western mountainous regions and deep groundwater levels in urban areas of central and eastern regions have rebounded (Yang et al. 2021).

(2) Exploration of WRA concepts: Formation of Basin-level WRA System

Before the 1980s, China's understanding of water resources was primarily focused on analyzing surface runoff and calculating aquifer storage. To support this, river hydrological stations and groundwater monitoring networks were established to systematically monitor river runoff, river water quality, sediment content, precipitation, evaporation, groundwater levels, and groundwater quality. This monitoring data was compiled annually, with various regional precipitation, runoff, and water level contour maps, as well as regional aquifer distribution maps, being produced. Publications such as the *China Hydrologic Atlas* (China Institute of Water Resources and Hydropower Research, 1963) and the *Hydrologic and Geologi-*

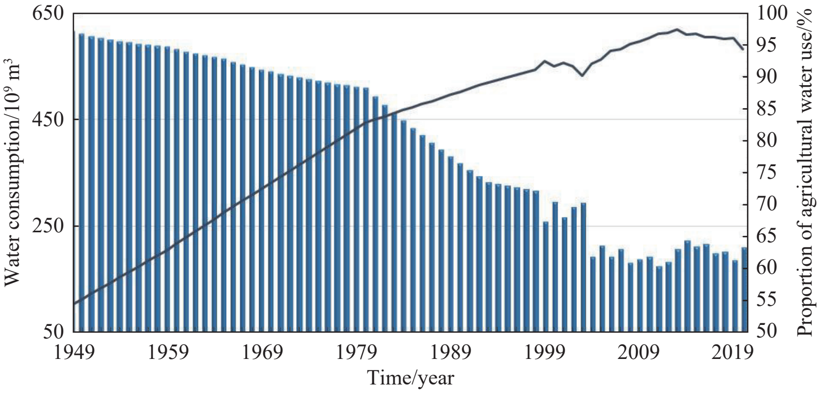

Fig. 1 Variations of China's water resources utilization and the proportion of agriculture water use

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[1] The WRA data in this paper does not include those in Taiwan Province, Hong Kong SAR, and Macau SAR.

cal Atlas of the People's Republic of China (Institute of Hydrogeology and Environmental Geology, CAGS, 1979) were released during this period.

In the 1970s, due to human interference in the water cycle, surface runoff decreased and overall groundwater levels declined, even under the same precipitation conditions. This led to the formation of groundwater depression cones in some areas and caused many rivers in northern China to dry up for entire years. For example, the Haihe River Basin experienced approximately 300 dry days annually from 1980 to 2003 (Zhang et al. 2009; Fei et al. 2001). In response to these challenges, China urgently needed to determine the available water supply and thus proposed the concept of WRA. Through groundwater balance experiments (Zhang, 1988), exploration of the coordination and balance between surface water and groundwater recharge and discharge (Fan, 1982), and establishment of WRA methods and theoretical systems (Chen et al. 1982; Chen, 1982), *A Guide to Water Resources Assessment* (SL/T238-1999) was developed to guide national WRA. China's WRAs are organized according to river systems and divided into 10 major basin regions, or 10 first-class regions. These regions include four in the south: Yangtze River Basin, Southeast Rivers, Pearl River Basin, and Southwest Rivers; and six in the north: Songhuajiang River Basin, Liaohe River Basin, Haihe River Basin, Yellow River Basin, Huaihe River Basin, and Northwest Rivers (Ministry of Water Resources, 2022).

(3) Construction of rational water resource utilization models: Achieving Cross-Basin water diversion and integrated management of surface water and groundwater

Monitoring and calculating available surface water and groundwater supplies have revealed that the water supply capacity in many regions of China cannot meet the demand required to drive economic development, particularly in the north. Statistics show that before 2000, China's average water shortage was 53.6×10^9 m^3, including approximately 30×10^9 m^3 for agricultural use. Water withdrawals from river channels has reduced ecological water use, resulting in a shortfall of around 13.2×10^9 m^3. This water scarcity has severely affected industrial and agricultural production, and urban and rural livelihoods in regions such as the Tarbagatay Basin, the northern slopes of the Tianshan Mountains, and the Turpan-Hami Basin in Xinjiang, the Heihe River Basin, the Shiyanghe River Basin, the Ordos Basin, the Guanzhong Plain, the North China Plain, the Shandong Peninsula, the northern part of the mid-reach of Huai River, and the Liaohe River Basin (MWR General Institute of Water Resources and Hydropower Planning and Design, China, 2010). The main reasons for the water supply-demand conflict are the arid climate and increased human water consumption. The former is mainly manifested in the mismatch between low rainfall in spring and crop water needs, while the latter is driven by the growth of industry and agriculture and population increase.

The primary means of addressing this conflict is to increase groundwater extraction and implement cross-basin water diversion projects. For example, in the 1960s and 1970s, groundwater extraction in northern China increased significantly. Shallow groundwater and deep confined water were extracted in parallel, reaching well depths of up to 400 meters. The Luanhe-Tianjin Water Diversion Project, which started operation in 1983, is an urban water supply project that transfers water from the Luanhe River in Hebei Province to Tianjin. This project combines new canal and natural river channels, transfering water through open channels over a distance of 200 km, stretching from the New Yongdinghe River to the Haihe River via new irrigation channels and the North Canal. The first phase of the South-to-North Water Diversion Central Route Project, which was fully operational in 2014, originates from the Danjiangkou Reservoir on the Hanjiang River in the Yangtze River Basin. It extends 1,277 km with open channel water transfer, benefiting Henan, Hebei, Beijing, and Tianjin by alleviating water shortages in North China. By the end of 2023, the project had transferred cumulative total of 60.6×10^9 m^3 of water (Tan, 2023).

2 Water resources distribution and variations

The following section presents data and diagrams in relation to water resources quantities and variations, duplicated measurement, restoration measurement, and water balance sources from the *Investigation and Evaluation of Chinese Water Resources and their Exploitation and Utilization* (MWR General Institute of Water Resources and Hydropower Planning and Design (GIWP), China. 2014).

(1) Water resources distribution

According to the assessment of data series from 1956 to 2000, China's average annual water resources amount to $2,841.2\times10^9$ m^3, with surface water resources totaling $2,738.8\times10^9$ m^3, groundwater resources 821.8×10^9 m^3, and duplicated measurement $719.4\times10^9 m^3$. Northern China's total resources amount to 526.7×10^9 m^3, while southern China's total is $2{,}314.5\times10^9$ m^3. The Water Yield Modulus in southern China greatly exceeds that of the north (Table 1).

Northern China's total water resources account for only 23% of those in southern China. In the semi-arid and arid regions of northern China, surface runoff is minimal and most water yield replenishes groundwater. As a result, groundwater resources constitute a higher proportion in the north (47%) compared to south (25%). In water-scarce regions like the Haihe River Basin, groundwater resources account for 64%, while surface water resources contribute 58%, and duplicated measurement 22%. In the Yellow River Basin, groundwater resources constitute 52% of the total, surface water resources 84%, and duplicated measurement 36% (Fig. 2).

(2) Changes in water resources quantity and causes of change

In the semi-arid and arid regions in northern China, human activities have significantly impacted the water cycle, leading to a decline in water resources. A comparison between the assessments of two time series (1956–1979 and 1956–2000) reveals a reduction in overall water resources. Surface water resources decreased from 450.7×10^9 m^3/a to 437.8×10^9 m^3/a, a decline of 2.9%. Groundwater resources decreased from 255.1×10^9 m^3/a to 245.8×10^9 m^3/a, a decline of 3.6%. Northern China has undergone more significant declines compared to the south. Water resources, surface water resources, and groundwater resources in river basins such as the Haihe River, Yellow River, and Liaohe River decreased by 12.1%, 25%, 11.4%; 3.3%, 8.2%, 7.2%; 13.7%, 16.2%, and −4.5%, respectively. In contrast, the water-abundant southern China has seen minimal variations, with slight increases in the total volume and surface water resources in the Yangtze River Basin (Fig. 3).

The main causes of variations in surface water resources include large-scale water conservancy projects, soil and water conservation projects, and groundwater extraction. These projects alter regional conditions for surface water yield and convergence, subsequently affecting the hydrological processes in a basin. The construction and operation of reservoirs regulate surface runoff through water storage and discharge, thus altering the distribution of runoff throughout the year (Sun and Zhao, 2019; Yang et al. 2023). Afforestation, terraces, and fish-scale pits designed to conserve water and reduce soil erosion have a strong capacity to intercept and store surface runoff. Experiments indicate that in moderate rainfall condition, forested areas can reduce surface runoff by 60% to 80% compared to bare land (Zhang and Wang, 2017; Chen et al. 2005; Zuo et al. 2008). Changes in land use, such as urban development and transportation infrastructure construction, increase surface runoff and runoff modulus, heightening the risk of urban waterlogging (Song et al. 2014). Additionally, changes in the way of land use also alter the composition of water resources (Liu et

Table 1 Average annual water resources

Water resource Region	**Precipitation (mm)**	**Surface water resources ($10^9 m^3$)**	**Groundwater resources ($10^9 m^3$)**	**Duplicated measurement ($10^9 m^3$)**	**Total water resources ($10^9 m^3$)**	**Water yield modulus ($10^4 m^3/km^2$)**
Northern China	328.2	437.8	245.8	156.9	526.7	8.7
Southern China	1,214.4	2,301	576	562.5	2,314.5	67.1
Total	649.8	2,738.8	821.8	719.4	2,841.2	30.0

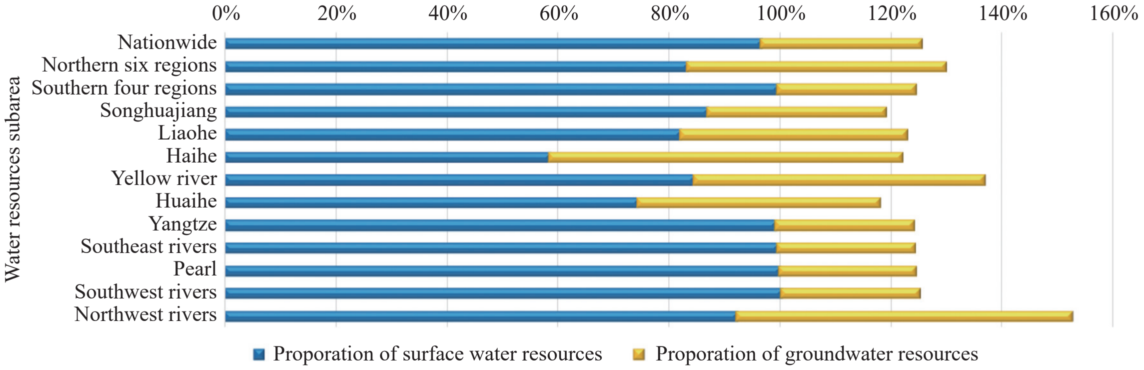


Fig. 2 Ratio of surface water and groundwater to total water resources

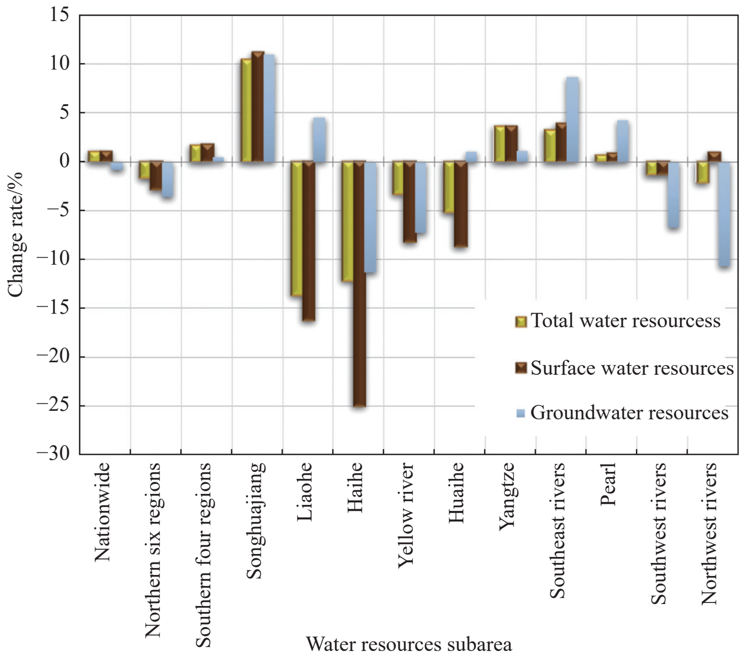


Fig. 3 Rate of change in water resources in different regions

al.). Human extraction of groundwater is a crucial factor influencing the variations in groundwater levels in semi-arid and arid regions (Fei et al. 2007; Meng et al. 2013).

(3) Characteristics of water balance

The water cycle initiated by precipitation includes three key components: Surface evapotranspiration, surface runoff, and infiltration that recharges groundwater, with the latter two contributing to the total water resources. Water that infiltrates underground is partially retained in the vadose zone, supporting plant growth (and is not considered here), while another portion flows as interflow and groundwater runoff into rivers, becoming part of river runoff. A portion of infiltrated water re-evaporates into the atmosphere, and the remainder percolates deeper to form groundwater.

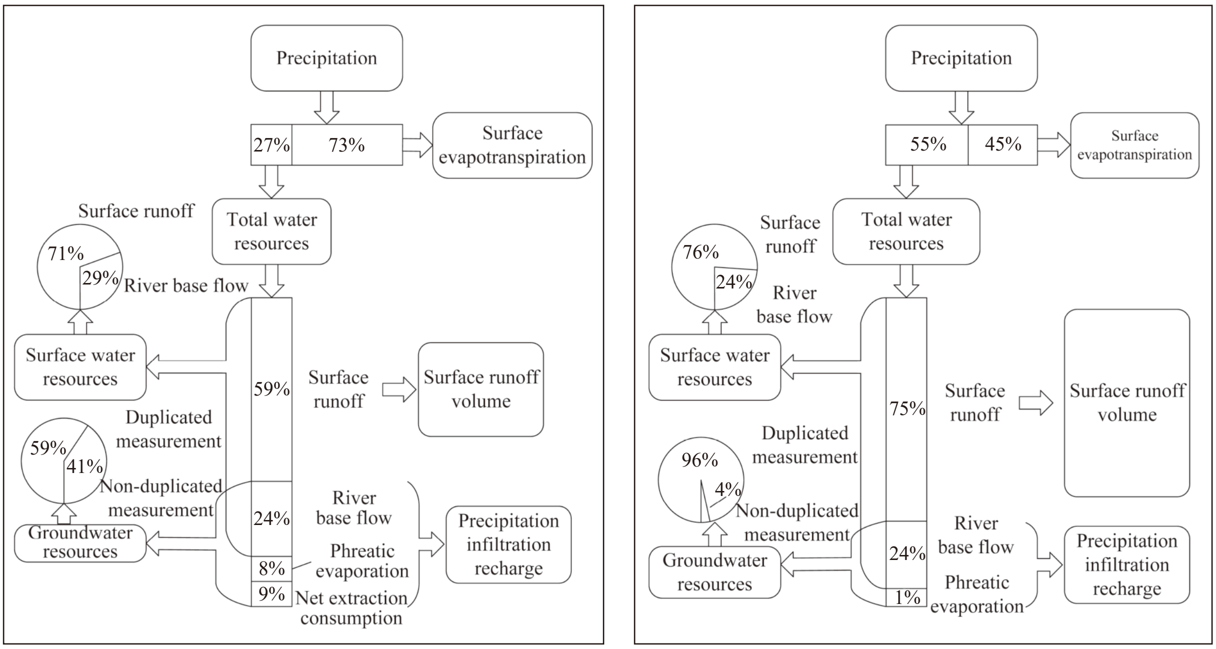
China's water resources assessments and water balance studies show that 54% of precipitation is lost to surface evapotranspiration, while 46% contribute to total water resources. Of this, 33% forms surface runoff, and 13% infiltrates to recharge groundwater. In northern regions, 73% of precipitation becomes surface evapotranspiration, with only 27% contributing to water resources—59% of which is surface runoff, 24% is river base flows, 8% is lost to phreatic evaporation, and 9% to underflows. In southern regions, 45% of precipitation becomes surface evapotranspiration, while 55% contributes to water resources—75% of which is surface runoff, 24% is river base flows, and only 1% is lost to phreatic evaporation (Fig. 4).

3 Key issues in quantitative Water Resources Assessment (WRA)

In WRA, the quantities of total water resources, surface water resources, and groundwater resources are essential for the rational development and utilization of water resources. The quantity of total water resources is defined as the algebraic sum of the quantity of surface water resources, groundwater resources, and the non-duplicated measurement within a basin or region (*Standard for Essential Technical Terminology and Symbol in Hydrology* (GB/T 50095—2014)). Surface water resources refer to the dynamic water volumes formed by local precipitation in surface water bodies such as rivers, lakes, and glaciers, which can be updated annually. Groundwater resources refer to the dynamic water volumes that are hydraulically connected to local precipitation and surface water bodies, participating in the water cycle and also subject to annual updates (commonly referred to as shallow groundwater resources). The WRA must address the following two key issues.

(1) Duplicated measurement: Significant volume for groundwater development

The water cycle involves an exchange between surface water and groundwater, resulting in a duplicated water volume measurement, commonly referred to as "duplicated measurement". This volume includes river base flows formed by precipitation infiltration that replenishes groundwater discharge and groundwater recharge caused by surface water infiltration. It is an indispensable



Northern regions Southern regions

Fig. 4 Water balance model

component of both surface water and groundwater resources. When calculating the total quantity of water resources, the duplicated measurement is subtracted from the sum of surface water resources and groundwater resources. Conversely, the portion of groundwater resources replenished by precipitation infiltration without being discharged via river base flows is termed "non-duplicated measurement". The total water resources quantity is calculated as the sum of surface water resources and the non-duplicated measurement.

The relationship between duplicated measurement, non-duplicated measurement, and the quantity of total water resources is as follows:

$$W=R+Q-D \tag{1}$$

$$W=R+P_r-R_g \tag{2}$$

Where: (P_r-R_g) is non-duplicated measurement. Combining Equations (1) and (2) will have:

$$Q = D+(P_r-R_g) \tag{3}$$

Where: W is quantity of total water resources; R is quantity of surface water resources; Q is quantity of groundwater resources; D is duplicated measurement; P_r is precipitation infiltration volume; and R_g is river base flow volume. All units are in cubic meters (m^3).

Equation (3) indicates that the sum of the duplicated measurement and non-duplicated measurement equals the total quantity of groundwater resources.

Duplicated measurement reflects the degree of hydraulic connection between surface water and groundwater, while non-duplicated measurement is proportional to the extent of groundwater development and utilization (Kang, 2022; Pan and Tong, 2013). According to data from 1956 to 2000, duplicated measurement accounts for 98% of groundwater resources in southern China, while non-duplicated measurement accounts for only 2%. In northern China, non-duplicated measurement constitutes 36% of groundwater resources, with duplicated measurements at 64%. In the Haihe River Basin, which faces water shortages, non-duplicated measurement reaches as high as 66% (Fig. 5).

Duplicated measurement represents existing water quantities within the water cycle, which can be obtained through experiments, monitoring, and calculations. Its quantity and spatiotemporal distribution are more suitable for the resources utilization and are crucial supporting volumes for both in-stream and off-stream ecosystems. This measurement is an important factor in guiding the development and utilization of water resources. Developing surface water resources can reduce groundwater recharge, while exploiting groundwater resources diminishes phreatic evaporation, river base flows, and underflows, but increases precipitation infiltration to recharge the groundwater. Non-duplicated measurement cannot be directly calculated but is derived after determining the quantity of groundwater resources and duplicated measure-

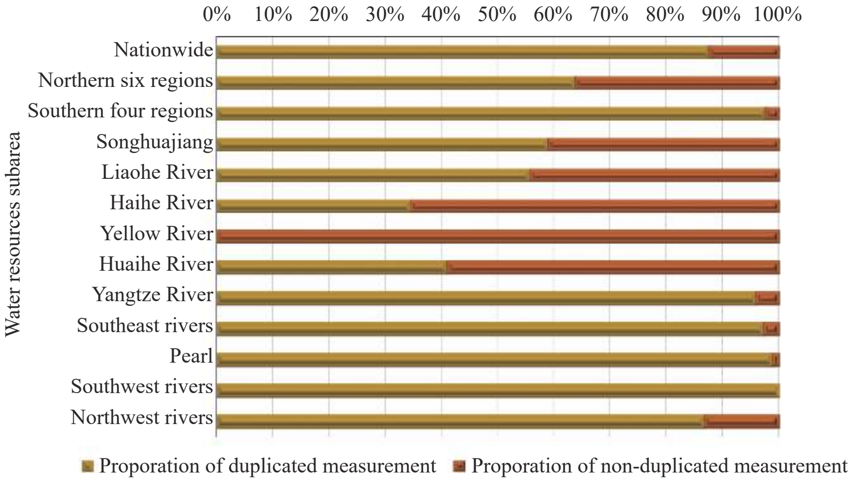


Fig. 5 Ratios of duplicated and non-duplicated measurement in groundwater resources

ment. The quantity of surface water resources and non-duplicated measurement may not accurately reflect the total quantity of water resources, which can obscure the role of duplicated measurement in water resource development and utilization planning, leading to an overemphasis on surface water resources and the effects of water interception and storage (Li, 2023).

(2) Consistency correction of runoff series: Distorting WRA results

Water Resources Assessment (WRA) aims to inform water resource planning and predict future available water resources. According to statistical theory, the conditions under which runoff occurs in random series should remain consistent over time. However, hydrological series are no longer consistent from year to year due to climate and human activities, including changes in land surface, in-stream water diversion, and groundwater extraction. For example, the measured runoff of the Haihe River decreased by 30% to 70% from 1950–1969 to 1970–2010 (Zhang et al. 2017), with human activities responsible for over 60% of the total reduction (Zhang et al. 2007). The measured runoff in the Liaohe River and Songhuajiang River has shown a non-significant decreasing trend since the 1970s (Wang et al. 2017; Tian and Wang, 2018). The Yellow River, Yangtze River, and Pearl River have experienced reduced runoff or seasonal variations (Liu et al. 2022; Zhou and Zhang, 2018; Chen et al. 2018).

To "eliminate" the impact of human activities, surface WRA employs a "measure-restore-correct" approach to restore measured water cycle fluxes to their natural states, a process known as consistency corrections. This involves two key steps: First, the annual runoff series are restored by converting measured annual runoff to natural annual runoff, accounting for surface water consumption variables such as agricultural irrigation, industrial and domestic use, inter-basin water imports and exports, river channel floodwater, and reservoir storage. Second, the annual runoff series are corrected, also known as "restoration". After identifying the turning point on the double accumulation correlation graph of annual precipitation and natural annual river runoff, where significant changes are evident, the graph is divided into two parts and the runoff before the turning point is then adjusted to be consistent with the subsequent period, following a certain proportion. Analysis reveals that as human activities intensify, significant changes occur in water cycle parameters, necessitating an increasing number of water cycle fluxes to be restored and corrected with growing restoration ratios. For example, in the area above the Guanting Reservoir on the Yongdinghe River, part of the Haihe River Basin, the restored series volume accounted for 31.3% of natural runoff between 1961 and 1970, 48.8% between 1971 and 1980, 67.5% between 1981 and 1990, and 62.6% between 1991 and 2000. In the area above the Huangbizhuang Reservoir on the Hutuohe River, another part of the Haihe River Basin, the restored volume accounted for 19.1% of natural runoff between 1961 and 1970, 28.1% between 1971 and 1980, 61.1% between 1981 and 1990, and 44.1% between 1991 and 2000 (Fig. 6).

The above methods are constrained by data limitation and subjective influences, leading to "restoration distortion" and "restoration failure". The long-term evolution of hydrological time series involves uncertainty, and "consistency correction" can only reflect changes in a specific period, making it difficult to accurately represent gradual hydrological processes or predict future changes in water resource series (Qiu, 2006). An effective way to address these challenges is to

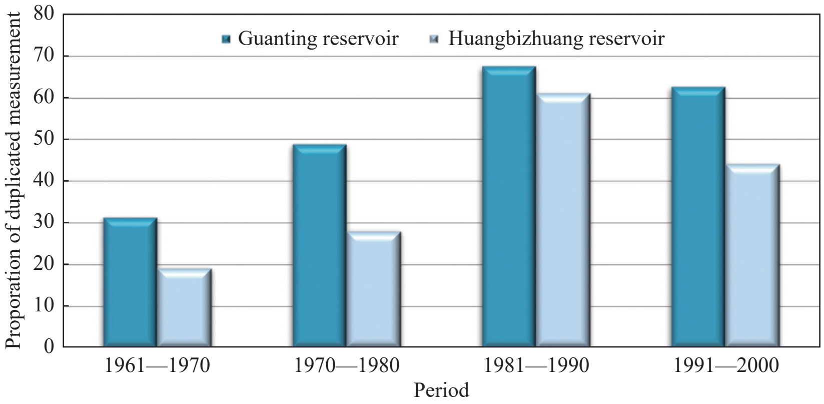


Fig. 6 Changes in the share of restored volume of Guanting and Huangbizhuang Reservoirs

establish a dynamic WRA concept. With comprehensive monitoring data and advancements in Remote Sensing (RS), drones, and communication technologies, hydrological models can now enable dynamic, efficient, and scientific WRA and prediction. In China, well-established models include distributed hydrological models (Wang et al. 2008; Wang et al. 2023; Yi et al. 2024), surface water and groundwater coupled models (Xie et al. 2002; Wang and Lu, 2020), and the WEP-L model which is based on watershed water cycles (Jia et al. 2006).

4 Conclusion

China's water resources are unevenly distributed across time and space, with arid and semi-arid northern regions experiencing scarcity and highly levels of utilization. Groundwater resources have supported local economic and social water use for decades, but the imbalance between supply and demand is becoming increasingly prominent. Establishing water balance-based WRA methods has provided a solid scientific basis for water resource management and development in China. Analysis of WRA over different periods reveals a declining trend in water resources. The duplicated measurement of surface water and groundwater plays a significant role in water balance calculations and WRAs, which can be used to guide the development and utilization of water resources. However, traditional series consistency correction in surface water assessments in no longer sufficient.

Recent initiatives, such as the South-to-North Water Diversion Project, reduced groundwater extraction, and ecological water replenishment in river channels, are contributing to a cross-basin system aimed at rebalancing water resources. In the current changing environment, there is an urgent need to strengthen fundamental research in hydrology and hydrogeology, improve monitoring, and to establish a dynamic assessment system for the efficient management and rational use of surface water and groundwater.

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