



# Sustainable water resources development and management in large river basins: an introduction

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## Abstract

Water resources are important in large basins which are important places for human habitation and industrial and agricultural development. The background of editing this thematic issue was introduced and the general water resources situation and water quality status in four major large river basins in the Asian and African continents were briefly summarized to give readers general pictures of water resources development and management in these basins, and these large river basins are the Yellow River Basin, the Yangtze River Basin, the Indus Basin, and the Nile Basin. The thematic issue papers were classified into four clustered topical categories, and the main points of the papers in this thematic issue were summarized. Finally, the perspectives of future sustainable water resources development and management in large river basins were proposed.

**Keywords** River basin · Water quality · Water pollution · Groundwater depletion · Water management

## Introduction

Water is one of our most important natural resources in the world, with the access to safe and clean drinking water being a fundamental human right (Oliveira 2017; UN 2019). Human activity and climate change are two important factors affecting water resources availability and water quality worldwide, especially in large basins where there are adequate spaces for human inhabitation and city expansion (Li et al. 2017). In addition, drought and water quality concerns are expected to increase in the coming years due to climate change and increasing water demand resulting from population growth and urbanization (Darko et al. 2022; Guo et al. 2022; Khan et al. 2021; Lee et al. 2019; Mukherjee et al. 2018). Unsustainable water resources development in large

basins has also induced various serious environmental problems and geohazards such as soil salinization, land desertification, earth fissures and ground subsidence (Huang et al. 2014; Wu et al. 2014). The sustainable development and management of water resources in large basins has become an important topic worldwide, requiring systematic and comprehensive scientific research.

There have been many achievements in water research in large-scale river basins. To reflect the latest research progress in water resources and water quality in large basins, this topical collection has been compiled to attract worldwide attention to the situation. It provides a platform for researchers, policy makers and stakeholders to share their opinions on how basin water should be managed and protected. There are many river basins in the world, and some of them are very large in area. Water resources in these large river basins are important for a country or even for several countries, because some big rivers are transboundary rivers. Management of big rivers is not easy, especially management of international transboundary rivers, which is also a political issue. It is hoped the findings reported in this topical collection can be useful for improving the scientific level of river basin supervision and management, securing the safety of water supply in the basins.

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## Water resources in the Yellow River Basin

The Yellow River originates on the Qinghai-Tibet Plateau, China. It flows through nine provinces including Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shanxi, Shaanxi, Henan, and Shandong, and finally runs into the Bohai Sea of the Pacific Ocean (Fig. 1). The main stream of the Yellow River has a total length of 5464 km. The Yellow River Basin is located between 96°–119° east longitude and 32°–42° north latitude, with a length of about 1900 km from east to west, and a width of about 1100 km from north to south, and covers an area of 795,000 km<sup>2</sup> including the internal flow area of 42,000 km<sup>2</sup> (Lin et al. 2019). In 2019, the ecological protection and high-quality development of the Yellow River Basin was proposed as the national key development strategy (Li 2020a, b).

In 2020, the mean precipitation in the Yellow River Basin was 506.90 mm, which is equivalent to a total amount of water of 403.04 billion m<sup>3</sup>. The total amount of shallow groundwater storage in the plains of the Yellow River Basin increased by 768.80 million m<sup>3</sup>. According to the Yellow River Water Resources Bulletin 2020 (Yellow River Conservancy Commission of MWR 2021), three shallow groundwater level depressions and 24 shallow groundwater over-exploitation areas have been formed in the whole basin. In 2020, the total amount of water supply in the Yellow River Basin was 53.62 billion m<sup>3</sup>, of which surface water accounted for 42.62 billion m<sup>3</sup> (including the amount of inter-basin water export) and groundwater accounted for 11.00 billion m<sup>3</sup>. Total water consumption was 43.54 billion m<sup>3</sup>, of which surface water consumption is 35.39 billion m<sup>3</sup>,

accounting for 81.3% of the total water consumption, and groundwater consumption is 8.15 billion m<sup>3</sup>, accounting for 18.7%.

The Yellow River Basin is of strategic importance. A number of water quality studies have been performed by Chinese researchers (Chen et al. 2018; He and Wu 2019; He et al. 2019, 2021a; Ji et al. 2020; Liu et al. 2020a, b; Su et al. 2018, 2020; Wu et al. 2020; Zhang et al. 2020a). These studies show that the water quality in the Yellow River Basin is generally good, and the overall water quality of the Yellow River has gradually improved, which shows that China's ecological civilization construction has achieved remarkable results in the Yellow River Basin. Spatially, the water quality in the upper reaches of the Yellow River is excellent (grade 1), while the water quality in the middle and lower reaches is medium. Some sections are polluted severely throughout the year, and the general pollution factor is nitrate (Chen et al. 2007; Li et al. 2021; Liu et al. 2013). However, the main pollutants observed in the Yellow River Basin are organic matter, nitrate and trace metals which are mainly sourced from industrial point sources and agricultural nonpoint sources (Wang et al. 2021; He and Li 2020; He et al. 2022a, b), and arsenic and fluoride that are mainly of geogenic origin (He et al. 2020, 2021b; Liu et al. 2021a; Li et al. 2019; Wei et al. 2021).

The Yellow River Basin has entered a new developmental stage, facing both challenges and opportunities (Li et al. 2017). However, the natural environmental conditions of the Yellow River Basin have resulted in the fragility of its ecological environment, resulting in very limited capacity of it to support social and economic development in the basin. Water-related problems are prominent (such as flood

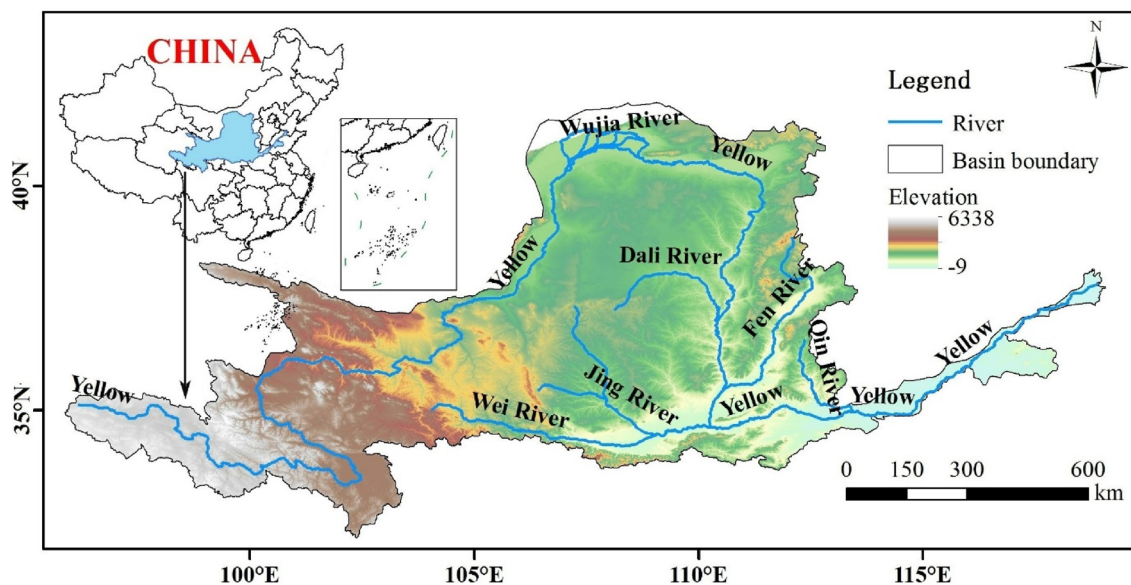


Fig. 1 Geographical location and surface elevation of the Yellow River Basin

and waterlogging disasters, water shortages and water pollution). Due to its location in the monsoon climate zone, it is more likely to have extreme climate events which are very difficult to prevent. With the increase of urbanization and population in the basin, protecting people's lives and property from extreme climate disasters is a big challenge (Huang et al. 2007; Chen et al. 2012). At the same time, water shortage cannot be ignored. The total amount of water resources in the Yellow River Basin is less than one-tenth of the Yangtze River Basin, and the per capita share of water resources in the basin is relatively low. Coupled with the problems of low agricultural water use efficiency and waste of water resources, there is a significant shortage of water resources in The Yellow River Basin. In addition, the pollution problem of the Yellow River is still a concern, though the situation is gradually improving.

## Water resources in the Yangtze River Basin

The Yangtze River is the third largest river in the world and the largest river in China. It has a total length of more than 6300 km and a drainage area of approximately 1.8 million km<sup>2</sup>, which accounts for about one-fifth of China's total land area (Zhang et al. 2006). It originated from the southwest of the Geladandong Snow Mountain, the main peak of the Tanggula Mountain on the Qinghai–Tibet Plateau (Fig. 2). The source area of the Yangtze River is controlled by the plateau climate, which is cold, dry and long in sunshine. Most of the remaining areas, especially the middle and lower reaches, have a typical monsoon climate; the four seasons are distinct (Bai et al. 2021). Yangtze River Basin is high in the west and low in the east. The upper reaches are mainly covered by mountains, and the plains are mostly distributed in the middle and lower reaches. Excessive development and

utilization of the Yangtze River, as well as the poor river basin management will cause water pollution and decrease ecosystem functions. In the upper reaches of the Yangtze River, hydropower development is highly developed, which has significantly changed the temporal and spatial distribution characteristics of natural runoff and reduced the self-purification capacity of the water body (Cheng et al. 2022; Ji and Zhang 2022; Jin et al. 2022; Yang et al. 2022; Zhang et al. 2020b). At the same time, the massive discharge of wastewater in the Yangtze River Economic Zone has caused water pollution.

The average annual runoff of the Yangtze River is 960 billion m<sup>3</sup>. However, due to the influence of rainfall, temperature and human activities, the annual runoff in the Yangtze River Basin is decreasing. The average annual runoff in the Yangtze River Basin decreased by 1.088 billion m<sup>3</sup> from 1937 to 2016 (Shi 2019). The runoff of the source region, usually originating from mountain glaciers, accounts for about 20% of the total runoff of the Yangtze River (Mao et al. 2016). In recent years, there has been a warming trend in global temperature. Liu et al. (2009) had indicated that the contribution rates of glacier mass loss to annual river runoff from 1961 to 2000 and from 1986 to 2009 were 11.0% and 17.5%, respectively. However, Liu et al. (2020a, b) indicated that melting glaciers was not the main water resource of runoff in the source region in recent decades, and from 2000 to 2018, the contribution rate was only  $1.9 \pm 0.3\%$ .

The water quality of the Yangtze River is extremely important to the development of society in this region. The Yangtze River is seriously polluted by TP and TN, especially in Sichuan and its lower reaches. Wang and Xia (2006) confirmed by a statistical analysis that the natural factors controlling the hydrochemical types of the Yangtze River Basin are mainly rock weathering. However, revealed by Yang et al. (2021) that the water quality of the Yangtze River

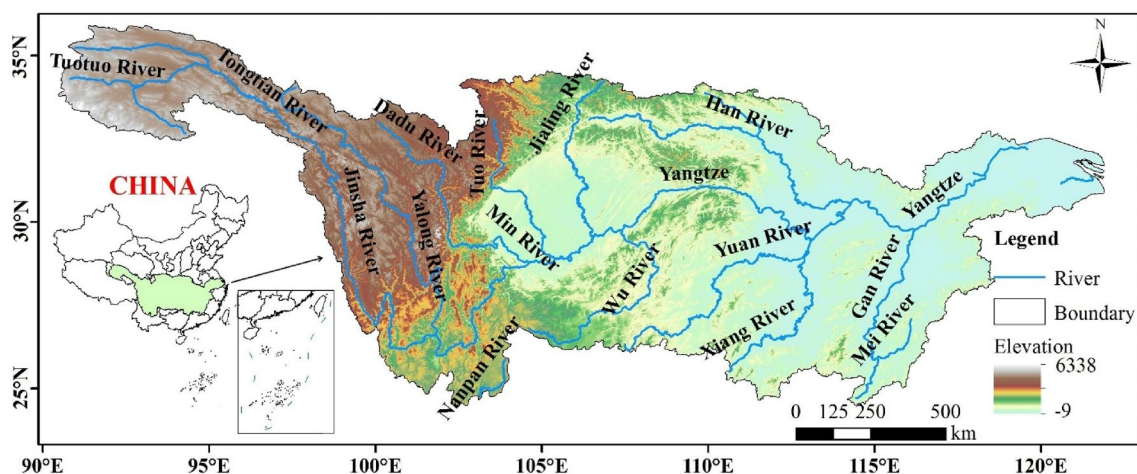


Fig. 2 Geographical location and surface elevation of the Yangtze River Basin



Basin is affected by GDP and urbanization. The Han River is the biggest tributary of the Yangtze River. The South-to-North Water Transfer and the Yangtze River Mitigation Project can have certain impacts on the water quality of the Han River (Liu et al. 2021b).

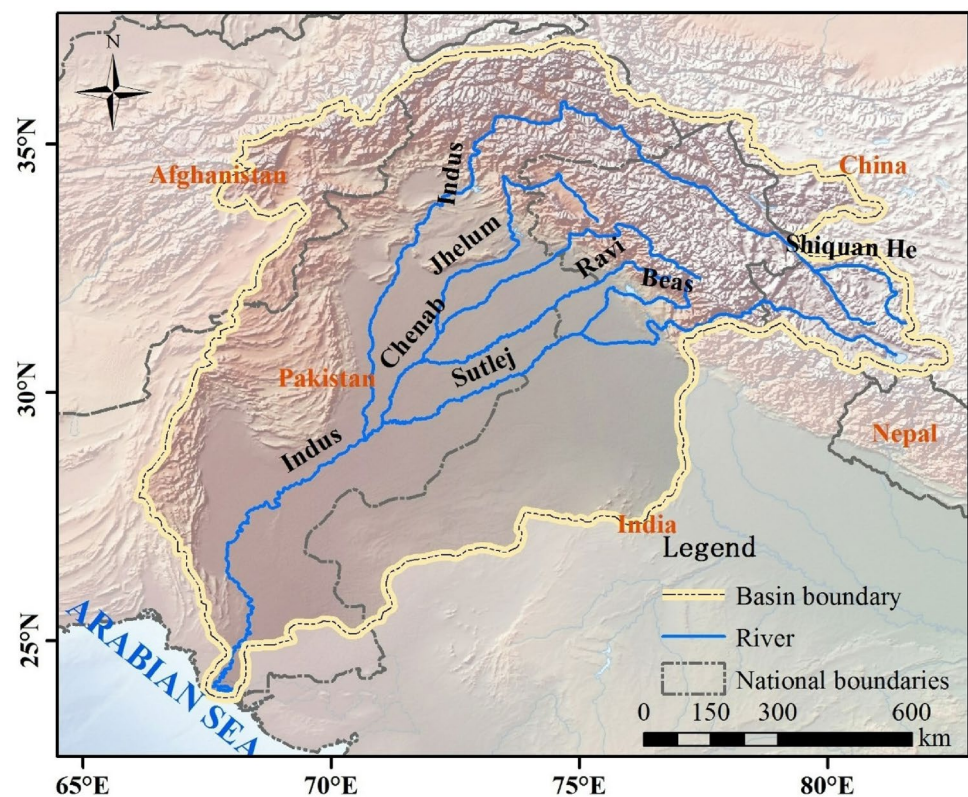
## Water resources in the Indus Basin

The Indus Basin is located in South Asia, and extends between 22–38° N and 65–87° E (Khan et al. 2019). The Indus Basin covers an area of approximately 1.1 million km<sup>2</sup>, and is about 3200 km long (Su et al. 2016). The main stream of the Indus originates from the Qinghai-Tibet Plateau of China, flows from the northeast to the southwest through the north part of India and Pakistan and finally merges into the Arabian Sea (Fig. 3). The north part of the river basin is dominated by mountains areas, and most areas are above 7000 m above the mean sea level. The southern part of the basin and the Arabian Sea coast are flat agricultural plains (Hasson et al. 2014). Indus Basin is mainly controlled by the tropical monsoon climate and tropical desert climate. The precipitation in different regions shows obvious differences with altitude, with 600–2000 mm in the mountainous areas and 100–500 mm in the southern basin (Zhao 2020). The main tributaries include Kabul, Jhelum, Chenab, Ravi, and Sutlej.

The annual runoff of the Indus Basin is about 207 billion m<sup>3</sup>, originating mainly from the melt water of glaciers (Gascoine 2021). Global warming has accelerated the melting of Himalayan glaciers, raising the river runoff in a short period of time, but the amount of river water resources will be greatly reduced in the next few decades (Hussain et al. 2020). Study has found that the rate of temperature rise in the upper Indus Basin is higher than that in the lower Indus Basin, and the river flow in the sub-basin is positively correlated with the average temperature and rainfall (Ashraf and Hanif-ur-Rehman 2019). The Indus Basin is mainly located in Pakistan, a drought-prone country with poor water storage capacity and poor irrigation infrastructure, and most of the water resources in the Indus Basin are used for agricultural irrigation and industry (Archer and Fowler 2004). Pakistan has built many dams to store water. However, sedimentation has reduced the dam's water storage capacity over time, which is also believed to be one of the causes of downstream flooding (Shahid 2019).

The water quality in the Indus Basin meets the WHO drinking water standard, but it may deteriorate soil quality and degrade the downstream water quality for irrigation purposes due to high concentrations of major ions (Rehman Qaisar et al. 2018). Study has shown that human activities and soil erosion are the main causes of water pollution (Baluch and Hasmi 2019). Research conducted during the COVID-19 period in the Buddha Nala River, a tributary of

**Fig. 3** Indus River and surface elevation of the Indus Basin



Sutlej, has shown that industry and the household sewage do affect the water quality in the midstream of the river (Das et al. 2021). This confirms once again that industrial and human activities are the major factors affecting the water quality in the Indus Basin. The Indus Basin is rich in water resources, but population growth, rapid industrialization, and inefficient water use as well as global warming has caused the water crisis in this basin. In addition, due to the unrealistic water resources management system in agricultural production, water resources are wasted and agricultural output is restricted (Johnson et al. 2010).

## Water resources in the Nile Basin

The Nile is the longest river in Africa and also in the world with a length of 6670 km. It flows through eastern Africa from south to north and finally joins the Mediterranean Sea. It has two main tributaries, the White Nile and the Blue Nile (Melesse et al. 2014). The Blue Nile, which originates from the Ethiopian Plateau, is the source of most of the water and nutrients in the lower reach of the Nile (Langman 2015), though the White Nile is the longest tributary of the Nile (Fig. 4). The Nile plays an important role in agriculture, drinking water, cargo transportation and desert soil replenishment. The Nile Basin can be divided into seven major regions: the East African lacustrine plateau, the mountainous river region, the White Nile region, the Blue Nile region, the Atbara River region, the Nile Region to the north of Khartoum, and the Nile Delta.

The Nile Basin covers an area of approximately 3.11 million km<sup>2</sup>, and flows through nine countries. It is an international river that spans the most countries in Africa (Langman 2015). The Nile River has very limited water resources, and its annual average runoff is only 84 billion m<sup>3</sup>. Since the Nile River flows through nine countries in Africa and there are few other large rivers nearby, the production and living of nearly 200 million people in the Nile Basin depend on the water supply of the Nile River, making the water shortage in the basin very serious (Boru et al. 2019). In addition, there are obvious regional differences in water resources reserves in the Nile Basin. The upstream area is rich in water resources, but the utilization efficiency is extremely low. Most of the water resources directly feed the river or infiltrate underground without being used. On the contrary, the water resource reserves in the middle and lower reaches are significantly less than those in the upper reaches due to multiple factors such as climate and land cover conditions, and most of the water resources are stored as groundwater (Melesse et al. 2020). Due to limitation of technological and socio-economic developments, fresh water resources in the middle and lower reaches of the Nile are in short supply,

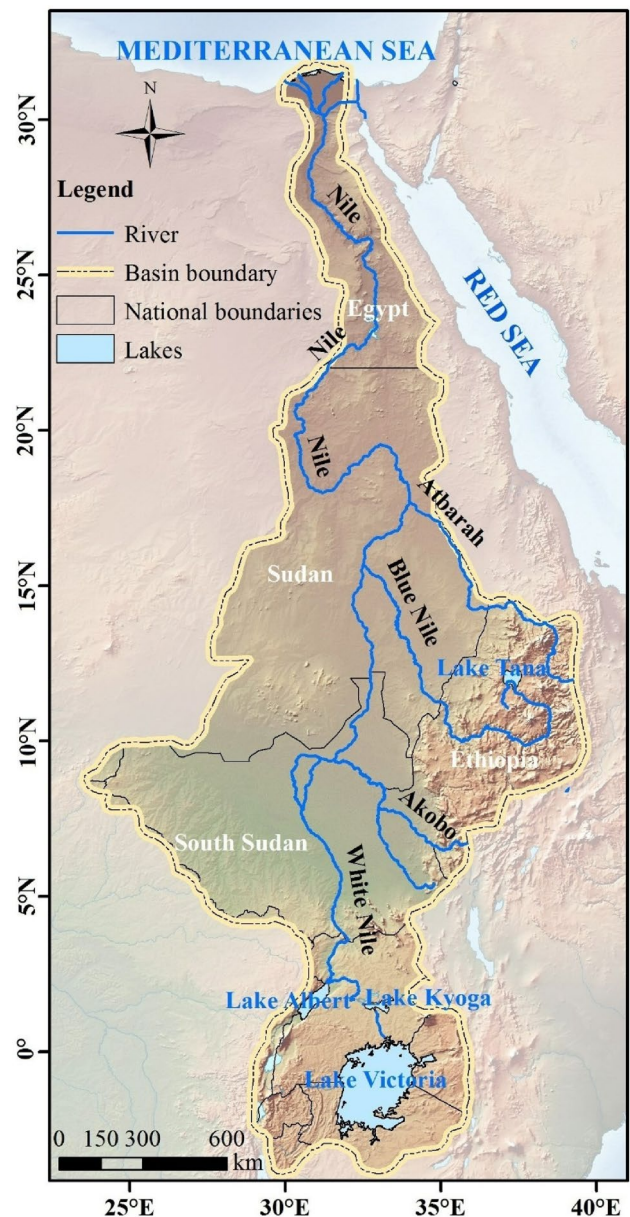


Fig. 4 Nile River and surface elevation of the Nile Basin

especially in Sudan and Egypt where water is even more expensive than petroleum (Hamad and El-Battahani 2005).

The Nile Basin is greatly affected by environmental pollution. The economies of the countries which the Nile River flows through are relatively backward, and they are all in the stage of striving for economic development. As such, they have not had enough funds to improve the environment. The rapid industrialization and the abuse of chemical products, as well as the discharge of untreated domestic sewage, and the discharge of agricultural wastewater and the agricultural residues are the main reasons responsible for the pollution of the Nile (El-Sheekh 2009). The pollution of the Nile can be divided into two categories: chemical

pollution and biological pollution. Chemical pollution includes various pesticides, herbicides, trace metals such as arsenic, cadmium, lead, and mercury, nitrate, nitrite, and various organic compounds. Biological pollution mainly comes from bacteria, viruses and other microorganisms in river water, and their content exceeds ten times the normal standard (El-Khayat et al. 2021). These toxic substances can induce significant health risk to people, resulting in various neurological diseases, kidney diseases, blood diseases and cancers (Ibrahim et al. 2018).

The Nile provides the countries that it flows through with valuable water sources. However, in recent years, as the population of the upper Nile countries continues to increase and the economic construction continues to expand, these countries have an increasing demand for water. Therefore, it is urgent to change the share of water resources to enable upstream and downstream countries to be able to enjoy equal water rights (Tesfaye 2012). Serious disasters from flooding occur during the season, but hydropower development is extremely low and loss of surface water resources is also very serious. Therefore, effective and efficient water resources allocation and management is needed in this basin.

## Papers in the thematic issue

This thematic issue contains 20 research papers contributed by active researchers from China, India, Brazil and Malaysia (Table 1). The topics of these articles are truly diverse, and the word cloud generated from the titles and abstracts demonstrates that the most common terms in these titles and abstracts are water, groundwater, basin, quality, river, dew, China, risk and recharge, ... (Fig. 5). Articles can be roughly classified into four topic clusters: hydrochemistry and water quality issues in river basins, water resources and water cycle, geochemistry of geothermal water, and hydro-ecosystems and influencing factors.

The first topic cluster includes six articles contributed by researchers from China and Malaysia. Topics of articles under this cluster include assessment of groundwater quality and human health risk, hydrogeochemical processes regulating the evolution of groundwater in coal mine areas in Ordos Basin, China, groundwater quality appraisal and human health due to groundwater pollution in heavily populated river basins of China, human health risk assessment due to intake of tap water and large sized bottled water in the Guanzhong Basin of China, and treated water quality in Langat River Basin, Malaysia. Most of these articles focus on groundwater as it is the most important water supply source in these basins, but bottled water and treated water are important supplements to the traditional source of water supply. Therefore, the articles under this topic cluster

provide important and comprehensive guidance for securing safe water supplies.

Hydrological cycle and hydrogeological processes such as groundwater recharge are constant topics in water research. In this thematic issue, seven articles focus on groundwater recharge, regional groundwater circulation, meteorological drought, vertical distribution of soil moisture, and dew water in soil and plant leaves in river basins. Factors such as climate change, artificial aquifer recharge and land use/land cover are discussed in selected articles to reveal their effects on water resources and water cycle in these basins.

Geothermal water is regarded as clean energy to foster the achievement of carbon neutrality. However, research on geothermal water is still relatively inadequate in literature. In this thematic issue, three articles reported the hydrogeochemical characteristics and recharge sources of geothermal water in the piedmont region of Qinling Mountains of the Guanzhong Basin, Eastern Sichuan Basin and Simao Basin. These findings are instrumental for geothermal water development in river basins by providing important information of geothermal water recharge sources and potential of being exploited.

Topic cluster four consists of four articles which range from assessment of eco-geo-environment to land use/land cover changes and from anthropogenic impacts on lakes to climate and land use change impacts on water yield ecosystem service. All these articles are more relevant to environmental research in river basins topics, but are also related to water in the basins. Findings reported in these four articles can be helpful for the management and supervision of environmental media including water in the basins.

## Final words

Large river basins are the home of people and water resources in the basins are critical for the survival of humans and the development of industry and agriculture. Water is not only a vital resource, but also an important ecological element. To achieve harmony among water resources, humanity, economic development and ecological environment, we propose the following actions to be taken.

- To give full play to the resource and ecological functions of the surface water–groundwater system in large basins, main hydrological elements affecting the ecological environment should be determined, and the impacts of key surface–subsurface hydrological processes and their interactions on basin water resources and ecology should be clarified. The multi-scale co-evolution model of surface water, groundwater and ecological environment systems should be constructed to reveal the coupling and mutual-feedback mechanism of hydrologi-



**Table 1** Information of published articles in this thematic issue

Topic cluster	Author name	Article title	DOIs
Hydrochemistry and water quality	Wu J, Zhou H, He S, et al.	Comprehensive understanding of groundwater quality for domestic and agricultural purposes in terms of health risks in a coal mine area of the Ordos basin, north of the Chinese Loess Plateau	<a href="https://doi.org/10.1007/s12665-019-8471-1">https://doi.org/10.1007/s12665-019-8471-1</a>
	Liu F, Qian H, Shi Z, et al.	Long-term monitoring of hydrochemical characteristics and nitrogen pollution in the groundwater of Yinchuan area, Yinchuan basin of northwest China	<a href="https://doi.org/10.1007/s12665-019-8695-0">https://doi.org/10.1007/s12665-019-8695-0</a>
	Wang Q, Dong S, Wang H, et al.	Hydrogeochemical processes and groundwater quality assessment for different aquifers in the Caojiatan coal mine of Ordos Basin, northwestern China	<a href="https://doi.org/10.1007/s12665-020-08942-3">https://doi.org/10.1007/s12665-020-08942-3</a>
	Zhang Y, He Z, Tian H, et al.	Hydrochemistry appraisal, quality assessment and health risk evaluation of shallow groundwater in the Mianyang area of Sichuan Basin, southwestern China	<a href="https://doi.org/10.1007/s12665-021-09894-y">https://doi.org/10.1007/s12665-021-09894-y</a>
	Ahmed MF, Mokhtar MB	Treated water quality based on conventional method in Langat River Basin, Malaysia	<a href="https://doi.org/10.1007/s12665-020-09160-7">https://doi.org/10.1007/s12665-020-09160-7</a>
	Deng L, Xu B, Yang X, et al.	Water quality and health risk assessment based on hydrochemical characteristics of tap and large-size bottled water from the main cities and towns in Guanzhong Basin, China	<a href="https://doi.org/10.1007/s12665-021-09415-x">https://doi.org/10.1007/s12665-021-09415-x</a>
Water resources and water cycle	Wang J, Huo A, Zhang X, et al.	Prediction of the response of groundwater recharge to climate changes in Heihe River basin, China	<a href="https://doi.org/10.1007/s12665-019-8752-8">https://doi.org/10.1007/s12665-019-8752-8</a>
	Arya S, Subramani T, Karunanidhi D	Delineation of groundwater potential zones and recommendation of artificial recharge structures for augmentation of groundwater resources in Vattamalaikarai Basin, South India	<a href="https://doi.org/10.1007/s12665-020-8832-9">https://doi.org/10.1007/s12665-020-8832-9</a>
	Qiao X, Wang W, Duan L, et al.	Regional groundwater cycle patterns and renewal capacity assessment at the south edge of the Junggar Basin, China	<a href="https://doi.org/10.1007/s12665-020-09045-9">https://doi.org/10.1007/s12665-020-09045-9</a>
	Chen Y, Qian H, Hou K, et al.	Vertical distribution characteristics of soil moisture with different strata in deep profile in Guanzhong Basin, China	<a href="https://doi.org/10.1007/s12665-020-8836-5">https://doi.org/10.1007/s12665-020-8836-5</a>
	Jia Z, Ma Y, Liu P, et al.	Relationship between sand dew and plant leaf dew and its significance in irrigation water supplementation in Guanzhong Basin, China	<a href="https://doi.org/10.1007/s12665-019-8345-6">https://doi.org/10.1007/s12665-019-8345-6</a>
	Swain S, Mishra SK, Pandey A	A detailed assessment of meteorological drought characteristics using simplified rainfall index over Narmada River Basin, India	<a href="https://doi.org/10.1007/s12665-021-09523-8">https://doi.org/10.1007/s12665-021-09523-8</a>
	dos Santos VJ, Calijuri ML, de Assis LC	Land cover changes implications in energy flow and water cycle in São Francisco Basin, Brazil, over the past 7 decades	<a href="https://doi.org/10.1007/s12665-022-10210-5">https://doi.org/10.1007/s12665-022-10210-5</a>

**Table 1** (continued)

Topic cluster	Author name	Article title	DOIs
Geochemistry of geo-thermal water	Xu P, Zhang Q, Qian H, et al.	Characterization of geothermal water in the piedmont region of Qinling Mountains and Lantian-Bahe Group in Guanzhong Basin, China	<a href="https://doi.org/10.1007/s12665-019-8418-6">https://doi.org/10.1007/s12665-019-8418-6</a>
	Ta M, Zhou X, Guo J, et al.	Hydrogeochemical characteristics and formation of the hot springs occurring in the plunging ends of an anticline in Chongqing, Eastern Sichuan Basin, China	<a href="https://doi.org/10.1007/s12665-019-8486-7">https://doi.org/10.1007/s12665-019-8486-7</a>
	Zhang Y, Zhou X, Liu H, et al.	Geochemistry of rare earth elements in the hot springs in the Simao Basin in south-western China	<a href="https://doi.org/10.1007/s12665-020-8883-y">https://doi.org/10.1007/s12665-020-8883-y</a>
Hydroecosystems and influencing factors	Li L, Ni W, Li T, et al.	Influences of anthropogenic factors on lakes area in the Golmud Basin, China, from 1980 to 2015	<a href="https://doi.org/10.1007/s12665-019-8770-6">https://doi.org/10.1007/s12665-019-8770-6</a>
	Li L, Ni W, Cheng Y, et al.	Evaluation of the eco-geo-environment in the Qaidam Basin, China	<a href="https://doi.org/10.1007/s12665-020-09312-9">https://doi.org/10.1007/s12665-020-09312-9</a>
	Yang J, Xie B, Zhang D, et al.	Climate and land use change impacts on water yield ecosystem service in the Yellow River Basin, China	<a href="https://doi.org/10.1007/s12665-020-09277-9">https://doi.org/10.1007/s12665-020-09277-9</a>
	Xu B, Qi B, Ji K, et al.	Emerging hot spot analysis and the spatial-temporal trends of NDVI in the Jing River Basin of China	<a href="https://doi.org/10.1007/s12665-022-10175-5">https://doi.org/10.1007/s12665-022-10175-5</a>

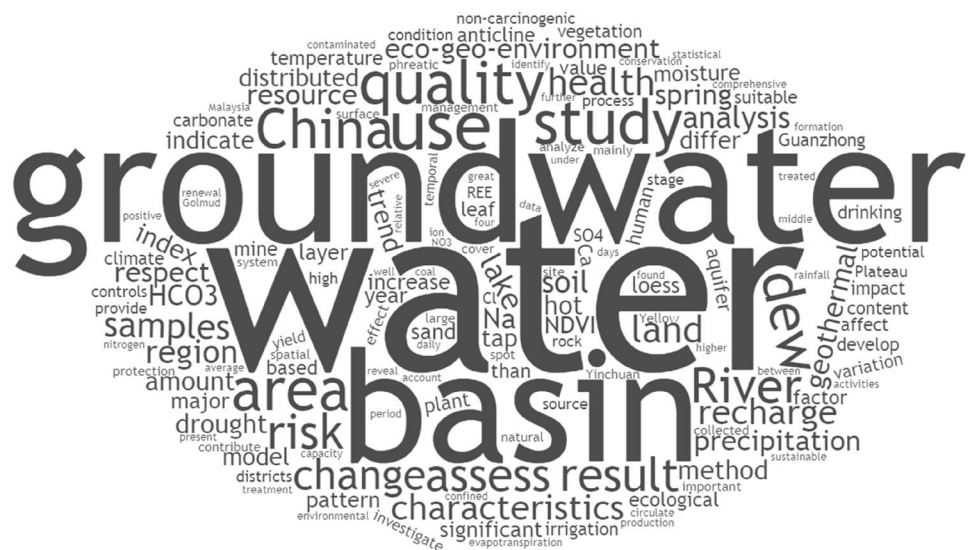
cal processes and ecological processes as well as their dynamic changes.

- Climate change and human activities are the main drivers of water resources and water environment changes in large basins. Understanding the water resources change trends under these influences is critical for using the water scientifically. Therefore, the key elements and characteristics of water circulation systems should be comprehensively investigated and identified. Water resources carrying capacity in large basins should be fully assessed

in the context of future climate change and economic development. The status quo of water resources development and utilization should be clarified to infer the water resources security in large basins.

- Large rivers usually flow through different states or provinces of a country or international transboundary rivers flow through several countries. Therefore, it is essential and critical to make a more scientific water resources allocation of cross-border rivers to maximize the benefits of water resources. It is also necessary to establish a uni-

**Fig. 5** Word cloud generated using paper titles and abstracts





fied water resource scheduling system to coordinate and balance water needs in various regions or countries of the basin and an ecological flow early warning system to meet the demand for ecological water.

- Wastewater recycling action should be encouraged to achieve a win–win situation between water resources conservation and water pollution control. It is highly desired that wastewater recycling and reuse facilities can be reasonably set up in the river basins to increase wastewater treatment capacity, and promote the utilization of wastewater resources in multiple sectors.

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**Data availability** This article does not have associated data.

## Declarations

**Conflict of interest** The authors declared that they have no known conflict of interest.

**Consent to participate and publish** All authors participating in this research agreed to publish.

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