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Water Demand Framework and Water Development: The Case of China

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Abstract: Water resources management is increasingly important for sustainable economic and social development. A coherent division of the development stages is of primary importance for selecting and implementing related water resource management strategies. Using evolving supply–demand relationships, this paper proposes a framework that considers water development stages to present a series of dynamic relationships between water demand changes and overall economic development. The framework is applied to China to advance the understanding of how demand evolves at different stages of water resources development under specific socioeconomic circumstances, and of strategic choices in general. The case of China explains how water resources management has gradually improved during distinct socioeconomic development stages. It illustrates the varieties and effectiveness of water policies made to adapt to changing demand over the course of socioeconomic development. The framework can be potentially applied to other countries or regions to identify the development stage in order to select proper water management strategies.

Keywords: water resources management; water demand; evolving supply–demand relationships; China

1. Introduction

The nature of the relationship between humans and water has become more complex with time because of increasing uncertainties in rapidly changing socioeconomic and climatic conditions. Sustainable water management is a formidable challenge for most developing countries to support sustainable development.

Water resources management is a purposeful activity to maintain and improve the state of water resources, required for numerous human and economic needs. Water as a public good needs to be managed, and is concerned with policy framings of choices according to contextual factors [1]. Though it is subject to much debate, a major shift towards more efficient water resources management involves the change from an engineering-dominated approach to an adaptive learning approach which refers to a systematic process of holistic management of water resources with continuous improvements in related practices and policies [1–3]. Engineering projects have been developed for millennia for numerous purposes, including for basic human needs and productive uses. The hydraulic mission era played a prominent role in water development. It was characterized by rapid and massive construction of hydraulic infrastructure, representing the importance of planned interventions that have shaped national bureaucracies' identities [4]. This is viewed as a traditional approach for water provision, compared to integrated water resources management in the modern sense, which is a process of coordinating the management and development of water, land, natural, and other resources within a river basin to promote economic and social development and protect freshwater ecosystems [5,6].

In this study, "hydraulic mission" refers to a supply-focused approach which focuses on expanding supply that emphasizes infrastructure investments [7,8], while the "water demand framework" is a demand-side approach that seeks an insightful understanding of water management paradigms respecting the principles of demand changes with economic growth [9]. In light of the pressures of population growth, urbanization, changing standards of living, increasing irrigated agriculture, industrial development, and environmental deterioration, it is crucial to use an adaptive approach as socioeconomic development to manage water demand rather than relying on a supply-oriented approach [10,11].

The interrelations between humans, water resources, and the natural environment have been addressed in studies that discuss the necessity of a paradigm shift from an engineering-dominated approach to an adaptive learning approach to achieve sustainable water resources management [12–14]. The process of an adaptive learning approach has been further developed to include collective learning processes in managing complex ecological and environmental issues [15–18], in which various social actors are continually informed by the feedback from a changing socio-ecological system [19,20].

The above reinforces the importance of studying a demand-side approach that looks into evolving human needs for water at different stages of social and economic development [21], and in addition, reflects the impacts of economic development on governance actors' decisions. Our analysis aims to deepen the discussion of the relation between socioeconomic development and sustainable water resources management within a water demand framework.

The main contribution of this paper is the framework that considers water development stages as a series of dynamic relationships between water demand changes and overall economic development. The framework provides the basis for investigating changing patterns of water demand at different socioeconomic stages. This is fundamental for policy reframing during the transition from water management with an engineering focus to more holistic water management. It also offers a comprehensive view of water resources management and indicates how water demands have evolved under changing conditions and what have been the results in terms of sustainable water resources and related policy making and legal and regulatory instruments. Furthermore, the framework can also be potentially applied with a broader perspective, which is important to helping identify the development stage in order to select proper water management strategies.

The rest of this paper is structured as follows. We propose a conceptual framework for water demand on the basis of new water demand categories and evolving demand corresponding to specific development stages. Taking China as a case, we then apply this framework to empirically analyse the division of water development stages in China. Following China as a case study, we conduct a discussion to demonstrate the value of the framework, including the importance of understanding the dynamics of water development and developing scientific water strategy accordingly, as well as the potential applications beyond China. Finally, we summarize the main findings of this study and point out the limitations of the framework.

2. A Water Demand Framework

This study aims to understand how water demand evolves under particular socioeconomic circumstances, and how this impacts water management strategy. Water demand can be understood as the willingness and capacity of a society to consume water goods or water services at any given development stage, under the constraint of environmental and geographical conditions e.g., natural endowment, water availability, environmental capacity. The water demand framework is conceptualized on the basis of indicators of economic development and its impact on water development. Water development offers resources, material support, and services for economic development. In turn, economic development can promote water development. Integrated water management is underlined in water resources management studies, and the key elements of integration are identified by its managerial units and phases of management [22]. This study argues about the importance of understanding water demand at different phases of water resources management by employing the case of China. Based on commonalities of water development paradigms in developing countries, three development stages can be identified: basic well-being, social well-being, and economic advancement [23].

In practice, the contents of water goods and services are rich and diverse for the characteristic of water, which are classified as basic demand, economic demand and advanced demand in this study. Meeting basic water demands is always underlined as the main priority [24], and basic demand is concerned with provision of essential services, such as safe drinking water, sanitation, and prevention of soil erosion [25]. Economic demand supports economic growth through water infrastructure, irrigated agriculture, industrial development, hydropower, and navigation [26]; advanced demands include river landscaping, recreational activities, and prevention of soil erosion. These three types of demand correspond to different levels of socioeconomic development (Figure 1). The listed aspects in the three rectangles on the top are concerned with the relation between water resources management and socioeconomic development. The issues listed in the two rectangles at the bottom are about the relationship between water resources management and ecological environment and restoration, including water pollution prevention and control, water source protection, and prevention of soil erosion. These are directly related to basic demand and advanced demand.

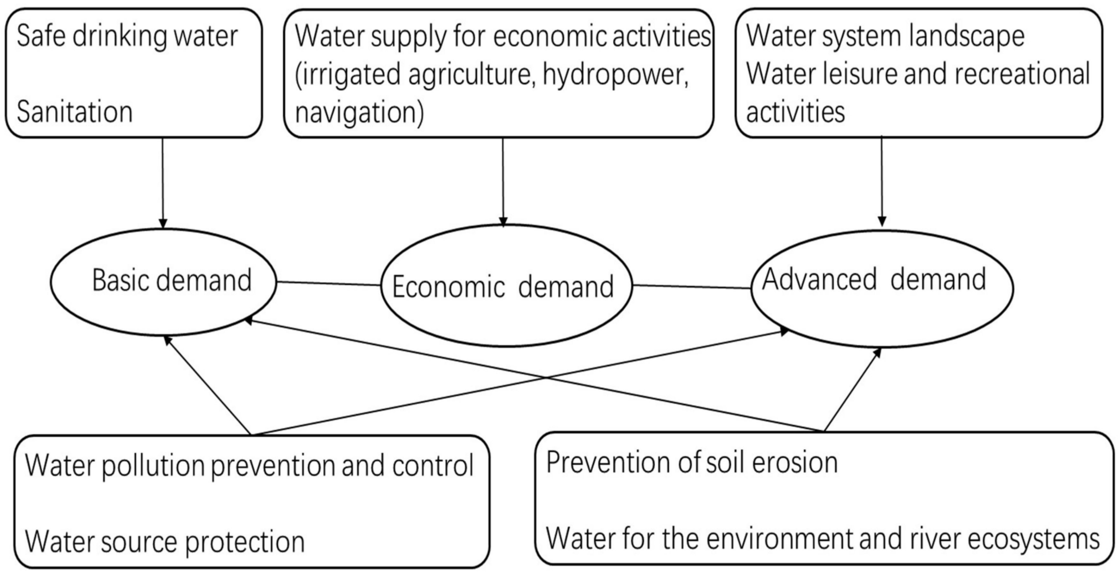

Figure 1. Categories of water demand corresponding to different levels of socioeconomic development.

For economic development, there has been some theoretical understanding of the process. Based on Gross National Income (GNI) per capita, the World Bank [27] divides economic development into four levels: low income, medium-low income, medium-high income, and high income. Different levels of economic development have differing impacts on water demand. As economic development progresses and quality of life improves, demand shift is indicated by income elasticity [26,28]. We choose a quantity S Curve to reflect the features of the water demand growth over time, which denotes the tendency of the cumulative curve to form a shallow "S" shape: flatter at the start, steeper in the middle, and flattening off again towards the end. The S Curves do not reflect the exact quantities, and are not to scale, thus only conceptually reflecting the growth trend and relative size of various water demands over time.

Now we establish the links between the water demand and economic development. The core hypotheses are: (1) the economy can maintain sustained growth over time; (2) water demand will increase over time; and (3) in terms of quantity, basic demand is greater than economic demand and economic demand is greater than advanced demand at any given time. As shown in the Figure 2, the three water demand categories are described by an S Curve depending on economic development over time. The feature of the S Curve is reflected in Figure 2 as the elasticity rises rapidly in the period from low income to middle income, and then gradually decreases from middle income to high income.

The conceptual framework (as shown in Figure 2) is suitable for examining the dynamics of water demand in some countries, but it is not a universally applicable framework. For example, since the hypothesis of sustained growth is only true in some economies for some specific periods, it cannot be simply applied to economies with discontinuous growth. Furthermore, it should also be noted that the water demand framework and the environmental Kuznets Curve represent different analytical approaches. Water demand framework explores the relationship between changing demand and economic development, while the environmental Kuznets Curve model focuses on the relationship between economic development and environmental quality [29].

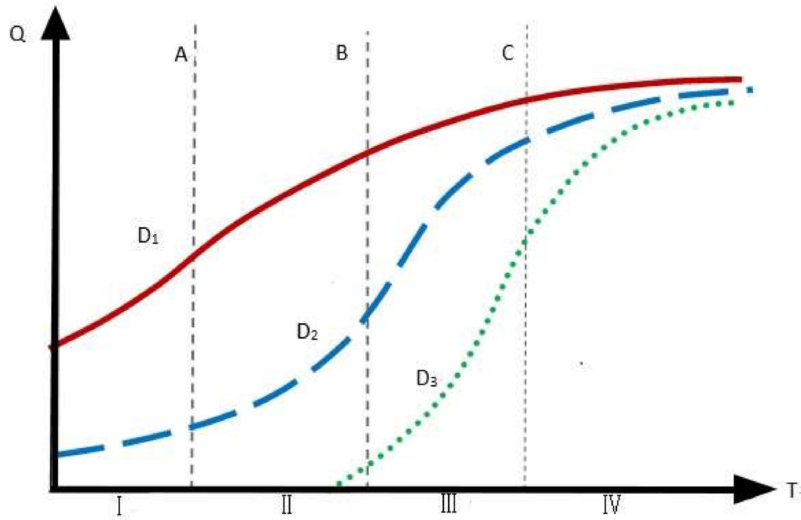

Figure 2. Conceptual curves of water demand changes with economic development. Q denotes quantity; T denotes time; D denotes demand curve: D1, basic demand curve; D2, economic demand curve; D3, advanced demand curve. I, II, III and IV are different stages; A, B and C are dividing lines among different stages.

In Figure 2, the inflexion in the middle of the S Curve is the turning point in terms of the growth rate from fast to slow. We assume that the inflexions in the three demand curves D1, D2, and D3 correspond to lines A, B, and C, respectively. Demand for water resources can then be divided into four stages according to the locations of lines A, B, and C; demand is also closely related to economic development in the four stages (I–IV in Figure 2 and explained below). This situation reflects Gu's [30] description of water development at different stages, i.e., the stages of development are normally connected to the level of socioeconomic and scientific as well as technological development.

In Stage I, the primary concern is to cover the basic demand, which increases faster than economic demand, while advanced demand does not exist. This stage is characterized by construction of water infrastructure and normally corresponds to low income levels and low levels of industrialisation and urbanisation. During this stage, the structure of water demand is relatively simple and the primary concern is health requirements and provision of basic services.

Economic demand grows rapidly during Stage II, while basic demand slows down and advanced demand emerges. This stage represents a shift in development from low income to medium income, with rapid industrialisation and urbanisation. Because of the rapid economic development, this stage sees multiple development goals, with growing economic demand and emerging advanced demands.

Stage III corresponds to a more comprehensive water resource management and increasing multiple demands for water. The growth in basic demand continues slowing down, economic demand continues to grow quickly, and advanced demand rises sharply. At this stage, the level of economic development shifts from medium income levels to high income levels, with further urbanisation and the reaching of mid- and post-industrialisation.

Water ecosystem restoration and protection become the major concern in Stage IV. As socioeconomic development reaches higher levels, basic and economic demands stabilize and advanced demand increases in relative importance. This stage is characterised by high incomes, high and stable levels of urbanisation, and a steep increase in tertiary industrial development. Thus, this stage involves increasing demands for quality of life including enhanced ecosystems.

3. A Water Resources Management Shift in China

The above discussion illustrates how water demand changed under different socioeconomic circumstances. We now use China as a case study to demonstrate how the above framework can be applied from a supply–demand perspective to analyse how water resources management evolved in the country from an empirical viewpoint.

Since the founding of the People's Republic of China in 1949, China's water resources management has been constantly adapting to the changing socioeconomic, political, and ecological contexts, from a productivity-oriented viewpoint [31] to one that focuses on green development and environmental protection [14]. Pietz [32] defines four transitions in China's water resources management between 1949 and 1999: from traditional water infrastructure construction to modern hydraulic engineering in 1949–1957; from local to central planning in 1958–1961; from international technical cooperation to self-reliance in 1962–1977; and from economic development to environmental protection in 1978–1999. These transitions emphasise the principal characteristics of each development stage, illuminating the paradigm shift from engineering-dominated water development to environmentally-concerned adaptive management [33]. In addition, it offers a reference point for analysing China. We advance this point and argue that the fundamental cause of this paradigm shift is an increasingly affluent society and the associated growing awareness of sustainable development over economic development as described in the framework.

In this paper, we discuss the division in China's water resources management stages from 1949 to 2050. This is informed by the framework of water demand and income categories from the World Bank, income being a major indicator for the division of stages of water resources management [25]. With the continuous economic growth in China, social structures and related demand structures have changed dramatically, significantly influencing water development. From 1949 to now, water resources management in China has changed from a basic demand-focused stage to a stage where basic, economic, and advanced demands coexist. Advanced demand is considered the key demand in the future management of water resources [34,35]. China faces advanced demand with a transformation of its economy from medium income to high income from 2011 to 2030, and a further developed economy and prosperity from 2031 to 2050 with growing demand for sustainable access of water resources. These several socioeconomic-development stages and the policy and legal instruments for more comprehensive water resources management in the country are discussed in detail below. A timeline is presented in Figure 3.

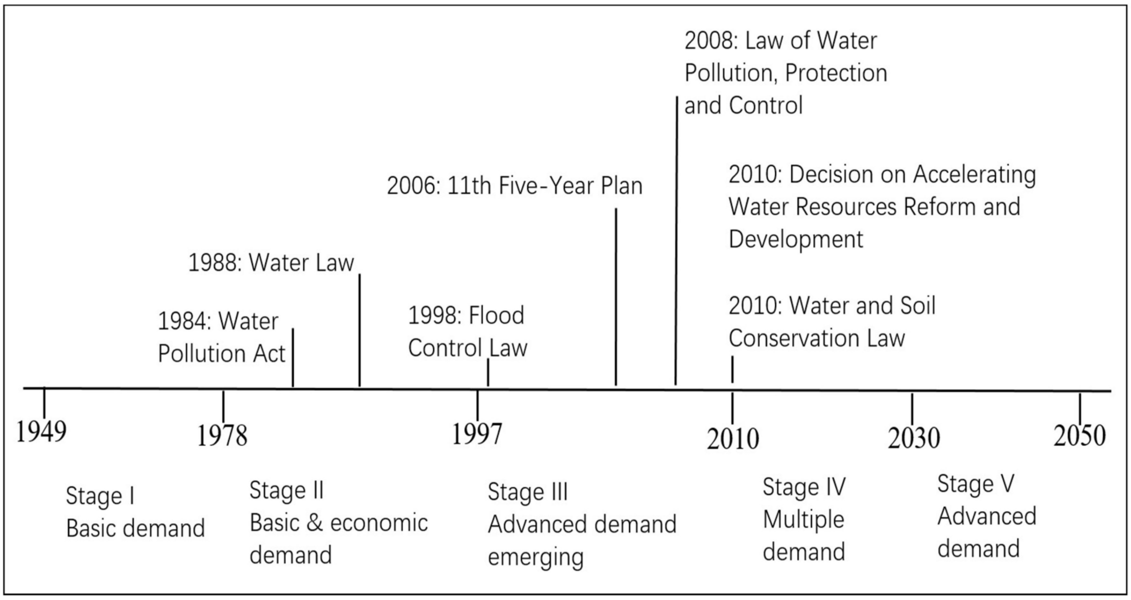

Figure 3. Timeline showing socioeconomic-development stages and policy and legal instruments for comprehensive water resource management.

3.1. Stage I (1949–1977). Planned Economy with Extremely Low Incomes; Large-scale Water Infrastructure Construction; Basic Demand Dominates

After the founding of the People's Republic of China, industrialisation and modernisation became the main priorities of national development. Disparity between water supply and demand was largely due to underdeveloped water infrastructure. Demand for safe drinking water and irrigation infrastructure was the result of population growth, food shortages, and natural disasters. As the economy grew and the population continued increasing, economic growth required hydropower development; although important, however, it was still secondary to provision of basic services. The overall national economy was underdeveloped at this stage, which explains why advanced demand was extremely weak. Hu points out that China's GNI per capita in 1949 was extremely low, at only USD 50 (in 1956 dollars) [36]. However, an independent and relatively well-equipped industrial sector and an economic system were rapidly established. The economy's growth rate was 6% annually throughout the whole period of the command economy (1949–1977), when China launched its industrialisation and modernisation strategies. At this stage the primary concern was providing people with sufficient safe drinking water and related basic services, and basic water resources demand was particularly prominent in the planned economy with extremely low incomes [37].

3.2. Stage II (1978–1997). Transition to a Market-Oriented Economy with Low Income Levels; Slow Progress in Water Resources Management; Higher Demand for Basic Services and Rapidly Growing Economic Demand

China's economy grew rapidly because of economic reforms. The "Open-door" policy initiated in 1978 and Chinese economic development progressed from poverty conditions to those where food and clothing were adequate [38]. At this stage, shortage of drinking water in rural areas was acute. This resulted in the demand for emergency responses including policies and implementation, as well as long-term support and investments. Under the opening-up policy, policies for economic investment were prioritized over commercial projects. Therefore, investment in construction of water infrastructure was reduced significantly. On the other hand, urbanisation and industrialisation created a demand for provision of water services with the resulting decrease in agricultural development. The changing focus of the economic reforms and related policies led to stagnated construction of irrigation infrastructure in rural China, which became evident in the 1990s [39]. Additionally, economic reform and development from the late 1970s resulted in water ecosystems that deteriorated rapidly (in approximately 20 years) resulting in reduced stream flows, lake shrinkage, wetland drainage, land subsidence, saltwater intrusion, forest degradation, and soil desertification [40,41].

With the significant increase in demand for domestic and industrial sectors, economic demand also grew rapidly. However, the rapid deterioration of water ecosystems resulted in increased demands for ecological remediation and environmental protection. This stage saw the transition from the single goal of large-scale water infrastructure construction to water resources management with multiple goals. However, the water resources infrastructure could not catch up with the rapidly growing social and economic service. The Water Law enacted in 1988 was a milestone in water reform in China [42], highlighting the central government's willingness to adopt legal instruments for improving the management of water resources.

3.3. Stage III (1998–2010). Rapid Development at Medium-Low Income Levels; Water Development Reform; Emergence Of Advanced Demand

China rose from low to medium-low income and then reached medium-high by 2010. With the growing industrial and urban water consumption, water shortages became more severe, with approximately two-thirds of China's cities experiencing water shortages to varying degrees. Policymakers responded to the destructive flood of 1998 in Jiangxi, Hubei, Hunan, Heilongjiang, and over 20 more provinces by improving flood control measures and addressing the importance of soil erosion [43]. With socioeconomic development and rising income levels, demand increased for water landscapes, improved ecosystems, leisure and recreational activities, and reliable and efficient water services. The emergence of advanced demand has been considered an impetus for sustainable socioeconomic development [37].

Although the provision of services did not meet the fast-growing advanced demand, this stage witnessed a historical shift in water resources management by introducing a more holistic approach. The transition in governance practices was reflected in the enactment of laws and regulations. In 2006, the central government released the 11th Five-Year Plan of National Rural Drinking Water Safety Project [44], and the Law of Water Pollution, Protection and Control was enacted in 2008 [45]. In 2010 the Decision on Accelerating Water Resources Reform and Development was issued by the State Council of the Central Committee of the Communist Party [46]. In addition, technological, management and development issues received prominent attention in order to meet coexisting basic, economic, and advanced demands [31,47].

3.4. Stage IV (2011–2030). Transformation from Medium Income to High Income; Golden Phase of Accelerating Water Development; Sharp Growth of Advanced Demand

By 2030, China's agriculture and industry sectors are projected to account for about 5% and 30% of Gross Domestic Product (GDP), respectively; Population growth will reach a peak and then start to fall, with urban populations accounting for over 65% of the total population [37]. With the population growth beginning to slow down, the pressure on natural resources and the environment will begin to lighten. Demand-oriented construction of water system landscapes for water-related leisure and entertainment activities will take place in more regions and cities. When incomes get high enough, advanced demand for these water services will rise rapidly. This will encourage leisure and water recreational activities, and the quality of drinking water will reach higher standards. In addition, building a water-saving society and efficiency of water consumption are highlighted in the 13th Five-Year Plan (2016–2020). This is expected to slow down the overall water consumption [48], and create a transition from "supply-oriented" water resources management to a "demand-oriented" approach.

Governance mechanisms will become of primary concern and sustainable development will play a critical role in water resources management. The 2011 document entitled "The Decision on Accelerating Water Resources Reform and Development" focused on the strategies and policies for water resources management in China, giving a set of guidelines for comprehensive water infrastructure construction, water ecosystem and environmental protection, and sustainable development [49]. The document states that the 10 years from 2011 to 2020 will be a critical phase of accelerating development of water resources, aiming to develop a Chinese model of managing and modernizing water resources that is congruent with economic growth [49]. In addition, in 2012 the central government released the 12th Five-Year Plan of National Rural Drinking Water Safety Project [50]. This establishes a more concrete vision and mission for water resources management, placing it closer to sustainable human and water development.

3.5. Stage V (2031–2050). Developed Economy and General Prosperity, and Sustainable Human and Water Development, with a Focus on Advanced Demand

China is expected to achieve general prosperity after 2030 and become a moderately developed country by 2050. The agricultural sector will then represent 2% of GDP, and the industrial sector less than 20%. Over 78% of the total population will be urban [27,51]. As China's socioeconomic development progresses to a higher level, multiple water resource development goals will be achieved. Safe drinking water, flood control, and agricultural irrigation will be of higher standards at this stage. Water environment will also be significantly improved by further restoration of water ecosystems. Economic demand will be met with zero or negative population growth and a stable economic growth. Advanced demand for well-being considers potential impacts of climate change, water ecosystem protection and governance, water systems landscape, and water-related cultural activities. It is expected that by 2050 modern green water management and sustainable water resources management will be achieved in China.

Studying how demand evolves at different levels of economic development provides an account of how society and water interact towards a more comprehensive water resources management. At extremely low and low-income levels, basic demand dominates, and water resources management is characterized by large-scale infrastructure construction, with a single goal of meeting basic water requirements. At medium–low income levels, water resources planning involves setting multiple development goals, and basic demand continues to grow, while economic demand emerges and then grows rapidly. Advanced demand emerges and becomes prominent when economic development reaches medium-to-high income levels. At high income levels, sustainable societal and water management will be achieved by adequate water services meeting the coexisting basic, economic; advanced demands and extreme weather events and complex climate situation still pose challenge to safeguarding water security in China [52].

Using data from the "China Water Statistical Yearbook" [53], "Compilation of Statistics on China in 60 Years" [54], and "The 2011 No. 1 Documents" [49], Figures 4–7 illustrate how the water demand framework explains the development stages of water development. The relationship between basic demand and basic supplies is elaborated in Figure 4. It shows three types of supply–demand relations, focusing on basic demand, economic demand, and advanced demand, from 1949 to 2050 [36,55–57]. The basic demand has also been presented as D1 in Figure 2.

In the graph of basic demand in Figure 4, S1, S2 and S3 refer to the supply curves denoting the quantity of goods and services supplied for safe drinking water, farmland irrigation, and disaster prevention and mitigation, respectively. It is projected that a balance between supply and basic demand will be achieved in the country by 2030 [56].

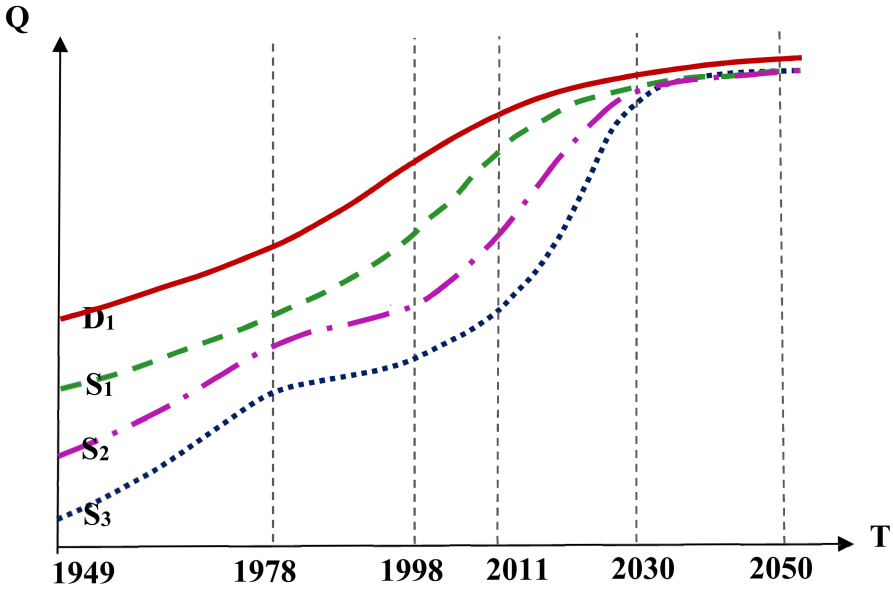

Figure 4. Supply–demand relation of basic demand. Q denotes quantity; T denotes time; D1, basic demand curve; S denotes supply curve: S1, supply curve of safe drinking water; S2, supply curve of farmland irrigation; S3, supply curve of disaster prevention and mitigation; vertical dashed lines divide different stages.

Economic demand is shown in the Figure 5 (the demand curve of D2 in Figure 2). It is apparent that since the economic reform in the 1980s, economic demand has risen sharply, and the gap between supply (S) and economic demand (D) has widened. However, due to the emphasis on water-saving activities by society in recent years, the gap is narrowing, and, according to the economic view, supply and demand will be balanced by 2030 [37,56]. Advanced demand is represented by the demand curve of D in Figure 2, where the time difference between advanced demand and the other two types of demand is highlighted. Basic and economic demand are developed in Stage I, and advanced demand emerges at the end of Stage II around 1998 in China, stimulated by socioeconomic development [37].

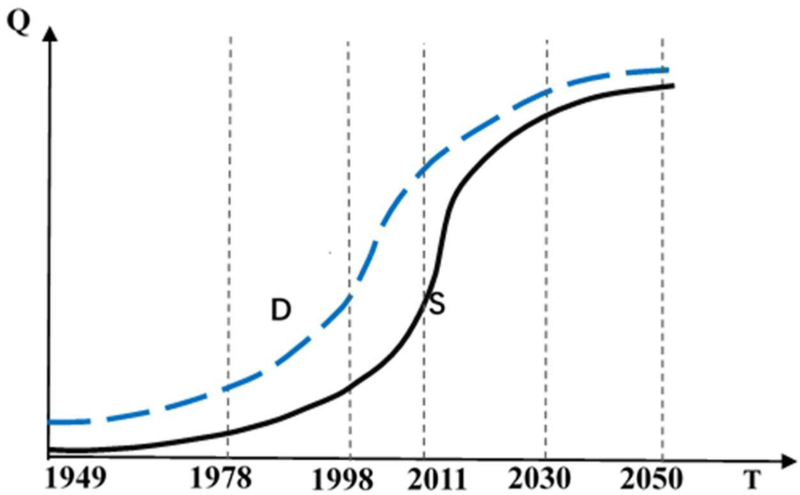

Figure 5. The supply–demand relation of economic demand. Q denotes quantity; T denotes time; D denotes economic demand curve; S denotes economic supply curve; vertical dashed lines divide different stages.

In Figure 6, it is clear that advanced demand depends on the improvement of well-being and quality of life when China becomes a well-off state.

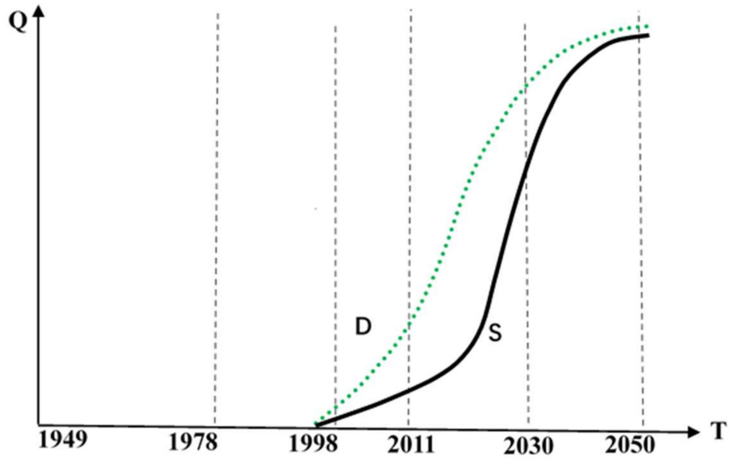

Figure 6. The supply–demand relation of advanced demand. Q denotes quantity; T denotes time; D denotes advanced demand curve; S denotes advanced supply curve; vertical dashed lines divide different stages.

Furthermore, concerning how the changing patterns of basic, economic and advanced demand impact on water ecology and environment, the transition of water ecological environment (Figure 7) indicates the changing situation of water environment (solid curve) and water ecology (dashed curve) from 1949 to 2050.

Due to growing demand for basic and economic development, water ecology and environment have experienced rapid deterioration since the Chinese economic reform at the end of the 1970s. Water ecology and environment renovation policies have been implemented since the late 1990s and improved the conditions in the 2000s. The emergence and development of advanced demand after 2011 brought a further improvement of the water ecology and the environment. By 2030, water ecology in China will see a substantial improvement because of the increasing awareness of sustainable development and improvement of the environment. The outlook for 2050 is the achievement of harmonious coexistence between humans and nature.

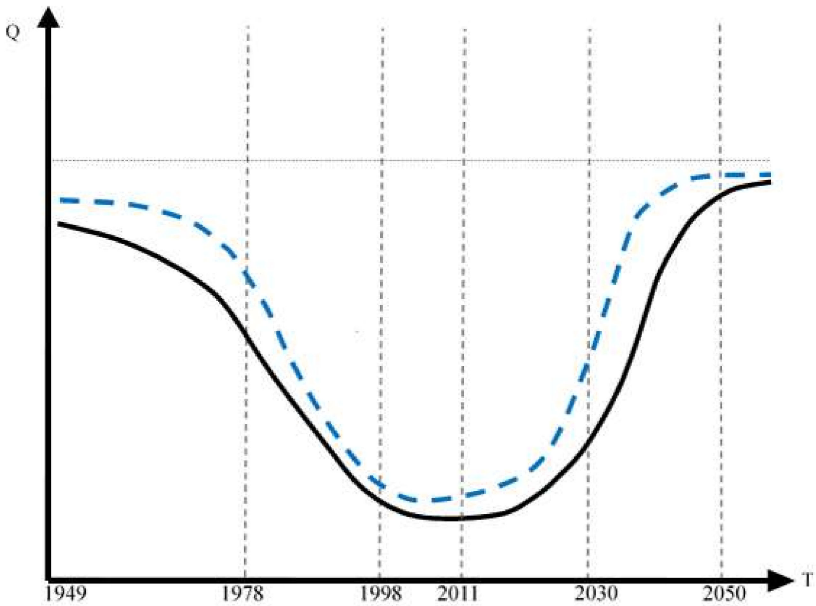

Figure 7. Transition of water ecology and environment in China. Q denotes quality; T denotes time; dashed curve denotes the quality of water ecology; solid curve denotes the quality of water environment; vertical dashed lines divide different stages.

4. Discussion

A supply–demand framework for the evolving stages of water resources management helps to understand the dynamics between society and water resources in different countries or regions in the world. The value of this framework is to help identify the development stage in order to select proper water management strategies. In this study, we apply this framework to analyse the changing patterns of demands at different stages in China. Basic and economic demands are determined by the level of socioeconomic development, and advanced demand emerges when basic and economic demands are met. Particularly in Stages IV and V, advanced demand becomes prominent and is expected to impact the quality of water services as essential elements towards improved quality of life towards a sustainable development [58].

The water demand framework provides the basis for investigating changing patterns of water demand at different socioeconomic stages. This is fundamental for policy reframing during the transition from an engineering focus to a more holistic water management [59,60]. It also offers a comprehensive view of water resources management and indicates how water demands have evolved under changing conditions and what have been the results in terms of sustainable water resources and related policy making and legal and regulatory instruments.

There was limited use of laws and regulations from 1978 to 1987, except for the Water Pollution Act of 1984. The Water Law was enacted in 1988, but from 1988 to 2001 the development of the country was focused on maximising economic growth [61]. From 2002, sustainable water resources management has been highlighted as an objective in both the Water Law and the Water Pollution Act [62]. We highlight the national development documents during stages II to IV and illustrate that sustainability and pollution reduction has a prominent position in water resources management when both economic and advanced demand are stimulated by a developed economy and general prosperity. For developing countries in particular, the water demand framework points out the critical issues of water resources management and related policies formulation when water demands shift from the basic level to the advanced level. In the case of China, it is clear that economic development drives investment and development of infrastructure and technology, while advanced water demand emerges from stakeholders and the ecological system is often downplayed.

In this study, a key question is posed: Why is the categorization of water demand important? By using the demand-stage divisions and related social and economic circumstances, we argue that this approach offers adequate explanations of the paradigmatic characteristics of water resources management, and it also facilitates the understanding of how human activities, water resources, and ecosystems interact and mutually affect each other. Importance of water demand rather than primarily to water supply and thus to sustainable water development is not unique to China. In a discussion of sustainable water development in the western United States, Gleick [63] points to a shift from a focus on supply to one on water demand, including policies that encourage major improvements in water-use efficiency while reducing total water use. In most of developing countries, however, management approaches and planning are developed considering development patterns and evolving demands at each stage, while the primary concern is still the basic demand for water [64].

Promoting green water management and sustainable human and water development are pushed ahead by growing advanced demand in the water development process [65]. In this light, water demand is also shaped by institutional, technological and cultural factors. It is thus clear that the realization and enhancement of advanced demand at later stages require a multiple-demand management, because water has cultural values and plays a part in shaping the social fabric of our communities. Arguably, sustainability is also achieved by the means of governance and politics in the course of transformation. Socio-technical transitions, social-ecological systems, sustainability pathways, and transformative adaptation are the main approaches [66]. The role of technology is emphasized in engineering solutions to the numerous problem of water scarcity and pollution, and water infrastructure is argued to be a driver of sustainable development within a comprehensive institutional and legal management framework [67,68]. Institutions, infrastructure, technology, and culture are thus solutions or reconciling supply and demand in the course of sustainable water resources management [58,66,69].

Besides the application in China, the water demand framework can be potentially applied to the study of the other countries, to explain the transition of water development as well as the shift of water management paradigm with socioeconomic development. For example, in the United States, water resources management has experienced a transition from a single goal of large-scale water infrastructure construction before the 1930s to integrated water resources development with multiple goals from the 1930s to the 1970s. Since the 1970s, water resources development has stressed the importance of ecological rehabilitation [30,37]. Japan's experience offers another angle on the importance of demand-related policy framing. Dam development has had significant impacts on the Japanese natural and social environment. The Act on Special Measures for Reservoir Area Development in 1973 is considered a turning point in Japan's reservoir policies, which led to depopulation of rural communities and overpopulation in the cities, in turn resulting in the decline of the reservoir areas and water shortages in overpopulated cities [70,71]. Related policy making failed in understanding the balance between basic demand and economic demand in the 1960s and 1970s, an era of rapid economic growth in Japan. Advanced demand for sustainability and water recreation emerged after the 1970s, calling for high quality of life, local residents' participation in management, and recognising rivers as a crucial aspect of local cultural development [70]. The Japanese case also underlines the problem that policy making lags behind demand development. Compared with developed countries such as the United States and Japan, for developing countries, water resources development is still at the level of pursuing basic living standards because of insufficient economic resources for water-management-related investments and developing advanced demand. For example, water safety has been the top priority in India and in the majority of developing countries in Africa, and economic development is argued as the impetus for solving basic water supply problems in domestic water consumption [72]. The above observations are consistent with the water demand framework and provide more empirical evidence to verify the robustness of the framework.

5. Conclusions

Discussing water resources management as stages based on an analysis of changing demand provides a unique research perspective. The above analysis of demand change and its relation with supply looks into trends that are consistent with social, economic, and ecological development. This approach explores the connection of patterns of changing demand with the level of economic development in the water demand framework. The analytical focus is how demand evolves and impacts sustainable water resources management.

Demand can be categorized as basic, economic, or advanced. The levels of these three kinds of demand correspond to stages of water development. Basic demand exists at the basic level of water management; economic demand increases when the basic demand is being met; and advanced demand emerges when both basic and economic demands are being met. The emergence of each kind of demand and water resource use is determined by the level of socioeconomic development. Understanding the water demand at different economic development levels is central to the understanding of the development process at each stage and its practical implications.

Sustainable water resources management in China has been achieved through five stages of water resources management since the founding of the People's Republic of China in 1949. The case of China shows how China's historical and present practices of water resources management evolved and how they match each socioeconomic developmental phase. Water resources management used to be heavily dependent on infrastructure construction and engineering solutions, responding to rapidly growing safety and economic demands. It is noticeable that such an engineering-dominated strategy was subject to the constraints of the level of economic and social development. Conversely, it is essential that a transition from the engineering paradigm to an integrated water resources management, which is reflected in the development of water policies.

The water demand framework illuminates the varieties and effectiveness of water policy made to adapt to changing demand over the course of socioeconomic development. It also draws the implications for water resources management in the global context. Examining changing demand with respect to past and present experiences is important for framing the development of water resources to support sustainable development. For developing countries in particular, the water demand framework points out critical issues of the integration between water development and socioeconomic development, and associated challenges of developing adaptive policies responding to various aspects of water demand in a long-term vision.

Although the water demand framework has been presented as a general framework, there may be some limitations which hinder the generalisability of this framework to be applied in a wider range. First, as a highly conceptual framework, the water demand framework only captures some key features of various water demands, especially the S Curve growth character, but ignores the impacts of some specific important factors, e.g., water pricing, technological advancement, climate change, and culture. This may result in the situation that the framework more applicable as a macro guidance. Second, the framework presents the S Curve growth over time as a continuous function, which relies on a precondition of long sustainable economy growing from low income to high income coherently. However, in the real world, only a dozen countries strictly comply with this precondition. In many countries, economic growth has been interrupted, or even fallen into the middle income trap. Thus the water demand framework is likely to provide an ideal model and cannot be used directly in some countries. Third, the specific measures on water demands and supplies under the framework should be developed if the framework wants to gain more applicable value in practice.

Looking forward, we suggest additional research to address the gaps mentioned above. The dynamics of demand and supply deserve to be studied both in theory and practice, to capture richer features of water demand beyond the S Curve as the economic development. It is also worth studying climate change as an important factor that affects water demand systems in different regions all over the world. Finally, considering the limitation of a single case study of China in this paper, we would like to encourage international comparative studies to further understand the advantages and disadvantages of the water demand framework, and help improve the framework accordingly.

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