MODELLING THE CARRYING CAPACITY OF WATER RESOURCES FOR SUSTAINABLE WATER ECOLOGY USING VENSIM

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ABSTRACT

Purpose: The purpose of this study is to address the growing challenges associated with water resources due to population growth, rapid economic expansion, and the imbalance between supply and demand. It aims to investigate the importance of water as a fundamental resource for ecological preservation and sustainable economic development.

Design/Methodology/Approach: In this study, a comprehensive approach was taken to analyze water resources carrying capacity (WRCC) using the Vensim modeling tool. The research methodology involves considering the multifaceted roles of water resources within the complex ecological, environmental, societal, and economic systems, as well as their interrelationships with other system components.

Findings: The findings of the study highlight the critical need for increasing investment in environmental protection and initiating new water storage projects to enhance the region's water resource carrying capacity. This research underscores the importance of sustainable water ecology in addressing the challenges posed by population growth and economic expansion.

Research, Practical & Social Implications: This study has significant implications for research, practical applications, and societal well-being. It emphasizes the importance of understanding and managing water resources in a sustainable manner to ensure ecological health, economic development, and social progress. The findings can inform policy decisions and guide actions to address water resource challenges.

Originality/Value: The originality and value of this study lie in its holistic approach to assessing WRCC and its consideration of the complex interactions between water resources, ecology, environment, society, and the economy. The research provides insights into the unique challenges faced by regions with increasing water resource demands and pollution and offers a modeling tool for measuring and enhancing water carrying capacity.

Doi: https://doi.org/10.26668/businessreview/2023.v8i9.3846

MODELAGEM DA CAPACIDADE DE CARGA DE RECURSOS HÍDRICOS PARA A ECOLOGIA SUSTENTÁVEL DA ÁGUA USANDO VENSIM

RESUMO

Objetivo: O objetivo deste estudo é abordar os desafios crescentes associados aos recursos hídricos devido ao crescimento populacional, rápida expansão econômica e o desequilíbrio entre oferta e demanda. O objetivo é

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investigar a importância da água como um recurso fundamental para a preservação ecológica e o desenvolvimento econômico sustentável.

Design/Metodologia/Abordagem: Neste estudo, foi adotada uma abordagem abrangente para analisar a capacidade de transporte de recursos hídricos (WRCC) usando a ferramenta de modelagem Vensim. A metodologia de pesquisa envolve considerar os papéis multifacetados dos recursos hídricos dentro dos complexos sistemas ecológicos, ambientais, sociais e econômicos, bem como suas inter-relações com outros componentes do sistema.

Constatações: Os resultados do estudo destacam a necessidade crítica de aumentar o investimento na proteção ambiental e iniciar novos projetos de armazenamento de água para melhorar a capacidade de transporte de recursos hídricos da região. Esta pesquisa ressalta a importância da ecologia da água sustentável na abordagem dos desafios colocados pelo crescimento populacional e expansão econômica.

Pesquisa, Implicações Práticas e Sociais: Este estudo tem implicações significativas para a pesquisa, aplicações práticas e bem-estar social. Ressalta a importância de compreender e gerenciar os recursos hídricos de forma sustentável para garantir a saúde ecológica, o desenvolvimento econômico e o progresso social. As conclusões podem fundamentar decisões políticas e orientar ações para enfrentar os desafios relacionados aos recursos hídricos.

Originalidade/valor: A originalidade e o valor deste estudo residem em sua abordagem holística para avaliar o CCR e sua consideração das complexas interações entre os recursos hídricos, a ecologia, o meio ambiente, a sociedade e a economia. A pesquisa fornece uma visão sobre os desafios únicos enfrentados pelas regiões com demandas crescentes de recursos hídricos e poluição, e oferece uma ferramenta de modelagem para medir e melhorar a capacidade de transporte de água.

Palavras-chave: Capacidade de Transporte de Recursos Hídricos (WRCC), Ecologia da Água, Vensim, Água Sustentável.

MODELACIÓN DE LA CAPACIDAD DE CARGA DE LOS RECURSOS HÍDRICOS PARA LA ECOLOGÍA SOSTENIBLE DEL AGUA UTILIZANDO VENSIM

RESUMEN
Propósito: El propósito de este estudio es abordar los crecientes desafíos asociados con los recursos hídricos debido al crecimiento de la población, la rápida expansión económica y el desequilibrio entre la oferta y la demanda. Su objetivo es investigar la importancia del agua como recurso fundamental para la preservación ecológica y el desarrollo económico sostenible.

Diseño/Metodología/Enfoque: En este estudio se realizó un abordaje integral para analizar la capacidad de carga de los recursos hídricos (CRR) utilizando la herramienta de modelación Vensim. La metodología de investigación implica considerar los roles multifacéticos de los recursos hídricos dentro de los complejos sistemas ecológicos, ambientales, sociales y económicos, así como sus interrelaciones con otros componentes del sistema.

Hallazgos: Los hallazgos del estudio destacan la necesidad crítica de aumentar la inversión en protección ambiental e iniciar nuevos proyectos de almacenamiento de agua para mejorar la capacidad de carga de recursos hídricos de la región. Esta investigación subraya la importancia de la ecología sostenible del agua para abordar los desafíos planteados por el crecimiento demográfico y la expansión económica.

Investigación, implicaciones prácticas y sociales: Este estudio tiene implicaciones significativas para la investigación, las aplicaciones prácticas y el bienestar social. Destaca la importancia de comprender y gestionar los recursos hídricos de manera sostenible para garantizar la salud ecológica, el desarrollo económico y el progreso social. Las conclusiones pueden servir de base para la adopción de decisiones normativas y orientar las medidas para hacer frente a los problemas relacionados con los recursos hídricos.

Originalidad/Valor: La originalidad y el valor de este estudio radican en su enfoque holístico para la evaluación de la CCRM y su consideración de las complejas interacciones entre los recursos hídricos, la ecología, el medio ambiente, la sociedad y la economía. La investigación proporciona información sobre los desafíos únicos que enfrentan las regiones con crecientes demandas de recursos hídricos y contaminación y ofrece una herramienta de modelado para medir y mejorar la capacidad de transporte de agua.

Palabras clave: Capacidad de Carga de Recursos Hídricos (WRCC), Ecología del Agua, Vensim, Agua Sostenible.

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INTRODUCTION

There is increase in population, the economy is expanding quickly, and there's an imbalance between supply and demand for water resources. This leads to an increase in water resource demand and pollution. To depict how human society uses water resources, Tony Allan suggested the idea of virtual water in 1993 (Antonelli and Sartori, 2015). Hoekstra et al.(2007) then expanded it to specify the quantity of water required for the creation of goods and services (Hoekstra et al., 2007). The overall sum of freshwater resources required to generate the services and goods which are utilized by a population in a nation or region is how the idea of a water impact is further defined (Nouri and Hoekstra, 2019). Water usage, however, falls short in measuring the environmental impact brought on by the use of water resources (Zhai et al., 2019). With a focus on how humans use water and the health of aquatic ecosystems, some academics have proposed the water resources ecological footprint (WREF) model (Dai et al., 2019). This model has a unit of measurement that takes the ecological footprint into account.

For the preservation of ecological ecosystems, national or local socioeconomic development, including regional strategic resources for economic sustainable development, water is an essential and fundamental resource (Shi and Qu 1992). Water scarcity is a crisis that is limiting regional sustainable development as a result of population expansion and economic development. Achieving sustainable harmony among residential living, economic development, and the environment around water is crucial (Zhu et al., 2010). A sustainable development as well as water security plan are built on scientific understanding of the carrying capacity of water resources (WRCC).

Predictable levels of technological, economic, and social growth as a foundation, the notion of sustainable social development and the use of water resources, the requirement of maintaining a healthy ecological environment, and appropriate development and deployment as a prerequisite, of water resources (Gilmour et al., 2005). So, we gain some support for future synchronized development of the social, economic, and ecological environments in a particular location over a range of time scales. According to some, the WRCC represents the water resources' maximum carrying capacity for human activity at a particular socioeconomic level or standard of life in a supportive natural system (Motohashi and Nishi, 1991). Relying upon the concept of feedback control and processed through computer simulation, SD is a technique used to examine complex systems. This strategy may be successful in resolving connections between various systems.

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William created the ecological footprint (EF) in 1992 as a thorough accounting technique to assess resource use and the connection between human use of natural resources and ecological services offered by the environment (Inch, 2009). To assess the sustainability of water resources, the EF theory was created and gradually implemented to the field. When evaluating water resources, WREF considers the local water resources carrying capacity (WRCC), that considers the features of both surface and groundwater as well as how humans use water resources in their daily activities and how the natural environment continues to have its own water requirements (Huang et al., 2008). The ecological setting and socioeconomic roles of water resources are described in WREF, a back up account of EF. Water resources have been divided into sub, the ecological footprint of water resources per 10,000 yuan of GDP (WREF/10000Y), as well as the effects of water pollution on the environment have all contributed to the ongoing improvement and expansion of the meaning of WREF (Wang et al., 2013).

Through an attempt to solve these problems and promote sustainable development, research into the water resource carrying capacity (WRCC) has gained popularity. Whenever the financial system and society are developed in a coordinated manner in accordance with the sustainable development principle, the carrying capacity of the water resources represents the maximum economic development that can be afforded. The WRCC concept has advanced quickly despite being introduced somewhat late. Initially on, the WRCC's relationship with the amount of water resources was frequently isolated (Yang et al., 2015).

This study reviewed a modeling tool that could be applied to measure the water carrying capacity for sustainable water ecology. The approach simulates the causal links guiding the use of natural resources and the long-term responsiveness of the environment to governmental decisions influenced by stakeholder desires.

METHODOLOGY

In order to analyze the WRCC (water resources carrying capacity), an input-output multiple requirements scenario decision analysis model was employed, taking into account the function that water resources play in the complex ecology, environment, society, and economic system as well as their relationships to other system components. This offers a comprehensive framework for WRCC research using the Vensim model. A dynamic simulation analysis tool with visualizations was created by Ventana Systems, Inc. of Massachusetts, USA, and is called

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Vensim. For the development, analysis, and packaging of superior dynamic feedback models, Vensim is employed.

According to study in Yiwu, Vensim was used to build the model. The simulation's terminal year is 2020, with a step duration of one year, and the historical review's testing period is 27 years (1980–2006). Through study of parameter error and other data, it was demonstrated that the model's structure is plausible sensitive and accurately depicts the characteristics of Yiwu's water resources' carrying capacity. As a result, it may be utilized to precisely predict how the system will evolve as future policy settings are put into place (Feng et al., 2008).

Approaches to Decision-Support Modeling

By addressing "what if" and/or "which is best" questions, SD models were created to help decision-makers simulate and/or optimize alternative solutions for water-related issues under many probable situations. For this evaluation, 82% of the research were scenario-based techniques, which mimic the dynamic behavior of water resource systems given various scenarios or measures (Fig. 4). Prospective measures were also optimized using optimization-based techniques (2%). Just 7% of the studies that were assessed have predictive modeling as their main purpose.

Figure 1. SD models for various forms of water resource management decision support. OP&SB stands for optimization- and scenario-based approaches, OB is for optimization-based approaches, and PR stands for predictive only
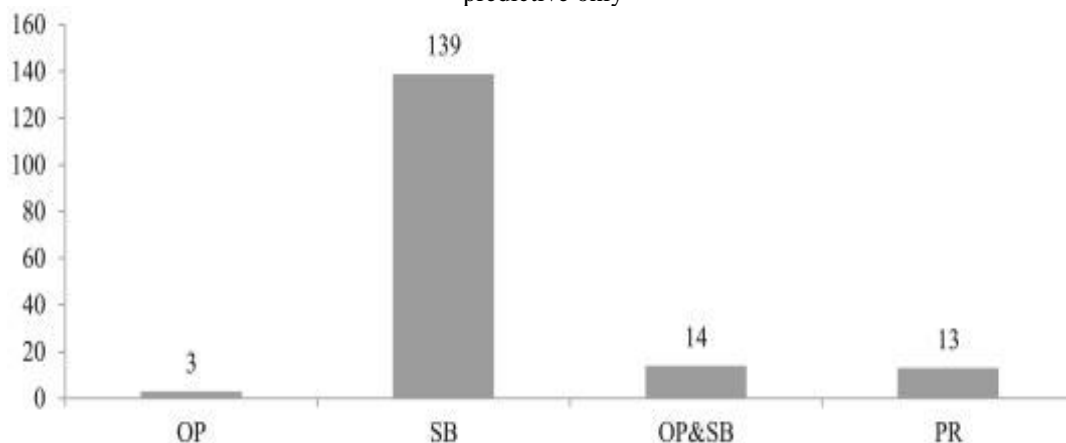

Source: Phan et al., 2015

Yiwu has a total water resource capacity of 6.03 108m3. Based on the most recent historical data and criteria for creating a society with higher standards of living, a number of indicators were chosen as policy parameters to model the development of the region's water resource carrying capacity and economy over the course of the next 10 to fifteen years. A few

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of these measures are irrigation quotas for agricultural, water consumption per unit of output with a value of one thousand RMB by industry, and the amount of sewage cleaned (Clarke, 2002).

The water consumption ecological footprint (WCEF) as well as the water pollution ecological footprint are the two water resources secondary accounts that we divide the WREF into (Figure 2) (Li et al., 2020).

Figure 2. Assessment of water resources utilization model
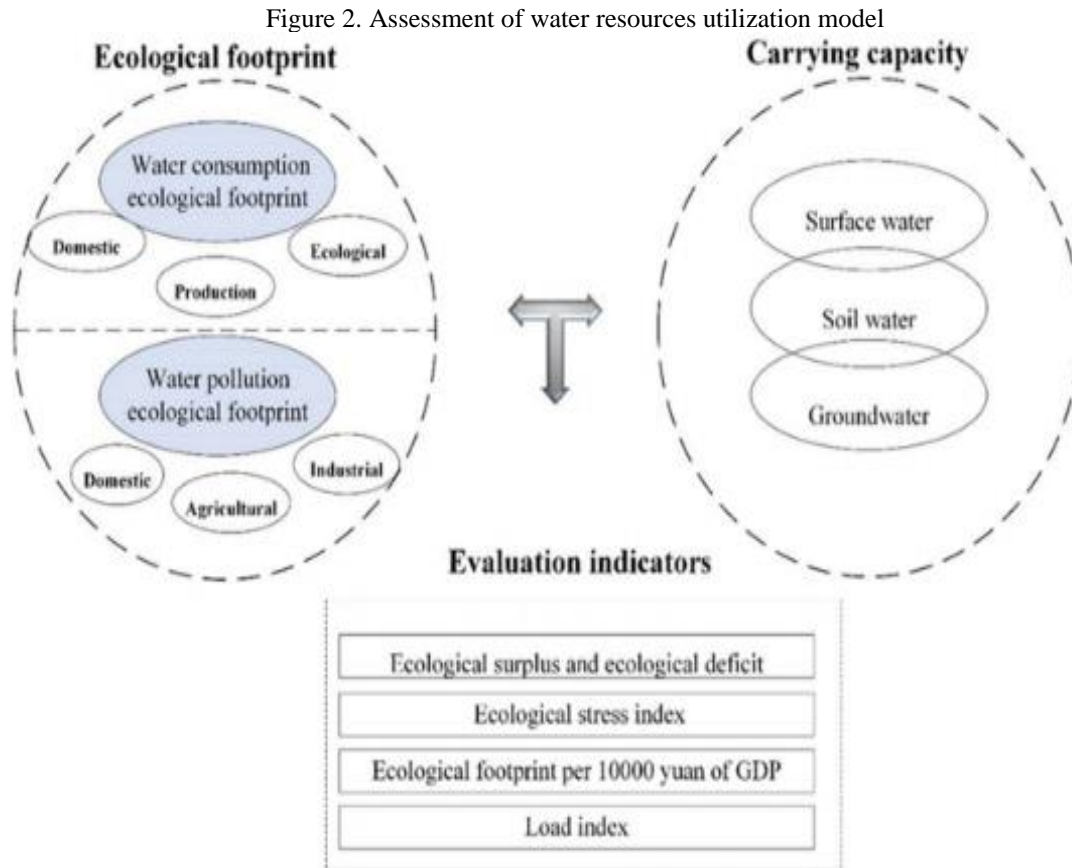
Source: Li et al., 2020

A three-level account is generated for every of the two secondary entities. WPEF is separated into chemical oxygen demand (COD) pollution and nitrogen pollution, whereas WCEF is divided into residential water usage, production water utilization, and ecological water utilization. Water resources carrying capacity, water resources ecological footprint, while water resources consumption evaluation indicators are the three components of the model for assessing the use of water resources depending on ecological footprint (Wang et al., 2019). The demand for water resources created and used by humans in their daily lives, in their work, and for the environment is reflected in the WREF. The WRCC measures how well water resources can support the growth of ecological and economic systems.Water resources carrying capacity,

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water resources ecological footprint, while water resources consumption evaluation indicators are the three components of the model for assessing the use of water resources depending on ecological footprint.(Zhao et al., 2017). The demand for water resources created and used by humans in their daily lives, in their work, and for the environment is reflected in the WREF. The WRCC measures how well water resources can support the growth of ecological and economic systems (Li et al., 2020).

Calculations for the Water Consumption

Water consumption ecological footprint (Li et al., 2020):

$$EFcw = EFcwd + EFcwp + EFcwe = N \cdot efcw$$

The following equation could be used for the calculation of the water carrying capacity

As society and the economy are developing so quickly, the water pollutant carrying capacity, which is established on the water environmental capacity theory, is a crucial factor in the control of water pollution. We decided on a water environmental capacity calculation using a one-dimensional model, as described in the following ,(Xie et al., 2014).:

$$Wi = 86.4 \times [Qi \times Csi \times \exp\{(Ki \times Li)/86400ui\} - Coi \times Qi]$$

Where,

Qi: Planned flow of reach I (m3), Wi: Residual water environmental capacity of reach I (kg/day)./s),
Ki: The rate at which contaminants degrade in reach I (1 day),
Csi: The target value for functional areas' water quality within reach (mg/L),
ui: Average velocity in reach i (m/s),
C0i: Water quality ratings for the reach above reach I as of the present (mg/L),
Li: Flow time of pollutants from initial to control sections (day)

DISCUSSION

The main strategy was to lessen the load of water pollution by increasing the rates at which home and industrial sewage was treated. Simulated outcomes are displayed in figure 3.

Pollution (COD) emissions have typically decreased, though the WRCC has increased 10% on average since Scheme I. As a result, although the impact was not immediately apparent, increasing total pollution treatment levels could enhance the WRCC. Due to changes in industrial structure, Scheme IV's water demand was lower than Scheme I's, and COD emissions were also marginally lower. The WRCC in the LRB was higher under Scheme V than under

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any earlier schemes, increasing by an average of 30%, and the rate of home sewage treatment was substantially improved. developing socially, economically, and environmentally in concert.

Figure 3. Pollution emissions from different programs and the environmental impact of water
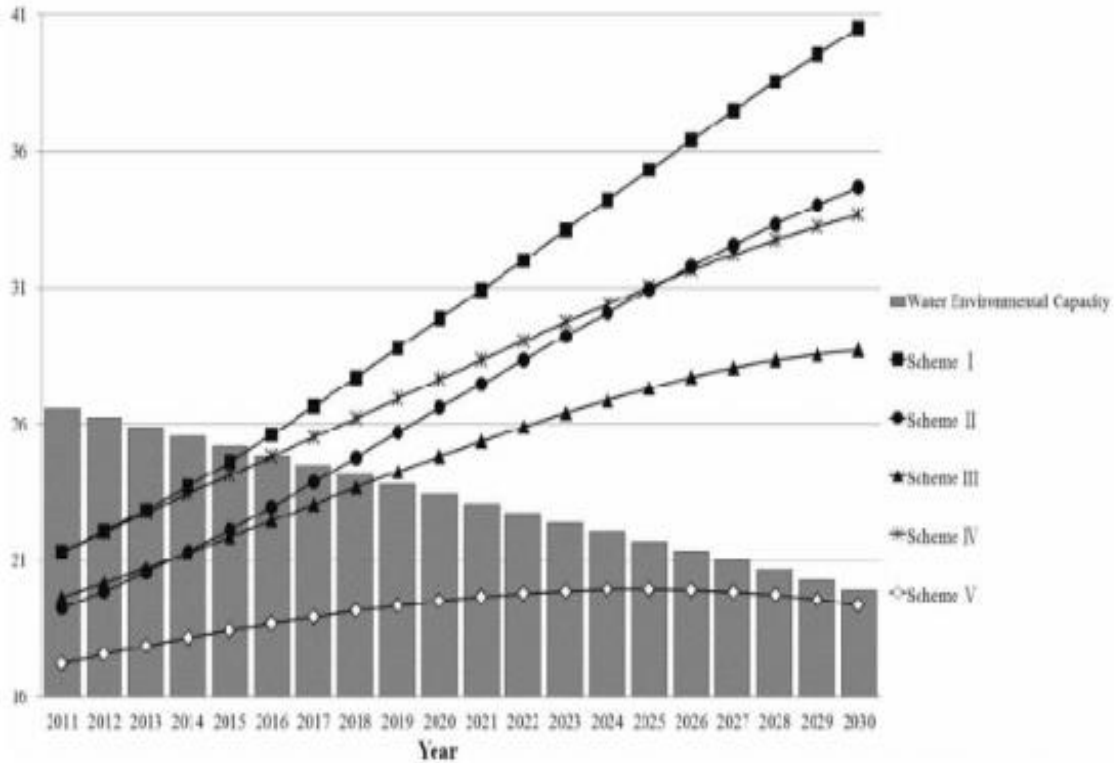
Source: Feng et al., 2008

The controlled concentration of COD according to that standard is 20 mg/L. With the development of technology, water quality needs will rise. As a result, we concluded that this characteristic controlled COD concentration in the LRB must comply with Class II standard, which is 15 mg/L.

It is clear that pollution cannot be prevented during economic growth. But the ecology cannot be harmed in the name of economic growth.

The ability of ecological systems to regenerate itself cannot be exceeded, in particular, by resource consumption. The ultimate goal in Yiwu ought to be simultaneous economic development and environmental protection. What is the connection between economic under the intermediate plan, development and additional issues like population, resource availability, and the environment are carefully taken into account. When analyzing benefits and drawbacks

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from an ecological perspective, it is necessary to take into account resource availability, the environment, industry needs, and market conditions (Feng et al., 2008).

The protection of the environment is the main objective of this plan. As a result, annual investment in environmental protection rises, which eventually reduces sewage discharge. By 2013, sewage treatment levels would have been at 100%, and the proportion of river length classified as below class IV PPR would steadily decline from 50.1% in 2005 to 32.7% in 2010 and then nil by 2013. Due to the city's emphasis on environmental conservation, sections of river with poor water quality would disappear. Beautiful beauty, including green hills and pure waterways, would emerge all around the city, radically altering its ecological environment (Feng et al., 2008).

Industrial water requirements in 2020 would be 0.99 108 m3 less than those of the primary system owing to the slowdown of industrial expansion. As a result, the total amount of water needed would be 2.58 108 m3, significantly less than the maximal water supply carrying capacity of resources for water. Even though this plan does a remarkable job of balancing the availability of water against demand, it will also lead to less resource utilization and constrained industrial and agricultural expansion.

According to the new method for improved ecological footprint study, water is the most active element in the ecological environment, which is the area for human survival and growth being completely aware of the status and function of water in the ecological environment is important for water allocation since it is simple to identify changes in water quantity and quality. The primary factors affecting the eco-environment subsystem are the total amount of wastewater discharged, industrial wastewater discharged, tertiary industrial wastewater discharged, domestic sewage discharged, and COD emissions from domestic, irrigation, industrial, and tertiary industries, among others. We adjusted the release of construction sewage to zero since the emission of wastewater is relatively low because it may be recycled in the construction business. The eco-environment subsystem involves factors for the industrial wastewater treatment capacity, domestic sewage COD concentration, industrial wastewater COD concentration, and others (Li et al., 2020).

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Figure 4. Lower reaches of the Yellow River's per capita water pollution ecological footprint
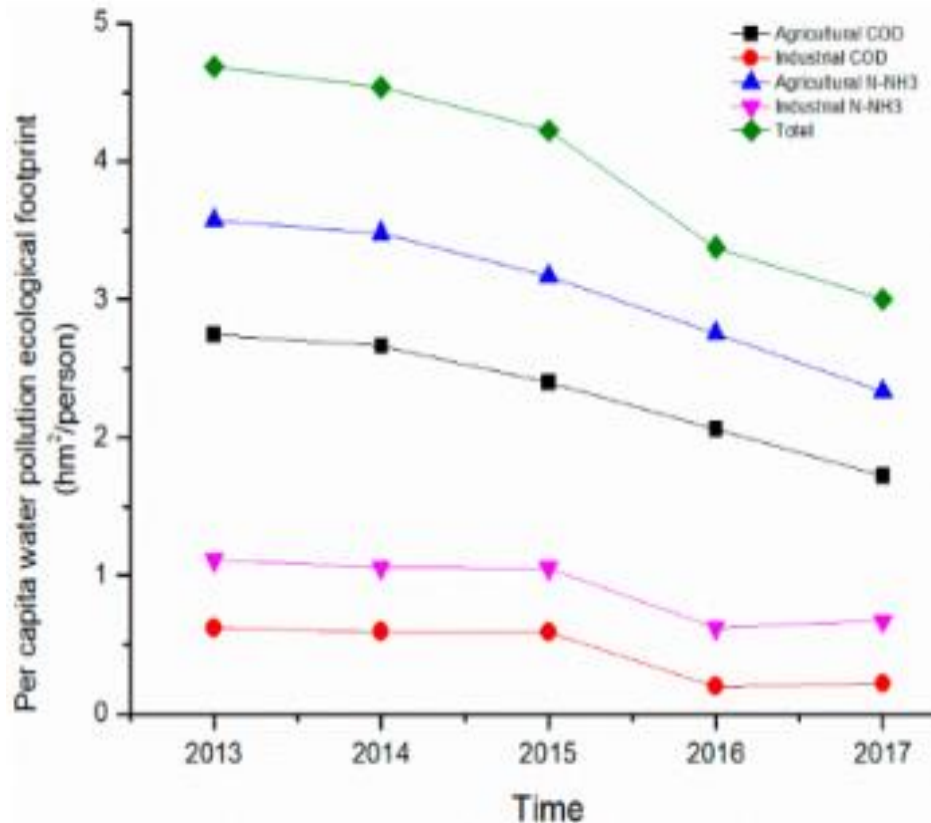
Source: PCWPEF from 2013 to 2017.

The urban aggregates in the lower Yellow River consume more than 70% of their water, with agriculture being the main consumer. Ammonia nitrogen pollutants from the use of chemical fertilizers in agriculture as well as pollution runoff from livestock farming are the main causes of water pollution. As a result, agricultural pollution discharge should be limited but also water-saving irrigation technology must be applied. In the five years between 2013 and 2017, the entire region's water resources reached an ecological deficit status, although this situation has improved, with a decline of 54.52% (Li et al., 2020).

CONCLUSIONS

This review article discussed the water resources carrying capacity (WRCC) for sustainable water ecology by using Vensim modelling technique. Modelling was discussed based on the previous researches carried out in some areas of China in Yiwu, northern china and Teijen city.

It was found that the only through increasing investment in environmental protection over the long term and starting new water storage projects will the carrying capacity of the region's water resources be increased. These initiatives include the construction of sizable or

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medium-sized reservoirs, the modification of industrial processes, and the development of a society where water conservation is second nature.

Both the primary plan, which would pursue rapid economic growth at the service of the environment, and the secondary plan, which would prioritize environmental protection over economic growth, are undesirable for Yiwu.

The supply and demand balance of water resources was developed as the main goal using the Vensim simulation software. The outcomes of the model testing showed that the structure and behavior of the model were consistent with practice. The WRCC SD model was used to simulate the WRCC under current trends in population, society, economics, and water resource development from 2011 to 2030. The main goals of this strategy were to reduce pollution, conserve water, and adapt the industrialized structure.

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