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A Dataset of Distribution and Characterization of Underground Wastewater Treatment Plants in China

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Underground wastewater treatment plants (U-WWTs) have emerged as a novel paradigm for urban wastewater pollutants management, offering benefits such as alleviating the Not-in-my-backyard (NIMBY) effect and utilizing land resources efficiently. China stands at the forefront, witnessing swift advancements in U-WWTP technology and deployment. However, the absence of a thorough understanding of their geographical distribution and operational characteristics could lead to misaligned planning and construction, resulting in inefficient resource allocation and treatment capacities for urban wastewater treatment. This dataset provides an up-to-date overview of the spatial distribution, process selection, and discharge standards for all U-WWTs in China (with a total number of 201) constructed since 1995. To enhance comparative analysis, the dataset has been supplemented with information on conventional aboveground wastewater treatment plants (A-WWTs), comprising a total of 2464 records, which enriches a more comprehensive evaluation of different wastewater treatment approaches. Utilizing this dataset can provide essential data support for the strategic management of urban wastewater systems and serve as a valuable reference for the paradigmatic renovation of existing wastewater treatment plants.

Background & Summary

As China undergoes rapid urbanization alongside economic growth, its wastewater treatment capabilities have significantly expanded. By 2022, China has boasted nearly 3,000 conventional aboveground wastewater treatment plants (A-WWTs), handling capacity of approximately $2.20 \times 10^8 \text{ m}^3/\text{d}^1$, positioning China as the world's largest wastewater treatment market². It is essential to highlight that the continuous on-going rapid urbanization over the past decade has led to many A-WWTs being surrounded by new-developed and expanding urban areas. This has created significant issues, as A-WWTs are often viewed as sources of Not-In-My-Backyard (NIMBY) effects due to the odours, noise, and unappealing aesthetics they generate³⁻⁵. Additionally, they occupy valuable city land, negatively impacting the surrounding environment and land resources⁶. In response to these challenges, underground wastewater treatment plants (U-WWTs) have gained attention for mitigating these negative impacts associated with A-WWTs by constructing treatment facilities underground and using the aboveground space for public amenities such as parks, gymnasiums, and museums^{7,8}. This approach has been increasingly adopted in Europe, Asia, and the Americas⁹. However, U-WWTs differ significantly from A-WWTs in terms of construction and operation characteristics, which are often overlooked. Opting for U-WWTs requires careful consideration of specific usage conditions and practical challenges, such as selecting suitable compact wastewater treatment processes for varying regional contexts and managing underground

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space requirements (ventilation, lighting, etc.). A lack of understanding of these aspects can lead to inefficient resource allocation and reduced operational effectiveness, thereby failing to fully leverage the advantages of U-WWTPs and potentially undermining confidence in their effectiveness. Therefore, as the construction of U-WWTPs expands in highly urbanized areas, in-depth studies and comprehensive data collection on U-WWTPs are crucial for urban planning and decision-making regarding diverse wastewater treatment plant (WWTP) options.

Researchers have shown considerable interest in U-WWTPs and explored various aspects through case studies, such as land conservation analysis¹⁰ and treatment process application⁸. Despite these studies, the construction and operation of U-WWTPs remain controversial, with ongoing debates about weighing their advantages and disadvantages. For instance, quantitative analyses have assessed the socio-economic impacts of WWTPs on surrounding areas. A study in Beijing from 2016 and 2017 revealed that traditional A-WWTPs led to a substantial loss of at least 32.53 billion RMB in surrounding property values¹¹. Conversely, WWTPs near parks positively influence nearby real estate values, highlighting the necessity for U-WWTPs that utilize space-saving treatment processes and environmentally friendly aboveground facilities. What's more, there are two starkly contrasting conclusions regarding the carbon emission studies related to underground sewage plants. On one hand, a standardized Life Cycle Comprehensive Impact (LCCI) assessment indicates that U-WWTPs may have up to a 20% higher negative impact on environmental efficiency, infrastructure investment, and ecological efficiency compared to A-WWTPs¹². On the other hand, an assessment of the Bishui U-WWTP in Beijing demonstrates that its direct carbon emission intensity is 29.6% lower than that of conventional WWTPs (0.19 kg vs. 0.27 kg CO₂-eq/m³), and it is also 20.8% lower than the average intensity of 65 WWTPs (0.25 kg CO₂-eq/m³)¹³. These findings underscore the complexity and the need for a nuanced understanding of the environmental implications of U-WWTPs. All in all, the varying geographic characteristics, scales, process, and discharge limits between A-WWTPs and U-WWTPs contribute to these differing perspectives, indicating that careful consideration is essential before deciding on U-WWTP implementation. Unfortunately, relevant data and studies are lacking, which hampers informed decision-making. A comprehensive dataset that addresses the geographical distribution and operational features of U-WWTPs could effectively fill this knowledge gap and significantly help in designing U-WWTPs tailored to specific regional needs and considering local environmental, economic, and social factors.

This dataset provides an up-to-date overview of the spatial distribution and operational characteristics of U-WWTPs in China. Since the construction of the first U-WWTP in 1995, the dataset captures data on all 201 U-WWTPs in China, with a total treatment capacity of 2.30×10^7 m³/d. It details the geographical distribution, scale, processes, and discharge limits of these U-WWTPs. Additionally, the dataset also incorporates information on 2464 A-WWTPs to facilitate comparative analysis. U-WWTPs exhibit a preference for locations in southeastern coastal and southwestern mountainous regions, often employing compact processes like membrane bioreactors (MBR). Overall, this dataset documents the construction and operational data of U-WWTPs at both provincial and municipal levels in China, enabling a wide range of spatial and temporal analyses and developmental studies. Furthermore, it provides robust data support for evidence-based decision-making in urban wastewater management, optimizing resource allocation in the construction and operation of WWTPs. This dataset serves as a crucial reference for the planning and construction of U-WWTPs.

Methods

Data collection procedures. The procedures of data collection about U-WWTPs in this dataset are outlined in Fig. 1. A collection was conducted in both Chinese and English by searching two scientific citation indexing services, Web of Science (<https://www.webofscience.com/>) and China National Knowledge Infrastructure (CNKI) (<http://www.cnki.net/>), respectively. The search keywords used in Web of Science (WOS) were ((U-WWTP OR Underground wastewater treatment OR Underground sewage treatment plant) AND China), while in China National Knowledge Infrastructure (CNKI) were ((地下式污水处理厂 + 地下式污水处理厂 + 地理式污水处理厂) * 中国). A total of 1,553 publications were retrieved, with 106 from WOS and 1,447 from CNKI. Subsequently, the publications were reviewed to delete duplicates and excluded publications that did not provide specific information on U-WWTPs. Then, full texts were further examined to extract the required data. Notably, despite the increasing number of U-WWTPs in operation over the past few decades, studies on U-WWTPs are not widely reported. Consequently, some data was obtained by consulting WWTP operators or reviewing official public information. Finally, compiling all of the recorded information, data on 201 U-WWTPs were obtained, with the earliest record dating back to 1995. Furthermore, data on A-WWTPs was collected from the Urban Drainage Statistical Yearbook of China to facilitate comparative research between U-WWTPs and A-WWTPs. Due to discrepancies in recording methods across different years, a comprehensive review was necessary to eliminate duplications and remove blank records. Eventually, information on 2,464 WWTPs was collected. It is important to note that all the WWTPs included in this dataset are centralized facilities located within Chinese cities.

In order to ensure the accuracy and validity of the data, multiple researchers conducted a comprehensive review and standardized the dataset. This process involved reorganizing and categorizing process types and discharge limits, as detailed in Tables 1 and 2. Simultaneously, to maintain data comprehensiveness, some WWTPs with missing data were retained. After extensive screening, classification, and organization, a combined dataset of U-WWTPs together with A-WWTPs in China was established, including (i) WWTPs types (U-WWTPs and A-WWTPs), (ii) Geographical location information, (iii) Scale, (iv) Process types, (v) Discharge limits, and (vi) Influent water quality. The dataset contains information on 201 U-WWTPs from 1995 to 2025 and 2464 A-WWTPs.

It is noteworthy that several studies have indicated the establishment of a significant number of A-WWTPs in China dating back to the 1970s, marking a period of significant expansion in urban sewage treatment



Fig. 1 Schematic overview of the literature search and data collection procedure and results.

capacity^{2,14}. To this day, the construction of A-WWTPs has reached a mature phase, with a substantial number of these plants successfully built and operated. In contrast, the construction of U-WWTPs has seen a more recent and rapid rise. Despite the historical significance of A-WWTPs, we face challenges in procuring uniform construction year data for these long-standing facilities. Considering the potential impact on the overall quality and availability of our dataset, we have made a deliberate decision not to include the construction year for A-WWTPs.

Regarding influent water quality indicators, such as Sample_COD and Sample_NH₃-N, this dataset encounters limitations due to scarce records or undisclosed information, which has hindered the ability to acquire specific data for each U-WWTP. Nonetheless, it is generally accepted that the sewage treated by U-WWTPs is of comparable quality to that treated by A-WWTPs in the same region. Consequently, within a specific provincial or municipal context, it is reasonable to assume similar influent water quality for both types of facilities.

The discharge limits for WWTP effluents in this dataset are based on the national standard - Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB18918-2002)¹⁵ shown in Table 3. In China, national standards are mandatory, and local discharge limits are required to be more stringent than the national standards. Consequently, when compiling this dataset, if a WWTP operates under local discharge standards, we consider these standards to be superior to the national standards and categorize them as “Above Class 1A”.

Geo-positioning. We extracted the geographical coordinates of each WWTP by following established methods¹⁶. We used the georeferencing function of Baidu Maps (<https://map.baidu.com/>), the commonly used online location service in China, via using a Web API (application program interface) to record their latitude and longitude coordinates. The coordinates in the dataset are limited to city-level precision due to challenges in acquiring precise geographic data and the associated sensitivity issues. These locations were then visualized using ESRI ArcGIS 10.7.

Data Records

The dataset on U-WWTPs in China (available from [figshare](https://www.figshare.com/)¹⁷) consists of 14 columns, each row representing information about one WWTP:

Number	Category	Sub-category
1	AO (Anoxic/Oxic)	AO, Modified AO, Multiple AO, Inverted AO, Activated sludge process
2	AAO (Anaerobic/Anoxic/Oxic)	AAO, Modified AAO, Inverted AAO, AO +AAO, Bardenpho, UCT (University of Capetown), AAO+BAF
3	OD (Oxidation Ditch)	OD, Modified OD, Pasveer OD, Carrousel OD, Orbal OD, Integral Combined OD, DE-OD (Dual channels oxidation ditch), T-OD (Triple channels oxidation ditch), A+OD (Carrousel with pre-anaerobic zones), Micro-aeration OD, AO/AAO+OD
4	MBR (Membrane Bioreactor)	AO/AAO+MBR, SBR+MBR/AAO
5	SBR (Sequencing Batch Reactor)	SBR, Modified SBR, Unitank, CASS (Cyclic Activated Sludge System), CAST (Cyclic Activated Sludge Technology), AICS (Alternated internal cyclic system), ICEAS (Intermittent Cycle Extended Aeration), C-TECH (Cyclic Activated Sludge Technology), DAT-IAT (Demand Aeration Tank-Intermittent Aeration Tank), MSBR(Modified Sequencing Batch Reactor)
6	Biofilm	Biological filter, BAF (Biological Aerated Filter), Botating biological contactor, Biological contact oxidation process, Biological fluidized bed, MBBR (Moving biological bed reactor), FBBR (Fixed-bed biofilm reactor), HBR (Hybrid biofilm reactor), HPB (High concentration powder carrier bio-fluidized bed), STCC (Standard combination carbon)
7	Others	BIOLAK, Constructed wetland, BFBR (Biofilm biological-Reactor Three-dimensional Ecological Technology), Biological double-efficiency process, AB (Adsorption Biodegradation), Physico-chemical and biological treatment, AmOn (An integrated nitrogen and phosphorus removal process), UASB (Upflow anaerobic sludge blanket reactor)

Table 1. Categorization Explanation of Process Standards.

Number	Category	Content
1	Class 2 and below	Class 2, Below Class 2
2	Class 1B	Class 1B
3	Class 1A	Class 1A
4	Above Class 1A	National Surface Water Standards, Local Surface Water Standards, Local Effluent Discharge Standards
5	Others	No discharge limits recorded

Table 2. Classification Explanation of Effluent Discharge Limits.

Number	Basic Control Parameter	Class 1		Class 2	Class 3	
		A	B			
1	Chemical Oxygen Demand (COD, mg/L)	50	60	100	120	
2	Biochemical Oxygen Demand (BOD ₅ , mg/L)	10	20	30	60	
3	Suspended Solids (SS, mg/L)	10	20	30	50	
4	Animal and Vegetable Oils (mg/L)	1	3	5	20	
5	Petroleum Compounds (mg/L)	1	3	5	15	
6	Anionic Surfactants (mg/L)	0.5	1	2	5	
7	Total Nitrogen (as N, mg/L)	15	20	—	—	
8	Ammonia Nitrogen (as N, mg/L)	5 (8)	8 (15)	25 (30)	—	
9	Total Phosphorus (as P, mg/L)	Constructed Before December 31, 2005	1	1.5	3	5
		Constructed Since January 1, 2006	0.5	1	3	5
10	Color (Dilution Factor)	30	30	40	50	
11	pH	6–9				
12	Fecal Coliform Count (term/L)	10 ³	10 ⁴	10 ⁴	—	

Table 3. Maximum Permissible Concentrations of Basic Control Parameters in Wastewater Treatment Plant Effluents (Daily Average) according to national standard.

1. Type_WWTP: Type of construction for the WWTP, including underground and aboveground, with U-WWTPs further distinguished as full-UWWTP and semi-UWWTP. Additionally, U-WWTPs with unspecified types are grouped into the category of other-UWWTP.
2. Name_WWTP: Name of the WWTP.
3. Local_province: Province-level information of the WWTP's location (name of Chinese province/municipality/autonomous region/special administrative region).
4. Local_city: City-level information of the WWTP's location.
5. Local_lon: Longitude of the WWTP's location at the city level.
6. Local_lat: Latitude of the WWTP's location at the city level.

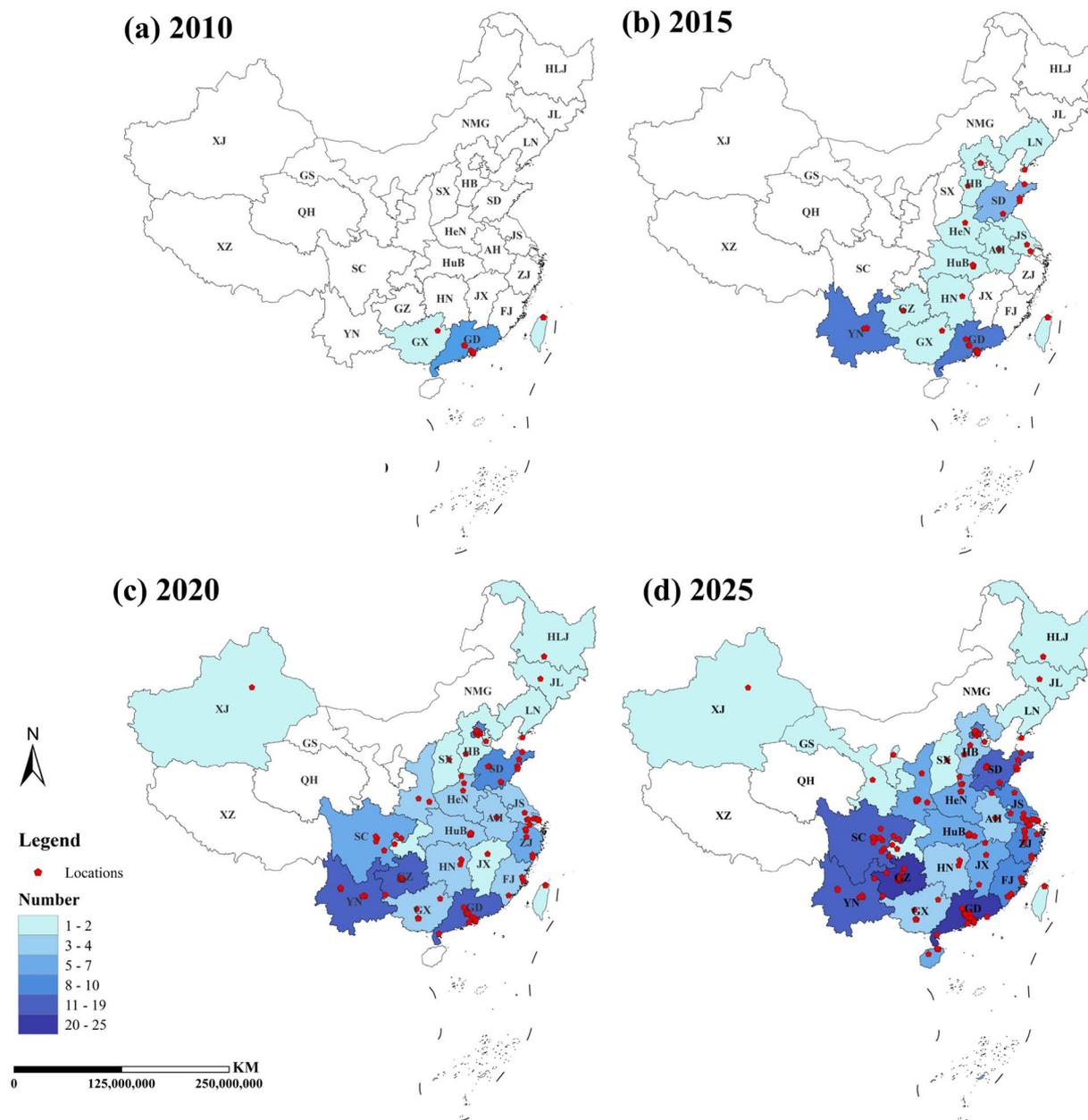


Fig. 2 The increasing number of U-WWTPs in China from 2010 to 2025.

7. Scale_WWTP: Scale of the WWTP (10^4 m³/d).
8. Process_category: Category of processes used in the WWTP.
9. Process_sub-category: Sub-category of processes used in the WWTP.
10. Discharge_standard_WWTP: Discharge standards/limits for the WWTP's effluent.
11. Sample_COD: Annual average concentration of COD (Chemical Oxygen Demand) in the WWTP's influent (mg/L).
12. Sample_NH₃-N: Annual average concentration of ammonia nitrogen (NH₃-N) in the WWTP's influent (mg/L).
13. Construction_Year: Year of construction of the U-WWTP.
14. Source: Data source.

The temporal evolution of U-WWTPs is depicted in Figs. 2 and 3. In 2010, there were only five U-WWTPs located in the coastal areas such as Guangdong Province (Fig. 2a). Over the next two decades, there was a notable increase in U-WWTPs construction, especially in southeastern coastal regions led by Guangdong and the southwestern regions led by Yunnan (Fig. 2b and c). At the provincial level, all regions except Inner Mongolia (NMG), Qinghai (QH), and Tibet (XZ) have established U-WWTPs, totalling 201 U-WWTPs in China (Fig. 2d). Fig. 3 illustrates the developmental trend of U-WWTPs in China. The number of U-WWTPs has increased annually,

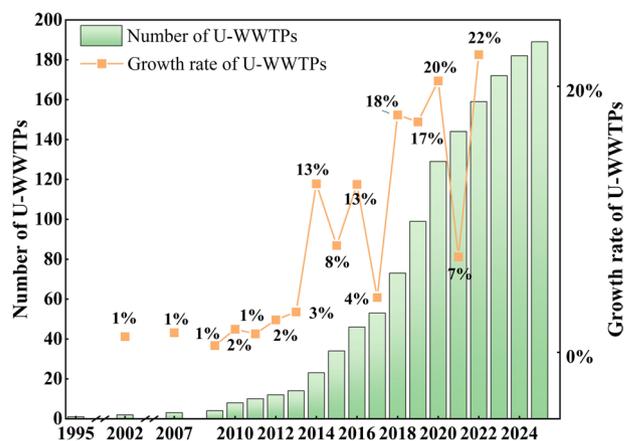


Fig. 3 The development of U-WWTPs in China. *The growth rate of U-WWTPs is determined by dividing the incremental number of U-WWTPs by the total incremental number of WWTPs in China.

with the highest annual increase being 30 new U-WWTPs. This corresponds to a rise from 1% to over 20% of the total new WWTPs constructed nationwide. Notably, there was a significant surge in 2022, with new U-WWTPs accounting for 22% of all new WWTPs in China.

The distribution and scale of both U-WWTPs and A-WWTPs in China are illustrated in Fig. 4. Currently, U-WWTPs in China boast a capacity of 2.30×10^7 m³/d, representing approximately one-tenth of the nation's total wastewater treatment capacity. Among all A-WWTPs, over 1,900 have capacities exceeding 1×10^4 m³/d. Generally, conventional A-WWTPs serve all cities in China. In contrast, U-WWTP construction is predominantly concentrated in coastal cities, particularly in Guangdong, and Zhejiang provinces (Fig. 4a and c), as well as in mountainous regions within Yunnan, Sichuan, and Guizhou provinces (Fig. 4b and d). The geographic distribution of U-WWTPs is influenced by several factors. Coastal areas, with their large populations and rapid economic development, prefer U-WWTPs to conserve space and minimize environmental impact. In contrast, mountainous regions, with complex terrain and limited land availability, opt for U-WWTPs to overcome these challenges and integrate the facilities more harmoniously with the landscape.

The process selection and the water quality discharge limits of U-WWTPs and A-WWTPs in China are shown in Fig. 5. U-WWTPs predominantly utilize the AAO and MBR processes, accounting for around 70% of the total processes employed (Fig. 5a). In contrast, most A-WWTPs across provinces primarily employ the OD, AAO, and SBR processes (Fig. 5b), which is similar to previous research results¹⁸, reflecting a broader range of options for A-WWTPs. Natural conditions, influent water quality, and cost-effectiveness influence process selection for A-WWTPs. However, U-WWTPs prioritize space and energy efficiency to reduce construction difficulties and operational costs^{8,10}. The vast majority of U-WWTPs meet Class 1A and higher standards for discharge (Fig. 5c). In contrast, most A-WWTPs primarily meet Class 1B standards, with fewer achieving above Class 1A standards (Fig. 5d). This indicates that U-WWTPs focus on higher water quality for reuse and environmental protection. The aboveground parts of U-WWTPs are often designed as parks that require high-quality water, ensuring the safety of reused water on-site. The influent COD and NH₃-N concentrations of A-WWTPs in China are shown in Fig. 6. The influent COD concentrations in most provinces range from 200 to 400 mg/L, while influent NH₃-N concentrations range from 20 to 40 mg/L, consistent with previous literature records².

Technical Validation

This dataset comprises 2665 records, extracted from various sources, including published literature, yearbooks, operator consultations of WWTPs, and public information. Due to variations in data recording methods, a specialized team was tasked to ensure data accuracy and validity. All data were reviewed by at least two people. One researcher entered the records while others checked the dataset to ensure accuracy and avoid duplication. At the stage of geo-positioning, the accuracy and validity of each WWTP were rechecked.

To ensure correctness and usability, the dataset was compared with existing records. Despite inconsistencies from incomplete historical documentation and confidentiality constraints, the dataset provides a comprehensive overview. For instance, data from the 2015 Urban Drainage Yearbook showed that A-WWTPs, accounted for a total wastewater treatment capacity of 1.25×10^8 m³/d, representing 89% of the national volume as documented in the 2015 Urban Construction Statistical Yearbook by the Ministry of Housing and Urban-Rural Development (1.40×10^8 m³/d¹⁹), indicating significant representation. Moreover, given the extended operational period of WWTPs and the nearing completion of the rapid expansion phase of WWTP construction in China²⁰, the dataset is representative of the current majority. Additionally, this dataset provides an updated and comprehensive compilation of existing U-WWTPs in China, covering previous information related to U-WWTPs^{11,21}. For A-WWTPs, the dataset includes information on treatment process selection and the discharge limits with previously reported information^{18,20}.

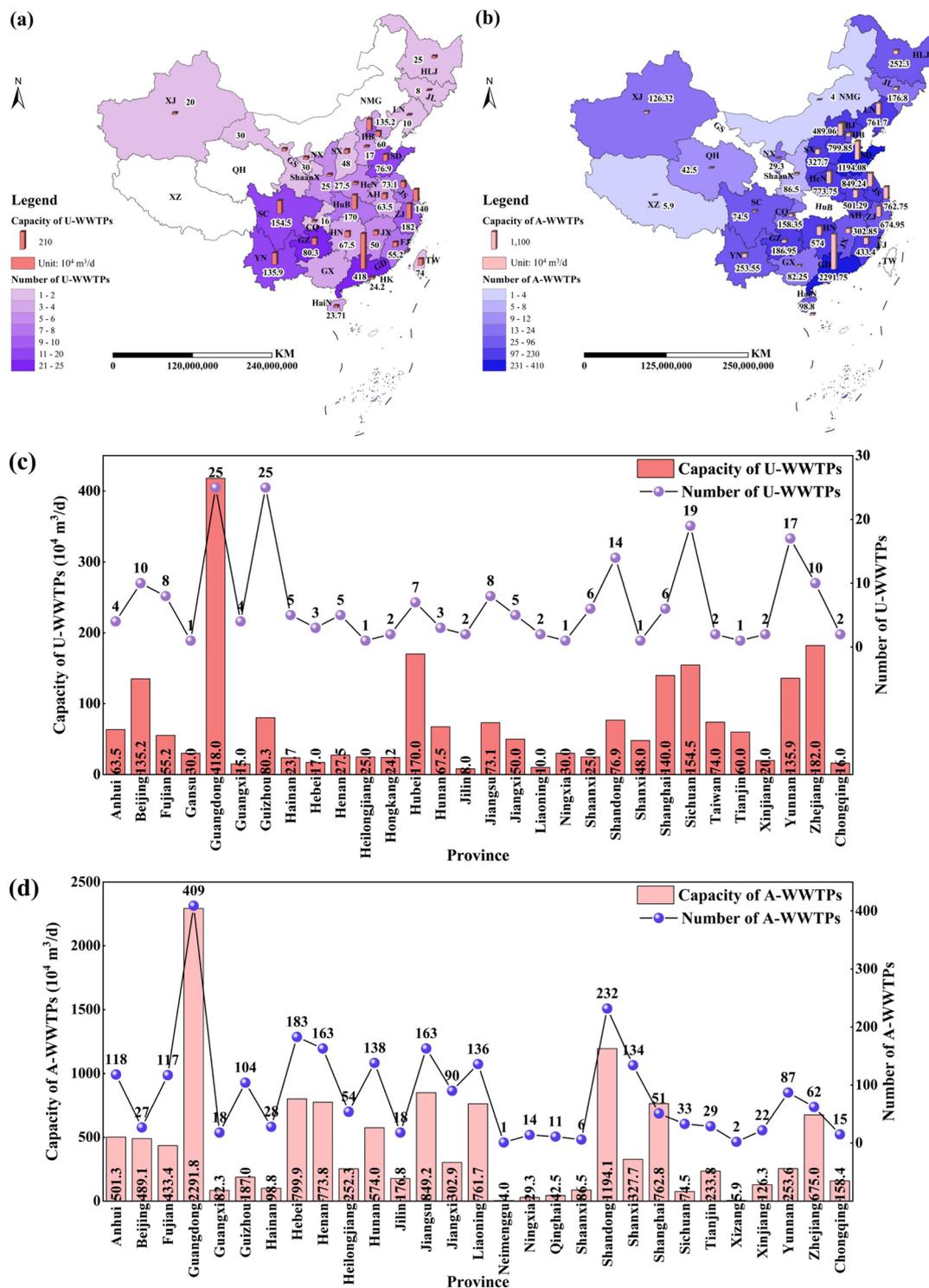


Fig. 4 The regional distribution of both U-WWTPs and A-WWTPs in China. (a) U-WWTPs. (b) A-WWTPs. *Blank space indicates that no valid values were collected. The number and capacity of U-WWTPs and A-WWTPs in various provinces. (c) U-WWTPs. (d) A-WWTPs.

Usage Notes

U-WWTPs offer a strategic, paradigm-shifting solution for controlling urban wastewater pollutants and mitigating NIMBY effects by situating treatment facilities underground and using the aboveground space for public amenities such as parks, gymnasiums, and museums. The unique distribution, design, and operational characteristics of U-WWTPs, which differ from A-WWTPs (a realistic scenario of U-WWTPs versus A-WWTPs depicted in Fig. 7), necessitate specialized knowledge to address challenges related to space management, water recycling, process efficiency, and environmental impact. This dataset captures the significant expansion of

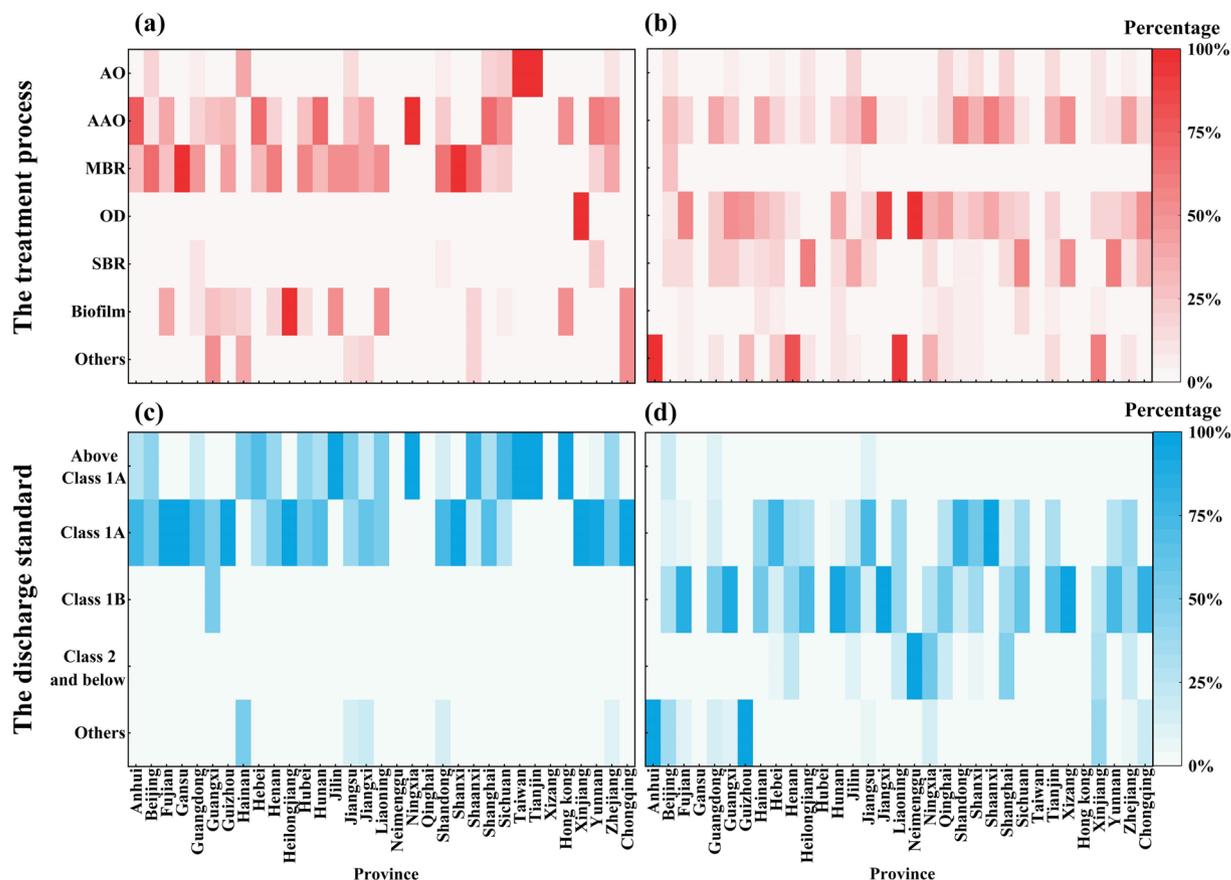


Fig. 5 The treatment process and discharge standards selection of both U-WWTPs and A-WWTPs in across various provinces in China. The treatment process selection of U-WWTPs (a) and A-WWTPs (b). In Fig. 5a and b, the percentages in these subfigures denote the proportion of WWTPs within each province that utilize a specific treatment process compared to the total number of WWTPs in that province. Darker colors indicate a more frequent adoption of the particular treatment process within the province. The discharge standards selection of U-WWTPs (c) and A-WWTPs (d). In Fig. 5c and d, the percentages in these subfigures denote the proportion of WWTPs within each province that utilize a specific discharge standard compared to the total number of WWTPs in that province. Darker colors indicate a more frequent adoption of the particular discharge standard within the province.

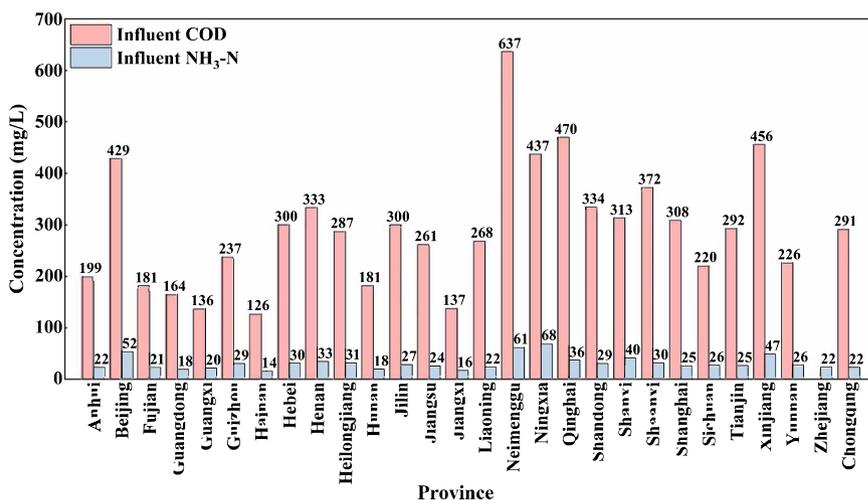


Fig. 6 Influent COD and NH₃-N concentrations of A-WWTPs in various provinces in China.

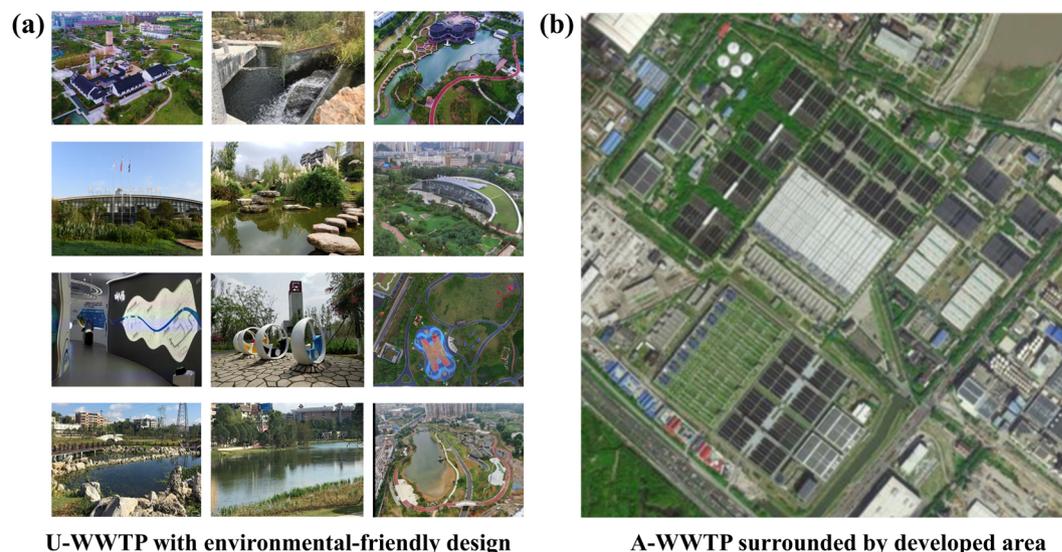


Fig. 7 A realistic scenario of both U-WWTPs and A-WWTPs in China. **(a)** U-WWTP. **(b)** A-WWTP. * Fig. 7b is Shanghai Zhuyuan No.1 WWTP from Baidu map.

U-WWTPs in China, characterized by accelerated construction, selective treatment processes, and higher discharge limits. It provides a comprehensive and detailed record of U-WWTPs in China, including construction and operational characteristics at a fine geographical level. This resource enables exploration of the spatial and temporal dimensions of U-WWTPs, evaluation of their multi-scaled characteristics, and informed planning and development aligned with local environmental, economic, and socio-cultural factors. The dataset is valuable for policymakers, urban planners, environmental scientists, and others interested in the management and development of U-WWTPs. For example, it aids in strategic planning by identifying areas where wastewater treatment infrastructure requires reinforcement, thereby minimizing the risk of inappropriate planning decisions. The comparative analysis allows for an assessment of the suitability of constructing U-WWTPs based on the geographical and operational characteristics of a region, which is invaluable for optimizing resource allocation and infrastructure development. Furthermore, the dataset deepens our understanding of U-WWTPs' construction and operations, inspiring the adoption of advanced, eco-friendly treatment solutions. This knowledge is essential for guiding technological innovation, ensuring that U-WWTPs contribute effectively to urban ecology and sustainability. It supports evidence-based decision-making and aids in formulating strategies for the future development of this critical infrastructure.

This dataset may have inherent uncertainties and gaps due to the ongoing construction of U-WWTPs and undisclosed information. Future efforts should aim to collaborate with stakeholders or operators of WWTPs to regularly update data on urban wastewater treatment facilities or modify existing entries based on any changes in operations or treatment processes. This will help to expand the dataset, thereby providing long-term, comprehensive information and guidance for the upgrade and development of WWTPs in urban water management in China and other countries facing ongoing urbanization and limited land resources.

Code availability

There is no custom code produced during the collection and validation of this dataset.

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Author contributions

Shuyan Zhou and Hui Gong conceived and designed the study. Shuyan Zhou, Hui Gong, Xiang Chen, Xiankai Wang and Hang Wang developed data search and abstraction protocols. Shuyan Zhou, Yanyan Zhang and Danyang Zhu collected the raw data. Shuyan Zhou, Hui Gong and Sen Li performed the technical validation. Xiaoxin Cao, Sen Li and Xiaohu Dai provided feedback on data implementation. Shuyan Zhou and Hui Gong drafted the manuscript with editing and approval of all authors.

Competing interests

The authors declare no competing interests.

Additional information

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