Wastewater Treatment in the Yangtze River Delta: Techniques, Challenges, and Potential

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***Abstract*—In the process of writing the article on sewage treatment technology, the water pollution in the Yangtze River Delta as the background, the water pollution situation, and the treatment plan adopted by the local government are summarized. In the first half of the article, the introduction of the degree of water pollution in China and the Yangtze River Delta water body aims to present the complete picture of the Yangtze River Delta water body and express the specific degree of water body pollution. In the second half of the article, different sewage treatment methods and technologies are discussed in depth, and their applications and benefits are studied and summarized in detail.**

***Keywords*—biochar technology, composites, wastewater treatment, water body status, Yangtze River Delta**

I. Introduction

Water, often referred to as the lifeblood of our planet, sustains human life and underpins countless ecological and social-economic systems, it shapes our agriculture, industry, health, and overall well-being. The phenomenon of water pollution caused by the existence of water pollutants is gradually appearing in different water bodies all over the world. A water pollutant can be defined as a physical, chemical, or biological factor causing detrimental effects on aquatic life and on those who consume the water. According to Goel, the majority of water pollutants are, however, in the form of chemicals that remain dissolved or suspended in water and give an environmental response that is often objectionable [1]. When a region's water bodies become polluted, it will threaten both human life and the broader social fabric, inflicting profound adverse effects.

In China, the degree of water pollution also can be seen as the water quality assessment is mostly based on hydrochemical analysis. In reference to the China Environment Quality Standards for surface water (GB 3838-2002), the established benchmarks for key water quality parameters involve the Permanganate Index, Total Phosphorus concentration, Ammonia Nitrogen Grades, Dissolved Oxygen concentrations, and the concentration of metal cations, etc., the quality of the water body is divided into five categories according to the function Grade: I, II, III, IV, V. Grade I is mainly applicable to source water and national nature reserves. Grade II is mainly applied to the primary protection area of the surface water source of concentrated drinking water, the habitat of rare aquatic organisms, the spawning ground of fish and shrimp, and the feeding ground of young and young fish. Grade III is mainly applicable to the secondary protection area of the surface water source of centralized drinking water, the winter farm of fish and shrimp, the migration channel, the aquaculture area, and other fishery waters and swimming areas. Grade IV is mainly suitable for general industrial water use areas and recreational water use areas where the human body is not in direct contact. Grade V is mainly applicable to agricultural water use areas and general landscape waters. The Yangtze River Delta (YED), one of China's most developed, dynamic, densely populated, and concentrated industrial areas, is growing into an influential world-class metropolitan area and playing an important role in China's economic and social development [2]. The core areas of this study are the provinces of Jiangsu, Zhejiang, and Shanghai. With an area of 36,900 cubic kilometers and a total population of more than 67.55 million, it has an average population density of 1,830 people per cubic kilometer. It is one of the regions with the most rapid economic development and the highest degree of urbanization in China [3]. The Yangtze River Delta boasts a well-developed river system characterized by an intricate network of waterways, situated within a geographically expansive low-lying plain primarily formed through extensive alluvial deposition by the Yangtze River. Approximately one-third of the region's total area is encompassed by these water bodies.

However, because of over-industrialization, water bodies in the Yangtze River Delta are seriously polluted. Given this economic significance and the large population, water pollution has already inflicted widespread damage upon every facet of this region, increasing the uncertainty over its future development: It can be deduced that local water scarcity may lead to economic output losses, and the risk can be transmitted to downstream sectors through reduced input supplies. The context underscores the rationale for the focus on this specific area. The main reason is the discharge of untreated or inadequate industrial and domestic wastewater has led to the contamination of rivers, lakes, and groundwater sources in this region. In recent years, municipal governments across the Yangtze River Delta region have shown close collaboration, making substantial efforts in the mitigation of water body pollution. Their collective aim is to enhance the water quality of present water bodies to address the core challenges impacting sustainable development. The impact of technological innovation on water pollution is an important parameter to determine and monitor while promoting and furthering a region's economic development [4].

This paper aims to highlight the significance of water treatment technology in addressing water pollution challenges in the YRD region. Existing technologies (not limited to physical, chemical, biological, etc.) will be listed, compared, and discussed in terms of current achievements and sustainable development, then combined with the policy in order to achieve a comprehensive and synergistic approach.

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Despite potential limitations that may impede the optimal efficacy of the studied technical methods, the analytical process remains valuable in offering insights that can guide local governments in their efforts to combat water pollution.

II. Status of the Water Body

Since the initiation of the reform and opening-up policy in 1978, the process of socialization and industrialization in the YED has never stopped. In just under three decades, a multitude of cities, previously scattered at agricultural terrain, swiftly expanded and seamlessly merged, giving rise to a cohesive urban agglomeration. According to state data in 2000, the YED accounted for only about one-tenth of the country's population but accounted for about 22% of the country's gross domestic product, this is an increase of 6 percentage points from 15.1% in 1978.

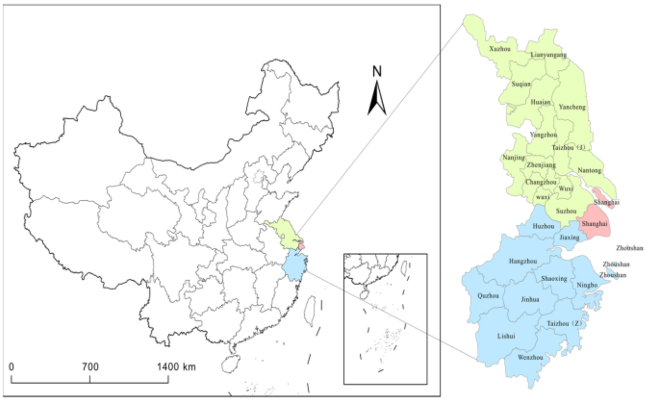

Fig. 1. Overview map of the Yangtze River Delta [4].

However, the extensive growth of China's economy has increasingly intensified ecological imbalance and environmental pollution [4]. Not surprisingly, the deterioration of water quality around the Yangtze River Delta, which enjoys the most economic development dividend, is prominent in domestic environmental problems after entering the millennium. According to the National Natural Science Foundation of China (2001), the water quality of the upper reaches of the Huangpu River, which is the last tributary of the Yangtze River before it enters the East China Sea, usually varies between Grades III and IV, but that of the lower (the location of a large part of the Yangtze River Delta) region reaches is below Grade V. The water quality of the city stretches of the Jianghang Canal is bad and generally below Grade V, whereas that of rural stretches is above Grade IV. The water quality of city rivers is usually far below Grade V, and that of suburban and rural rivers is below Grade IV. See State Environmental Protection Administration and State General Administration of the People's Republic of China for Quality Supervision and Inspection and Quarantine Environmental quality standards for surface water published jointly in 2002, this situation indicates that the water quality of most of the water bodies in the Yangtze River Delta during this period can only be suitable for the most basic agricultural production, and only a small part can meet the relatively high-quality water demand for drinking, aquaculture and industrial production.

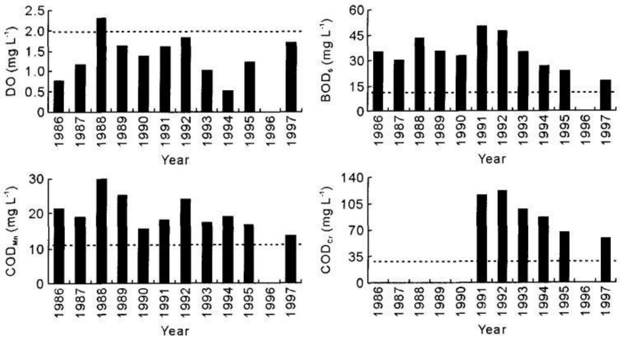

Fig. 2. Variations around the 1990s in DO, BOD5, COD Mn, and COD Cr in the urban sector of Suzhou Creek, Shanghai. The dash line represents Grade V of the National Surface Water Standard of China (National Natural Science Foundation of China, 2001).

Detected surface water raises health concerns for human and aquatic ecosystems even at low concentrations with long-term exposure.

The surface water pollution of the Yangtze River Delta is categorized as comprehensive organic pollution. The main pollutants include BOD5 (5-day biochemical oxygen demand), CODCr (dichromate oxidizability), CODMn (permanganate oxidizability), NH4-N, Total P, and petroleum. It can be summarized that river networks, characterized by braided and dense rivers, have been destroyed by intense human activity in the delta plains [5].

III. Treatments

Sewage treatment technology can be summarized into the following three broad categories:

(1) Physical methods: pollution control through simple physical changes, which is also one of the oldest methods. The physical methods commonly used for water treatment now include gravity separation, filtration, evaporation crystallization, and physical conditioning.

(2) Chemical methods: pollution control through chemical reactions. The most basic example is: if there is acid in sewage, the method of alkali neutralization is used; If there are polluted substances dissolved in water, the method of chemical reaction is used to generate precipitation, and the insoluble matter or harmless matter is generated, that is, the treatment effect is achieved.

(3) Biological methods: that is, the use of biological metabolic activities to reduce the concentration of toxic and harmful substances in the environment, or make them completely harmless so that the polluted environment can be partially or completely restored to its original state. Many algae and plants have the ability to purify water, as long as they are kept in the water, they can treat some pollutants in the sewage.

When water is polluted and decontamination becomes necessary, the best purification approach should be chosen to reach the decontamination objectives (as established by legislation) [6]. A purification process typically involves five essential steps to ensure the effective treatment of water or wastewater, as shown in Fig. 3.

Preliminary Treatment: This initial step focuses on preliminary or pre-treatment processes, involving physical and mechanical methods. During this stage, large debris, solids, and other visible contaminants are removed by sedimentation and elementary coagulation.

Primary Treatment: Following preliminary treatment, the primary treatment phase employs a combination of physicochemical and chemical processes. This step aims to further remove suspended solids and contaminants that might have escaped the preliminary treatment, ensuring the water undergoes significant purification. Common methods include coagulation, precipitation, and flocculation.

Secondary Treatment or Purification: The next phase takes a mix of chemical and biological methods. The focus is on breaking down dissolved and organic pollutants through the action of beneficial microorganisms and chemical agents.

Tertiary or Final Treatment: Also referred to as the final treatment. The main techniques used are relatively advanced oxidation, membrane, and filtration. This step aims to achieve the desired water quality standards by removing remaining contaminants and impurities, ensuring the water is safe for various uses.

Treatment of the Formed Sludge: Throughout the purification process, proper management of this sludge is crucial. It can be treated through supervised tipping, recycling methods, or incineration, ensuring environmentally responsible disposal or potential reuse of the byproduct.

It is important to note that the initial two steps, namely preliminary and primary treatment, are often grouped together under the term "pre-treatment" or the preliminary step, depending on the specific situation and the nature of the water source being treated.

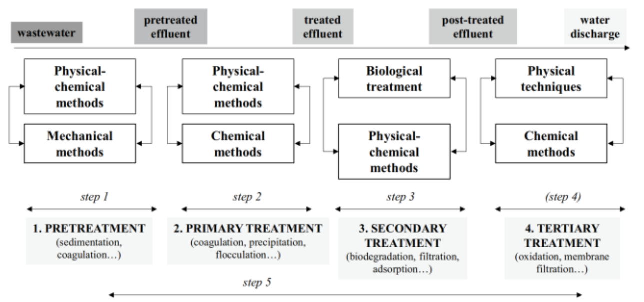

Fig. 3. Main processes for the decontamination of industrial wastewater [6].

At present, many traditional water treatment techniques have been used maturely.

Chemical precipitation: chemical precipitation in water and wastewater treatment is the change in the form of materials dissolved in water into solid particles. Chemical precipitation is used to remove ionic constituents from water by the addition of counter-ions to reduce the solubility. It is used primarily for the removal of metallic cations, but also for the removal of anions as well as organic molecules [7].

Coagulation and flocculation, Due to Jiang, is a process for combining small particles into larger aggregates (flocs) and for adsorbing dissolved organic matter onto particulate aggregates so that these impurities can be removed in subsequent solid/liquid separation processes [8]. The mechanism for the removal of organics via coagulation has three main aspects: (1) positively charged metal ions and negatively charged organic colloids are electrically neutralized, destabilized, and aggregated; (2) metal ions and soluble organic matter molecules form insoluble complexes and precipitates; and (3) physical and chemical adsorption of organics occurs on the surface of alum [9].

In general, there are four steps in the coagulation/flocculation mechanism, including charge neutralization, sweep coagulation, bridging, and patch flocculation [10].

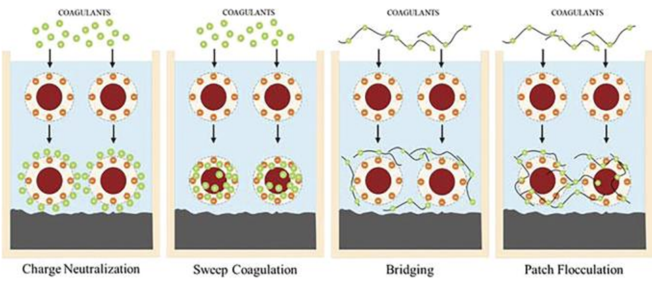

Fig. 4. Coagulation/flocculation mechanisms at the treatment process [11].

Chemical oxidation is the general term for many oxidation processes. It includes Simple oxidation, Ozone, Hypochlorite treatment, Hydrogen peroxide, etc [6]. Each processes play several important roles in the treatment of water. Chemical oxidation aims at the mineralization of the contaminants to carbon dioxide, water, and inorganics or, at least, their transformation into harmless products [12]. Chemical oxidants are used for the oxidation of reduced inorganic species, such as ferrous iron [Fe(II)], manganous manganese [Mn(II)], and sulfide [S(-II)]; hazardous synthetic organic compounds, such as Trichloroethene (TCE) and atrazine; and other emerging contaminants, such as Methyl-Tert-Butyl-Ether (MTBE), Pharmaceutically Active Compounds and Personal Care Products (PPCPs), Endocrine Disrupting Chemicals (EDCs) and algal toxins. The most common chemical oxidants used in water treatment are chlorine, ozone, and chlorine [13].

Biological Membrane: All living cells, and many of the structures within these cells (mitochondria, nuclei, chloroplasts) are surrounded by biological membranes which serve to separate the cell contents from the surrounding environment [14]. According to Stephenson [15], combining membrane technology with biological reactors for the treatment of wastewater has led to the development of three generic Membrane Bioreactors (MBRs): for separation and retention of solids; for bubble-less aeration within the bioreactor; and for extraction of priority organic pollutants from industrial wastewater.

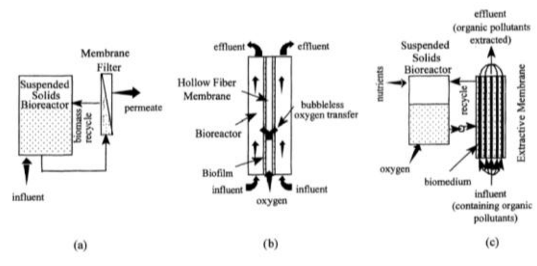

Fig. 5. Mean features and three different MBR processes [15].

In addition to the traditional technology that has been common in the world, the emergence of some emerging technologies in recent years has led to a new road for water treatment:

Biochar is a porous carbonaceous material produced during the thermochemical decomposition of biomass feedstock in the presence of little or no oxygen [16].

Xiang [16] also mentioned that Biochar can be used as an effective adsorbent to remove different pollutants in water and wastewater. Here, this paper mainly discusses its use for the removal of heavy metals, organic contaminants, nitrogen, and phosphorus, due to its special properties. Thus, biochars have become increasingly important as a solution to remediate pollutants in the industrial and agricultural sectors to improve environmental quality.

Biochar technology is generally used for the treatment of four types of water: Industrial wastewater, municipal wastewater, agricultural wastewater, and stormwater.

Industrial wastewater treatment: industrial wastewater comes from various sources including mining, smelting, battery manufacturing, chemical industry, leather manufacturing, dyes, and others. The pollutants are mainly heavy metals and organic pollutants in industrial wastewater. Due to the discharge of large amounts of metal-contaminated wastewater, industries bearing heavy metals, such as Cd, Cr, Cu, Ni, As, Pb, and Zn, are the most hazardous among the chemical-intensive industries [17]. Biochars have been applied in the treatment of industrial wastewater. A biochar mixed with chitosan after cross-linking can be cast into membranes, beads, and solutions. It can be effectively utilized as an adsorbent for heavy metals adsorption in industrial wastewater [16].

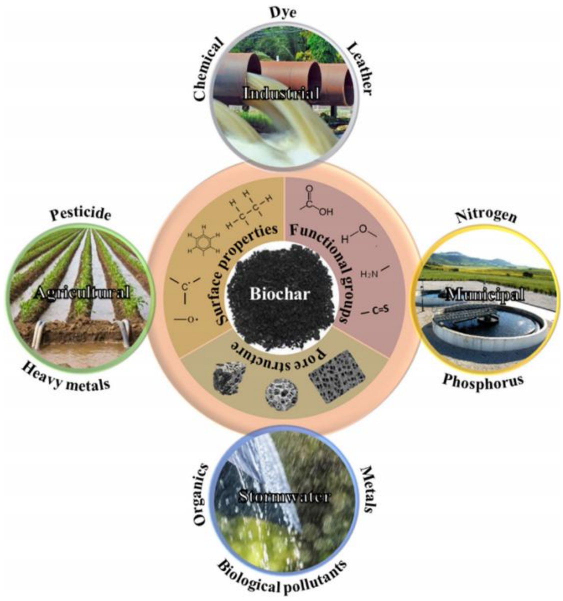

Fig. 6. Biochar application in water treatment [16].

Composites generally are an amalgamation of constituents (two or more) differing in properties, usually made to make a single material with an integrated property set [18].

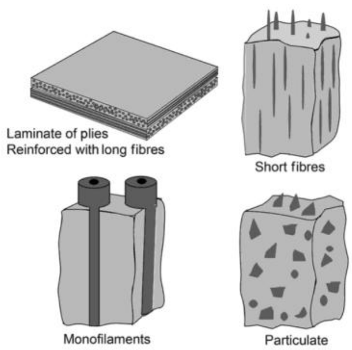

Fig. 7. Many different types of composites [19].

At present, composite materials can be used as an effective medium to remove heavy metals from water. For example, there is a method for the removal of cadmium (Cd (II)) ions from contaminated water using ligand-coated functionalized Composite Material (CPM). The fabricated materials have demonstrated an excellent ability in the detection and removing Cd (II) ions due to unique features such as high porosity, stability, homogeneous large surface area, as well as more accessible active functional sites [20].

The compound materials are also commonly used in sewage treatment, such as biochar/layered double hydroxide composites (biochar/LDH). The synergistic effect of LDH with biochar exhibited significant improvement in physicochemical characteristics such as specific surface area, surface functional groups, structure heterogeneity, stability, and adsorption characteristics of the resulting biochar/LDH composites [21]. Zubair also mentioned that acting as a catalytic degradation of pollutants is one of its advantages: The immobilization of LDHs onto biochar has resulted in improved characteristics of the composite material. The high degradation performance of biochar/LDH is due to substantial inhibition of aggregation of LDH structure due to the presence of biochar as a support material. The presence of biochar greatly enhanced the separation of photogenerated charge carriers.

IV. Advantages and Disadvantages of Treatment Techniques

Chemical precipitation is most widely practiced in industry, mainly for the simplicity of process control, effective over a wide range of temperature, and low cost of operation. It employs pH adjustment to convert heavy metal ions to hydroxide, sulfide, carbonates, or other less soluble compounds, which then can be removed by physical means such as sedimentation, flotation, or filtration [22]. Also, this technique is adapted to high pollutant loads, it is not metal selective especially Very efficient for metals and fluoride elimination [6]. On the other hand, chemical precipitation was the requirement of large doses of reagent to increase and maintain pH values typically from 4.0 to 10.0 for removal efficiencies [23]. It needs high Grade of chemical consumption (lime, oxidants, H2S, etc.). It is also ineffective in the removal of the metal ions at low concentrations. Requires an oxidation step if the metals are complex.

Coagulation is one of the most common phenomena in nature and artificially enhanced water treatment systems. It has several advantages: Process simplicity, a wide range of chemicals available commercially, inexpensive capital cost, good sludge settling and dewatering characteristics, a significant reduction in the chemical oxygen demand, and biochemical oxygen demand reduction in total organic carbon and adsorbable organic halogen (pulp and paper industry), Bacterial inactivation capability, and Rapid and efficient for insoluble contaminants (pigments, etc.) removal. However, they exhibit several disadvantages, such as the need for pH adjustment before or after treatment, the sensitivity to temperature changes, the need for higher dosages because the charge neutralization is not usually sufficient, the sensitivity to sample-specific characteristics and composition, as well as the excessive sludge production [24]. As environmental pollution problems become more serious and water quality standards become more stringent, conventional coagulation technology has clearly failed to meet people's requirements for water quality safety [9].

Chemical oxidation is an integrated physicochemical process, it is a simple, rapid, and efficient process, also achieves high throughput, no sludge production, and also the possibility of water recycling [6].

The methods based on chemical destruction, when properly developed, offer a complete solution to the problem of pollutant abatement, different from those in which only a phase separation is realized with the consequent problem of the final disposal [25]. To explain it in detail, Ksibi, M mentioned the advanced processes for wastewater decontamination like chlorination, UV irradiation, or ozonation are compact and guarantee a better quality of water produced [26]. However, the choice of the treatment sequence should be carried out considering wastewater characteristics and process suitability (technical and economical). The biological oxidation is generally cheaper than chemical processes [27].

The membrane separation techniques have offered many advantages as compared to other methods. The following are the advantages of membrane separation technology [28]. Membrane separation methods are applicable at both molecular as well as scale up to Grade and thus many separations need to be met by the membrane process [29]. It could be adjusted in small occupation areas with high processing efficiency [6]. Bera also mentioned that there is no need to change the phase to make out the membrane separation processes [29]. So, the energy requirement is less unless it needs to be required to increase the pressure of the feed stream to drive the permeate stream across the membrane. As many polymers and inorganic compounds can be used to make membranes and thus there are more

chances of having control over the separation selectivity. Membrane techniques are also able to recover minor components from the feed stream without making any increase in the energy cost value [30]. The drawbacks associated with the membrane separation technique indicate a major phenomenon: membrane fouling, which is also harmful to the environment.

V. Progress and a Vision for the Future

According to Chen *et al.*, during 2010–2015, the scale of water pollutant emissions in the YRD decreased significantly. Specifically, COD emissions decreased 41.36% from 3.15 million tons to 1.85 million tons, and total NH3-N emissions decreased 35.54% from 41.90 million tons to 27.01 million tons [22]. The intensity of water pollutant emissions in counties also showed a downward trend. In 2010, the average emissions of COD and NH3-N in a county were 10,328.42 tons and 1373.67 tons, respectively. By 2015, they had decreased to 6065.58 tons and 885.50 tons, respectively. A comparison of the emissions of various provinces revealed that COD and NH3-N emissions in Jiangsu Province accounted for about 40% of the total amount in the YRD in the 5 years. The rates of emissions reduction for these two pollutants were 34.93% and 34.11%, respectively. The spatial distribution of water pollutant emissions by counties in the YRD is shown in It can be seen from Table 1 that the number of counties whose COD emissions decreased by 1, 2, 3, and 4 Grades are 130, 55, 2, and 1 respectively.

Table 1. Change in pollutant emission grades (Chen *et al*., 2022)

	4Grades	3Grades		2 Grades			1 Grade			
	V-I	V-II	IV-I	V-III	IV-II	I-III	V-IV	IV-III	III-II	II=I
COD	1	1	1	33	13	9	18	42	44	26
NH3-N	0	0	1	17	8	5	39	58	26	14

Among them, the number of counties with COD emission grades of V and IV, with emission intensities of more than 10,000 tons, decreased from 128 to 43. Similarly, the NH3-N emissions of 137, 30, and 2 counties decreased by 1, 2, and 3 Grades respectively, and the number of counties with NH3-N emission grades of V and IV decreased from 179 to 100. Comparing these four sub-figures, we can see that no matter what kind of pollutant, the distribution of V-class counties shrank from the large-scale, continuous distribution in Shanghai; provincial capital cities, such as Hangzhou, Hefei, and Nanjing; the eastern coastal area and the Northern region in 2010, forming a scattered distribution pattern in 2015.

The reduction of pollutant content is the reason for the optimization of water quality, which can be reflected in the water quality of the YED city. Take Jiaxing City, Zhejiang Province as an example: In 2012, around 80% of Jiaxing's water was categorized as Class V or above, limiting usable water resources. However, between 2013 and 2015, there was a significant decline in Class V water, replaced by about 60% of Class IV water throughout the city. Type III water, previously rare, emerged, constituting less than 10%. Smooth sewage treatment progress over the past six years is evident in the bar chart. A milestone was reached in 2021 when Class V water was eliminated, followed by another achievement in 2022, where Class IV water was largely replaced by the more versatile Class III water, suitable for treatment and use. Additionally, the proportion of second-class water has been gradually increasing each year.

The above examples illustrate that modern water pollution treatment technology has made remarkable progress in some aspects, but there are still some shortcomings. Current challenges include high technology costs, high energy consumption, and inconsistent processing efficiency. In addition, the monitoring and treatment of emerging pollutants and micropollutants also face difficulties. Yet the outlook remains bright. With the continuous progress of science and technology, we can look forward to the emergence of more efficient, more economical, and more environmentally friendly water pollution treatment technologies. Research in the fields of biological treatment, nanomaterials application, and intelligent monitoring systems is constantly expanding, providing a broad space for future development.

VI. Conclusion

This paper discusses the history and present status of the

Yangtze River Delta water body and summarizes the advantages and disadvantages of various wastewater treatment methods. According to the data of the past 20 years, it can be seen that with the help of the above treatment steps, the average water quality of the Yangtze River Delta has been improved from Grade V to Grade III, which has been significantly improved. In the results, we can see that under the implementation of technology, the water quality in the Yangtze River Delta has been improved. In the hope that water bodies will become better and more suitable for people's lives, All kinds of technologies need to face the challenge of their shortcomings. In terms of compatibility, the type and concentration of metal ions, including the PH of the environment, can be problems that hinder the efficient operation of the process. Scientists need to optimize existing techniques to make them less limiting. At the same time, some technologies will produce sludge or form membrane pollution. These technologies not only solve environmental problems but also do harm to the environment, which must be optimized in the subsequent technology development. Finally, existing high-efficiency methods sometimes require costs that governments and companies cannot afford for a long time. Laboratories may consider using lower-cost raw materials or reducing the consumption of reagents. Advanced biochor and composite technologies currently under development need to be put to practical use in real-world models to test the true benefits of these emerging technologies. At the same time, strengthen the cooperation between governments, government and enterprises, and the public, continue to promote regional integration, and further optimize the cost, materials, and processes required for the use of technology, so as to achieve cleaner and more sustainable water use.

Conflict of Interest

The author has claimed that no conflict of interest exists.

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