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Comparing Water Treatment Systems in China and Canada: Technologies, Policies, and Historical Contexts

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Abstract. Water treatment is a challenge to every country, given the diversity of its environmental, industrial, and demographic situations. The paper delineates the historical development, technological innovations, and policy frameworks regarding water treatment systems in China and Canada. The huge population and rapid industrialization within China have forced investments in advanced technologies, such as membrane bioreactors and chemical precipitation, for the treatment of industrial pollutants. Contrary to this, in view of its abundant freshwaters, Canada promoted more emphasis on biological treatments, such as constructed wetlands and activated sludge, for the remediation of organic and microbial contaminants. The paper also compares the two countries based on their management of municipal and industrial wastewater, agricultural run-off, and energy sector pollution. The drawbacks, however, are matched to the advantages because although centralized governance can implement large-scale technologies, rurality still lacks such access. The decentralized Canadian system allows room for localized solutions but at the cost of struggling with lax consistency in enforcement and aging infrastructure, especially where Indigenous communities live. This paper provides a comparative analysis to give an insight of how those two countries can learn from each other to improve water management and sustainability on a global level.

Keywords: Water treatment systems; Wastewater management; Comparative analysis; China; Canada.

1. Introduction

Water treatment is inseparable from either environmental sustainability or public health, especially under the impacts of population growth and industrialization being felt cooperatively by the countries globally. These have created two different water treatment models between China and Canada due to their specific historical, geographical, and policy settings. China, with a population of over 1.4 billion people, has an incredible problem coupled with industrialization going on at breakneck speed, water becoming a scarce commodity, and the infrastructural development looming large with the expanding population. On the other hand, Canada, with a meager approximate figure of 40 million, is quite rich in freshwater resources. However, the country is challenged with the real problem of providing equitable access to clean water, particularly among Indigenous and rural communities.

With countries facing shrinking water resources as well as the environmental effects of industrial practices, study on water treatment systems take on ever-greater relevance. After facing tremendous problems of water pollution due to its rapid urbanization and industrialization, China has been compelled to adopt very strict policies and invest in technologies for advanced treatment. In Canada, a slower evolution of the water treatment system has taken place with an emphasis on biological and natural treatment systems; however, microplastics, pharmaceuticals, and aging infrastructure are relatively new issues.

It discusses the development path, technological approach, and policy framework of the water treatment system in China and Canada. The paper attempts to explore how the two countries are managing municipal sewage, industrial effluent, agricultural runoff, and energy-sector pollution to bring out any best practices and the challenges one should work on. It therefore creates an awareness that through such comparative studies, the two countries can borrow lessons in advancing sustainable water management for the greater good of water conservation and preservation.

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2. Literature Review

2.1. Historical Context of Water Treatment in China and Canada

According to Wang et al., water treatment history in China goes back over several millennia to the Han Dynasty, when preliminary methods of filtration and boiling were recorded [1]. Official efforts in modern water treatment began to be formed only in the middle of the 20th century after the founding of the People's Republic of China. Accelerated industrialization in the seventies and eighties had caused massive water pollution especially in urban and industrial areas which prompted the government to start large scale water treatment projects [2]. A major legislative milestone was the Water Pollution Prevention and Control Law of 1984 later amended in 2008 which laid down the regime of regulation of management of water pollution and enforcement of stringent industrial discharge standards. The most recent focus has been on water quality through initiatives such as the 2015 "Water Ten Rules" and the 14th Five-Year Plan (2021-2025) to reduce the number of pollutants from industries and increase water reuse [3].

By contrast, Canada's water treatment system has been slow to develop; European colonizers arrived there only in the 17th and 18th centuries. Indians in Canada had for centuries depended on natural water sources since they used ways like plant filtration and boiling to purify water [4]. As the 19th century development of urban centers began to raise water quality issues due to pollution coming from human sources and industry, more advanced water treatment plants in cities like Toronto were also established at that time [5]. The practice of chlorination got real impetus at the beginning of the 20th century in Canada when according to the (World Health Organization [WHO], 2006) it brought a significant decrease in waterborne diseases of cholera and typhoid [6]. By adding to the books its water protection regulation and policing of pollution, the Canadian Water Act of 1970 increased the regulation of water management in Canada federally. Despite most of Canada's abundant freshwater resources, clean water is still a central issue of concern among rural and Indigenous communities. It serves to underline the necessity for sustained infrastructure investment and more inclusive policy frameworks.

2.2. Technological Approaches to Water Treatment

It is through technological advancements that both China and Canada have been able to address water challenges. The rapid industrialization in China has also upheld subsequent advancements in treatments to tame the level of complexity of industrial effluents. The principal technologies applied in China are mainly biological methods with such methods as the activated sludge process, and physical and chemical methods, including membrane bioreactors (MBRs), and ultrafiltration membranes, among others [7]. They are effective in the elimination of heavy-metal pollution, organic pollution, and microbial contamination, among others. Still, one big problem subsists for it. The rural water treatment infrastructure lags far beyond that of the urbanized centers, and as a result, millions are left without protective measures ensuring access to clean drinking water [8].

Canada, on the other hand, has always preferred traditional treatment systems, such as activated sludge and constructed wetlands, which have gained much perfection in the treatment of municipal sewage and agricultural runoff. Lately, concerning the menace posed by emerging pollutants, Canadian wastewater treatment plants are seen avoiding disinfection byproducts by applying current technologies like UV disinfection and ozone treatment [9]. To enhance water quality, especially in regions where infrastructure is old and withering away, membrane filtration (MF) systems, including reverse osmosis and nanofiltration, are being developed. Challenges for Canada in the sector are maintaining its achievements in an old infrastructure, where efforts seem centred on remote and Indigenous communities [10].

2.3. Policy Frameworks and Environmental Governance

The main difference between the two nations is the focus and efficacy of the policies that consider water quality and the utilization of resources. In China, where the government system is centralized, large-scale water management policies may be implemented quickly. The Ministry of Ecology and Environment is the leading organization in the implementation of water quality standards and pollution control. There are very stringent regulations on industrial and agricultural pollution under key legislations of 2002 Water Law and 2015 Water Ten Rules, with heavy penalties for non-compliance [3]. However, enforcement is still uneven, especially in rural areas, because of underinvestment in infrastructure and local governance problems [11]. A recent initiative that gives water protection responsibility to governmental officials under the River Chief System of 2017 would enhance local transparency [12].

Decentralization is the keynote of water governance in Canada; responsibilities are shared among federal, provincial, and municipal governments. The Canada Water Act and the Clean Water Action Plan empower, respectively, the Canadian Government to undertake works of collaboration with provinces on water quality and pollution prevention. These are strong federal legislations over industries regarding discharges and water-bodies pollution in Canada, as indicated by the Environment and Climate Change Canada [13]. Those federal regulations are strong, but still not sufficient since water quality remains a concern especially for Indigenous people who maintain that they are still under boil-water advisories [14]. Although the Government of Canada has committed substantial resources to reduce these disparities, the rate of progress has continued to be slow with many communities that still have difficulty accessing safe drinking water.

3. Comparative Framework

3.1. Historical Development

Hence, the water treatment system of China has arisen with markedly different historical development patterns from Canada. Whereas in China, the water treatment methods have passed gradually from the old day’s filtration and boiling to new large-scale industrial methods, rapid industrialization of China in the last decades of the 20th century caused enormous water pollution problems. The government was, in turn, forced to make comprehensive efforts in managing its waters. On the other hand, due to European colonization and then urbanization, the water treatment system in Canada slowly evolved. While these filtration systems from the late 19th century and chlorination from the early 20th century did wonders at improving urban water supplies, clean water is still not readily available to rural and Indigenous people.

3.2. Technological Implementation

In both countries, technologies for municipal sewage, industrial effluent, and agricultural runoff have been introduced. In China, it has mainly been about the upscaling of the industrial wastewater treatment technologies to cope with fast urbanization and industrial growth. Among these, MBRs and ultrafiltration systems have mostly contributed to treating enormous wastewater volumes from industries. But while for Canada, the major focus has been on biological treatment systems such as constructed wetlands and activated sludge processes, which are very efficient when used to treat organic pollutants in municipal wastewater. This technological divergence is representative of different industrial and demographic challenges in each country.

3.3. Policy Enforcement

The governance model of water management is different for the two countries, China and Canada. China has a highly centralized system that can ensure the formulation of a policy at a very high speed and to cover a wide area; this is more so in urban policy implementation. Yet, the real problem is not whether it can be enforced in rural areas but where it has worked its way into the very low infrastructure and local governmental capacity of rural areas. This is in contrast to Canada's decentralized governance model, where matters are devolved to federal, state, and local governments. Here, although it allows more local solutions, there can also be a lack of consistency in the implementation of policies from one region to another. Through comparison of such governance models, the paper assesses to what level a country deals with the complex issue of policy implementation in water and relates it to possible areas for enhancement.

4. Technologies for Municipal and Industrial Wastewater

4.1. China's Approaches

The wastewater treatment practices in China are highly dependent on the sheer mass of its population and industrial activity. Highly developed technologies for water treatment are rapidly being embraced in China to meet the ever-increasing need for water treatment in industrialized and urbanized areas. For example, in Dalian City, the wastewater is treated by a three-stage treatment process [15], including physical, chemical, and biological treatments, as shown in Figure 1. In the first stage, it removes large particles and suspended solids with grated filtration and sedimentation. Organic pollutants are eliminated by the second stage using biological treatment methods based on either activated sludge MBRs. Finally, heavy metals and pathogens will be under control by using chemical precipitation and ozone for tertiary treatment to make sure that the water is compliant with the national discharge standard.

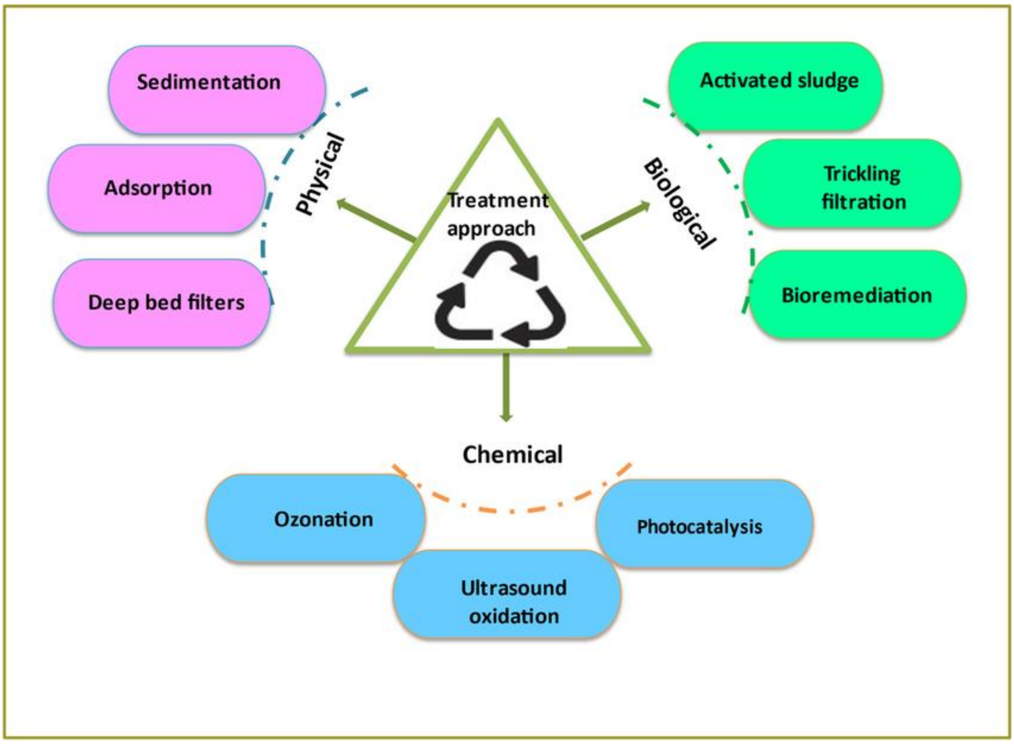

Figure 1. Three-stage treatment process in Dalian, China [15].

MF technologies and advanced oxidation processes for complex industrial pollutants heavy metals, and organic compounds among other complex industrial pollutants that revealed China's increased attention toward industrial wastewater treatment. The urban areas are using the advanced technologies while the rural parts are still fighting with insufficient infrastructure of municipal sewage treatment.

4.2. Canada's Approaches

The treatment approach in Canada would be defined as predominantly relying on biological treatment systems. Municipal wastewater is principally treated by constructed wetlands and activated sludge processes, both being highly effective methods of organic pollutant removal and BOD reduction. As is evident for many of the Canadian municipalities in the schematic of Figure 2, besides a number of other technologies, such as UV disinfection and ozonation are being incorporated into the wastewater treatment plants for specifically addressing the pollutants of emerging concern including microplastics and pharmaceutical residues [16].

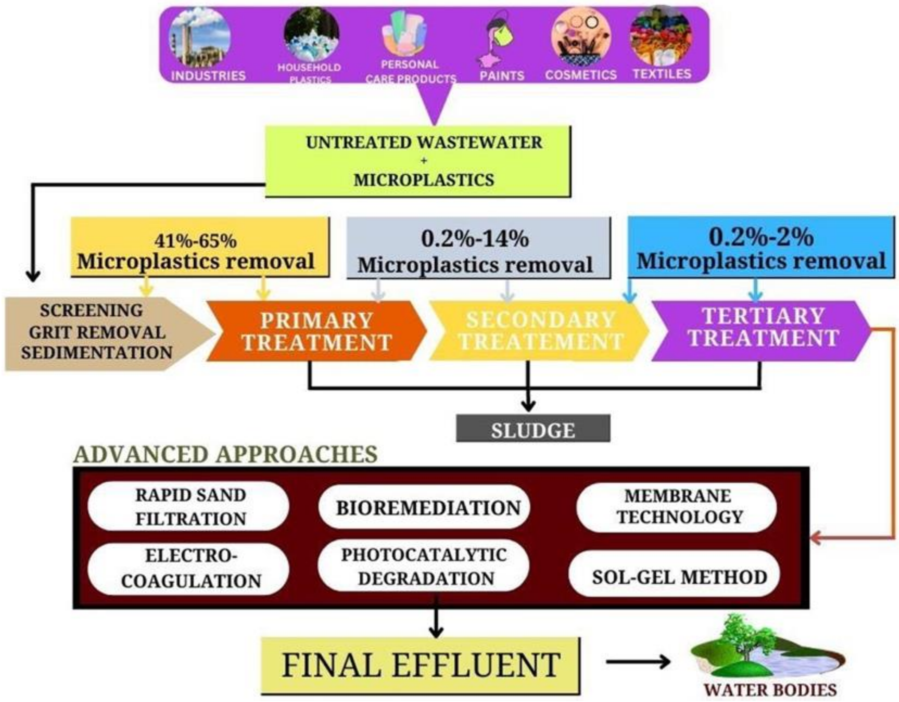

Figure 2. Advanced wastewater treatment technologies in Canada [16].

Canada has also adopted MF technologies, such as reverse osmosis and nanofiltration, for upgrading the quality of water in regions having old conventional treatment plants. It adds an extra security level by rejecting suspended solids, bacteria, and even some dissolved impurities. The country has difficulties in sustaining the water treatment infrastructure improvements, especially in remote and indigenous communities, and the availability of clean water is far from acceptable.

4.3. Comparative Analysis

As depicted in Table 1, both China and Canada are using advanced technologies for water treatment, such as MBRs and UV disinfection. However, it is the major emphasis that is different; for instance, China is more concerned with the removal of industrial pollutants, whereas Canada primarily considers organic and microbial contaminants from municipal wastewater. This kind of difference reflects the industrial structures and demographic needs of the two countries. The role of such industrial technologies as chemical precipitation and MF in China gains significance in isolating the huge volumes of wastewater generated by its industrial sectors. This again contrasts with the situation in Canada, where attention on biological treatment and environmental technologies, such as constructed wetlands, fits in with their environmental focus and smaller, more dispersed population.

Table 1. Comparative technologies analysis for Municipal and Industrial Wastewater Treatment in China and Canada [17, 18].

Aspect	China	Canada
Focus Areas	Heavy industrial pollution control	Compliance with environmental regulations
Common Technologies	Oxidization ditches, ANANOX, SBR	Secondary treatment systems, AOPs
Investment Trends	Significant government funding for infrastructure	Emphasis on innovative technologies and best practices
Environmental Challenges	High levels of pollution due to rapid industrialization	Aging infrastructure and variability in treatment quality

5. Agricultural Runoff Treatment

5.1. China's Approaches

In China, agricultural runoff is also the largest pollution source to water bodies, resulting mostly from extensive uses of fertilizers and pesticides in countryside areas. Accordingly, China has integrated in situ wetlands together with biological treatment systems like oxidation ditches and sequencing batch reactors (SBR) to treat high nutrient-rich runoff. The system, as shown in Figure 3, is designed toward nitrogen and phosphorus reduction since both elements are the key pollutants causing water eutrophication. In recent years, China has installed Membrane Aerated Biofilm Reactors (MABR) that provide energy-efficient nutrient removal by passive aeration for driving biological degradation. Moreover, the China water discharge standards was also presented in Table 2.

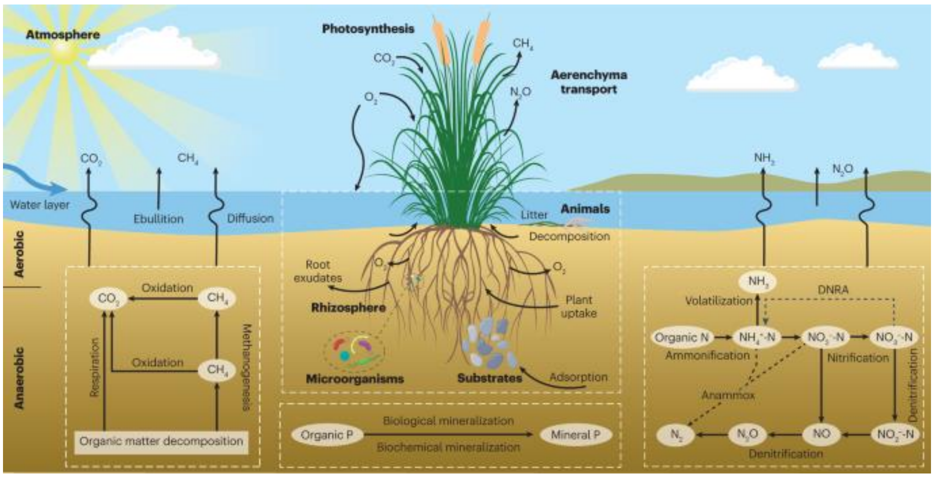

Figure 3. Constructed wetlands and oxidation ditches for agricultural runoff in China [19].

Table 2. China water discharge standards [20].

Parameter	Standard Class 2	Standard Class 1B	Standard Class 1A	Influent and effluent quality of scenarios Scenario 1A	Influent and effluent quality of scenarios Scenario 1B	Influent and effluent quality of scenarios Scenario 2	Influent and effluent quality of scenarios Influent
Chemical oxygen demand (COD)	100	60	50	29.8	42.6	80	259.2
Biochemical oxygen demand (BOD_5)	30	20	10	–	16.2	–	153.6
Suspended solids (SS)	30	20	10	8.2	16.3	24	187.4
Total nitrogen (TN)	–	20	15	12.8	14.2	22.6	28.7
NH_3—N	25 (30)[a]	8 (15)[a]	5 (8)[a]	–	5.7	–	23.5
Total phosphorus (TP)	3	1	0.5	0.5	0.8	2.2	3.4
Facilities Primary treatment				√	√	√	–
Facilities Secondary treatment				√	√	√	–
Facilities Phosphorus removal				√	√	–	–
Facilities Tertiary treatment				√	–	–	–

(√) present and equal; (-) indicates not present.
[a] Figures in parentheses are the standards when water temperature is lower than 12 °C.

5.2. Canada's Approaches

Constructed wetlands are widely used in Canada to treat agricultural runoff, particularly in the southern regions where climatic conditions are suitable for wetland systems. These wetlands utilize such mechanisms as plant uptake and microbial degradation to execute purification of water with respect to nutrients and pesticides (see Figure 4). Because wetlands in cold regions are less efficient, agricultural wastewater treatment technologies include MBRs and aerobic treatment systems. Canadian provinces also have very prescriptive regulations regarding nutrient discharge to avoid eutrophication, as shown in Table 3.

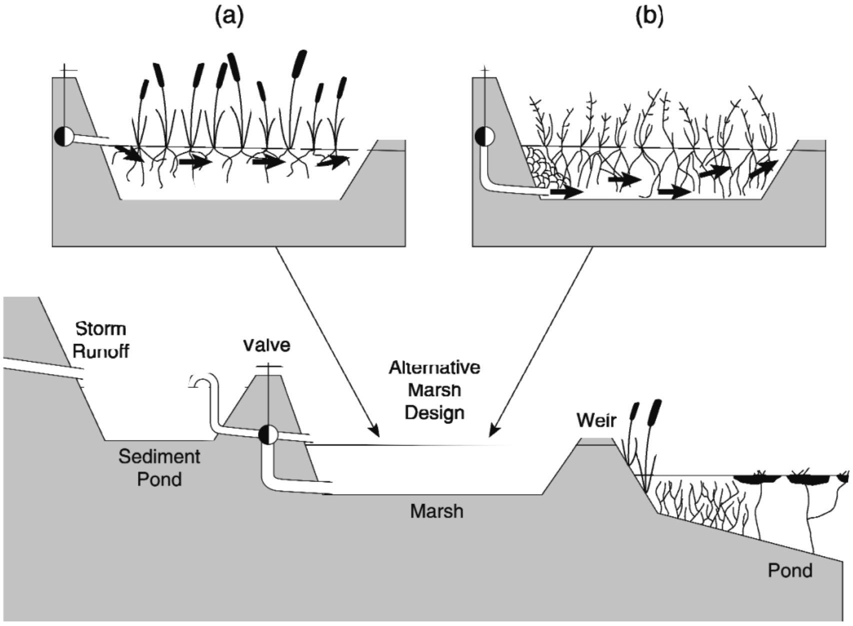

Figure 4. Design of constructed wetlands (a) free water surface (FWS) wetlands, and (b) subsurface flow (SSF) wetlands [21].

Table 3. Canada's water discharge standards for agricultural runoff pollutants [22].

Water quality index	**First grade A standard**	**First grade B standard**	**Effluent from WWTP (A-A-O)***
COD	50	60	<50
BOD_5	10	20	<10
SS	10	20	15-20
Animal and vegetable oils	1	3	<1
Petroleum	1	3	<1
Anionic surfactant	0.5	1	<0.5
TN	15	20	<15
NH_3-N	5(8)	8(15)	<5(8)
TP Built before 12/31/2005	1	1.5	1.0-1.5
TP Built after 1/1/2006	0.5	1	
Color	30	30	<30
pH	6-9	6-9	6-9
Fecal Escherichia coli	10^3	10^4	10^3

5.3. Comparative Analysis

The challenges faced by both China and Canada—nutrient pollution management from agricultural runoff—are even addressed diversely between the countries. A view to further developing MABR technologies by China contrasts with its more local-specific use in Canada, such as constructed wetlands and MBRs, developed according to the environmental conditions of the regions. As depicted in Table 4, nutrient pollution regulations have been established in both China and Canada, but the level of implementation and enforcement mechanisms scales is drastically different due to governance model differences and different agricultural practices. The comparative analysis of key elements of agricultural runoff regulation in both countries is presented in the table below.

Table 4. Comparison of agricultural runoff regulations in China and Canada.

Aspect	China	Canada
Primary Pollutants	Nitrogen (N), Phosphorus (P)	Nitrogen (N), Phosphorus (P)
Regulatory Framework	National Water Discharge Standards (e.g., Class 1A, Class 1B)	Provincial regulations (e.g., Ontario, Alberta)
Pollutant Discharge Limits	Total Nitrogen (TN) ≤ 15 mg/L, Total Phosphorus (TP) ≤ 0.5 mg/L (Class 1A)	TN ≤ 15 mg/L, TP ≤ 1 mg/L (varies by province)
Enforcement Mechanism	Centralized enforcement through the Ministry of Ecology and Environment (MEE)	Decentralized enforcement through provincial and municipal governments
Technologies Used	Membrane Aerated Biofilm Reactors (MABR), Constructed Wetlands, SBR	Constructed Wetlands, Membrane Bioreactors (MBR), Aerobic Treatment Systems
Challenges	Limited infrastructure in rural areas, enforcement gaps, funding gaps for eco-compensation	Aging infrastructure, inconsistent enforcement, challenges in remote and Indigenous communities
Eutrophication Control	Focus on reducing nitrogen and phosphorus in agricultural runoff to prevent eutrophication in major water bodies	Strict provincial regulations to prevent eutrophication in lakes and rivers, focus on nutrient reduction

6. Energy Industry Wastewater Treatment

6.1. China's Approaches

Water pollution from heavy metal and acid mine drainage has been identified as a resultant effect in China's energetic sector, particularly coal mining and oil extraction. Technologies for the treatment of such pollutants are widely achieved through chemical precipitation and bioremediation (see Figure 5). Although the stringent policies of China, such as the Water Ten Rules from 2015, have been very successful in reducing a lot of the environmental damage, enforcement is still a very big issue, especially in rural areas where industrial activity is less controlled.

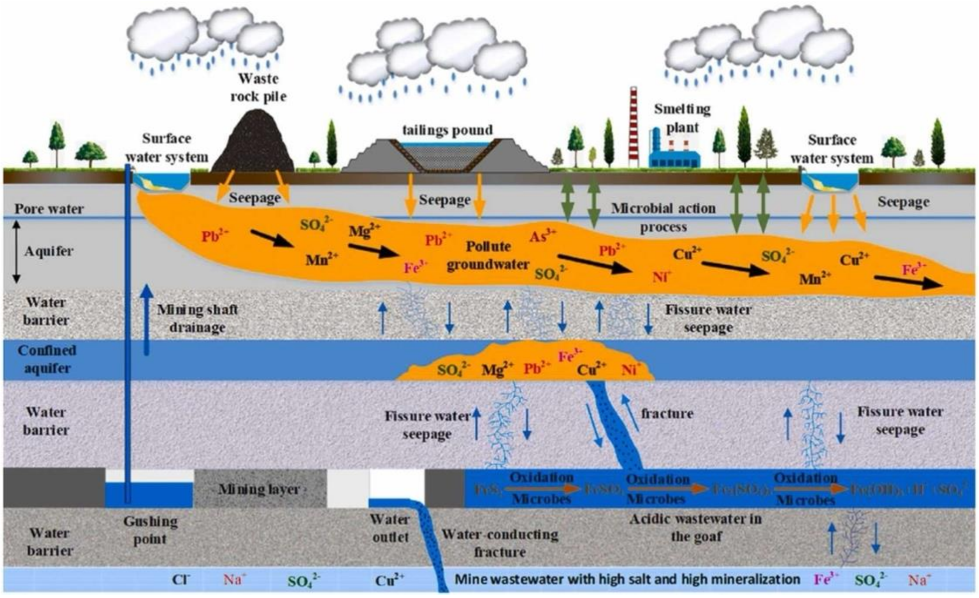

Figure 5. Acid mine drainage from coal mining operations [23].

6.2. Canada's Approaches

Water treatment remains one of the challenging aspects of Canada's energy industry, especially in its oil sands in Alberta. As a result of oil sands extraction, vast volumes of tailings come out. The tailings generally contain PAHs and heavy metals. As illustrated in Figure 6, nanofiltration and advanced oxidation processes (AOPs) are some of the technologies that Canada uses for the treatment of oil sands tailings to prevent water bodies like the Athabasca River from getting contaminated. These technologies become necessary in breaking down complex hydrocarbons to make sure the treated water meets environmental standards.

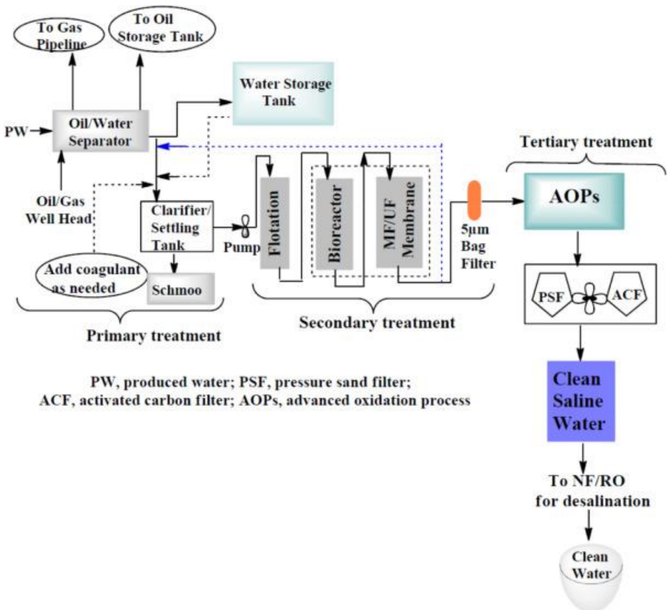

Figure 6. Oil sands pollution and treatment technologies in Canada [24].

6.3. Comparative Analysis

These are the major pollutants for China and Canada from the energy sector. While the primary pollutants are different for the most part (heavy metals in coal mining for China in contrast to hydrocarbons for Canada), both countries have made impressive progress applying technologies that will bring dissolution to these specific environmental problems. The difference lies in the fact that China has been investing more in chemical precipitation and sludge management, whereas the investments in Canada have been more in nanofiltration and AOPs, which indicates different environments and industries within the country.

7. Conclusion

In summary, this study has portrayed the salient disparities that have shaped the pursuits of China and Canada in water treatment. These pursuits are shaped by distinctiveness in the challenges of geography, industry, and population incumbent to both countries. While China's major effort is invested in control measures for large-scale industrial pollution mostly in urban areas, Canada has based its efforts on biological treatment systems for domestic sewage and agricultural runoff management. Such developed countries share common problems, such as nutrient pollution and threat from microplastics and pharmaceutical residues, but the ways to solve them are different by reason of the different policy frameworks and technological focuses.

A major finding is that in China, the central approach can promptly implement large-scale technologies with MBRs and chemical precipitation methods. The rural areas still do not have adequate water treatment infrastructure. It clearly brings out the need for policy reforms that would target those regions. Equitable access issues to clean water face Canada, an abundant country regarding fresh water. Especially in its rural and Indigenous communities, far from that decentralized governance model really performing well in some regions will undoubtedly bring about disinclination in implementations and infrastructures.

Both countries have a lot to learn from each other. The technologies in which China has made advances include industrial wastewater treatment and membrane technology. Canada can better address its rural water quality issues with China by it borrowing a leaf from its localized constructed wetland systems, and decentralized water governance models. In the face of increasingly acute global water scarcity and pollution, only joint efforts of countries like China and Canada will be able to develop new sustainable solutions for treating water.

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