

Assessment of Municipal and Industrial Wastewater Impact on Yamuna River Water Quality in Delhi

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Abstract. Delhi's Yamuna River serves as a notable illustration of an ecologically compromised system that has undergone a transition into a conduit for sewage due to pervasive pollution and escalating anthropogenic influences. Delhi, being the primary contributor to pollution, is responsible for over 70% of the total pollutant load in the Yamuna. The city's drainage systems discharge a substantial Biological Oxygen Demand load into the river daily, resulting in severe pollution. This research utilizes pre-existing data to examine diverse factors, evaluating the quality of water at distinct observation locations along the Yamuna. The utilization of correlation analysis aids in recognizing connections among elements influencing the pollution of river water. The outcomes of the correlation analysis disclose a notable link between COD-BOD factors, whereas the connections among alternative factors like BOD-DO, BOD-pH, COD-DO, COD-pH, and DO-pH range from moderate to negligible. The majority of observed parameters exceed hazardous levels deemed acceptable for river water utilization. The evaluation of Sewage Treatment Plants highlights the imperative to augment capacity in terms of treatment, storage, reactivation of closed plants, and efficient operation to meet the growing demand for fresh water. Additionally, there is a pressing need to generate demand for wastewater in diverse urban sectors.

1. Introduction

The escalating global population has led to an increasing demand for fresh water, particularly driven by the surge in industrial and agricultural activities. At present, around 70 billion individuals across 43 nations contend with a shortage of water resources and pressure [1,2]. Wastewater, denoted as the remaining water arising from a mix of residential, industrial, business, or agricultural pursuits, along with surface runoff, stormwater, sewer inflow, or sewer infiltration, encompasses diverse pollutants and attributes that depend on its origin [3,4].

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The comprehensive classification of wastewater is illustrated in Figure 1. Several megacities in Asia, grappling with substantial environmental challenges, paradoxically witness an exacerbation of drainage and wastewater treatment issues alongside the rise in water supply and water-borne sanitation facilities. India, bearing almost 4% of the world's renewable water resources and supporting approximately 18% of the global population [5,6], faces heightened challenges. States such as Delhi, Uttar Pradesh, Haryana, and Madhya Pradesh rely on the Yamuna River for their water needs. Regrettably, this reliance has converted the river into a conduit for untreated sewage from diverse origins, turning it into one of the nation's most contaminated aquatic environments and positioning Delhi among the globe's most polluted urban areas. There are approximately 580 km of the Yamuna River extending from the Wazirabad Barrage in Delhi to the Chambal River near Panchnada village, with the part of the river within Delhi spanning 54 km between Palla and Badarpur experiencing significant pollution in recent years. It is important to note that there are only 22 km of the river between Wazirabad and Okhla that are responsible for 76% of the river's pollution, which is significantly less than 2% of its total length [7,8].

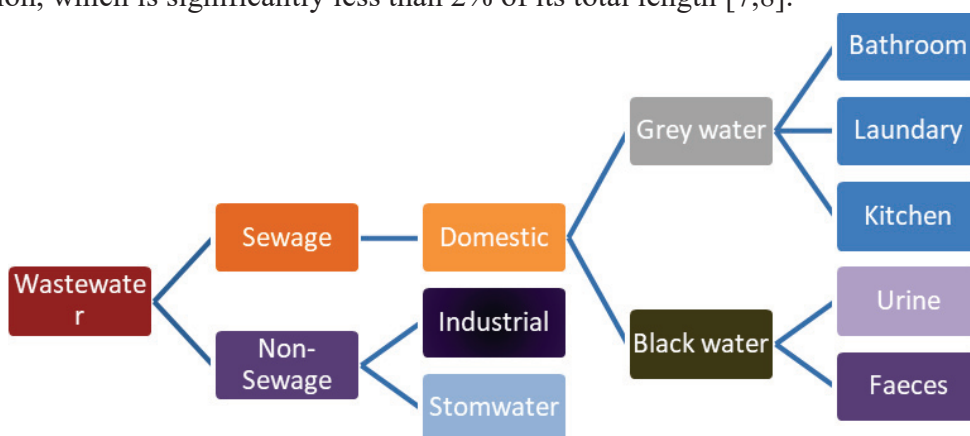


Fig .1. Types of wastewater [9]

The Yamuna is heavily polluted by a variety of sources and comes in many forms at different places, resulting in a wide range of pollution. The primary contributing factor is sewage from the domestic sector, including unauthorized human settlements and commercial centers, which account for over 80% of the total wastewater discharge. Delhi is home to a significant number of small-scale industrial waste generators, both legal and illegal [10]. There has been a significant increase in the amount of municipal wastewater over the years due to the expansion of urban populations, the expansion of domestic water supplies, and the production of sewage. As a result of actions like livestock movement in water, dairy waste, and open defecation in informal communities along the Yamuna riverbank, encompassing rural areas, contamination of water can be caused by a variety of factors, including biological material, particles suspended in water, cleansing agents, and fats. Several sites in Delhi, including Wazirabad, ISBT, Loha Bridge, ITO, Nizamuddin and Okhla, are displaying substantial quantities of solid waste, including religious tributes, that are conspicuously discarded. Aside from hotels, restaurants, banquet halls, dhabas, and healthcare establishments, commercial and mixed-use land use areas also contribute to pollution. There was a significant amount of pollution in Delhi's catchment areas two decades ago, with approximately 3296 MLD of sewer discharged into the Yamuna. Based on Economic Survey of Delhi, 2019-20, a total of 3026 MLD of wastewater is discharged into the river by 18 major drains Figures 2 and 3.

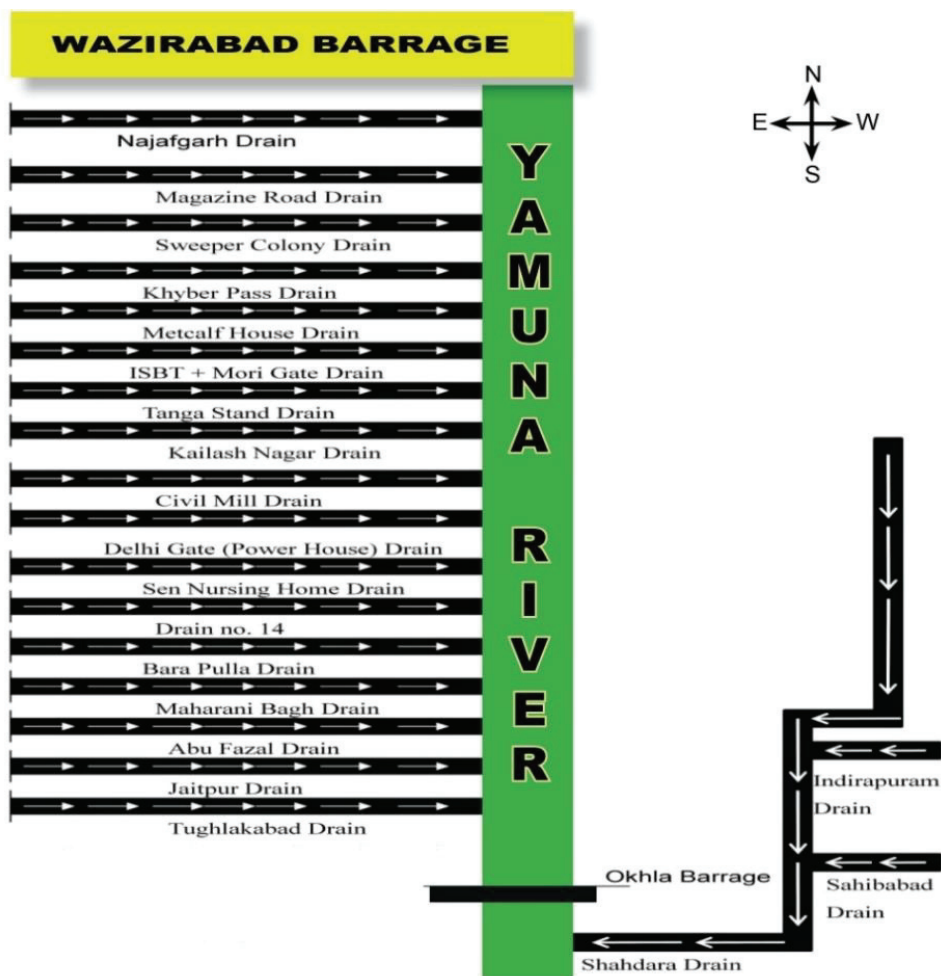


Fig. 2. Drains falling in Yamuna in Delhi region [11]

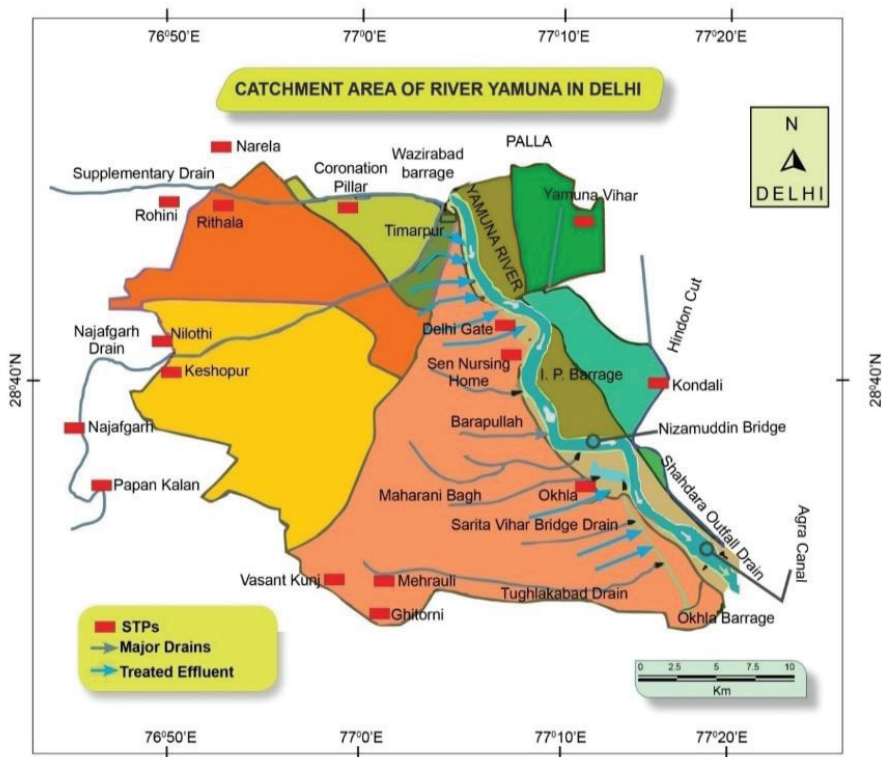


Fig. 3. Major Pollution Sources of River Yamuna [12]

In recent years, industrial activities have had a substantial effect on the level of Chemical Oxygen Demand (COD), an indicator of industrial waste. Generally speaking, water quality in the upper reaches of the river is considered good (Class 1); however, in the lower sections, particularly from Delhi, it is classified as Class IV. As the water quality improves downstream of Delhi, this can be seen. Despite the fact that Common Effluent Treatment Plants (CETPs) have been constructed through government initiatives, they have only been partially successful, which has necessitated the relocation of polluting industries and strong measures for abating industrial pollution. Due to a number of factors that have been contributing to the persistent rise in COD levels at Nizamuddin Bridge, including a lack of CETPs that can handle industrial waste, unintentional industrialization in residential neighborhoods, prioritization of water supply over wastewater management, and neglect of Yamuna River cleanup, the COD levels have persistently increased. It is interesting that the COD level at Wazirabad Barrage has remained steady, pointing out the significant impact of industrialization in Delhi alone [13,14].

As the Yamuna River flows through cities, its freshwater is used for many different purposes, but ultimately the wastewater that is generated is released into the river again. Consequently, the Yamuna River, which originates from the urban conglomeration of Delhi, is being depleted from its junction with the Chambal River because of this process. It is a city that rely heavily on its Yamuna River and groundwater for its potable water supply, but an aging water supply system has resulted in a substantial 40% loss which further reduces the availability of water. A number of challenges hamper the sustainability of the wastewater management practices in Delhi, such as hyper-urbanization, an increase in informality, planning failures, inadequate monitoring tools, ambiguous institutional responsibilities, corruption, multiple authorities, fragile financial bases, a lack of accountability, a lack of political will, and the absence of a coordination body [15,16].

As a result of large urban centers in the National Capital Territory of Delhi, followed by Agra and Mathura, the Yamuna is heavily polluted due to urban pollution. There are 85% of the total pollution in the river attributed to domestic sources. The extraction of a substantial amount of river water, which leaves the river with no fresh water and compromises the river's ability to assimilate, exacerbates deterioration.

According to the National Green Tribunal, 41 Sewage Treatment Plants (STPs) were located at 22 locations as of July 2018, of which six were closed for upgrades, 20 were receiving wastewater below the capacity that they were designed for, and 5 to 9 were not meeting design specifications. There were 14 out of 35 functional STPs that were non-compliant with various parameters as reported in the Delhi Pollution Control Committee's 2019 report. In order to ensure compliance with discharge standards for STPs and Common Effluent Treatment Plants (CETPs), it is imperative to conduct continuous monitoring of all STPs and CETPs.

It is crucial to resolve land allocation issues at various locations within the Delhi Jal Board (DJB), Delhi Development Authority (DDA), Gram Sabha, and private landowners in order to address sewage treatment needs resulting from the Sewerage Master Plan - SMP 2031. As of the moment, DJB produces around 935 MGD of fresh water per year, with approximately 80% of this water being treated as sewage, resulting in 748 MGD of sewage per year. At present, there is a treatment capacity of 540 MGD, in the process of being increased to 707 MGD by mid-2023, which will make use of nearly 90% of the total capacity of the plant. A major STP is currently being constructed in Okhla and will be finished by June 2022 [17,18].

In order to achieve a zero sewage flow into drains and rivers, DJB has undertaken the Interceptor Sewer Project, an integrated initiative. A total of 115 kilometers of interceptor sewers will be installed in the project, and wastewater will be collected from 135 sub-drains that discharge into major drains (Barapulla, Shahdara, Najafgarh), and diverted to STPs nearby. A total of 70% of the total amount of pollution in the Yamuna comes from these three

drains. By 2018, only 99 MGD of sewage was being trapped and treated, which was a far cry from the 242 MGD that was originally planned for commissioning by June 2014.

There are 28 industrial clusters in Delhi, of which 17 have water-consuming industries connected to 13 CETPs. Seven of these CETPs do not meet the prescribed standards, and are not in compliance with the standards. The enforcement actions have resulted in an increased inflow of water to CETPs, which means that units are able to discharge wastewater and industrial effluents into drains and other systems to a lesser extent.

2. Literature Review

Prior investigations have been conducted to assess the quality of the Yamuna River. [19] used the QUAL2Kw river quality model to assess the quality of water for a period of 1999 through 2009. This study focused on the total coliforms, BOD, DO, and total nitrogen concentrations observed at four monitoring stations located throughout Delhi, emphasizing that specific predictions are highly dependent on the flow and quality at point sources as well as headwaters.

[20] examined the effects of pollution on the Yamuna River at five locations from 2000 to 2005, analyzing the seasonal variation of pollutants as well as the geography of the region. They found that during the monsoon season, pollution levels were lowest, and there was a positive correlation between COD, BOD, DO, AMM, and TKN.

In order to assess the environmental flow of a site, various approaches have been proposed, including the perspective and interactive approaches, bottom-up and top-down approaches. In addition to [21-25], researchers have developed and evaluated these methods. An overview of various e-flow assessments that have been conducted in Indian rivers has been provided by [26].

As an example, NGT used the HEC-RAS model for environmental flow assessment of the Yamuna River [16] in a similar manner to the Ganga basin approach. In Delhi, DPCC has been monitoring the quality of the Yamuna River, focusing primarily on parameters such as pH, TSS, BOD, DO, COD, ammonia nitrogen, and phosphates. As a result of this study, it is highlighted that the Yamuna River is affected greatly and it proposes strategies for enhancing water quality and preventing further degradation.

Motivation

Motivation in Psychological Sciences:

Motivation is a fundamental concept in psychology and behavioral sciences.

It plays a crucial role in driving human behavior, cognition, and goal-oriented actions.

Intrinsic and Extrinsic Motivation:

Intrinsic motivation stems from inherent interest and enjoyment in an activity.

Extrinsic motivation is driven by external rewards or pressures.

Dimensions of Motivation:

Goal setting theory emphasizes the importance of specific, challenging, and attainable goals in stimulating motivation.

Self-efficacy, based on social cognitive theory, highlights an individual's belief in their ability to perform tasks and overcome obstacles.

Positive Psychology and Growth Mindset:

Positive psychology underscores how motivation contributes to well-being, resilience, and personal growth.

A growth mindset views challenges and failures as opportunities for learning and development, enhancing motivation.

Neuroscientific Underpinnings:

The mesolimbic dopamine system, often called the "reward center" of the brain, is closely tied to motivation.

Dopaminergic pathways are activated during success, reinforcing motivation and goal-directed behavior.

Real-World Examples:

Notable figures in various fields exemplify the impact of motivation, perseverance, and resilience.

Their journeys showcase the relentless pursuit of goals and an unwavering belief in their abilities.

Practical and Scientific Implications:

Understanding the mechanisms and determinants of motivation has practical applications in enhancing human performance.

It promotes personal growth, resilience, and well-being, making it relevant in both scientific research and real-world contexts.

In summary, motivation, a multidimensional concept, profoundly influences human behavior and achievement, with implications spanning psychology, neuroscience, and personal development.

3. Materials and Methods

As part of the analysis, secondary data were collected from Delhi Pollution Control Board, Delhi Jal Board (DJB), Central Pollution Control Board (CPCB), and Central Public Health and Environmental Engineering Organization (CPHEEO) for use in the analysis. For assessing the parameters that affect the water quality of the river, tabular analysis, graphical presentation, trend analysis, and correlation examination are employed. It is determined that the COD-BOD relationship is the most important factor that influences the results of the correlation study for nine locations in Delhi. This indicates that there is a positive correlation between these locations and the expected high correlation coefficient. Agra Canal Jaitpur, Agra Canal Okhla, Surghat, Khajori Paltoon Pool, Kudesia Ghat, Nizamuddin Bridge, ITO Bridge, Okhla Barrage (Downstream), and Agra Canal Okhla are some of the locations in which the water quality correlation matrix for the Yamuna River can be analyzed.

4. Results and discussion

Despite being a densely populated city in India, Delhi faces challenges as its population continues to grow, which requires a consistent supply of clean water and efficient waste disposal systems. It is estimated that more than half of the city's residents live in informal settlements which suffer from sanitation issues, sewerage problems, and a variety of water-related issues. There are 937 million gallons of water per day (Million Gallons Per Day) of water supply in Delhi from various sources out of which nearly 63% is destined for household use (NIUA - UNESCO, 2021), of which 19% is designated for institutional use, and 18% for industrial and commercial use. There are estimated to be 1800 million liters of untreated wastewater released into the Yamuna each day by Delhi, posing a significant problem (Zimmer, 2015). A total of 3,987 million liters of wastewater are produced each day by the city, but only 47% of them go through treatment, utilizing 63% of the total treatment capacity available. Approximately 20% of the total wastewater discharged by the city consists of pollutants like biological substances, heavy metals, particles in suspension, oil, and fat that are produced by 28 sanctioned industrial zones, 22 redevelopment areas, and non-conforming zones.

Although about 7,000 crores have been allocated over the years for rejuvenation of the Yamuna through initiatives such as the Yamuna Action Plans, the evaluation of the river's water quality indicates little or no improvement along its Delhi stretch (CPCB, 2017). In 2008, the Interceptor Sewer Project was initiated with an objective to achieve a level of BOD in the sewer that was 12 mg L⁻¹ by 2016, however success rates have been limited over the

past decade, with rates dropping from 55 mg L⁻¹ to 47 mg L⁻¹ by 2016, failing to reach the goal by 2016.

The state agency responsible for waste management and sewage treatment in Delhi, known as the Delhi Jal Board (DJB), is facing many challenges. The current capacity, which is more than 25% underutilized, is a result of land availability issues, inefficient sewage conveyance, and inaccurate population projections in the catchment areas for Sewage Treatment Plants (STPs). Furthermore, the overall capacity is not adequate, and approximately 30% of the operative capacities do not meet basic water quality standards, which is unacceptable. Even though substantial investments have been made in centralized STPs, the lack of a significant impact can be attributed to factors such as municipal waste dumping through storm-water drains, poor quality of treated water, and insufficient dilution as a result of freshwater scarcity, which contribute to the lack of significant impact. It is both laborious and costly to improve the quality and capacity of central STPs due to the complexity and large-scale technology involved. The DJB has estimated that, in order to address the 46% of the city without sewerage, it would take approximately Rs. 20,000 crores and approximately two decades to implement a centralized sewage system.

As a result of Delhi's significant involvement, almost 79% of the total pollution load in the Yamuna River comes from Delhi, far exceeding neighboring cities (Figure 4). As a result of the continuous discharge of wastewater from domestic sources within the city, the Yamuna River's water quality has been degraded for a number of years, particularly downstream of the Wazirabad barrage in the Delhi region. As a matter of fact, neither Delhi nor its nearby counterparts have adequate drinking water supplies, as they are both quantitatively insufficient and qualitatively unsuitable in quality. Additionally, the absence of freshwater in the river after the Wazirabad barrage when it is not monsoon season compounds the issue, reducing the river's ability to self-purify during non-monsoon periods. With nearly 41.1% of Delhi's water resources coming from the Yamuna River, the Ganga River (26%) and the Bhakra storage grounds (24%) provide the majority of Delhi's water resources Figures 5 and 6.

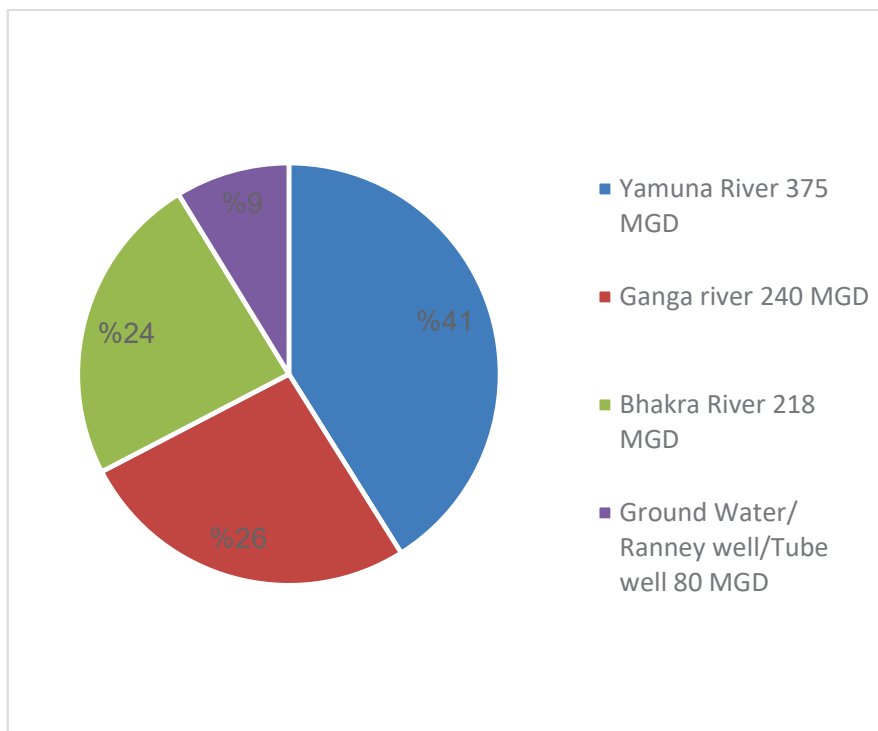


Fig. 4. Different Segments of River Yamuna, *Source:* Mishra, 2010

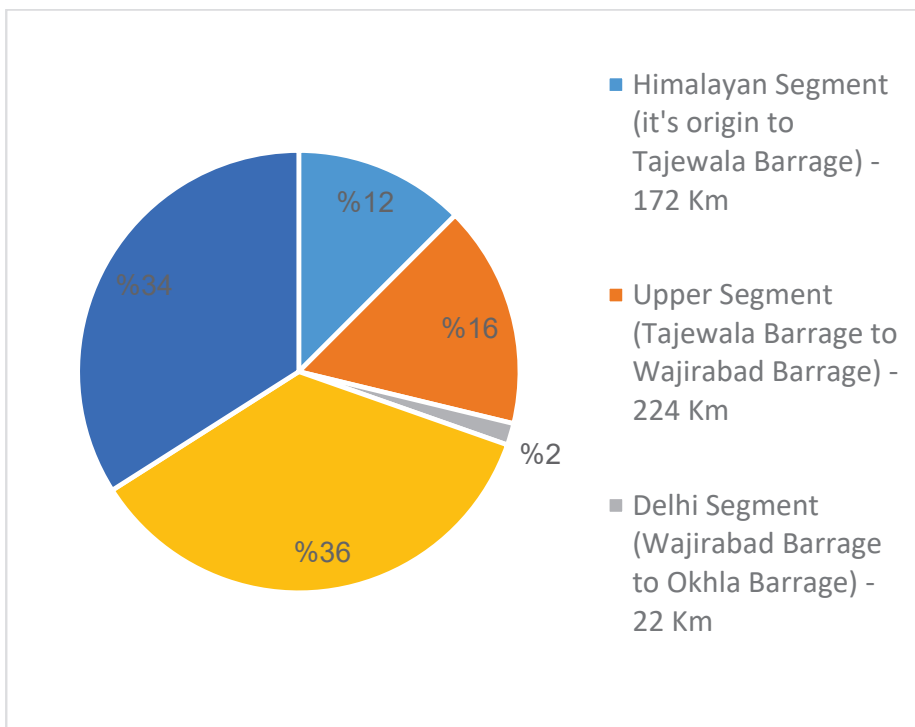


Fig .5. Water Resources in Delhi, Delhi Jal Board, 2019

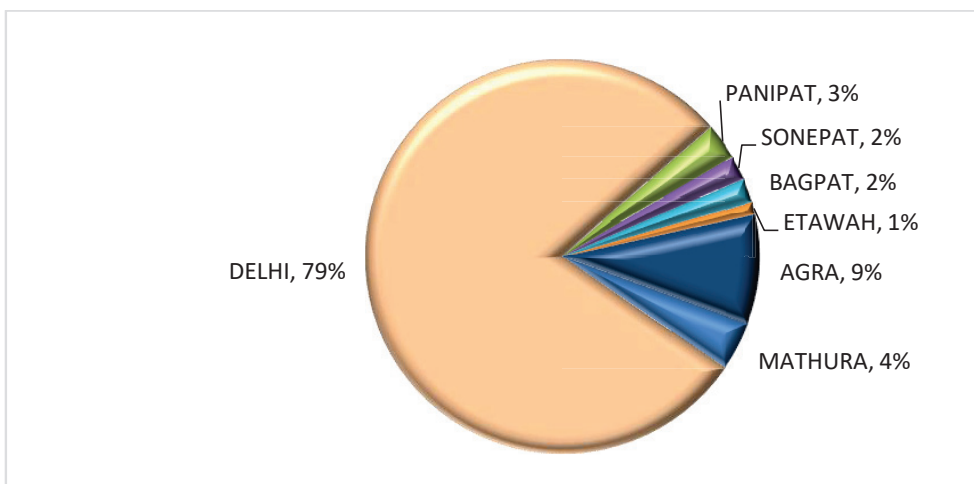


Fig. 6. Share of pollution load from different cities in River Yamuna, CPCB, 2017

An assessment of the status of drains in the Delhi region reveals noteworthy findings. During the past three years from 2017 to 2019, the total flow from all drains has consistently been above three thousand tons of water per year. Almost 90% of the total flow and more than 86% of BOD discharged into the Yamuna River originates from these six major drains, which contribute almost 90% of the total flow. In Delhi, the Najafgarh drain is the largest contributor, accounting for approximately 60% of the total flow. There have been a number of reports of BOD loads ranging between 100 and 134 tonnes per day (tonnes per day) in this drain, since it contributed approximately 2000 MLD of flow into the Yamuna River in the past three years. A flow rate of around 500 milliliters per day has been reported for the Shahdara drain, and this drain has a BOD load that varies from 39 to 61 tonnes per day. This report presents a detailed analysis of COD and BOD parameters for the largest Najafgarh drain, covering the period 2011 to 2017, based on data from alternate years, see Figures 7

and 8. Figure 9 depicts the BOD load for the six major drains over the three years of 2017-19.

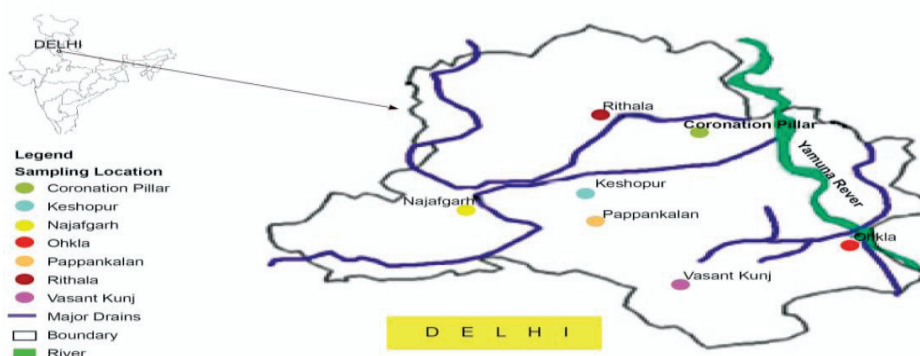


Fig. 7. Sewage treatment plants in Delhi

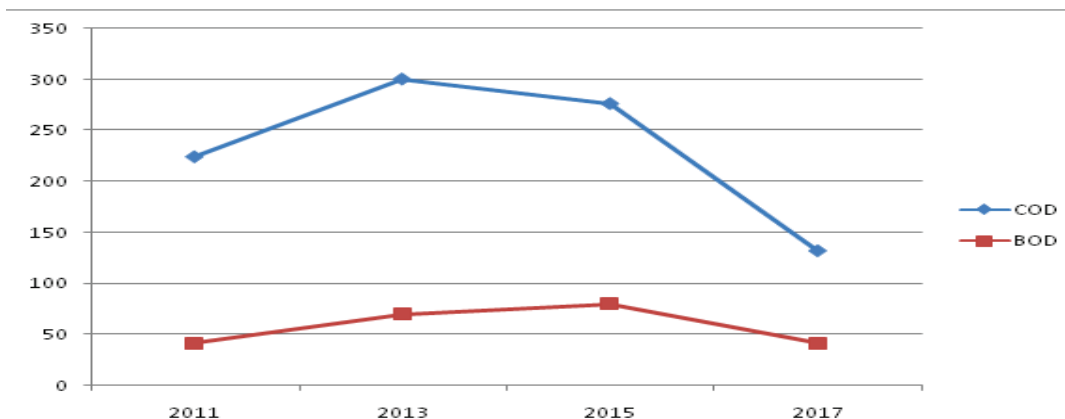


Fig. 8. COD and BOD status of Najafgarh drain for April 2011-2017, DPCC, 2017

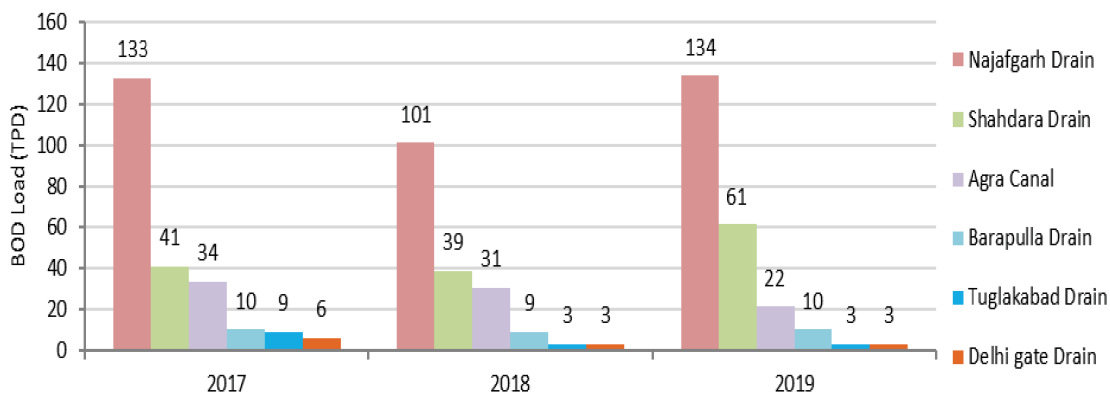


Fig. 9. BOD in major six drains of Delhi in recent period – 2017 to 2019.

It is the responsibility of the Delhi Water Quality Monitoring Center to evaluate water quality parameters at nine primary monitoring sites. These are Palla, Surghat, Khajori Paltoon Pool, Kudesia Ghat, Nizamuddin Bridge, ITO Bridge, Okhla Barrage (downstream), Agra Canal Jaitpur, and Agra Canal Okhla, among others. From April 2019 to November 2020, figures 10 to 12 show that these parameters have been measured at these locations in the Yamuna River for the last month of available time. This river's water is unsuitable for domestic use and industrial use since most parameters exceed the hazardous threshold. The analysis of monthly data indicates that there is a seasonal impact on water quality parameters, particularly during the monsoon season around August, when the parameters are observed to decline minimally. It has been noted that the BOD and COD levels at entry points to the Yamuna in Delhi are lower than those of other locations in Delhi. Figures 10 - 13 illustrate

the average trend of the water quality parameters over the last several years based on all nine monitoring sites in Delhi as a whole.

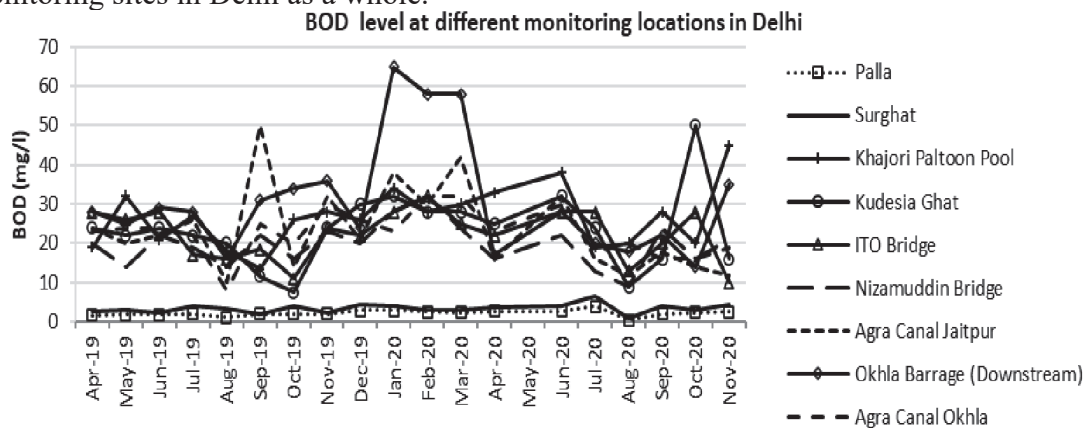


Fig. 10. BOD level at different locations in Delhi –April 2019 to Nov 2020, DPCC.

A correlation analysis of the parameters for the nine monitoring sites that were specified is then conducted on a monthly basis between them and the average values for all nine locations in Delhi. In order to compute a correlation between the average values of all study parameters across the nine locations, the average values of all study parameters need to be calculated across all of the nine locations. For almost all locations, there is a significant correlation between COD and BOD, with an association level of around 0.94 on a combined basis. Other parameter relationships appear to be less significant and the correlation level is very low. With a correlation level of 0.95, Kudesia Ghat, Agra Canal, and Okhla Barrage display the highest significance. It appears that the pH of water remains within a certain range, with few outliers, reflecting a low level of significance associated with BOD and COD.

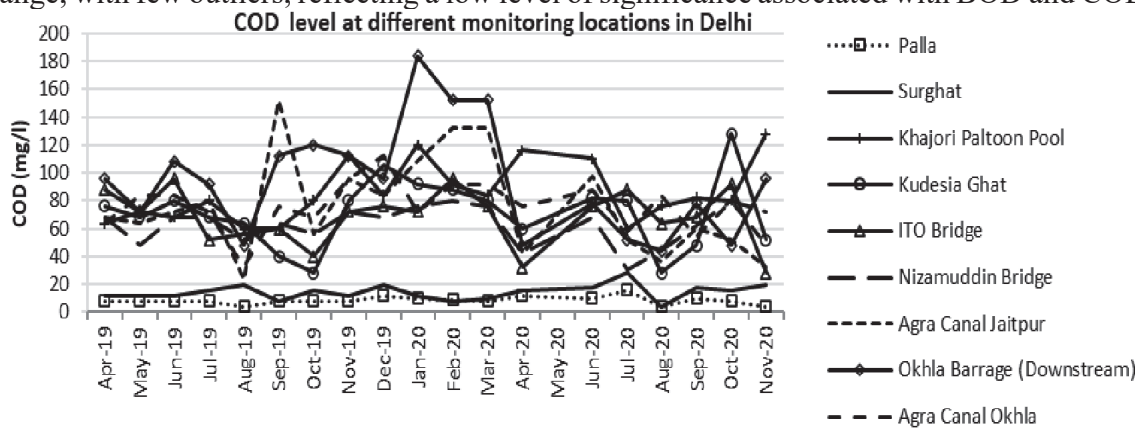


Fig. 11. COD level at different locations in Delhi –April 2019 to Nov 2020

Further, a cross-sectional analysis of 21 drain locations for a particular year, 2019, is used to calculate the correlation between the COD and BOD parameters, revealing a very strong correlation of 0.987 between these two parameters. In light of the close association between the levels of COD and BOD flow levels of all drains, this proves that they are all closely related.

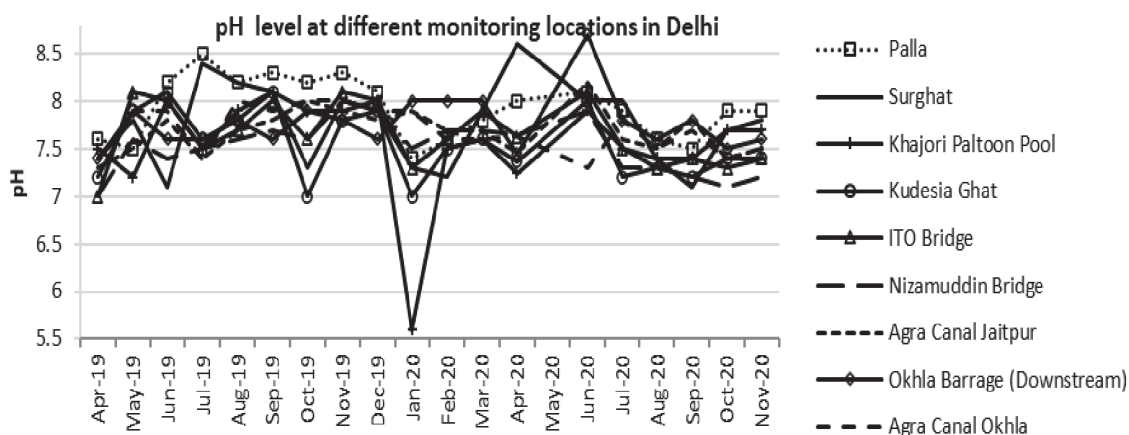


Fig. 12. pH level at different locations in Delhi –April 2019 to Nov 2020

The existing sewage system in Delhi requires the establishment of extensive infrastructure for operation and maintenance, thus requiring centralized supervision for performance and accomplishment, which is why it requires extensive infrastructure. Due to challenges such as clogging, rehabilitation, and leaks that arise in the extended conveyance system, it becomes more difficult to identify system issues, which leads to inefficiency and ineffectiveness. In order to deal with these concerns, the focus should be shifted toward managing domestic sewage through local and decentralized systems, rather than relying on centralized solutions. It is essential to emphasize the reuse of treated water in order to reduce the amount of sewage that is disposed of directly into the Yamuna by the 22 drains in Delhi.

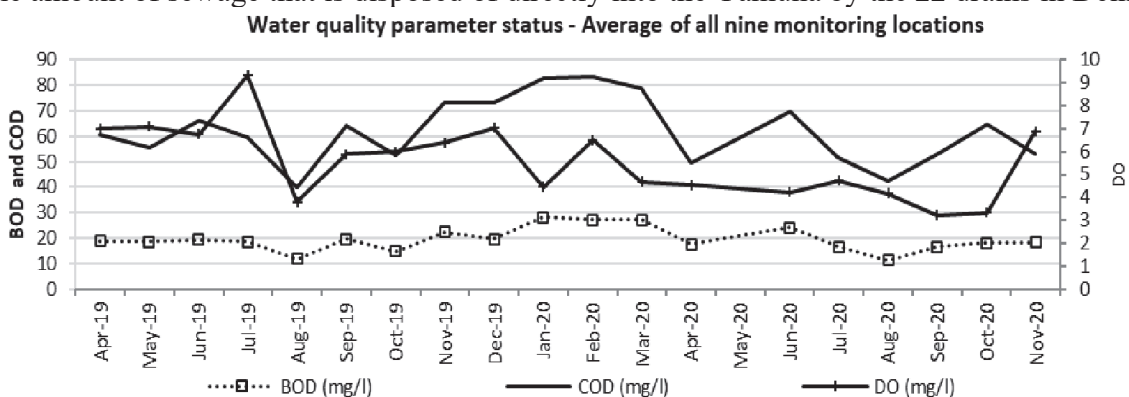


Fig. 13. The trend in COD, BOD, and DO (Average of nine monitoring locations) – April 2019 to Nov 2020

There has been significant evidence that decentralized systems are feasible on many fronts, encompassing socioeconomic, administrative, planning, technological, and environmental aspects, provided that shortcomings are diligently monitored. In order to improve the responsibility and accountability of the community, it is important for Delhi Jal Board (DJB) and community institutions to work together in a collaborative planning process, managed at the community level under the supervision of Resident Welfare Associations (RWAs) and DJB. A bottom-up approach to the planning and design of future sewage systems ensures foolproof designs and fosters a better bond with the community, resolving a lack of trust that exists there is, and it also enhances community participation and improves transparency in the way the system operates.

5. Conclusion

The current centralized approach employed for cleaning the Yamuna, encompassing initiatives like the Interceptor Sewer Project by the Delhi Jal Board (DJB) and Yamuna Action Plan I and II under the National River Conservation Plan (NRCP), has not

significantly reduced pollution levels in the Yamuna within Delhi. The traditional centralized approach faces crucial challenges in terms of economic, environmental, and infrastructural feasibility. Various inefficiencies related to the capacity and water quality treated by existing infrastructure, along with the time and cost required to incorporate various unsewered regions of Delhi into the centralized sewage system, have prompted the exploration of sustainable, innovative, and alternative sewage management solutions.

It has been determined that in the past few years, a total flow of over 3000 MLD has been consistently exceeding that from all Delhi's drains. In total, six major drains contribute about 90% of this flow and 86% of the Biological Oxygen Demand (BOD) load into the Yamuna, with the Najafgarh drain contributing the largest amount. The flow from these six major drains has, however, been decreasing for the last several decades.

According to a recent assessment of water quality in 24 drains in Delhi, the majority of drains have BOD levels that exceed permissible levels, and some drains reported values that were more than six times the set standards. There are several parameters for water quality that are affected by pH (7.6 to 7.8) for different drains. In addition, total suspended solids (TSS) are measured in the range of 48.5 mg L⁻¹ to 419 mg L⁻¹, chemical oxygen demand (COD) is measured in the range of 51 mg L⁻¹ to 554 mg L⁻¹, and biological oxygen demand (15 mg L⁻¹ to 187 mg L⁻¹). This is a warning that the water quality parameters are exceeding standards, as it shows that it is necessary to design monitoring schemes which are based on the locations of the drains, the seasonal load on them, and a focused focus on specific quality parameters.

In a correlation analysis among parameters at nine monitoring locations, the correlation between COD and BOD was highly significant for almost every location. Despite the high correlation between COD and BOD, correlations for other parameters seem low. Considering that the flow load in the river is highly correlated, it is likely that there will need to be a close relationship between solutions.

It was found that existing sewage management treatment systems are viable, however adaptive measures can be made, such as enhancing technology and making planning easier, as well as coordinating administrative analysis to provide cost comparisons for construction, operation, and maintenance. In this way, the water can be treated locally and reused in a manner that is socially acceptable. It is necessary to increase the capacity of the water system in terms of treating, storing, reopening closed plants, and running efficiently in order to meet the increasing demand for fresh water. For major drains that contribute a significant proportion of COD and BOD load, it is crucial that efficient and localized treatment solutions be managed.

The adoption of localized sewage management systems, on the other hand, seems more pragmatic in the future, providing a sustainable alternative. It is important to examine possible shortcomings in adoption approaches and systems, focusing on resolving these issues from a broader perspective. To preserve the Yamuna for both people and aquatic animals, effective wastewater management is essential at the municipal and industrial levels. In order to improve the quality of Yamuna's water, more interceptors will be constructed for collecting sewage water, treated water will be discharged into the river, Sewage Treatment Plants will be expanded, heavy tariffs will be imposed on businesses/units discharging untreated or partially treated wastewater into drains leading into the Yamuna river, awareness will be distributed among the population, and preventative measures will be encouraged to prevent pollution. Furthermore, different sectors of the urban economy, such as construction, horticulture, and industrial coolants, are emphasized as a potential consumer of wastewater.

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