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Statistical Assessment of Wastewater Quality of Untapped Drains Discharging Untreated Sewage into River Ganga at Prayagraj, Uttar Pradesh

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Abstract: *River Ganga at Prayagraj is experiencing severe pollution because of the presence of untreated domestic wastewater from a number of urban drains. In this context, the aim of this study is to analyze water quality of untreated domestic wastewater of 25 drains, which discharge into the river, based on data collected by the Uttar Pradesh Pollution Control Board (UPPCB) in July 2024. For the purpose, six key water quality parameters including pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Total Coliform (TC), and Fecal Coliform (FC) have been used in a correlation analysis. The study has shown that the water of the drains has a considerable organic and microbial pollution. In particular, very high BOD (111.68 mg/L) and COD (380.56 mg/L) levels indicate heavy pollution in terms of organic compounds. Moreover, a very high content of Total Coliform and Fecal Coliform also shows severe pollution with sewage posing serious environmental and health risks. Besides, the correlation analysis has revealed a strong positive relationship between BOD and COD (r = 0.78) as well as Total Coliform and Fecal Coliform (r = 0.89). In conclusion, it is important to note that this study has shown that untreated sewage contributes significantly to poor water quality in the river Ganga at Prayagraj, hence there is an urgent need for better wastewater management.*

Introduction

One of the most prominent river systems in India is the Ganga River, which acts as an important source of freshwater for consumption, irrigation, industries, fishing, and rituals. The Ganga River basin accounts for about 40 percent of the population in India. Moreover, it plays a critical role in maintaining ecological balance as well as fostering economic development in the basin. Nevertheless, this river system has been exposed to severe water degradation owing to rapid urbanization, industrialization, population growth, and improper management of wastewater. One of the most prominent sources of pollution in Ganga is sewage that goes into the rivers untreated or semi-treated (Birol and Das 2010).

There are many cities situated in the basin of the Ganga River, but Prayagraj is unique because it is located in a place where the Ganga meets the Yamuna River. This city has seen dramatic demographic change in recent years, which has led to the formation of more wastewater than can be handled by current sewage treatment plants. Hence, there are some drainage systems discharging untreated sewage directly into the rivers (Sharma, Bisht, and Sanu 2022).

Wastewater untreated has high amounts of organic matter, suspended particles, nutrients, dissolved salts, and disease-causing bacteria. Wastewater discharge into rivers causes changes in physical and chemical properties, an increase in oxygen consumption by living organisms and chemicals, causing eutrophication, decreases in dissolved oxygen concentration levels, and ultimately affecting aquatic diversity (Akpor et al. 2014). In addition, water contaminated with sewage can act as a carrier for waterborne diseases that affect people depending on river water for use in their day-to-day activities. River water contamination is becoming a major environmental and public health issue, especially in rapidly growing cities where untreated sewage is directly discharged into the river.

It has been observed through multiple researches that there is a strong correlation between microorganisms, organic contaminants, and increased health hazards among the community members inhabiting within the river basin (Singh et al., 2023). According to Alam et al., (2023), municipal wastage constitutes the most significant pollution sources, amounting to about 80% of all pollutants entering into the main channel of Ganga River. Monitoring conducted in various major urban cities has revealed that several key water quality parameters such as BOD, total coliforms, etc. exceed the permissible levels. Hence, the presence of dissolved oxygen gets reduced, thereby harming the aquatic ecosystem and makes the river water unsuitable for human consumption unless treated (Alam et al., 2023; Tiwari et al., 2024). Further, advanced methods such as the use of HRI have emphasized the need for concern with respect to increasing exposure to toxic metal content due to the combined impact of municipal and industrial effluents (Tiwari et al., 2024; Tiwari et al., 2025). These contaminants carry considerable health risks for cancer and neurotoxicity among the community members utilizing the river for domestic as well as agricultural purposes.

There have been numerous researches done to ascertain the quality of river water and evaluate the wastewater treatment techniques used in the Ganga basin. The use of natural filters like river sand bed filters for treating wastewater to improve its quality has been proved by several studies done at Varanasi(Dimri et al. 2021). This highlights the need for adopting low-cost sustainable methods for treating wastewater. While there has been an abundance of research on river water quality and wastewater treatment techniques, surprisingly very little research has been done about the characterization of raw wastewater from untreated urban drains, particularly in the city of Prayagraj. Earlier researches have concentrated mainly on studying river water quality by means of WQI and other evaluation measures that give a generalized idea about the river water quality. However, these studies usually neglect to analyze the characteristics of sewage drains discharging raw wastewater, although these are considered one of the primary sources of river pollution (Bhaduri, 2025; Kanaujiya & Tiwari, 2023). Large-scale monitoring of river water is helpful in comprehending the degradation in water quality in relation to the river due to urban and cultural festivals (Kanaujiya & Tiwari, 2023). However, such measurements may conceal the substantial effects of pollution originating from heavily polluted communities and industrialized regions that have been found to have a negative effect on the quality of the river water (Bhaduri, 2025; Tiwari et al., 2025). It is important for future research to focus on how pollutants from open drains can change water chemistry prior to discharge into the river.

The determination and evaluation of untreated sewage that reaches a river are vital steps toward coming up with the best pollution control plans and river rehabilitation programs. The process of analyzing the relationship between water quality parameters at various sampling points and among each other may be critical in gaining insights about the source of pollution, type of sewage, and degree of its treatment (Essam Sharaf El Din et al., 2020; Sun et al., 2019). In the analysis of complex data sets, statistical techniques can greatly contribute to gaining insights about relationships, variations, and the main factors behind water quality (Muniz & Oliveira-Filho, 2023). Through statistical techniques, researchers can gain a lot of insights regarding significant correlations, patterns of variability, and major influences on water quality.

Research Objectives

- To evaluate the physicochemical and microbiological characteristics of wastewater discharged through untapped drains into the River Ganga.
- To calculate descriptive statistics for major water quality parameters.
- To examine correlations among wastewater quality indicators.
- To assess the pollution status of drains and their potential impact on the River Ganga.

Study Area

Prayagraj lies in the southern region of Uttar Pradesh and boasts the confluence point of the three great rivers, the Ganga, the Yamuna, and the Saraswati (mythological). The city hosts many residential neighborhoods and urban villages, producing large amounts of domestic wastewater.

This project focuses on 25 unexploited drains found in the areas of Salori, Govindpur, Shivkuti, Shankarghat, Rajapur, ADA Colony, Jondhwal, Sadar Bazar, Nehru Park, Yadavpur, Indira Awas, Kashipur, and Gokula of Prayagraj.

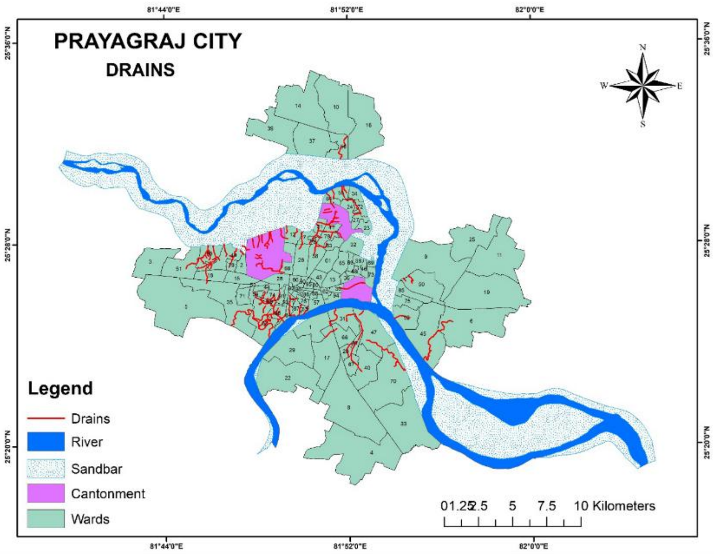

Figure 1: Prayagraj City Drains Map

Table 1: Waste Water Quality of Untapped Drains Discharging Untreated Sewage into River Ganga in Prayagraj

Sl. No.	Location of Sampling Point	Date of Sample Collection	pH	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	TC (MPN/ml)	FC (MPN/ml)
1	Salori Main/Ansh Bachchan Culvert before meeting with River Ganga	30.07.2024	7.31	110	390	294	2600000	1700000
2	Govindpur Colony Nala (Purani Basti) before meeting with River Ganga, Govindpur Prayagraj	30.07.2024	7.24	114	406	248	2100000	1100000
3	Govindpur Nala No. 1, before meeting with River Ganga, Govindpur Prayagraj	30.07.2024	7.38	118	434	290	2500000	1300000
4	Govindpur Nala No. 2, before meeting with River Ganga, Govindpur Prayagraj	30.07.2024	7.31	104	386	256	1700000	940000
5	Govindpur Nala No. 3, before meeting with River Ganga, Govindpur Prayagraj	30.07.2024	7.34	108	378	262	2800000	1200000

6	Govindpur Nala No. 4, before meeting with River Ganga, Govindpur Prayagraj	30.07.2024	7.27	116	390	256	2400000	1400000
7	Shivkuti Nala No. 1, before meeting with River Ganga, Shivkuti Prayagraj	30.07.2024	7.31	118	412	304	1400000	790000
8	Shivkuti Nala No. 2, before meeting with River Ganga, Shivkuti Prayagraj	30.07.2024	7.34	114	394	278	2000000	1100000
9	Shivkuti Nala No. 3, before meeting with River Ganga, Shivkuti Prayagraj	30.07.2024	7.21	106	384	268	2500000	1300000
10	Shivkuti Nala No. 4, before meeting with River Ganga, Shivkuti Prayagraj	30.07.2024	7.33	110	376	254	2400000	1400000
11	Shivkuti Nala No. 5, before meeting with River Ganga, Shivkuti Prayagraj	30.07.2024	7.29	108	380	266	2100000	1100000
12	Shivkuti Nala No. 6, before meeting with River Ganga, Shivkuti Prayagraj	30.07.2024	7.30	130	414	252	1500000	930000
13	Shivkuti Nala No. 7, before meeting with River Ganga, Shivkuti Prayagraj	30.07.2024	7.44	124	392	246	2400000	1400000
14	Shankargarhat Colony Nala before meeting with River Ganga, Shankargarhat Prayagraj	30.07.2024	7.51	104	370	244	1700000	790000
15	Shankargarhat Nala No. 1, before meeting with River Ganga, Shankargarhat Prayagraj	30.07.2024	7.49	110	370	242	1400000	790000
16	Shankargarhat Nala No. 2, before meeting with River Ganga, Shankargarhat Prayagraj	30.07.2024	7.38	104	314	248	2600000	1100000
17	Rajapur Nala, before meeting with River Ganga, Rajapur Prayagraj	30.07.2024	7.24	106	312	246	2700000	1400000
18	ADA Colony Nala, before meeting with River Ganga, near Jawaldevi Inter College, Prayagraj	30.07.2024	7.25	114	392	254	3300000	1700000
19	Jondhwal Drain, before meeting with River Ganga, Near Chhupur Mandis, Shankar Ghat, Prayagraj	30.07.2024	7.44	126	414	290	2600000	1400000
20	Sadar Bazar Drain, before meeting with River Ganga, Ashok Nagar near TV Tower, Prayagraj	30.07.2024	7.39	120	416	286	2200000	1100000
21	Nehru Park Nala, before meeting with River Ganga, Nehru Park, Prayagraj	30.07.2024	7.40	112	392	274	2500000	1300000
22	Yadavpur Nala, before meeting with River Ganga, Prayagraj	30.07.2024	7.32	110	386	270	2000000	920000
23	Indira Awas Drain, before meeting with River Ganga, Ashok Nagar near TV Tower, Prayagraj	30.07.2024	7.34	112	374	268	1700000	680000
24	Kashipur Nala, before meeting with River Ganga, Kashipur, Prayagraj	30.07.2024	7.29	102	334	254	1500000	930000
25	Gokula Drain, before meeting with River Ganga, Devrah Kachar, Prayagraj	31.07.2024	7.30	92	304	240	1100000	450000

Source: UPPCB, 2024

Materials and Methods

The data used in this research was secondary data obtained from the Uttar Pradesh Pollution Control Board (UPPCB), Regional Office, Prayagraj. The secondary data used in this research includes details of wastewater quality from 25 untapped drains that discharge their water directly into the River Ganga. Data collection was done in the month of July 2024 by sampling the water from sites just upstream where the drains connect to the river, thus making it possible to know the pollution load of the drains that enter the river.

There are six important wastewater parameters that have been selected for analysis in this paper. They include; pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Total Coliform (TC) and Fecal Coliform (FC). These parameters have been considered since they help to assess the physical and microbiological state of the wastewater. The pH value of the wastewater helps to determine its acidity or alkalinity. The levels of organic waste in wastewater are indicated by the Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) figures.

In order to determine the pollution status of the entire drainage system, descriptive statistics were used. The use of measures of central tendency such as the mean, minimum, maximum, and standard deviation was helpful in analyzing the variation in pollution levels in the drainage system. Moreover, Pearson correlation coefficient was employed in investigating the correlation coefficients between various parameters that affect water quality. This helped in analyzing the extent to which these variables were related to each other and thus helped in identifying sources of pollution.

Results and Discussion

- **Detailed Descriptive Statistical Analysis of Wastewater Quality Parameter**s

Analysis of the samples obtained from the 25 untapped drains, which feed the River Ganga, gives an insight into the amount of pollution that is carried by these streams into the river. In order to analyze the physical and chemical properties of the water samples, statistical methods were used. These included calculation of parameters such as mean, minimum, maximum, range, standard deviation, and coefficient of variation (CV).

Results have revealed that there was little variability in the pH value, which suggests that the acid-base condition of wastewater in the drains was quite stable. Other measurements provided evidence about a high concentration of organic matter, solid particles, and microbes in these wastewater samples. Such a result clearly indicates that these wastes are heavily contaminated and demonstrate discharge of untreated sewage into the Ganga at Prayagraj.

Table 2: Consolidated Descriptive Statistics of Wastewater Quality Parameters

Parameter	Mean	Minimum	Maximum	Range	Standard Deviation	Coefficient of Variation (%)	Unit
pH	7.34	7.21	7.51	0.30	0.08	1.1	pH Units
BOD	111.68	92	130	38	8.26	7.4	mg/L
COD	380.56	304	434	130	33.08	8.7	mg/L
TSS	263.60	240	304	64	18.14	6.9	mg/L
Total Coliform (TC)	2,148,000	1,100,000	3,300,000	2,200,000	537,835	25.0	MPN/100 ml
Fecal Coliform (FC)	1,128,800	450,000	1,700,000	1,250,000	308,374	27.3	MPN/100 ml

Source: Generated by Researcher

It should be pointed out that according to the analysis, all 25 drains have a significant amount of pollution loading into the River Ganga. Moreover, the mean pH value was 7.34 and remained stable at the neutral level, varying little among all drains (CV = 1.1%). Therefore, it can be concluded that water pollution is mostly similar and has the character of domestic sewage. On the contrary, mean BOD and COD values were quite high – 111.68 mg/L and 380.56 mg/L, respectively. The relatively low coefficient of variations of BOD (7.4%) and COD (8.7%) imply that organic pollution is widespread in all drains, not limited by a few of them.

The mean TSS content of 263.60 mg/L also suggests that there are significant amounts of suspended solids in the wastewater sample collected from all the drains, with very little variation in terms of their contribution (CV = 6.9%). On the other hand, the microbiological properties were found to be highly variable. The CV for total coliforms and fecal coliforms exceeded 25%, which is attributed to the differences in population density and availability of sanitation facilities as well as sewage flows in all the catchment areas. Nevertheless, the mean concentration of both the microbiological parameters was very high, indicating severe microbial pollution in the River Ganga.

Table 3: Comparison of Observed Mean Values with Typical Effluent Standards

Parameter	Observed Mean	Standard Limit	Exceedance Factor
pH	7.34	5.5–9.0	Within Limit
BOD (mg/L)	111.68	30	3.72
COD (mg/L)	380.56	250	1.52
TSS (mg/L)	263.60	100	2.64

Source: Generated by Researcher

Comparing the data obtained with the standard criteria for discharge indicates that all pollution parameters exceeded the permitted level, except for pH. On average, the level of biological oxygen demand is 3.7 times greater than the discharge standard, which shows that the organic load is extremely high. Similarly, chemical oxygen demand is 52% above the discharge standard, which means that both types of pollutants are present. Furthermore, the level of total suspended solids is about two times higher than the discharge standard, thus showing great particulate pollution.

It may be concluded that wastewater without treatment produces an elevated demand for oxygen in water, reducing the content of dissolved oxygen. Aquatic life forms will suffer due to stress and even death, whereas self-cleaning of the river becomes impossible.

Table 4: BOD–COD Relationship and Biodegradability Assessment

Parameter	Value
Mean BOD (mg/L)	111.68
Mean COD (mg/L)	380.56
BOD/COD Ratio	0.29

Source: Generated by Researcher

The BOD/COD ratio is commonly used in determining biodegradability of waste water. In this case, the ratio obtained of 0.29 implies that about 29% of the total oxidizable load of pollution is biodegradable. Ratios near 0.3 imply wastewaters from municipalities which have high loads of organic pollution and some fraction of the load is not biodegradable.

While biological methods can be used in reducing the organic pollution load, more steps may be needed to remove non-biodegradable elements that cause the COD. This ratio also confirms the hypothesis that domestic effluents are the main sources of the pollution in the area under study.

Table 5: Relative Variability of Wastewater Quality Parameters

Parameter	CV (%)	Variability Class
pH	1.1	Very Low
TSS	6.9	Low
BOD	7.4	Low
COD	8.7	Low
TC	25.0	High
FC	27.3	High

Source: Generated by Researcher

Coefficient of variation gives an idea of spatial uniformity in wastewater attributes. Attributes related to pollution with organic and physical contaminants (BOD, COD, and TSS) show low values for variation, implying that there is a spatial uniformity in the distribution of pollutants throughout the drainage network. Hence, organic pollution is considered to be a widespread issue in Prayagraj, and it can be attributed to the entire city's wastewater management process.

Microbial contamination was characterized by high spatial variation. Variability in Total Coliform and Fecal Coliform was due to disparities in sanitary practices, population density, sewer coverage, and inflow of raw sewage. There are some drains that receive excessive amounts of human waste.

Table 6: Environmental Implications of Observed Wastewater Characteristics

Parameter	Major Environmental Impact
pH	Suitable for microbial activity; not a major pollution concern
BOD	Oxygen depletion and aquatic ecosystem degradation
COD	Reduced self-purification capacity and chemical pollution
TSS	Increased turbidity and sediment accumulation
Total Coliform	Indicator of severe sewage contamination
Fecal Coliform	Direct evidence of fecal pollution and disease risk

Source: Generated by Researcher

Clearly, the descriptive statistics prove that all 25 drains play an important role as major pollutants of the River Ganga. Although the pH values fall within the acceptable ranges, high levels of BOD, COD, TSS, Total Coliform, and Fecal Coliform show that the quality of water becomes degraded at the extreme level. The low variability in case of organic pollutants proves the presence of some general problems in wastewater management throughout the whole city. In contrast to the organic pollutants, the high variability of microbe parameters implies the presence of some local problems.

As a result, it becomes possible to conclude that municipal sewage constitutes a major pollutant of the River Ganga. The impact of excessive organic load, sedimentation, and contamination by various pathogens can become dangerous for the ecology of aquatic ecosystems as well as the overall health of population members living nearby. Therefore, the regular interception, diversion, and proper treatment of sewage should be provided.

- **Spatial Variation of Pollution**

Spatial variability analysis is useful in identifying pollution hotspots and studying how the composition of wastewater differs between different drains dumping effluents into the River Ganga. The total 25 drains that have been studied belong to various urban watersheds of Prayagraj, which collect wastewater generated by residential colonies, commercial complexes, and heavily inhabited regions. There was a significant difference in organic, suspended solids, and microbial pollution.

Table 7: Spatial Variation of Wastewater Quality Parameters Across Major Drains

Parameter	Highest Value	Drain	Lowest Value	Drain
pH	7.51	Shankargarh Colony Nala	7.21	Shivkuti Nala No. 3
BOD (mg/L)	130	Shivkuti Nala No. 6	92	Gokula Drain
COD (mg/L)	434	Govindpur Nala No. 1	304	Gokula Drain
TSS (mg/L)	304	Shivkuti Nala No. 1	240	Gokula Drain
Total Coliform (MPN/100 ml)	3,300,000	ADA Colony Nala	1,100,000	Gokula Drain
Fecal Coliform (MPN/100 ml)	1,700,000	ADA Colony Nala / Salori Main Drain	450,000	Gokula Drain

Source: Generated by Researcher

Spatial variations in the parameters of wastewater quality indicate marked variability among the 25 drains. Though the pH values were fairly similar for all the drains, there were considerable variations in the degree of pollution with organic matter and microorganisms. Gokula drain exhibited the least BOD, COD, TSS, TC, and FC readings, thus signifying relatively low levels of pollution in this drain. Conversely, high pollution levels were noted in ADA Colony, Shivkuti, Govindpur, Salori, and Jondhwal drains. Such drains are significant contributors of polluted wastewater to the River Ganga.

These findings indicate that population density, sewage connectivity, and the nature of land use practices affect pollutant levels in different catchments.

Table 8: Classification of Drains Based on BOD Concentration

Pollution Category	BOD Range (mg/L)	Major Drains
High Pollution	≥120	Shivkuti Nala No. 6, Jondhwal Drain, Shivkuti Nala No. 7, Sadar Bazar Drain
Moderate Pollution	110–119	Govindpur Nala No.1, Govindpur Nala No.4, Govindpur Colony Nala, ADA Colony Nala, Salori Main Drain, Nehru Park Nala, Indira Awas Drain, Shivkuti Nala Nos.1, 2 & 4, Yadavpur Nala, Shankarghat Nala No.1
Relatively Lower Pollution	<110	Gokula Drain, Kashipur Nala, Rajapur Nala, Govindpur Nala Nos.2 & 3, Shivkuti Nala Nos.3 & 5, Shankarghat Colony Nala, Shankarghat Nala No.2

Source: Generated by Researcher

Concentrations of BOD showed marked spatial variations in terms of biodegradable organic pollutants. High BOD values were recorded in the Shivkuti area and Jondhwal drain, which are characterized by high organic load because of the insufficient sewage collection system. Most probably, these drains carry sewage water from dense residential areas where untreated domestic sewage gets directly discharged into the drains.

High frequency of BOD values exceeding 100 mg/L indicates that the problem of organic pollution is widespread across the entire city.

Table 9: Top Pollution Hotspots Based on Individual Parameters

Parameter	Top Polluted Drains
BOD	Shivkuti Nala No.6, Jondhwal Drain, Shivkuti Nala No.7, Sadar Bazar Drain
COD	Govindpur Nala No.1, Sadar Bazar Drain, Shivkuti Nala No.6, Jondhwal Drain
TSS	Shivkuti Nala No.1, Salori Main Drain, Govindpur Nala No.1, Jondhwal Drain
Total Coliform	ADA Colony Nala, Govindpur Nala No.3, Rajapur Nala, Salori Main Drain
Fecal Coliform	ADA Colony Nala, Salori Main Drain, Govindpur Nala No.4, Shivkuti Nala No.4

Source: Generated by Researcher

Pollution hotspot distribution shows clear variations in relation to various parameters. The concentration of organic pollutants, including BOD and COD, was relatively high in the Shivkuti, Govindpur, and Jondhwal drains, while microbial contamination was highly prevalent in the ADA Colony and Salori drains. It could be inferred that each catchment adds different amounts of organic pollutants and fecal matter.

COD concentrations in the Govindpur and Sadar Bazar drains could also be attributed to industrial contribution along with sewage.

Table 10: Integrated Pollution Ranking of Major Drain Clusters

Rank	Drain Cluster	Pollution Status	Key Characteristics
1	ADA Colony	Extremely High	Highest TC and FC concentrations
2	Shivkuti Cluster	Extremely High	Highest BOD, COD and TSS values
3	Govindpur Cluster	Very High	Highest COD and elevated microbial load
4	Salori Main Drain	Very High	Highest FC concentration and high TSS
5	Jondhwal Drain	Very High	High BOD, COD and TC
6	Rajapur Drain	High	Elevated microbial contamination
7	Sadar Bazar Drain	High	High organic and chemical pollution
8	Nehru Park Drain	Moderate-High	Elevated BOD and COD
9	Kashipur Drain	Moderate	Relatively lower pollution load
10	Gokula Drain	Relatively Lower	Lowest values for most parameters

Source: Generated by Researcher

From the above-mentioned results, the integrated ranking indicates that ADA Colony-Shivkuti-Govindpur region is the most vulnerable area to pollution in the city of Prayagraj. The ADA Colony region was found to be the most severe area for microbiological pollution while the region of Shivkuti represents high levels of organic and suspended solids pollution. Finally, the drains of the Govindpur region show maximum chemical oxygen demands (COD).

This suggests that only a few drains account for a very large percentage of the total volume of pollutants discharged into the River Ganga. Thus, intercepting and treating the sewage of Ada Colony, Shivkuti, Govindpur, Salori, and Jondhwal drains could help improve the water quality of River Ganga.

Overall Spatial Pattern

Based on the spatial analysis, the pollution is high for densely urbanized catchments that lack adequate sewer connections and have untreated sewage discharges directly into their drainage systems. While all the 25 drains showed features of domestic sewage, the highest pollution was found in drains from the catchments of ADA Colony, Shivkuti, Govindpur, Salori, and Jondhwal. These findings suggest that there is a need for proper intervention to address the pollution in the hotspot drains as part of conservation of the River Ganga.

As far as Section 5.3 Correlation Analysis goes, this section could be improved by making it more concise and including less tables with findings and more interpretations of the correlations found.

- **Correlation Analysis**

Correlation analysis between physicochemical and microbial parameters of the untreated drains discharging into the River Ganga was done using Pearson correlation test. Correlation coefficient values (r) lie within −1 and +1. Positive correlation values show a direct relationship whereas negative values represent an inverse relationship. The extent of correlation will help establish common sources of pollution as well as relationship between wastewater quality parameters.

Table 11: Pearson Correlation Matrix for Wastewater Quality Parameters

Parameter	pH	BOD	COD	TSS	TC	FC
pH	1.00	0.19	0.13	0.01	-0.16	-0.19
BOD	0.19	1.00	0.78	0.40	0.21	0.34
COD	0.13	0.78	1.00	0.61	0.16	0.29
TSS	0.01	0.40	0.61	1.00	0.15	0.22
TC	-0.16	0.21	0.16	0.15	1.00	0.89
FC	-0.19	0.34	0.29	0.22	0.89	1.00

BOD = Biological Oxygen Demand; COD = Chemical Oxygen Demand; TSS = Total Suspended Solids; TC = Total Coliform; FC = Fecal Coliform.

Table 12: Classification of Correlation Strength

Correlation Coefficient (r)	Relationship Strength
0.00–0.19	Very Weak
0.20–0.39	Weak
0.40–0.59	Moderate
0.60–0.79	Strong
0.80–1.00	Very Strong

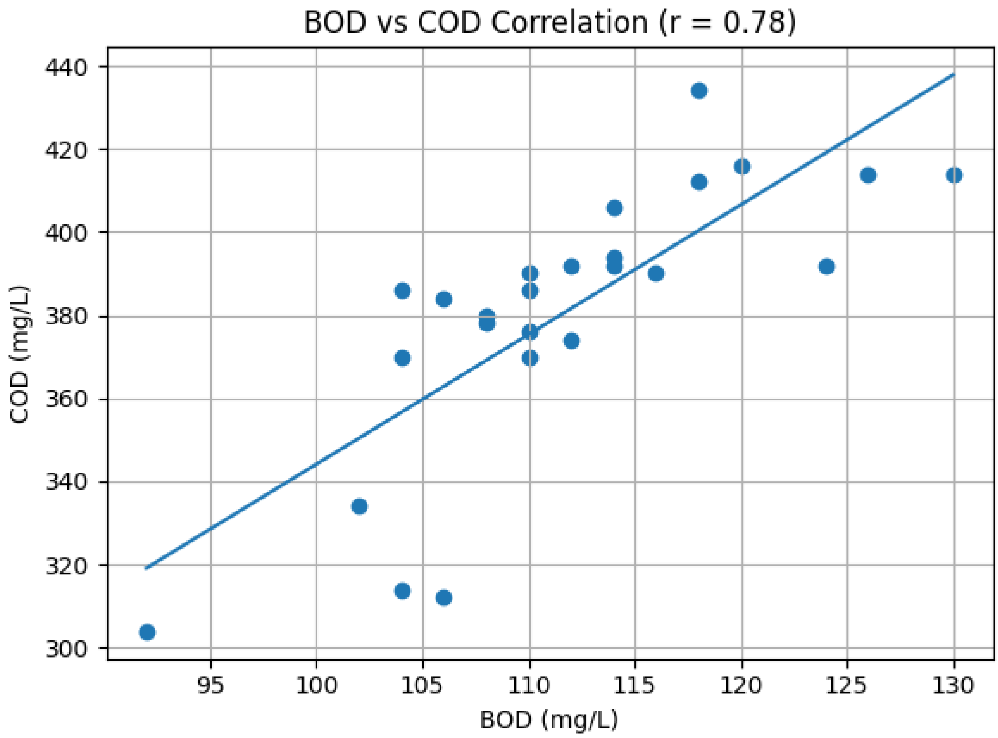

Figure 2: Scatter diagram showing a strong positive correlation (r = 0.78) between Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), indicating that increases in organic pollution load are associated with increases in chemically oxidizable substances in wastewater.

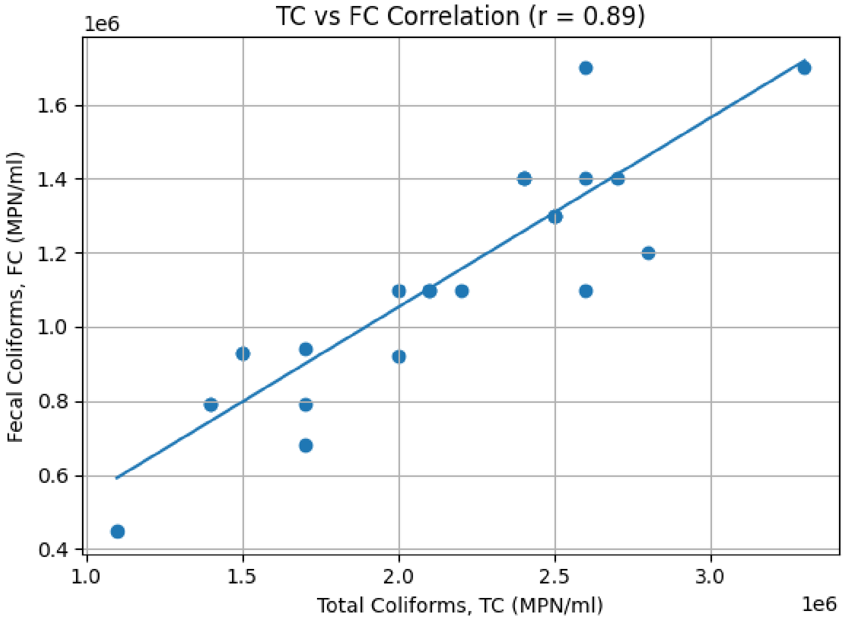

Figure 3: Scatter plot showing the relationship between Total Coliforms (TC) and Fecal Coliforms (FC) in wastewater of untreated drains discharging into the River Ganga at Prayagraj. The strong positive correlation (r ≈ 0.89) indicates that increases in total coliform concentrations are associated with corresponding increases in fecal coliform concentrations.

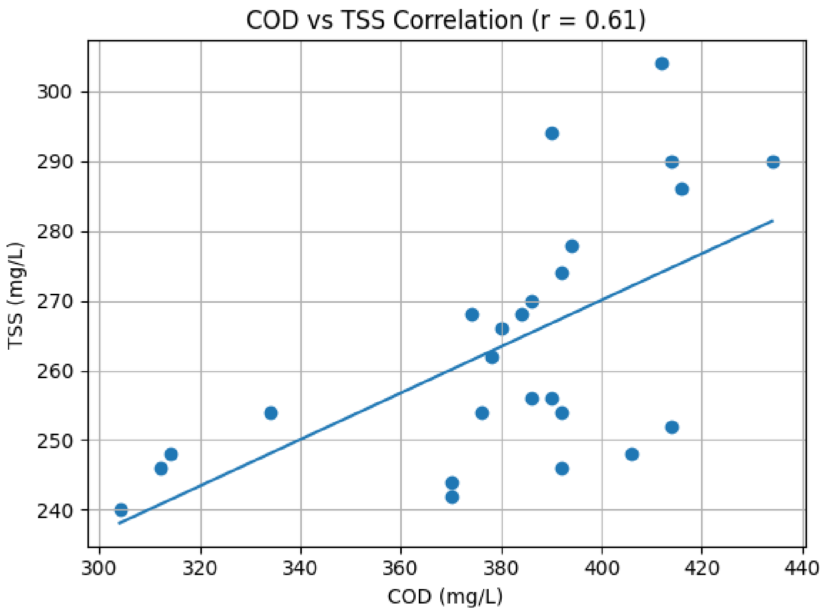

Figure 4: Scatter plot showing the relationship between Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS) in the wastewaters of untreated drains discharging into the River Ganga at Prayagraj. The moderate positive correlation (r ≈ 0.61) indicates that higher concentrations of suspended solids tend to be associated with increased levels of chemically oxidizable pollutants.

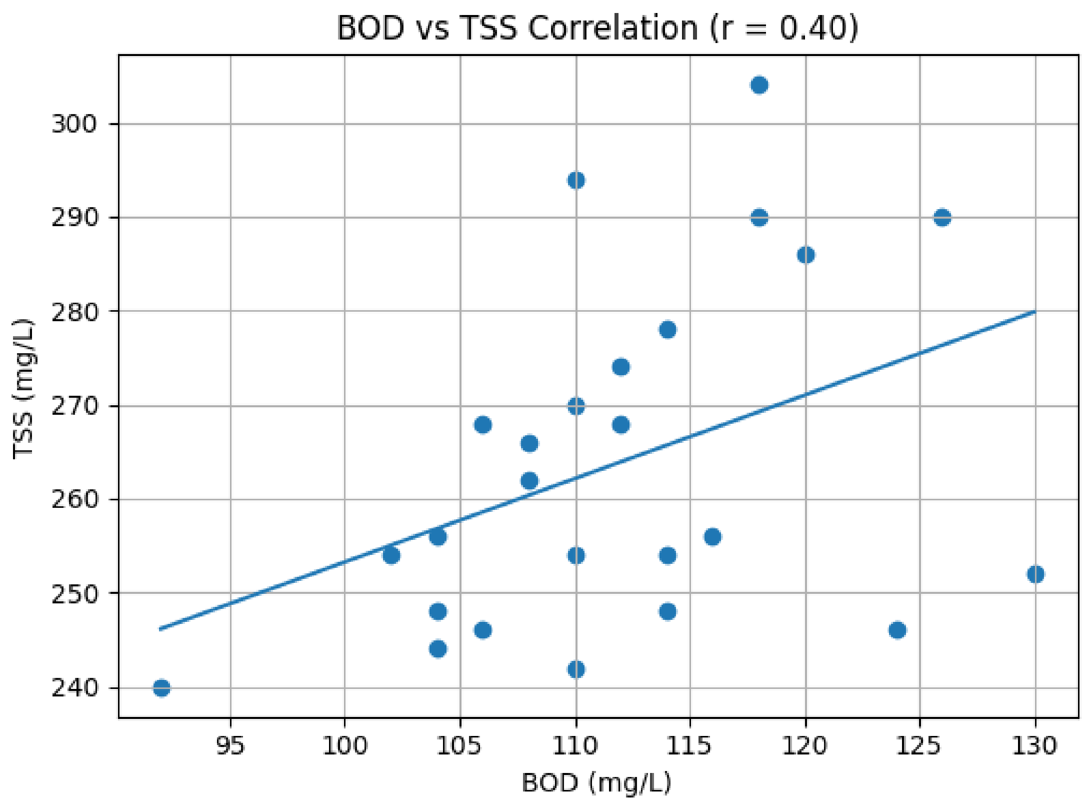

Figure 5: Scatter plot showing the relationship between Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS) in the wastewater of untreated drains discharging into the River Ganga at Prayagraj. The moderate positive correlation (r ≈ 0.40) suggests that wastewater with higher suspended solid concentrations generally tend to exhibit higher biodegradable organic loads

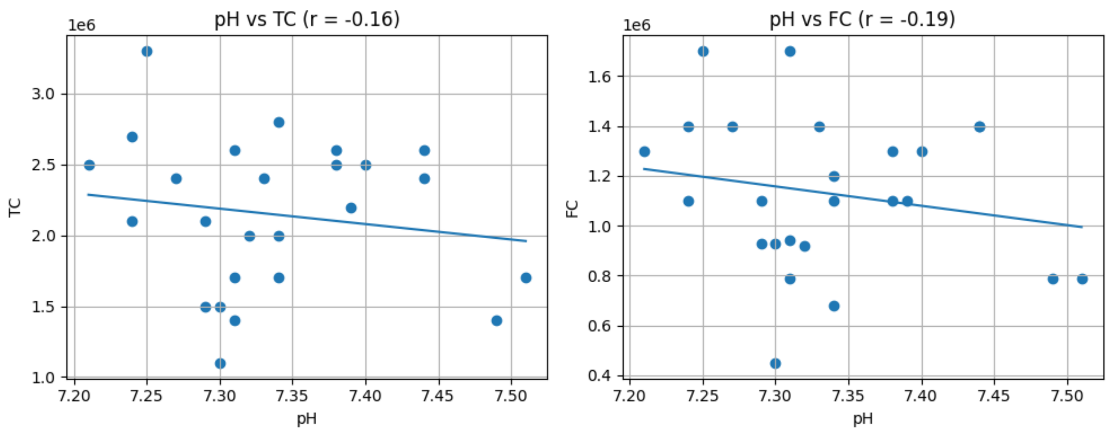

Figure 6: Scatter plots illustrating the relationship between pH and microbial indicators [Total Coliforms (TC) and Fecal Coliforms (FC)] in wastewater of untreated drains discharging into the River Ganga at Prayagraj. Weak negative correlations were observed between pH and TC (r ≈ −0.16) and between pH and FC (r ≈ −0.19), indicating that variations in pH had little influence on microbial contamination levels within the observed pH range.

Table 13: Major Correlations and Their Environmental Interpretation

Parameter Pair	Correlation (r)	Strength	Environmental Interpretation
TC – FC	0.89	Very Strong	Fecal contamination is the dominant source of microbial pollution
BOD – COD	0.78	Strong	Organic matter is the principal contributor to overall pollution load
COD – TSS	0.61	Strong	Suspended solids significantly contribute to chemical oxygen demand
BOD – TSS	0.40	Moderate	Organic pollution is partly associated with suspended particulate matter
BOD – FC	0.34	Weak	Organic pollution and fecal contamination share common sewage sources
COD – FC	0.29	Weak	Chemical pollution is only partially linked with microbial contamination
BOD – TC	0.21	Weak	Organic loading has limited influence on total bacterial abundance
TSS – FC	0.22	Weak	Microorganisms are only partially associated with suspended solids
pH with all parameters	-0.19 to 0.19	Very Weak	pH remains relatively unaffected by pollution intensity

The two major groups of pollution parameters that emerged from the analysis included BOD, COD, and TSS in one category, as well as Total Coliform (TC) and Fecal Coliform (FC) in another category. The first three parameters characterize the wastewater in terms of its organic and physical pollution, while the latter two indicate its microbiological pollution.

The highest coefficient value was established for the pair TC-FC (r = 0.89), suggesting that there exists a very high degree of positive correlation between the two parameters. This fact proves the hypothesis that the predominant source of the wastewater pollution is fecal contamination. Indeed, whenever the values of TC were high, the concentrations of FC could be expected to follow suit, implying a widespread discharge of raw domestic waste into the drains. It also implies the existence of pathogenic bacteria in water.

Furthermore, there was also a strong positive association between BOD and COD (r = 0.78). This means that there exists a significant amount of chemically oxidizable organic pollutants in the effluent which is biodegradable. This relationship is usually characteristic of urban wastewater dominated systems, hence indicating that organic pollutants are one of the important factors affecting water quality in the study area.

In addition, the positive relationship between COD and TSS (r = 0.61) also shows that the amount of suspended solids in the effluent plays an important role in contributing to its chemical oxygen demand. Since organic and inorganic pollutants can get attached to particulate matter, the removal of suspended solids in the initial stages of wastewater treatment will lead to a reduced number of pollutants flowing into the River Ganga.

The presence of a positive association between BOD and TSS (r = 0.40) indicates that there exists a link between the suspended particulate matter in the effluent and organic pollutants. Some of the examples of suspended organic matter include food, feces, and decomposed organic matter. Nevertheless, since this relationship is moderate, it can also be inferred that dissolved organic matter forms an important part of BOD.

However, there was no or little correlation between the organic pollution parameters such as BOD and COD and the microbiological pollution parameters such as TC and FC. Although both the organic and the microbiological pollution originate mainly from untreated sewage, it seems like the extent of microbiological pollution is affected by other factors such as the population density, sanitation facilities, wastewater retention time, and environmental conditions. This implies that microbiological pollution cannot be predicted from the organic pollution parameters and thus requires its own measurement and control.

There was very low correlation between the pH parameter and the rest of the water quality parameters. This indicates that the acidity and alkalinity levels in the wastewater were rather stable, which can only happen when the wastewater is mainly of domestic origin. In cases where there is industrial input into the water, there is high variability of the acidity and alkalinity levels.

Generally, the above correlations show that the pollution in this region originates mainly from domestic sewage. This conclusion is drawn from the very strong correlation among BOD, COD, and TSS, as well as the very high correlation between TC and FC.

Overall Interpretation

It is evident from the results of correlation analysis that untreated municipal sewage is the primary cause of pollution in the selected drains. The existence of strong correlations amongst BOD, COD, and TSS reveals that the sewage sample is contaminated to a large extent with organic substances and suspended matter. On the same note, the existence of a very strong correlation between TC and FC proves that the drains are severely contaminated with fecal bacteria, indicating the fact that sewage flows directly into the drains.

These results suggest that it is necessary to adopt an effective wastewater management program for improving the quality of the river Ganga. This should include the following actions such as the reduction of organic pollution through effective collection and biological treatment of sewage, elimination of suspended solids through proper treatment methods, and finally control over the microbial pollution through effective disinfection techniques. Physicochemical and microbiological pollutions contribute immensely towards degradation of river water.

In conclusion, the findings clearly indicate that the issue of untreated sewage is a serious problem affecting the ecological status of the River Ganga at Prayagraj. Additional future research and environmental impact assessments would help enhance scientific knowledge through the use of summary tables and analysis of important findings. This would facilitate a better understanding of the pollution status and its impacts on the environment and public health.

Environmental Implications

The results of this research make it quite clear that the wastewater discharge from 25 unutilized drains is a prime source of pollution in the River Ganga at Prayagraj. The high levels of organic matter, suspended solids, and microbial pollution in the drains indicate the degradation of the quality of water and an increasing stress on the river's ecosystem. These levels of pollution pose several dangers not just to the ecosystem but also to the lives of people living around this river and can even cause some socio-economic impacts. The major environmental issues that arise due to this wastewater quality are provided in Table 14.

Table 14: Environmental Implications of Major Wastewater Quality Parameters

Parameter	Mean Value	Major Environmental Impact
pH	7.34	Neutral conditions suitable for microbial activity; not a major pollution concern
BOD	111.68 mg/L	Dissolved oxygen depletion and aquatic ecosystem stress
COD	380.56 mg/L	Increased pollution load and reduced self-purification capacity
TSS	263.60 mg/L	Turbidity, sedimentation, and habitat degradation
Total Coliform	2.15×10^6 MPN/100 ml	Severe sewage contamination and pathogen risk
Fecal Coliform	1.13×10^6 MPN/100 ml	Direct evidence of fecal pollution and public health hazards

- **Impact on River Water Quality and Aquatic Ecosystems**

It should be noted that the BOD concentration recorded in the course of this investigation (111.68 mg/L) exceeded the permissible discharge limit almost three times and a half; the COD concentration was also above standards by about 1.5 times, while TSS was about 2.6 times greater than allowable levels. Hence, it can be concluded that considerable amounts of organic pollution and suspended solids are being discharged daily into the River Ganga via urban sewers.

Increased contamination of organic matter raises the need for oxygen in the water; therefore, it can lead to a drop in dissolved oxygen levels. As dissolved oxygen plays an important role in the survival of the aquatic organisms, its deficiency may impose serious pressure on fish and plankton populations. In turn, constant oxygen deficiency can adversely affect the aquatic environment by reducing its diversity and food chain. Moreover, in low flow, when the river has very poor capacity for pollutants' absorption, the development of anaerobic zones may become possible.

Table 15: Ecological Consequences of Wastewater Discharge

Pollution Component	Ecological Effect
High BOD	Oxygen depletion and fish mortality
High COD	Reduced river self-purification capacity
High TSS	Increased turbidity and sediment accumulation
Microbial contamination	Alteration of aquatic microbial communities
Continuous sewage discharge	Biodiversity decline and ecosystem degradation

- **Sedimentation and Habitat Degradation**

The high average value of Total Suspended Solids (TSS) content of 263.60 mg/L obtained in this experiment implies that a considerable quantity of suspended matter enters the River Ganga via the untreated drains. As these solids gradually settle, they deposit on the bed of the river and cause increased sedimentation, thereby altering its aquatic ecosystems. Sedimentation is known to have adverse effects on aquatic life by covering up breeding spots, destroying benthic habitats, decreasing diversity, and changing the physiognomy of the river.

An additional harmful effect of an increased concentration of suspended solids in the water is its increased turbidity, meaning that more light will be blocked, making the water less transparent. Turbid waters limit photosynthesis in plants, including aquatic flora such as algae, which are the basis for the entire aquatic food web. The decrease in primary production will have far-reaching effects on higher trophic levels in the ecosystem.

- **Public Health Implications**

Another significant finding from the current study is the very high levels of microbial pollution observed in all sampled drains. The total coliforms and fecal coliforms were over 2.1 million and 1.1 million MPN/100 mL, respectively, which implies that there was considerable disposal of domestic sewage without any treatment into the river.

High microbial levels clearly imply that pathogens exist in such water and those people who use river water directly or indirectly will be at greater risk of developing water-borne diseases like cholera, typhoid fever, dysentery, gastroenteritis, hepatitis A and E. Additionally, other diseases related to the use of polluted water include skin and eye infections. These results clearly indicate the risks associated with the disposal of raw sewage to the River Ganga and the need for proper treatment of wastewater.

Table 16: Public Health Risks Associated with Microbial Contamination

Indicator	Observed Mean	Potential Health Risks
Total Coliform	2,148,000 MPN/100 ml	Indicator of sewage contamination
Fecal Coliform	1,128,800 MPN/100 ml	Direct fecal pollution and pathogen presence
Likely Pathogens	—	Cholera, Typhoid, Dysentery, Hepatitis, Gastroenteritis

The health effects associated with these results become all the more significant in the case of Prayagraj since the River Ganga holds a special place in the lives of millions of people living there. The river finds widespread use for various activities like bathing, performing religious rites, and undertaking domestic chores, thus resulting in the increased interaction between many individuals and the river water. In addition, the issue assumes greater significance at times of religious occasions, since the usage of the river would increase dramatically during these times.

- **Implications for Agriculture and Water Use**

The poor quality of river water also affects agriculture and its associated uses in various ways. River water is usually used for irrigation, and the pollution of such water by toxins and organisms causing diseases has negative effects on agriculture. The use of polluted water in the long term results in poor soil quality and increases the chances of pathogens infecting crops. Pollutants found in the water also find their way to the food chain, which could have some health hazards for the consumers. Moreover, polluted river water seeps into the groundwater system, affecting the quality of water in these sources.

- **Implications for Ganga Conservation and Management**

The results from the study have indicated that the contribution made by untreated drains in polluting the River Ganga remains significant despite the numerous river rejuvenation and conservation initiatives that have been undertaken. Through spatial analysis, it has emerged that the drain outfalls located in ADA Colony, Shivkuti, Govindpur, Salori, and Jondhwal are of utmost importance as far as pollution of the river is concerned.

Table 17: Priority Pollution Hotspots for Management Intervention

Rank	Drain/Cluster	Priority Level	Major Concern
1	ADA Colony Nala	Very High	Extreme microbial contamination
2	Shivkuti Cluster	Very High	Highest BOD, COD and TSS
3	Govindpur Cluster	High	Highest COD concentrations
4	Salori Main Drain	High	Highest Fecal Coliform load
5	Jondhwal Drain	High	Elevated organic and microbial pollution

These hotspots should be prioritized for:

- Interception and diversion of sewage.
- Expansion of sewage treatment facilities.
- Continuous water-quality monitoring.
- Periodic microbial surveillance.
- Community-based sanitation improvements.

Overall Environmental Significance

The current study reiterates the role of un-treatment of urban drains as one of the significant sources of pollution in the River Ganga at Prayagraj. The high amounts of organic pollution, solid pollution, and microbiological contamination from the drains are affecting the water quality and posing significant hazards to aquatic flora and fauna, human health, agriculture practices, and cultural and religious significance of the river. The results stress the urgent requirement for appropriate measures in terms of sewage water treatment, urban drainage management, and monitoring of water quality. A hotspot approach for addressing the pollution problem is imperative to reduce pollution load, improve river quality, and promote Ganga conservation.

Recommendations

On the basis of the conclusions drawn from this study, there are certain practical recommendations for mitigating pollution from untreated drains and ensuring better quality of water in the River Ganga at Prayagraj.

- Drains carrying wastewater without any primary treatment have to be intercepted and then diverted into Sewage Treatment Plants (STPs), either already constructed or under construction. Immediate steps should be taken to intercept major pollution sources, including Shivkuti, Govindpur, ADA Colony, Salori, and Jondhwal drains, as they carry a significant amount of pollutant loads into the river.
- Wastewater treatment facilities must be developed further and existing plants upgraded in order to improve the efficacy of removing different types of pollutants, including organic and suspended solids as well as pathogenic microorganisms.
- Regular monitoring of major drains and stretches of river will help track changes in water quality and evaluate the efficiency of pollution reduction measures. Such parameters as BOD, COD, TSS, Total Coliform, and Fecal Coliform have to be monitored regularly.
- DEWATS may be used as a feasible solution in areas where it is not possible to install a centralized sewage system. It will make it easier to clean the wastewater closer to its source.
- It is necessary to improve and expand sewerage networks in order to stop untreated sewage from going into open drains. Areas which are more densely populated and do not have proper sewerage facilities should be prioritized.

- Uncontrolled dumping of solid waste into the drains should be avoided. Drainage canals can be cleaned regularly and desilted to improve flow and decrease pollution due to suspended particles.
- Since the total number of coliform bacteria is quite high in many drains, it becomes necessary to ensure that there is proper disinfection before wastewater gets discharged. Methods such as chlorination, ultraviolet light exposure, or even ozonation can be used for disinfecting water.
- Public awareness and community participation should be increased by means of education campaigns concentrating on sanitation, waste management, and river protection. The participation of local communities in pollution-control activities could have a considerable positive impact on the outcome.
- Tight coordination between local municipalities, pollution control bodies, water resources departments, and river conservation projects is very important when it comes to applying wastewater management techniques. Such coordination may improve planning, monitoring, and regulation processes significantly.

To summarize, there are several pollution-reduction measures which should be applied in order to restore and maintain the water quality of the River Ganga within the territory of Prayagraj. If these activities are implemented properly, it would help to lower the pollution load of the Ganga River.

Conclusion

In this study, the physico-chemical and microbiological parameters of the untreated effluents being drained by 25 drains into the River Ganga in Prayagraj were examined. From the results obtained, it is evident that all the observed drains contribute significantly to pollution of the river through effluents carrying high concentrations of organic content, suspended solids, and microorganisms. The presence of high levels of BOD, COD, and TSS indicates the level of effluent pollution in the drains, while elevated levels of Total Coliform and Fecal Coliform indicate the extent of domestic sewage pollution.

Spatial analysis revealed that Shivkuti, Govindpur, ADA Colony, Salori, and Jondhwal represent the most crucial pollution zones. Of these sites, the drains at Shivkuti had the highest levels of organic pollution while ADA Colony and Salori had the highest levels of microbial pollution. The highly polluted drains act as a source of pollution of the River Ganga.

Statistical analysis reinforced these deductions even further. The strong relationship between the amount of BOD and COD ($r = 0.78$) indicates that the major cause of pollution in the water body is organic pollutants. In the same way, the very strong relationship between total coliform and fecal coliform ($r = 0.89$) shows that untreated sewage is the main cause of biological pollution of the river.

Continuous disposal of untreated wastewater in the Ganga River has far-reaching consequences on both the environment and people relying on it. Oxygen depletion, degradation of the aquatic ecosystem, loss of biodiversity, and outbreaks of diseases can occur from such pollution. This study emphasizes the importance of measures to combat the problems identified. These include intercepting and diverting the drains, treating the sewage, monitoring water quality, and adopting proper wastewater management techniques.

As such, the findings highlight how untreated urban drains continue to contribute as significant point sources of pollutants in the River Ganga at Prayagraj. In order to sustainably protect and improve the quality of water in the river, it is crucial to ensure that appropriate actions are taken to address pollution at the hotspot areas identified.

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