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RESEARCH ARTICLE

The plight of Najafgarh drain in NCT of Delhi, India: assessment of the sources, statistical water quality evaluation, and fate of water pollutants

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Abstract
The Najafgarh drain is the first major drain that joins the Yamuna River at Wazirabad in Delhi, India, and is known to contribute to the maximum pollution load to this river. The drain is originally an extension of the Sahibi River and was intentionally constructed as a canal to carry stormwater, but presently, it is carrying more of sewage, agricultural, and industrial effluents received through various small and large secondary drains. The present study has analyzed the water quality status of this interconnected system, i.e., the Najafgarh drain, its associated secondary drains, and the Yamuna River for physicochemical parameters ($n = 16$), microbiological parameter ($n = 1$), and heavy metal concentrations ($n = 8$). The analysis of the surface water samples collected during pre- and post-monsoon seasons showed that secondary drain discharges significantly impacted the water quality of the Najafgarh drain, which in turn affected the Yamuna River. Out of the eight selected secondary drains for this study, the Goyla dairy outlet came out as the most polluted site in terms of organic pollutants while the Basaidarapur drain was loaded with heavy metal contaminants. Statistical tools comprising hierarchical cluster analysis (HCA), Pearson's correlation, and principal component analysis (PCA) were further implemented on the water quality dataset for a better understanding of the possible sources of contamination for organic and inorganic pollutants in the selected sampling sites. The present study, thus, might help in providing key highlights to the policymakers for effective regulation and management of the point source discharges in Najafgarh drain, which will ultimately restrict its pollution loadings in Yamuna River, Delhi, and also help in the restoration of this important water body.

Keywords Water pollution · Najafgarh drain · Yamuna River · Statistical analysis · Wastewater management

Introduction

The twenty-first century is burdened with the concern of ever-increasing water pollution and depleting freshwater resources. The ecological stability of urban cities is being crushed with immense population density, urbanization, and industrialization which are ultimately leading us towards an unsustainable and dysfunctional environment. Megacities like Delhi in Northern India with a massive population of approximately 16 million (Census of India 2011) and many small- and medium-scale industrial units are putting enormous pressure on their water resources. The Yamuna River is one of the most important freshwater resources in the Delhi megacity of India. The river course in this city is less than 2% of its entire length but the proportion of wastewater load received here is approximately 71% of its entire wastewater load (Mutiyar and Mittal 2014). Around 21 major drains carrying municipal sewage, industrial effluents, and agricultural runoff fall into the river and convert it into a degraded lotic ecosystem (Parween et al. 2017; CPCB 2016). The Najafgarh drain is the first drain that joins the Yamuna River at Wazirabad in Delhi and it contributes approximately 40% of the total pollution of this river (DPCC 2017). The intermixing zone of the river and the Najafgarh drain has reportedly been indexed as a highly polluted region by many

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researchers (Jaiswal et al. 2019; Bhardwaj et al. 2017; Khan and Singh 2013; Katyal et al. 2012; Upadhyay et al. 2011).

Najafgarh drain has a historic significance and importance. This drain is originally an extension of the Sahibi River which originates in the Aravalli hills in the Alwar-Rewari region of Rajasthan and Haryana. During the 1960s and before, the Sahibi River entered Delhi near Dhansa and completely drained its flow into the Najafgarh Jheel, which caused submerging of nearby areas during the monsoon season. Due to this, the river was completely channelized into a storm water canal; however, due to the high pollution load, it is now more commonly termed a drain known as the Najafgarh drain (Nema and Agrawal 2003). The drain passes through a variety of land use and land cover patterns constituting urban, forest land, cropland, fallow land, grassland, and water bodies (IIT Delhi 2016). Besides this, industrial areas like dairy, plastic manufacturing, chemical, dyeing, steel fabrication, electroplating, and others are also present in the drain basin, which discharge their effluents directly or indirectly into the Najafgarh drain (Bhardwaj et al. 2017; Bhattacharya et al. 2015). The various sewage treatment plants (STPs) and common effluent treatment plants (CETPs) installed in the drain basin are inefficient and operating below their installed capacity, and as a consequence, a large volume of partially treated sewage and industrial effluents are being released into the drain (Table 1). Further, a number of small and large secondary drains traversing through these areas discharge their wastewaters into the Najafgarh drain eventually building in it a mass of water pollutants which have their ultimate fate in the Yamuna River.

The poor water quality of Najafgarh drain directly impacts the groundwater in its vicinity and significant presence of chemical species like nitrate (NO_3^-), chloride (Cl^-), sulfate (SO_4^{2-}), and fluoride (F^-), and heavy metals like chromium (Cr), manganese (Mn), iron (Fe), cadmium (Cd), and lead (Pb) have been reported in the groundwater samples tested at different locations through the course of the Najafgarh drain in Delhi (Shekhar and Sarkar 2013). The irrigation of fields with the Najafgarh drain and its associated secondary drain water also affect the vegetables growing in these areas. Studies have shown a significant presence of various heavy metals in the vegetables irrigated with water from the Najafgarh drain (Bhattacharya et al. 2015; Kaur and Rani 2006; Singh and Kumar 2006). Apart from causing variable levels of toxicity to the plants, consumption of such contaminated vegetables by human beings can cause retardation in mental growth, gastrointestinal cancer, impaired immunity, fragility in bones, kidney problems, respiratory complications, and many other health issues (Rai et al. 2019).

Presently, Najafgarh and its associated drains are imposing a severe threat to the Yamuna River system, groundwater in their proximity, crops that are irrigated with their contaminated water, and the various trophic levels including humans that are coming in contact with its pollutants directly or indirectly. Despite serious consequences, a limited number of studies have been conducted to analyze the surface water quality of the Najafgarh drain, and still, very less emphasis has been given to its associated drains which are playing a significant role (Gola et al. 2020; Nehra and Singh 2020; Rahman and Singh 2018; Kaushik et al. 2018, 2008; Meena et al. 2016; Bhattacharya et al. 2015; Paul et al. 2014; Kumar et al. 2009; Pratima et al. 2009; Kaur et al. 2009; Rattan et al. 2005; Meenakshi et al. 2002).

The present study has therefore been designed with the following objectives:

- To critically analyze the water quality status of the Najafgarh drain and evaluate the impact of various secondary drains discharging their wastewaters into it.
- To assess the impact of the Najafgarh drain on the Yamuna River water quality.
- To analyze the seasonal variations in physicochemical and microbiological water quality parameters in the study area.
- To understand the significant relationships between water quality variables for their common sources of origin and influence in the study area using statistical tools (Pearson's correlation, principal component analysis, and hierarchical cluster analysis).

The study is the first of its kind which is comprehensively analyzing the water quality of the entire stretch of the Najafgarh drain along with its associated secondary drains which play a very important role in degrading its eminence. Originally, the Najafgarh drain was channelized as a canal to discharge stormwater, but presently, it is being heavily loaded with wastewater from residential, industrial, and agricultural areas which is ultimately deteriorating the water quality of the Yamuna River stretch in Delhi. The present study thus

Table 1 Status of wastewater treatment plants in Najafgarh drain basin (DPCC 2017)

Type of treatment plant	Total installed capacity	Actual treatment capacity
Common effluent treatment plant (CETP)	195.00 MLD[a]	44.95 MLD
Sewage treatment plant (STP)	482.00 MGD[b]	307.47 MGD

[a]MLD refers to million liters per day

[b]MGD refers to million gallons per day

aims to address the abovementioned issues of this important water body and bring the attention of the concerned stakeholders in taking necessary steps for effective management of this interlinked system so as to restore and preserve its pristine water quality and ecological balance.

Materials and methods

Description of the study area

Delhi is a metropolitan city in Northern India with a geographical area of 1483 km^2. The climatic conditions of the city fall between humid subtropical and semi-arid with annual precipitation of 800 mm (Budhiraja et al. 2020). The temperature in the megacity ranges from as low as 2 °C in the winter season to more than 45 °C during the summer season (Tyagi et al. 2020; Sahay 2018). A major part of the city falls on the western side of the Yamuna River, an important freshwater resource. Due to certain limitations in the drainage infrastructure and sewerage system, a large amount of partially treated and untreated wastewater is channelized in the Yamuna River through various drains.

The Najafgarh drain is the first drain that joins the Yamuna River in Delhi. It enters on the southwestern side in Delhi, i.e., Dhansa, and traverses a length of 57 km before its final confluence with the Yamuna River at Wazirabad. It has a catchment area of 374 km^2 (Bhattacharya et al. 2015). Through its course, approximately 78 major and minor secondary drains discharge their wastewaters into it. Due to such consistent discharges, the water quality of the Najafgarh drain has severely degraded as reported by Kaur et al. (2013) and Nema and Agrawal (2003) which requires in-depth investigations of the concerned study area. Thus, for the present study, water quality analysis was conducted for twenty-five sampling locations comprising fifteen points on the Najafgarh drain (N1–N15), eight points on secondary drains prior to their outfall in the Najafgarh drain (S1–S8), and two points in the Yamuna River (Y1–Y2).

Sampling

Surface water samples were collected from the Najafgarh drain, its associated major secondary drains, and the Yamuna River following the standard protocols as discussed below. In the Najafgarh drain, sampling points were purposely located at approximately 500 m upstream and downstream locations to each selected secondary drain so as to find the effect of that particular secondary drain on the Najafgarh drain water quality. The selection of this distance from the point source was based on the range of values chosen by Adeogun (2012) and Musyoki et al. (2013) in their research on the Alaro stream, Nigeria, and Nairobi River, Kenya, respectively. Further, the selection of secondary drains was done on the basis of their discharge load and the diversity of land use patterns through which they are passing. The background data for the location and discharge load of the various secondary drains was collected from Irrigation and Flood Control Department (Delhi). The details for the selected secondary drains are described in Table 2. The two points in the

Table 2 Description of secondary drains discharging their wastewater load into NG drain segment in Delhi

Code of the sampling site	Name of the sampling site	Location	Discharge (cusec)	Remarks
S1	Badshahpur & Basai drain	28° 29′ 35.69″ N 76°56′ 50.80″ E	161.45*	First major drain. These two drains mix before discharging effluents majorly from agricultural, industrial, and residential areas
S2	Goyla dairy outlet	28° 34′ 37.46″ N 77° 2′ 10.46″ E	1.80	Underground outlet discharging effluents from Goyla dairy
S3	Palam drain	28° 34′ 46.10″ N 77° 2′ 19.56″ E	78.97	Discharging effluents majorly from residential areas
S4	Mungeshpur drain	28° 37′ 34.78″ N 77° 1′ 16.07″ E	1.52	Discharging effluents majorly from agricultural and residential areas
S5	Keshopur STP outlet	28° 39′ 14.20″ N 77° 4′ 42.13″ E	34.16	Discharging effluents from Keshopur sewage treatment plant
S6	Basaidarapur drain	28° 39′ 30.45″ N 77° 7′ 29.17″ E	7.05	Underground outlet discharging effluents majorly from industrial and residential areas
S7	Kanhaiya Nagar drain	28° 40′ 34.78″ N 77° 10′ 4.98″ E	1.41	Western Yamuna Canal discharging Yamuna River water contaminated due to discharges majorly from residential and industrial areas
S8	Supplementary drain	28° 42′ 42.53″ N 77° 13′ 38.34″ E	519.85	Discharging effluents majorly from residential and industrial areas

*Discharge volume for this drain is for the month of November while the remaining values are for the month of May

Yamuna River were then selected on a similar basis, i.e., upstream and downstream locations to the Najafgarh drain outfall. Figure 1 shows the location map of all the selected sampling locations. Well-mixed surface water samples were collected biannually from these selected locations during the pre-monsoon (May 2019) and post-monsoon (November

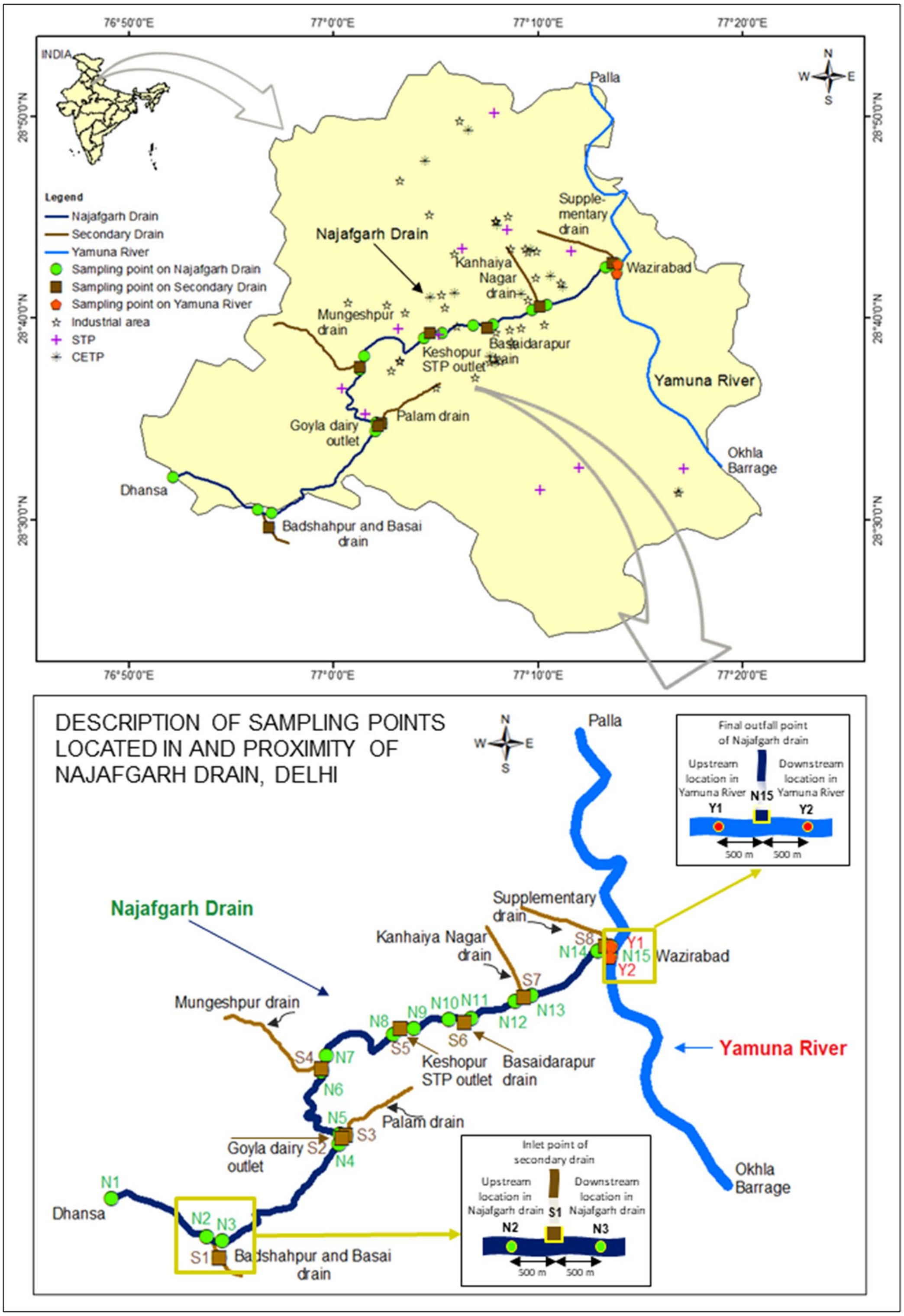


Fig. 1 Map of study area developed using ArcGIS Desktop Advanced 10.8.1 and Google Earth Pro 7.3.4.8573 (refer to supplementary material for details of sampling sites)

2019) seasons. The months of these seasons were selected according to the Indian Meteorological Department (IMD) classification, i.e., pre-monsoon season from March to May and post-monsoon season from October to December. Grab samples were collected from a depth of approximately 30 cm in high-density polyethylene bottles and immediately stored at 4 °C until further analysis. The samples collected for COD and nitrate-nitrogen (nitrate–N) were additionally acidified with sulfuric acid ($pH < 2$), and for metals, acidification was done using nitric acid ($pH < 2$) for preservation as per the CPCB protocols for water and wastewater analysis (CPCB 2011). Samples for dissolved oxygen analysis were collected in BOD bottles (300 ml) and fixed immediately on-site using manganous sulfate and alkali iodide azide reagents until further processing and analysis.

Reagent preparation and analysis

Physicochemical parameters including temperature (TEMP), pH, electrical conductivity (EC), salinity (SAL), and total dissolved solids (TDS) were measured in situ using Eutech make multiparameter PCSTestr™ 35. Turbidity (TURB) in the samples was analyzed using Eutech make turbidimeter (TN-100). The remaining physicochemical ($n = 16$) and microbiological ($n = 1$) parameters in the present study were analyzed using standard protocols and methods given for water and wastewater analysis by American Public Health Organization (APHA 1999) and Central Pollution Control Board (CPCB 2011). Briefly, dissolved oxygen (DO) and biochemical oxygen demand (BOD, 3-day BOD, 27 °C) content was analyzed using Winkler's method with azide modification. For determination of chemical oxygen demand (COD), nitrate-nitrogen (NN), phosphate (PHOS), total alkalinity (TA), and chloride (Cl^-), open reflux, UV spectrophotometric, stannous chloride, standard titrimetric, and argentometric titration method were used, respectively. Total suspended solid (TSS) was determined by filtering a fixed volume of a well-mixed sample using glass fiber filter paper, followed by drying in an oven (103–105 °C), and weighing the residue collected on the filter paper. For microbiological parameters, i.e., total coliforms (TC), the most probable number (MPN) test was performed.

For the estimation of heavy metals ($n = 8$) including chromium (Cr), lead (Pb), iron (Fe), nickel (Ni), manganese (Mn), zinc (Zn), cadmium (Cd), and copper (Cu) and other metals ($n = 2$) like sodium (Na) and potassium (K), nitric acid digestion was performed followed by atomic absorption spectroscopy (AAS) (APHA 1999). Briefly, the samples were digested on a hot plate using nitric acid till a pale-colored clear solution was formed and further cooled and filtered using a Whatman No. 42 filter paper. The final volume of filtered and digested samples was adjusted to 100 ml using double-distilled water and concentrations of respective metals in the samples were determined using an atomic absorption spectrometer (Agilent AAS 280FS AA). The accuracy of the atomic absorption spectrophotometer for heavy metal analysis was tested using standard reference material NIST 1640(a). The recovery rate was obtained in the range of 91.7–98.2%. The chemicals used throughout the study for reagent preparation were of analytical grade (AR) and the measurements for all the parameters were carried out in duplicates. Procedural blanks were also run for each analytical method and the resultant values were subtracted from the sample values so as to maintain the accuracy and consistency of the results.

Statistical analysis

The matrix of water quality data was analyzed using the software Statistical Package for the Social Sciences (SPSS) v.16.0 and Microsoft Excel (2007). The dataset was subjected to Pearson's correlation analysis and multivariate analytical techniques including hierarchical cluster analysis and principal component analysis (PCA). Pearson's correlation analysis is a bivariate statistical tool that helps in analyzing the strength and direction of the relationship between two variables (Rawat and Tripathi 2015). The association is defined on the basis of a coefficient that ranges between − 1 and + 1. Negative values indicate an inverse relationship while positive values suggest a relationship in the same direction. According to Schober et al. (2018), the magnitude of correlation coefficient varies in the order: 0–0.10 (negligible), 0.10–0.39 (weak), 0.40–0.69 (moderate), 0.70–0.89 (strong), and 0.90–1.00 (very strong).

Multivariate statistical tools like cluster analysis and PCA have been widely used for the analysis of complex water quality datasets (Tyagi and Sarma 2021; Gradilla-Hernández et al. 2020; Kumar et al. 2018, 2009; Bhattacharya et al. 2015; Gvozdić et al. 2012). Hierarchical cluster analysis is an investigatory technique that is quite prevalent in hydrological studies for identifying natural grouping in the dataset based on the similarities and associations between the variables (Gradilla-Hernández et al. 2020; Kumar et al. 2018; Bhattacharya et al. 2015), while PCA is mostly selected for reducing the dimensionality of a large dataset without any loss of information (Tripathi and Singal 2019; Kumar et al. 2018; Jolliffe and Cadima 2016). It is a powerful tool for analyzing the structure of variables and observations in the dataset, their inter-correlations, and subsequent extraction of a new set of orthogonal variables which are known as principal components, from the original dataset (Abdi and Williams 2010). The factor loadings on individual PCs can be classified as strong (> 0.75), moderate (0.75–0.50), and weak (0.50–0.30) (Muangthong and Shrestha 2015). Before conducting PCA, the dataset is generally pre-tested for sampling adequacy and suitability using Kaiser–Meyer–Olkin

(KMO) and Bartlett's test of sphericity (Haghnazar et al. 2021). For the interpretation of the KMO test, values close to zero indicate inappropriateness, greater than 0.5 represents satisfactory condition while close to one indicates higher reliability for conducting PCA (Tripathi and Singal 2019). On the other hand, Bartlett's test of sphericity is used to measure the normality of the multivariate dataset and identifies whether the correlation matrix obtained for the selected parameters is an identity matrix or not. In this test, if the significance value $P < 0.05$ is obtained; it indicates that the correlation matrix produced is not an identity matrix and the dataset is appropriate for PCA analysis (Ul Hadi et al. 2016).

Results and discussion

Water quality degradation of Najafgarh drain in Delhi (from Dhansa to Wazirabad)

It has been highlighted previously that the Najafgarh drain is the largest of all the drains that are discharging their wastewater in the Yamuna River. This drain is particularly of prime importance because it is the first drain that is contributing to the maximum pollution load to the Yamuna River in Delhi, and further, this drain in itself is an extension of the Sahibi River that has lost its existence in the Delhi megacity due to its channelization in the form of the Najafgarh drain rather than in a canal. For the analysis of drains' water quality, a total of twenty-five physicochemical, microbiological, and heavy metal parameters were determined for all the samples collected as described in "Materials and methods" section. The present water quality analysis has revealed that the water quality in the Najafgarh drain has deteriorated starting from its entry point at Dhansa in southwestern Delhi to its final outfall point in the Yamuna River at Wazirabad during both the seasons. The comparison of the 25 selected water quality parameters specifically at these two locations is shown in Table 3. Bhattacharya et al. (2015) have also found that the Najafgarh drain is a severely polluted waterbody and falls under the unfit category as per Food and Agricultural Organization (FAO) standards for irrigation water. This scenario can be majorly attributed to the discharges from various secondary drains which start meeting the Najafgarh drain after its entry into Delhi. Despite the fact that a sharing agreement is already sanctioned for the five riparian states of the Yamuna River to dilute and increase the flow of the Najafgarh drain through the Western Yamuna canal (Nema and Agrawal 2003), which has been referred to as Kanhaiya Nagar drain in the present study, no fresh flow of water was detected in the drain during both the sampling seasons. The water quality trends of the selected eight secondary drains discharging their wastewater into the Najafgarh drain are discussed in detail in the next section. In addition to the various pollutants, a large amount of settled sludge was also observed during field visits across the entire stretch of the Najafgarh drain starting from N2 till N15. Since the flow velocity of the Najafgarh drain was also very low in the entire stretch (0–1 m/s, measured using a flow meter of Global Water Instruments make: model FP211), it could have led to the higher sludge deposition rate and silting.

Sources of wastewater inputs in Najafgarh drain: the secondary drains' water quality

The Najafgarh drain is receiving wastewater discharges from approximately 78 major and minor drains, as mentioned earlier. However, on the basis of field survey, location, discharge, and land uses, eight drains were selected for the present work. The samples collected from these secondary drains were analyzed for the same 25 parameters as mentioned earlier for the Najafgarh drain. The range of different water quality parameters found in these secondary drains is mentioned in Table 4. According to the water quality analysis of these selected eight secondary drains in the present study, the Goyla dairy outlet (S2) was found to be the organic pollution hotspot with maximum values of BOD, COD, TSS, nitrate–N, phosphate, total alkalinity, Na, K, and Mn. The raw wastewater from this outlet was found being discharged directly into the Najafgarh drain despite the fact that it contained an exceptionally high organic load and thus is a serious issue of concern. Being a dairy farming unit, the wastewater discharge from this point was of brown color comprising straws (a typical cattle feeding material) and cow dung which had a peculiar smell. The wastewater collected from this location was significantly loaded with the abovementioned organic material and it also formed a thick layer at the bottom of the sample collection bottles, while in terms of heavy metal contamination, the Basaidarapur outlet (S6) was found to be greatly influenced by various industrial areas in its vicinity like Basaidarapur, Naraina, Mayapuri, and Dabri. The Basaidarapur drain is located near Punjabi Bagh and studies conducted by Gola et al. (2020) in this area of the Najafgarh drain have revealed similar findings. Since drainage water has been an attractive option of choice for irrigation in Delhi (Bhattacharya et al. 2015), the compliance check of wastewater flowing in these secondary drains with suitable standards becomes really important. In accordance with FAO standards for irrigation water, various metals were observed beyond their permissible limits in these secondary drains, like chromium exceeded the limit (0.10 mg/L) at sites S1 and S6 during the post-monsoon season. Iron was present beyond the standard limit (5.00 mg/L) at sites S2 and S8 (pre-monsoon) and S1, S2, S6, and S7 (post-monsoon). Nickel exceeded its limit (0.20 mg/L) at sites S6 (pre-monsoon) and S1 and S6 (post-monsoon). Manganese was present either at the borderline or beyond

Table 3 Comparison of Najafgarh drain water quality at its entry and exit point in Delhi

Parameter	Pre-monsoon		Post-monsoon	
	Entry point of Najafgarh drain in Delhi (N1)	Final outfall of Najafgarh drain entering in Yamuna River (N15)	Entry point of Najafgarh drain in Delhi (N1)	Final outfall of Najafgarh drain entering in Yamuna River (N15)
TEMP (°C)	27.5	30.8	21.5	23.1
pH	6.5	6.5	7.6	7.5
TURB (NTU)	4.6	42.6	5.2	47.2
EC (μS/cm)	1005	2110	672	1924
SAL (mg/L)	495	1070	337	1000
TDS (mg/L)	711	1480	477	1360
TSS (mg/L)	1.5	227.0	3.2	84.0
DO (mg/L)	4.4	ND*	4.1	ND*
BOD (mg/L)	5.8	60.4	12.8	44.8
COD (mg/L)	15	250	30	168
NN (mg/L)	0.9	9.6	0.3	0.6
PHOS (mg/L)	0.4	2.5	0.2	2.9
TA (mg/L)	112.2	555.1	141.5	431.9
Cl^- (mg/L)	222.6	357.4	65.0	304.9
Na (ppm)	144.41	388.16	65.59	152.07
K (ppm)	15.97	59.72	7.82	36.30
Cr (ppm)	ND*	0.09	ND*	0.07
Pb (ppm)	ND*	ND*	ND*	ND*
Fe (ppm)	0.22	5.48	0.38	2.90
Ni (ppm)	0.02	0.19	ND*	0.15
Mn (ppm)	0.06	0.47	0.03	0.31
Zn (ppm)	0.06	0.24	0.18	0.21
Cd (ppm)	ND*	0.004	ND*	ND*
Cu (ppm)	0.01	0.10	0.01	0.05
TC (MPN/100 ml)	2.1×10^3	9.3×10^5	1.1×10^5	2.4×10^6

**ND* refers to not detected

the standard limit (0.20 mg/L) for most of the sites. Zinc exceeded its limit (2.00 mg/L) at site S6 during the post-monsoon season only. Copper exceeded its standard limit (0.20 mg/L) only at site S6 during both the seasons, while for cadmium, S6 was present at the borderline (0.01 mg/L) during the pre-monsoon season only. Results of heavy metal concentration ranges are presented in Table S1 and S2.

The obtained water quality dataset for these secondary drains was also subjected to agglomerative hierarchical cluster analysis in order to group the drains with similar water quality trends. The analysis was conducted using Ward's method with squared Euclidean distance (Gradilla-Hernández et al. 2020; Bhattacharya et al. 2015). Figure 2 shows the results of the cluster analysis for the eight secondary drains during the pre- and post-monsoon seasons. It is clear from Fig. 2a that during the pre-monsoon season, the eight studied drains got clustered into three groups, namely A, B, and C (Fig. 2a), wherein group A constituted a total of five drains in two sub-groups: one contained S3, S5, and S7 and another contained drains S4 and S8. Drains S3, S5, and S7 were characterized by low levels of EC, salinity, TDS, Na, K, Cl^-, total alkalinity, nitrate–N, Cr, Fe, Mn, and moderate levels of total coliforms while drains S4 and S8 were characterized by high levels of EC, salinity, TDS, Na, K, Cl^-, nitrate–N, and total alkalinity, moderate levels of Cr and Mn, and low levels of phosphate and total coliforms, while group B constituted drains S1 and S6, which were found to have the highest levels of total coliform and moderate to high level of heavy metals indicating significant sewage and industrial effluent contamination in these drains. On the other hand, group C which consisted of drain S2 only, formed a separate group due to the exceptionally high levels of pollutants in this drain as discussed earlier.

However, during the post-monsoon season, the drains were clustered into three different groups D, E, and F (Fig. 2b). Group D consisted of two sub-groups, with drains S3, S5, S8, S1, and S4 in one sub-group and S7 in a separate sub-group. This group was collectively characterized by low

Table 4 Range of physicochemical and microbiological water quality parameters in secondary drains ($N=8$)

Parameter	Pre-monsoon		Post-monsoon	
	Minimum	Maximum	Minimum	Maximum
TEMP (°C)	28.6 (S5)	31.6 (S4)	21.2 (S7)	25.7 (S2)
pH	6.2 (S2)	6.7 (S4)	6.8 (S7)	7.8 (S1)
TURB (NTU)	41.7 (S7)	731.0 (S2)	11.3 (S6)	1768.0 (S2)
EC (µS/cm)	546 (S7)	3560 (S4)	605 (S7)	4390 (S2)
SAL (mg/L)	265 (S7)	1870 (S4)	301 (S7)	2400 (S2)
TDS (mg/L)	387 (S7)	2530 (S4)	428 (S7)	3120 (S2)
Cl^- (mg/L)	30.0 (S7)	874.7 (S4)	5.0 (S7)	707.3 (S2)
TSS (mg/L)	74 (S5)	2300 (S2)	11 (S4)	2500 (S2)
DO (mg/L)	ND* (S1–S8)	ND* (S1–S8)	ND* (S1–S8)	ND* (S1–S8)
BOD (mg/L)	32.8 (S4)	626.8 (S2)	32.8 (S4)	664.2 (S2)
COD (mg/L)	120 (S7)	3150 (S2)	132 (S4)	4440 (S2)
NN (mg/L)	4.3 (S5)	144.7 (S2)	0.1 (S1)	9.9 (S2)
PHOS (mg/L)	1.1 (S7)	4.0 (S2)	0.8 (S7)	5.8 (S2)
TA (mg/L)	205.0 (S7)	951.6 (S2)	305.0 (S7)	1085.8 (S2)
Na (ppm)	72.00 (S7)	733.95 (S2)	29.75 (S7)	647.74 (S2)
K (ppm)	37.36 (S1)	186.57 (S2)	26.66 (S7)	167.58 (S2)
Cr (ppm)	ND* (S2,S5,S7)	0.09 (S1,S6)	ND* (S2,S3,S4,S7)	0.43 (S6)
Pb (ppm)	ND* (S1–S8)	ND* (S1–S8)	ND* (S3,S4,S5,S8)	0.06 (S6)
Fe (ppm)	0.89 (S5)	11.31 (S8)	0.69 (S3)	25.44 (S7)
Ni (ppm)	0.08 (S3)	0.24 (S6)	0.01 (S2)	0.56 (S6)
Mn (ppm)	0.10 (S3)	0.98 (S2)	0.10 (S3)	1.85 (S2)
Zn (ppm)	0.07 (S7)	0.51 (S1)	0.10 (S3)	2.53 (S6)
Cd (ppm)	0.001 (S1)	0.01 (S6)	ND* (S1–S5,S7,S8)	0.006 (S6)
Cu (ppm)	0.002 (S7)	0.421 (S6)	0.003 (S4)	1.263 (S6)
TC (MPN/100 ml)	3.6×10^4 (S4)	4.6×10^6 (S1,S6)	4.3×10^5 (S8)	2.1×10^7 (S2)

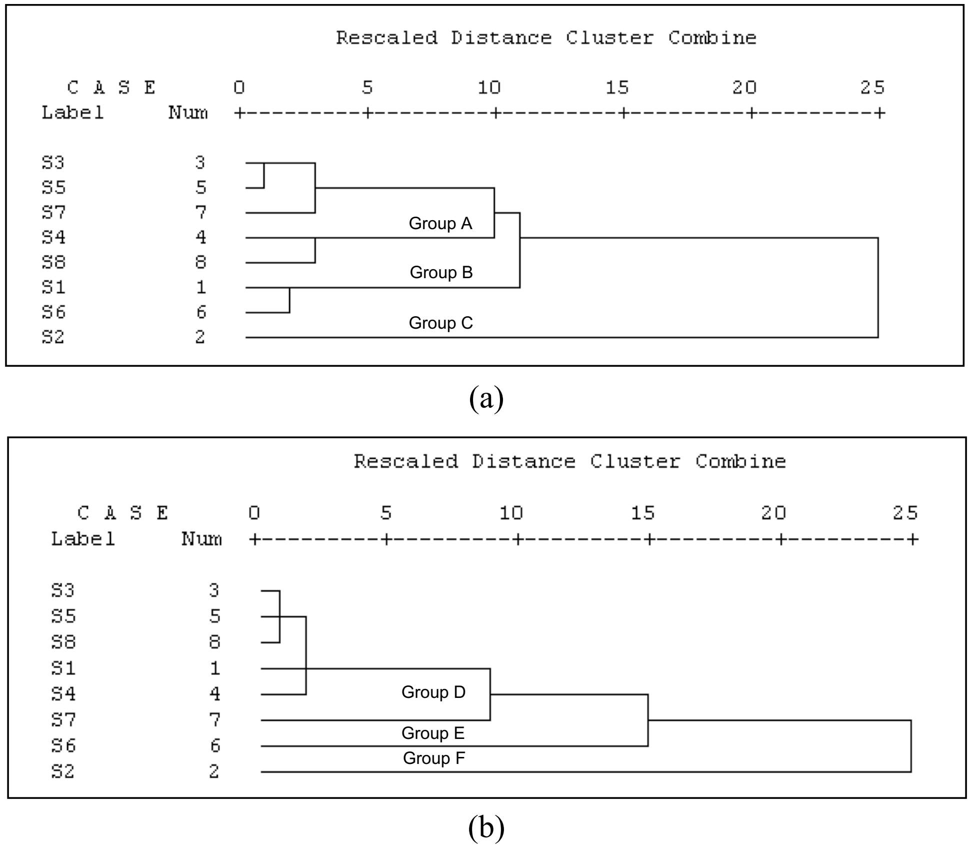
*ND refers to not detected

to moderate levels of BOD, COD, turbidity, nitrate–N, total coliforms, Ni, Cu, and Zn while separation of drain S7 in a separate cluster was due to comparatively lower levels of EC, salinity, TDS, total alkalinity, Cl^-, phosphate, K, and Na and higher levels of turbidity, TSS, Pb, and Fe than the rest of the group. The next group E contained only drain S6 which is a similar clustering trend as observed during the pre-monsoon season but the difference in this cluster during this season was that drain S1 was removed from this group and shifted to group D. The separation of S6 is attributed to high levels of heavy metals (Cr, Cd, Ni, Zn, and Cu) in this drain in comparison to the rest of the drains. Group F comprised only of S2, similar to the clustering trend for the pre-monsoon season and majorly due to the exceptionally high level of pollutants in this drain.

Impact of secondary drains on Najafgarh drain water quality

The Najafgarh drain is one of the major drains in Delhi which receives partially treated and untreated wastewater discharges from residential, agricultural, and industrial areas. The channelization of such wastewater into the Najafgarh drain is conducted through various secondary drains. So far, the effect of these secondary drain discharges on the Najafgarh drain water quality has not been reported to the best of our knowledge. But a similar study conducted on Alaro stream, Nigeria, has shown quite a destructive impact on the water body and the organisms inhabiting it after receiving a polluted discharge from a point source (Adeogun 2012). In another study by Chakraborti (2021), the negative influence of wastewater discharges on downstream locations of the receiving waterbody has been further ascertained. In view of the above literature survey, the present study was undertaken and this section describes the detailed impact of the selected eight secondary drains on Najafgarh drain's water quality by determining various parameters at upstream and downstream locations to these drains' discharge points (sampling points are marked in Fig. 1). The graphical representation of the few important selected water quality parameters is shown in each sub-section in order to visualize the changes in Najafgarh drain's water quality. These parameters have been selected for graphical representation based on their importance and the trend of parameters selected by

Fig. 2 Hierarchical cluster analysis of the selected secondary drains. (**a**) Pre-monsoon season. (**b**) Post-monsoon season



Central Pollution Control Board (CPCB) and Delhi Pollution Control Committee (DPCC) for different surface water resources in Delhi.

a) Badshahpur & Basai drain (S1)

Badshahpur & Basai drains are two separate drains, which mix before their final outfall in the Najafgarh drain. These drains discharge their wastewater approximately 8.5 km after the entry point of the Najafgarh drain in Delhi. The wastewater in S1 is primarily originating from industrial, residential, and agricultural areas. The sampling conducted on upstream and downstream locations of the Najafgarh drain with reference to this secondary drain showed variable changes in the water quality. During the pre-monsoon season, the downstream location in the Najafgarh drain showed a decrease in the levels of pH, EC, salinity, TDS, Cl^-, total alkalinity, nitrate-N, Fe, and Mn, and an increase in the levels of temperature, BOD, COD, TSS, total coliforms, Cr, and Cd in comparison to its upstream location. This scenario was in accordance with the fluctuations found in the water quality of Badshahpur & Basai drains during this season. However, few parameters like turbidity, phosphate, Na, and K, showed increasing levels despite their decreasing values in S1, and almost similar upstream-downstream levels for Ni, Zn, and Cu, despite their higher levels in S1, while during the post-monsoon season, the downstream location in the Najafgarh drain showed an increase in the levels of temperature, pH, EC, salinity, TDS, turbidity, Cl^-, BOD, COD, TSS, phosphate, Na, K, Cr, Fe, Ni, Zn, and Cu, and a decrease in the levels of nitrate-N, in comparison to its upstream location, which was also in accordance with the levels found in Badshahpur & Basai drains. But few parameters like dissolved oxygen, total coliforms, Pb, and Mn showed inverse trends in comparison to the source drain. The influence zone of Badshahpur & Basai drains was present in Najafgarh Jheel, which was an active fishing zone and a favorable site for migratory birds. These anthropogenic and natural activities might have also contributed to the water quality variations observed at this particular sampling site along with discharges from Badshahpur and Basai drains. Figure 3 shows the graphical representation of selected important water quality parameters where each individual graph represents the value at three sampling locations; (i) Upstream to Secondary drain, (ii) Secondary drain outfall, (iii) Downstream to Secondary drain.

b) Goyla dairy outlet & Palam drain (S2 & S3)

The Goyla dairy outlet (S2) and Palam drain (S3) discharge their wastewater in the Najafgarh drain approximately 22 km after its entry into Delhi. The

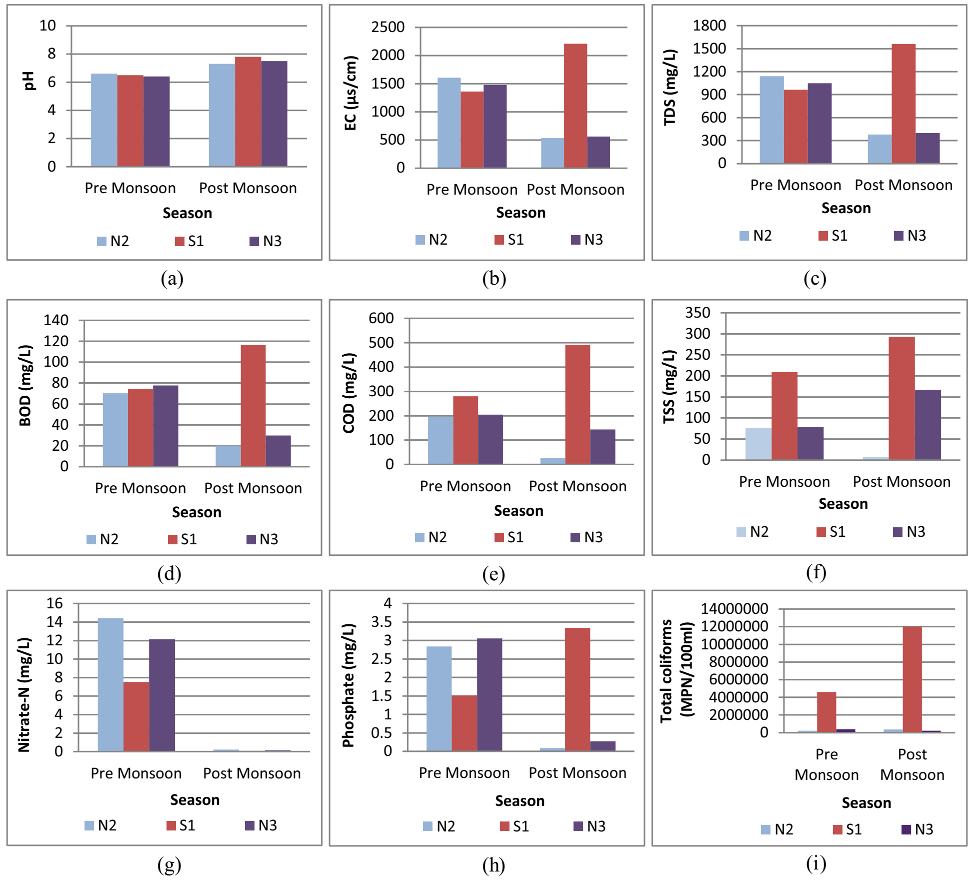


Fig. 3 Changes in water quality of Najafgarh drain (N2 and N3) after receiving wastewater discharges from Badshahpur and Basai drain (S2) for selected water quality parameters (**a** pH; **b** EC; **c** TDS; **d** BOD; **e** COD; **f** TSS; **g** nitrate–N; **h** phosphate; **i** total coliforms)

wastewater in S2 comprises of effluents released from the Goyla dairy farming unit while S3 comprises of effluents from agricultural and residential areas. The consistent discharge of variable effluents from these drains created a rise in the levels of EC, salinity, TDS, turbidity, Cl^-, total coliform, Na, and K while a fall in temperature, pH, BOD, COD, TSS, nitrate-N, phosphate, total alkalinity, Cr, Fe, Ni, and Cu at the downstream location in Najafgarh drain during pre-monsoon season, while during the post-monsoon season, it was observed that in addition to EC, salinity, TDS, turbidity, and total coliforms, few other parameters (total alkalinity, BOD, COD, nitrate-N, and Fe) also increased and the remaining parameters decreased. Figure 4 shows the graphical representation of selected important water quality parameters as discussed above.

c) Mungeshpur drain (S4)

The Mungeshpur drain discharges its wastewater in the Najafgarh drain approximately 30 km after its entry into the Delhi megacity. The flow regime in this drain is dominated by various anthropogenic activities like agricultural, domestic, and industrial, and their impact could easily be observed on the Najafgarh drain water quality. The pre-monsoon season showed a decrease in turbidity, COD, TSS, nitrate-N, Fe, Mn, Zn, and Cu while an increase in pH, EC, salinity, TDS, total alkalinity, and Na, which was in concordance with the rise and fall observed in the water quality of this drain. During the post-monsoon season, a decrease in BOD, COD, nitrate-N, Zn, and Cu and an increase in EC, salinity, TDS, turbidity, total alkalinity, Cl^-, total coliforms, Ni, and Na were observed. The remaining parameters during both the seasons deviated from the trend. Figure 5 shows the graphical representation of selected important water quality parameters.

d) Keshopur STP outlet (S5)

The Keshopur STP outlet discharges its wastewater in the Najafgarh drain approximately 39 km after its entry into Delhi. With a capacity of treating 72 MGD of wastewater daily, this STP only treats 58.34 MGD of wastewater (DPCC 2017). Due to such a scenario, elevated concentrations of parameters pH, BOD, COD, TSS, Fe, Zn, and Cu (pre-monsoon), and temperature, pH, COD, total alkalinity, phosphate, Ni, Zn, Cu, and K (post-monsoon) were detected in the downstream stretch of Najafgarh drain, while EC,

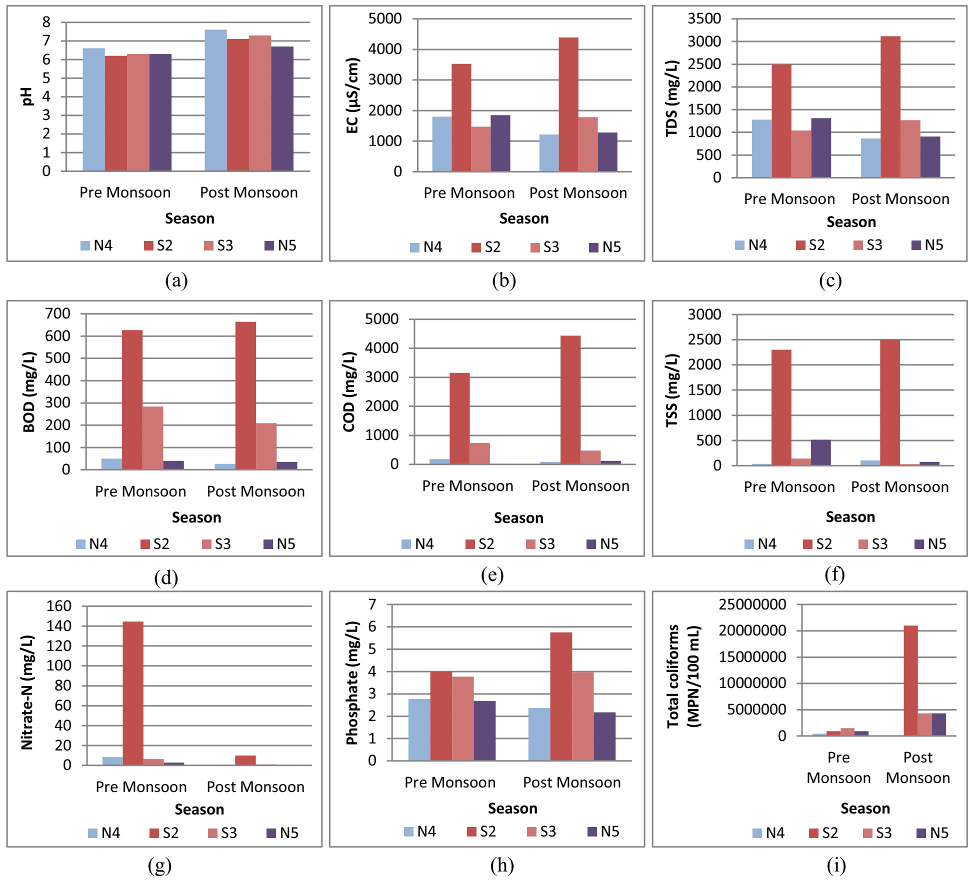


Fig. 4 Changes in water quality of Najafgarh drain (N4 and N5) after receiving wastewater discharges from Goyla dairy outlet (S2) and Palam drain (S3) for selected water quality parameters (**a** pH; **b** EC; **c** TDS; **d** BOD; **e** COD; **f** TSS; **g** nitrate–N; **h** phosphate; **i** total coliforms)

salinity, TDS, Cl⁻, Cd, Na, and K (pre-monsoon) and total coliforms, Fe, and Mn (post-monsoon) were found to decrease in concentration. This related well with the fluctuations observed in the water quality of this outlet. Figure 6 shows the graphical representation of selected important water quality parameters.

e) Basaidarapur drain (S6)

Basaidarapur drain discharges its wastewater in Najafgarh drain approximately 44 km after its entry point in Delhi. Numerous industrial clusters and residential areas are cluttered in the vicinity of this drain. In the present investigation, surge in the levels of parameters including BOD, COD, nitrate-N, total coliforms, Ni, Cd, Cu, and Na, as well as EC, salinity, TDS, BOD, COD, TSS, total alkalinity, phosphate, Cl^-, Fe, Ni, Cu, Na, and K was detected during the pre-monsoon and post-monsoon seasons respectively. But due to the decline in the levels of temperature, EC, salinity, turbidity, TSS, total alkalinity, Cl^-, Fe, Mn, and K, in the Basaidarapur drain during pre-monsoon season, a subsequent fall was observed in the downstream location of Najafgarh drain also. Figure 7 shows the graphical representation of selected important water quality parameters.

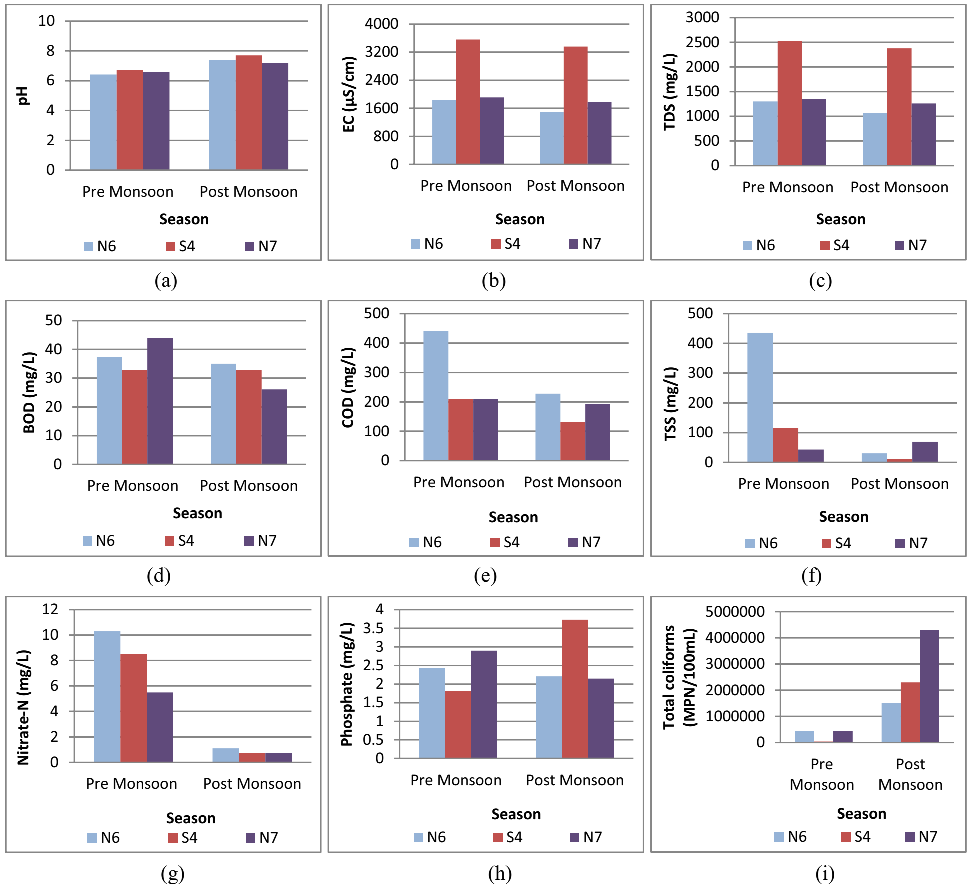
f) Kanhaiya Nagar drain (S7)

Kanhaiya Nagar drain discharges its wastewater in Najafgarh drain approximately 49 km after its entry into Delhi. During the pre-monsoon season, the downstream location in the Najafgarh drain showed a decrease in the levels of EC, salinity, TDS, turbidity, total alkalinity, Cl^-, Na, K, and Zn while increase in temperature, TSS, Fe, Ni, and Mn. During the post-monsoon season, a decrease in the levels of EC, salinity, TDS, total alkalinity, Cl^-, Ni, and Na and an increase in TSS, Fe, Mn, and Zn were observed. These variations in the above-mentioned parameters were in concordance with the water quality of Kanhaiya Nagar drain, however other characteristics deviated from the trend during both the seasons. Figure 8 shows the graphical representation of selected important water quality parameters.

g) Supplementary drain (S8)

The supplementary drain is a tributary of the Najafgarh drain. It bifurcates from the Najafgarh drain near Kakrola and re-joins it near Wazirabad (before the confluence with Yamuna River) after traversing a 37-km-long stretch in the Delhi city. This drain passes through diverse land use patterns. The water quality analysis post the discharge of this drains' wastewater

Fig. 5 Changes in water quality of Najafgarh drain (N6 and N7) after receiving wastewater discharges from Mungeshpur drain (S4) for selected water quality parameters (**a** pH; **b** EC; **c** TDS; **d** BOD; **e** COD; **f** TSS; **g** nitrate–N; **h** phosphate; **i** total coliforms)



in Najafgarh drain showed a decrease in temperature, BOD, COD, phosphate, Cr, Cu, and Zn, while an increase in pH, conductivity, salinity, TDS, TSS, Cl^-, Fe, Ni, Mn, Na, and K, during the pre-monsoon season, while parameters like turbidity, total alkalinity, nitrate-N, and total coliforms deviated from the trend. During the post-monsoon season, a decrease in temperature, BOD, COD, and total coliforms and an increase in TSS, total alkalinity, Cl^-, nitrate-N, and Fe were observed. These variations corresponded with the rise and fall observed in the water quality of the supplementary drain. Figure 9 shows the graphical representation of selected important water quality parameters.

Overall, the negative impact of secondary drains on the Najafgarh drain water quality was quite evident as its water quality significantly degraded from its entry to exit point in Delhi. The secondary drain-specific water quality changes observed at the downstream location in the Najafgarh drain were also observed to be very prominent as water quality at downstream of the specific secondary drain was found to be influenced by that particular secondary drain's water quality. However, along with water quality impact, these changes may also depend on various other factors including discharge volume of secondary drains, Najafgarh drains' background flow, and bank-specific natural or anthropogenic influences. Majority of the water quality parameters in the present study increased or decreased in the downstream location depending upon the scenario found in their influencing secondary drain. Only few parameters showed either reverse trends or no significant changes in their values. Some of these discrepancies might have also originated due to minor manual handling errors, while other possible reasons for this situation would have been the numerous point and non-point source discharges across the drain stretch along with the major secondary drains which might have also influenced the water quality of the Najafgarh drain. For instance, in the Kanhaiya Nagar drain influence zone, it was observed during the sampling that small outlets

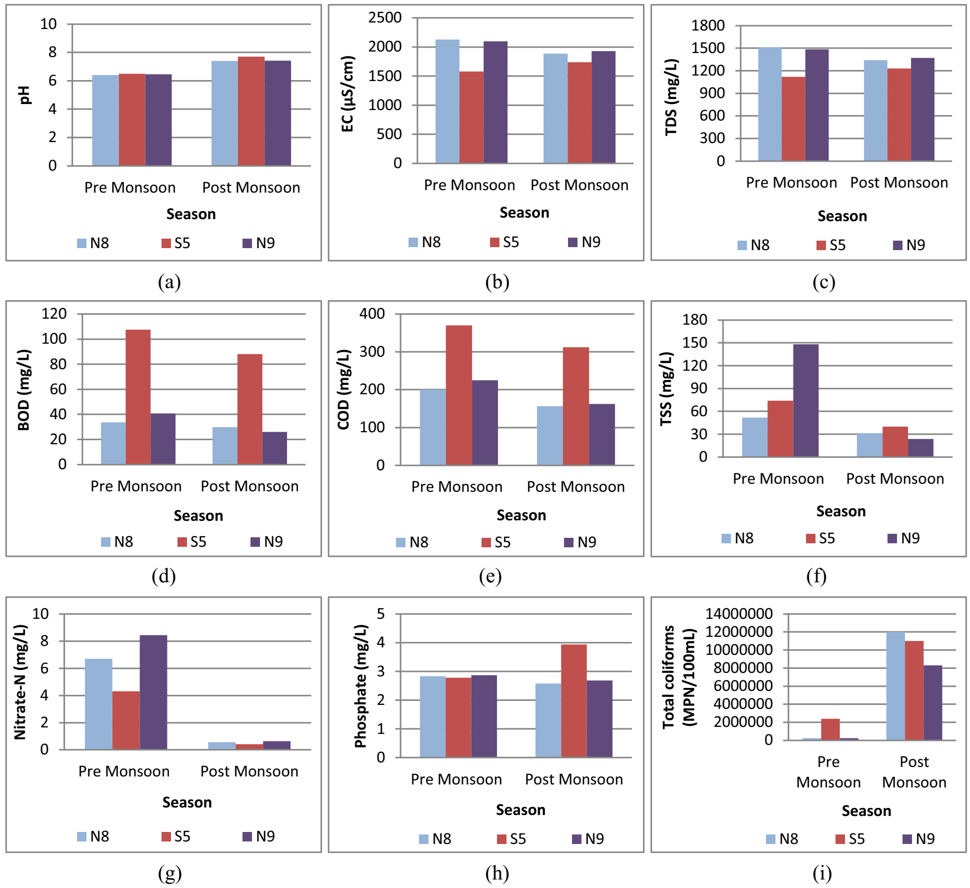


Fig. 6 Changes in water quality of Najafgarh drain (N8 and N9) after receiving wastewater discharges from Keshopur STP outlet (S5) for selected water quality parameters (**a** pH; **b** EC; **c** TDS; **d** BOD; **e** COD; **f** TSS; **g** nitrate–N; **h** phosphate; **i** total coliforms)

from residential colonies were concentrated between the secondary drain point and downstream point in the Najafgarh drain, which led to additional organic load, and thus might has caused an increase in BOD, COD, nitrate-N, phosphate, and total coliforms.

Impact of Najafgarh drain on Yamuna River water quality

The myriad of pollutants that Najafgarh drain receives from the various secondary drain ultimately gets discharged into the Yamuna River at Wazirabad. In a study conducted by Bhardwaj et al. (2017), it has been observed that due to the intermixing of wastewater of Najafgarh drain with Yamuna River, toxic pollutants like heavy metals get significantly increased in concentrations at the downstream location in the river. On the other hand, Nehra and Singh (2020) have also reported a rise in the levels of BOD, COD, nitrates, Cl^{-}, and EC in Yamuna River post the discharge of Najafgarh drain wastewater. To further investigate this impact, in the present study, water samples were also collected from Yamuna River from upstream and downstream locations to the Najafgarh drain outlet according to the previously discussed sampling protocol. Figure 10 shows that the impact of the Najafgarh drain on Yamuna River's water quality was quite significant. During the pre-monsoon season, the downstream location in Yamuna River showed a decrease in pH and DO, while an increase in temperature, EC, salinity, TDS, turbidity, BOD, COD, TSS, total alkalinity, Cl^{-}, nitrate–N, phosphate, total coliforms, Fe, Ni, Mn, Cu, Na, and K, in comparison to its upstream location, which was in concordance with the rise and fall observed in the water quality of Najafgarh drain, while parameters like Cr, Zn, and Cd showed almost similar upstream–downstream values. During the post-monsoon season, the downstream location in the Najafgarh drain showed a decrease in pH, DO, and nitrate–N, while an increase in the values of the remaining parameters. Figure 10 shows the graphical representation of selected important water quality parameters for (i) the Yamuna River upstream to the Najafgarh drain, (ii) the Najafgarh drain before mixing with the Yamuna River, and (iii) the Yamuna River downstream to the Najafgarh drain.

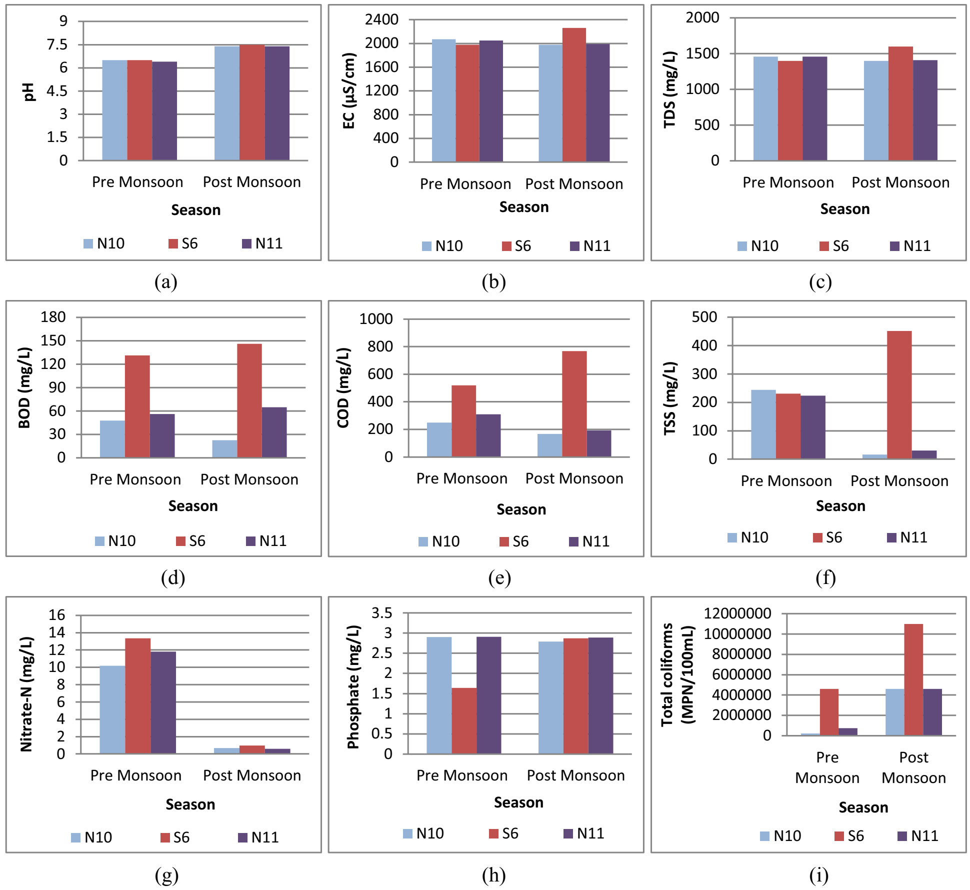


Fig. 7 Changes in water quality of Najafgarh drain (N10 and N11) after receiving wastewater discharges from Basaidarapur drain (S6) for selected water quality parameters (**a** pH; **b** EC; **c** TDS; **d** BOD; **e** COD; **f** TSS; **g** nitrate–N; **h** phosphate; **i** total coliforms)

Statistical analysis of the water quality parameters

Pearson correlation analysis

The raw water quality dataset was subjected to Pearson correlation analysis in order to analyze the associations between the various parameters and interpret their common sources of origin. Associations between the selected 25 variables were tested in two groups. First, relationships between temperature, pH, EC, salinity, TDS, TSS, turbidity, DO, BOD, COD, nitrate–N, phosphate, total alkalinity, Na, K, Cl^-, and total coliforms were analyzed, and then, individual metal-to-metal correlation comprising chromium, nickel, zinc, iron, lead, manganese, cadmium, and copper was conducted. The grouping was done particularly to avoid the complexity of the insignificant relationships and better interpret the associations between the selected variables for the understanding of their common sources of origin. Table 5 presents the associations between the selected parameters for the first group. It was found that pH had a strong negative correlation with temperature, which is generally due to the fact that with an increase in the temperature, the molecular vibrations between the water molecules increase, which eventually resists the hydrogen bonding and supports the presence of free hydrogen ions, causing a decrease in the pH. Salinity, EC, TDS, Cl^-, Na, and K were having a significant positive correlation with each other. These parameters have natural as well as anthropogenic sources. Natural sources could be the ionic releases from the soils and vegetation, over which these streams are passing while anthropogenic sources can include effluents originating from industrial, residential, and agricultural areas (Haghnazar et al. 2022b). Turbidity was found to have a significant positive correlation with salinity, EC, TDS, Cl−, BOD, COD, TSS, phosphate, total alkalinity, total coliforms, Na, and K. Since turbidity, a complex parameter, is influenced by various factors like ionic strength of water, the solubility of organic compounds, solid content, and color, this might have led to the above-observed correlation (Tomperi et al. 2020; Li et al. 2019). Apart from this, the parameters indicating the oxygen demand in the water column of the study area, i.e., BOD and COD, were found to be strongly correlated

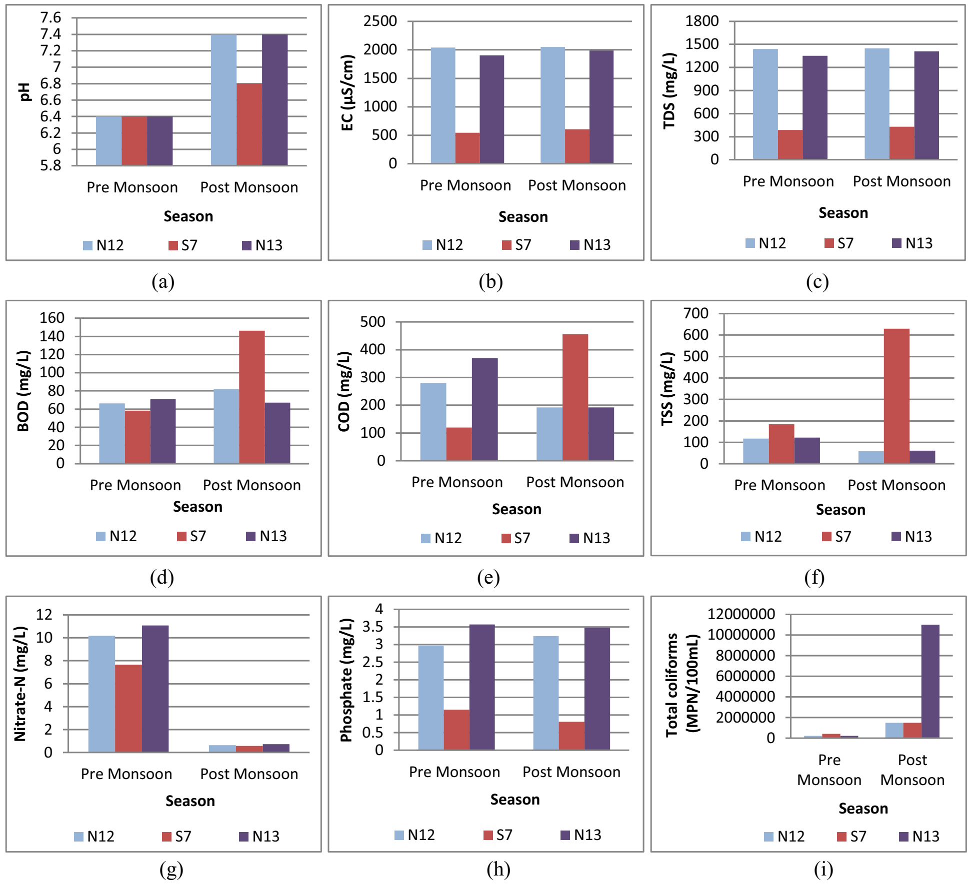


Fig. 8 Changes in water quality of Najafgarh drain (N12 and N13) after receiving wastewater discharges from Kanhaiya Nagar drain (S7) for selected water quality parameters (**a** pH; **b** EC; **c** TDS; **d** BOD; **e** COD; **f** TSS; **g** nitrate–N; **h** phosphate; **i** total coliforms)

to each other and positively correlated with remaining parameters like TSS, nitrate–N, Cl^-, Na, K, phosphate, total alkalinity, and total coliforms. These associations can be majorly attributed to the pertinent discharges of sewage and industrial effluents in these drains. Bathing, domestic washing, open defecation, animal bathing, dumping of animal wastes, submerging of idols, and other esthetics are some of the important sources which were prominently observed across these drains, while the dissolved oxygen was negatively correlated to most of the parameters to variable extents, indicating that the rise in the concentration of water pollutants ultimately leads to declining DO levels.

Table 6 presents the correlation between the eight heavy metals detected in the water samples collected from all sampling sites. The metal-to-metal interrelationships in the study area were positive in nature suggesting their common industrial sources like steel, alloying, galvanizing, and pickling in the Najafgarh drain basin (Bhattacharya et al. 2015). These positively significant associations between various heavy metals analyzed could have been exhibited due to the mixing of different types of industrial effluents which are being discharged directly or indirectly into the sampling locations.

Principal component analysis

Water quality data obtained for the 25 sampling locations (15 points on Najafgarh drain, 8 points on secondary drains, and 2 points on Yamuna River) was normalized and then subjected to PCA analysis and the results are presented in Table 7. The normality of the dataset was checked using the Shapiro–Wilk test. The varimax rotation method with Kaiser normalization was applied to the dataset (Kumar et al. 2018; Jolliffe and Cadima 2016; Bhattacharya et al. 2015; Gvozdić et al. 2012). The results of the KMO test gave a value of 0.796, and for Bartlett's test of sphericity, a significance level of 0.000 was obtained, which indicated that the present dataset was appropriate for PCA analysis. Based on the eigenvalues (greater than 1) and scree plot analysis, 5 principal components were selected and collectively, they accounted for 82.44% of the total variance in the water quality dataset. These principal components indicate that a common process is responsible for the linkage between

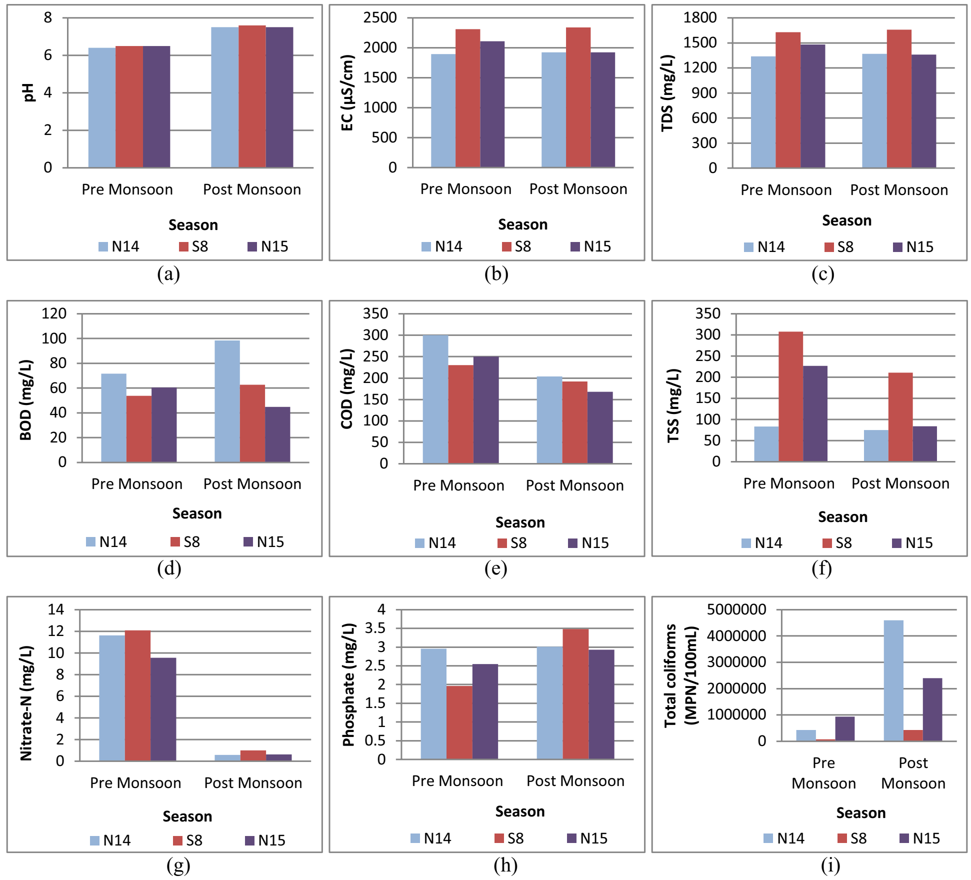


Fig. 9 Changes in water quality of Najafgarh drain (N14 and N15) after receiving wastewater discharges from Supplementary drain (S8) for selected water quality parameters (**a** pH; **b** EC; **c** TDS; **d** BOD; **e** COD; **f** TSS; **g** nitrate–N; **h** phosphate; **i** total coliforms)

the extracted variables and depending on the percentage loadings, the most significant variables that are dominating in the study are highlighted.

In the present dataset, PC1 explained 43.88% variance and had strong positive loadings of chloride, salinity, EC, TDS, and moderate positive loadings of Na, total alkalinity, and K, which could be linked to the high salt and mineral content in the wastewater released from natural or anthropogenic sources. Similar results were observed by Jaiswal et al. (2019) and Bhattacharya et al. (2015) in their study. PC2 was found to explain 14.27% variance and had strong positive loadings of nitrate–N and temperature; moderate positive loadings of Na, Cd, and K; and strong negative loading of pH. Gradilla-Hernández et al. (2020) have mentioned that such associations between water quality parameters could be the result of poorly treated wastewater effluents and agricultural effluents. Variation explained by PC3 was 12.37% and strong positive loadings of phosphate and BOD, and moderate positive loadings of total coliforms, COD, and turbidity while moderate negative loadings of DO were grouped in this component. The results of this component suggest that the discharge of organic pollutants through sewage or other anthropogenic activities could result in such relationships. In addition to this mismanaged wastewater released from STPs also affects the proportion of these parameters in lotic systems (Jaiswal et al. 2019; Upadhyay et al. 2011). PC4 explained 7.23% of the total variance wherein strong positive loadings of TSS and Fe and moderate positive loadings of Pb and Mn were observed. Heavy metals get attached to suspended solids present in their vicinity, and the process generally intensifies with increasing particle size. The large surface area and cation exchange capacity of sediment particles is a significant mediator in this process, as reported by Herngren et al. (2005) in their study on urban stormwater. PC5 explained 4.69% variation and had strong positive loadings of Cr, Ni, and Cu, and moderate positive loadings of Zn. This component represents the diversity of effluents being discharged from industries like steel, alloying, pickling, chemical, galvanization, and electroplating, which might be responsible for such associations between heavy metals in the study area (Haghnazar et al. 2022a; Bhattacharya et al. 2015).

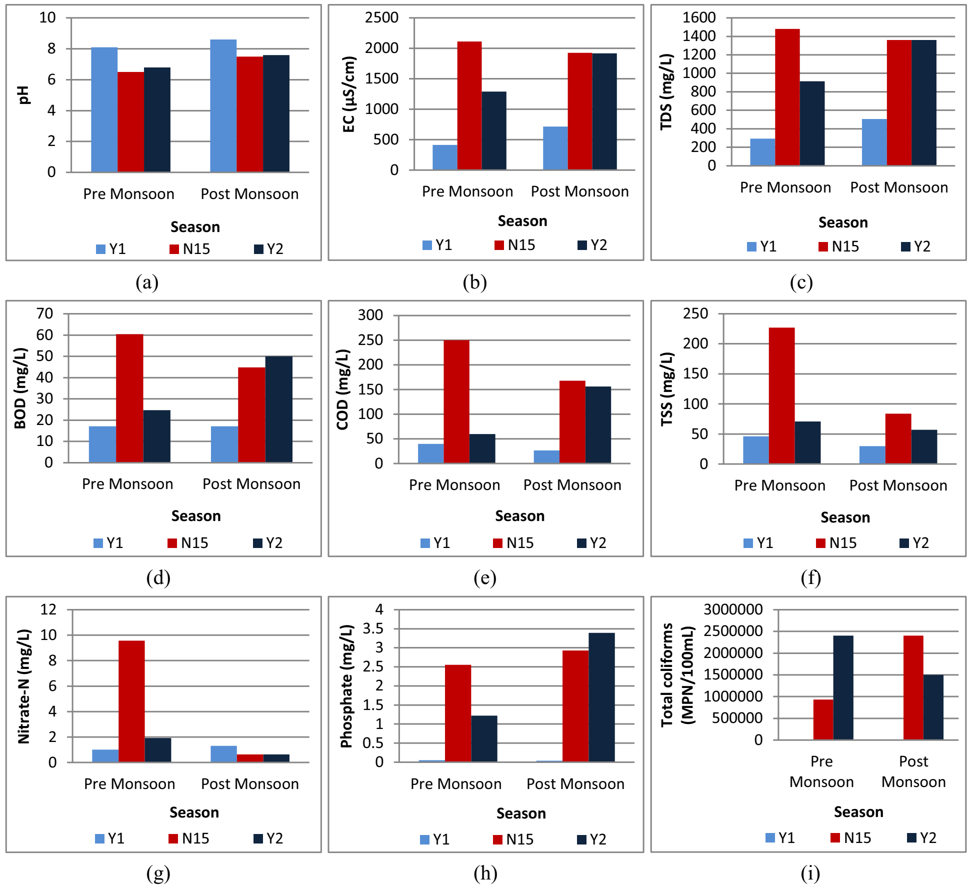


Fig. 10 Changes in water quality of Yamuna River (Y1 and Y2) after receiving wastewater discharges from Najafgarh drain (N15) for selected water quality parameters (**a** pH; **b** EC; **c** TDS; **d** BOD; **e** COD; **f** TSS; **g** nitrate–N; **h** phosphate; **i** total coliforms)

Conclusions

The Najafgarh drain is receiving significant quantities of water pollutants from various secondary drains present in its catchment basin. Due to their unregulated and pertinent nature, these secondary drain discharges are deteriorating the water quality of the Najafgarh drain after its entry at Dhansa in southwestern Delhi till its final outfall in Yamuna River at Wazirabad. The range of water quality parameters in most of these secondary drains was found well beyond the standard discharge limits prescribed by the Central Pollution Control Board (CPCB) and Food and Agriculture Organization (FAO) during pre-monsoon as well as post-monsoon seasons. Further analysis of the selected eight secondary drains using hierarchical cluster analysis revealed drain clusters that had similar water quality trends. During both the seasons, the Goyla dairy outlet was found to contain the maximum organic load, while the maximum heavy metal load was obtained in the Basaidarapur drain outlet. The present study further evaluated individualistic impacts of each selected secondary drain on the water quality of the Najafgarh drain. Depending on the secondary drain discharge volume, parameter range, seasonal influences, and predominant activities in the proximity, the values at the downstream location in the Najafgarh drain varied accordingly. Correlation analysis among the studied water quality parameters revealed significant positive relationships between parameters comprising BOD, COD, TSS, nitrate–N, and TC indicating their common sources of discharges majorly being unregulated sewage, industrial discharges, and agricultural run-off in these drains while associations between various heavy metals (Cr, Pb, Fe, Ni, Mn, Zn, Cu, and Cd) indicated their common industrial sources of origin. Principal component analysis (PCA) suggested five major components, each of which indicated the role of predominant anthropogenic activities influencing those parameters.

Originally built to carry stormwater as a canal, the Najafgarh drain is presently loaded with wastewater effluents, and is creating a serious threat to the Yamuna River system. Application of this contaminated wastewater for the irrigation of agricultural fields imposes a significant risk of declining soil fertility and contamination in crops. Serious

Table 5 Pearson correlation analysis of water quality parameters found in the selected sampling sites

	TEMP	pH	SAL	EC	TDS	Cl-	TURB	DO	BOD	COD	TSS	NN	PHOS	TA	TC	Na	K
TEMP	1																
pH	-0.763**	1															
SAL	0.119	-0.138	1														
EC	0.146	-0.165	0.999**	1													
TDS	0.144	-0.164	0.999**	1.000**	1												
Cl-	0.230	-0.196	0.950**	0.954**	0.954**	1											
TURB	0.022	-0.096	0.601**	0.582**	0.584**	0.431**	1										
DO	-0.165	0.467**	-0.493**	-0.506**	-0.506**	-0.434**	-0.115	1									
BOD	0.044	-0.178	0.564**	0.553**	0.554**	0.361**	0.857**	-0.189	1								
COD	0.051	-0.150	0.632**	0.618**	0.619**	0.448**	0.947**	-0.157	0.957**	1							
TSS	0.054	-0.171	0.571**	0.559**	0.559**	0.400**	0.905**	-0.122	0.921**	0.965**	1						
NN	0.266	-0.367*	0.363**	0.373**	0.372**	0.276	0.373**	-0.110	0.635**	0.572**	0.664**	1					
PHOS	0.084	-0.160	0.754**	0.756**	0.756**	0.601**	0.466**	-0.668**	0.533**	0.510**	0.388**	0.220	1				
TA	0.340*	-0.405**	0.853**	0.858**	0.858**	0.728**	0.687**	-0.568**	0.737**	0.755**	0.701**	0.516**	0.810**	1			
TC	-0.342*	0.311*	0.426**	0.405**	0.405**	0.267	0.524**	-0.227	0.439**	0.502**	0.400**	-0.121	0.460**	0.345*	1		
Na	0.595**	-0.590**	0.731**	0.746**	0.746**	0.743**	0.509**	-0.348*	0.507**	0.561**	0.542**	0.568**	0.464**	0.786**	0.027	1	
K	0.337*	-0.390**	0.790**	0.791**	0.791**	0.687**	0.790**	-0.353*	0.841**	0.871**	0.864**	0.730**	0.598**	0.878**	0.279*	0.812**	1

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

Color coding: dark orange ( ) represents very strong correlation; light orange ( ) represents strong correlation; green ( ) represents moderate correlation; pale yellow ( ) represents weak to negligible correlation

Table 6 Pearson correlation analysis of heavy metals found in the selected sampling sites

	Cr	Pb	Fe	Ni	Mn	Zn	Cd	Cu
Cr	1							
Pb	0.717**	1						
Fe	0.573**	0.833**	1					
Ni	0.822**	0.653**	0.578**	1				
Mn	0.199	0.437**	0.517**	0.160	1			
Zn	0.861**	0.854**	0.668**	0.830**	0.374**	1		
Cd	0.295*	0.161	0.211	0.550**	0.111	0.344*	1	
Cu	0.843**	0.842**	0.645**	0.846**	0.308*	0.963**	0.445**	1

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

Color coding: dark orange ( ) represents very strong correlation; light orange ( ) represents strong correlation; green ( ) represents moderate correlation; pale yellow ( ) represents weak to negligible correlation

Table 7 Principal component analysis of the selected sampling locations

Variable	Component				
	PC1	PC2	PC3	PC4	PC5
Cl^-	0.94	0.24	0.06	0.05	0.12
SAL	0.94	0.03	0.26	0.17	0.11
EC	0.93	0.06	0.25	0.18	0.11
TDS	0.93	0.07	0.25	0.18	0.11
Na	0.68	0.63	0.20	-0.02	0.12
TA	0.62	0.41	0.45	0.26	0.11
NN	0.20	0.86	-0.01	0.07	0.09
TEMP	0.21	0.83	0.01	-0.02	0.15
pH	0.05	-0.79	-0.32	0.01	0.06
Cd	0.02	0.70	-0.18	0.11	0.42
K	0.59	0.62	0.32	0.19	0.05
PHOS	0.46	0.00	0.79	0.00	0.03
BOD	0.11	0.15	0.76	0.44	0.27
TC	0.20	-0.39	0.71	0.15	0.20
DO	-0.32	-0.25	-0.65	-0.10	-0.13
COD	0.26	0.29	0.64	0.49	0.24
TURB	0.29	0.28	0.52	0.48	-0.31
TSS	0.16	0.27	0.20	0.84	0.25
Fe	0.09	0.05	0.07	0.84	0.39
Pb	0.10	-0.29	0.15	0.67	0.33
Mn	0.49	-0.06	0.21	0.59	0.13
Cr	0.11	0.00	0.12	0.12	0.86
Ni	0.18	0.30	-0.04	0.21	0.79
Cu	0.11	0.16	0.26	0.43	0.77
Zn	0.12	0.10	0.32	0.38	0.72
Eigenvalue	10.97	3.57	3.09	1.81	1.17
% Total variance	43.88	14.27	12.37	7.23	4.69
Cumulative % variance	43.88	58.15	70.52	77.75	82.44

Color coding: dark orange ( ) represents strong factor loading; blue ( ) represents moderate factor loading; pale yellow ( ) represents weak factor loading

health implications to humans after ingesting such crops or consuming the contaminated groundwater is another issue of concern. Our findings clearly indicate that secondary drains are responsible for the pollution in the Najafgarh drain which in turn is affecting the Yamuna River water quality. Therefore, regular monitoring and treatment of water pollutants at these two stages, i.e., secondary drains prior to their outfall in the Najafgarh drain and the Najafgarh drain prior to its outfall in the Yamuna River, could significantly help in reducing the load of pollutants in these interlinked systems. This will not only be helpful towards Govt. of India's efforts to clean the Yamuna River but might also open up avenues to rejuvenate the Najafgarh drain as the Najafgarh canal to serve as an important water resource for local people.

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Author contribution Mansi Vaid: Conceptualization, methodology, formal analysis and investigation, writing-original draft, resources

Kiranmay Sarma: Supervision, conceptualization, methodology, writing-review and editing, resources

Pramod Kala: Conceptualization, resources

Anshu Gupta: Supervision, conceptualization, methodology, writing-review and editing, resources

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Data availability The datasets generated or analyzed during this study are included in this published article (and its supplementary information files). The data cited in the current study are available in the reference list with their respective digital object identifier (DOI) wherever possible.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

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