Assessment of Surface Water Quality of River Kali-east: A Tributary of River Ganga in Uttar Pradesh, India

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Research Article

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Abstract

River Kali-East, a tributary of river Ganga, is a non-perennial river of India which is highly driven by the discharge of sewage and industrial effluent. Twenty-seven locations on the entire stretch (approx. 550 km) of river Kali-East were monitored which indicated that color varied as 20-200 Hazen, dissolved oxygen (DO) as 0-8.16 mg/l, biochemical oxygen demand (BOD) as 6.6-410 mg/l, chemical oxygen demand (COD) as 22-1409 mg/l, total suspended solids as 38-4386 mg/l, total dissolved solids as 180-2536 mg/l and fecal coliform as 4.9×10^2 - 34×10^7 MPN/100 ml. High BOD and COD in the river revealed untreated/partially treated industrial discharge into the river and the self-purification capacity of the river Kali-East has been inhibited for a long distance by heavy and undiminished influx of domestic sewage into the river. Twenty-six drains discharge a total organic load of 148 tonnes per day into the river. Maximum pollution load was contributed by Odean Nala (42%) in Meerut district. This study recommends strict regulatory norms for discharge of industrial effluents by the industries in the catchment area of the river, reduction in sewage treatment gap by utilizing alternative treatment technologies (such as constructed wetlands) and proper dilution of polluted river water to improve the overall quality of the river.

1. Introduction

Ganga is a perennial sacred river of India which is a life-line to millions who live on its course. Rapid urbanization and industrialization in the country is deteriorating the quality of river Ganga due to the increasingly high input of urban-industrial discharge (CPCB 2013). This increasing aquatic pollution is also affecting human health. In India, 80% of all diseases and 1/3rd of deaths were reported to be attributed to water-borne diseases (Puttick 2008). For abatement of pollution in river Ganga, the Government of India formulated the Ganga Action Plan (GAP) in 1986 to reduce sewage discharge in the Ganga river. Thereafter, GAP phase II was launched in 1993 to reduce the pollution load through its tributaries. In 2009, the National Ganga River Basin Authority (NGRBA) was formed for cleaning and conservation of river Ganga. However, a nine-fold increase in the discharge of sewage into the river is observed in recent years in comparison to 1985 (Dwivedi et al. 2018). In India, there is a huge gap (65%) between sewage generation and treatment in India and untreated sewage is being discharged into the river ecosystem (CPCB 2009).

Various researchers have assessed the water quality of river Ganga and its tributaries and the effects of anthropogenic activities on river water quality (Mandal et al. 2009; Dwivedi et al. 2018). Haritash et al. (2016) found high fecal coliform levels at Rishikesh (Uttarakhand) whereas Matta et al. (2018) reported high levels of turbidity, total solids and suspended solids at Rishikesh (Uttarakhand). Chaudhary et al. (2017) reported high metal concentration in the Ganga river in the stretch from Haridwar to Garh Mukteshwar. Siddiqui and Pandey (2019) reported high metal contents at Kanpur (Uttar Pradesh). Among tributaries of river Ganga, Mishra et al. (2015) reported the water of river Hindon unfit for human use, irrigation, and other life-supporting activities. Anthropogenic as well as natural factors degrade surface river waters and impair their use for drinking, industry, agriculture, recreation, and other purposes. This mandates a water quality monitoring program to safeguard freshwater resources (Pesce and Wunderlin 2000). In the present study, the catchment area of the Kali-East river consists of sugar, textile, pulp & paper, dairy & food, distillery, and chemical industries. The industrial effluents are characterized with high BOD, high COD, high amounts of organic and inorganic contaminants. Some of the difficult-to-treat pollutants such as chlorinated organics, suspended solids and organic wastes (released by pulp and paper mill effluents), phenols and mineral oils (released by petrochemical industry), etc. are also among the released industrial pollutants. These toxic industrial pollutants, if released untreated into the river stream, may degrade the quality of the river severely. These organic and inorganic pollutants are carcinogenic and cause serious physiological and neurological disorders (Ejaz et al. 2004; Pal et al. 2012).

The Hon'ble National Green Tribunal (NGT), Government of India stated that river water is considered to be fit for bathing when it meets the criteria of having Biochemical Oxygen Demand (BOD) less than 3.0 mg/l, Dissolved Oxygen (DO) more than 5.0 mg/l and Faecal Coliform (FC) bacteria to be less than 500 MPN/100 ml (NGT 2019a). Also, Environment Protection (Amendment) Rules, 2000 suggest pH 6.5–8.5, BOD $\leq$ 3 mg/l, DO $\geq$ 5 mg/l, and FC $<$ 2500 MPN/100 ml as the primary water quality criteria for outdoor bathing.

Considering the pollution load in the river Ganga, there is a strong need to assess and regulate pollution sources in the river Ganga and its tributaries. River Kali-East (a tributary of river Ganga) is a non-perennial river driven by sewage and industrial effluent discharge in non-rainy seasons. For assessing river pollution, studies are restricted to small stretches however for an efficient management strategy to control river pollution there must be a comprehensive study. The study should encompass the monitoring of water quality throughout the river and assessment of pollution sources in river Kali-East due to the release of industrial and domestic wastewater.

Considering these issues, the present study was carried out with following objectives: (i) to carry out a comprehensive evaluation of surface water quality of river Kali-East from its origin to the confluence with river Ganga; and (ii) to evaluate the status of pollution load and treatment in the catchment area of river Kali-East.

2. Materials And Methods

2.1. Description of the study area

Kali-East river is a non-perennial tributary of the holy river Ganga in India. The flow in the river is mainly due to industrial wastewater discharge or rainfall. It originates in Khatauli town (29°16'45.09"N, 77°47'18.96"E) in Muzaffarnagar district of Uttar Pradesh state of India where the flow in the river is attributed to a sugar mill drain. Thereafter, it traverses a distance of approximately 550 km through the districts of Meerut, Hapur, Ghaziabad, Bulandshahar, Aligarh and Kasganj in Uttar Pradesh. The river Kali-East meets river Ganga in Kannauj district of Uttar Pradesh at 27°0'45.34"N, 79°59'6.76"E. In the catchment area of river Kali-East, various industries (sugar, distillery, chemical, pulp & paper, and textile) are located. Climate is humid sub-tropical with predominantly three seasons namely summer season (March-May) which is extremely hot, winter season (November-February) which is cold and rainy season between June and October. The temperature in the area varies from 0 to 50°C. The Bay of Bengal branch of the Indian monsoon is the major bearer of rain in this area with an average annual rainfall of 840 mm. Approximately, 80% of the annual rainfall is received from the south-west monsoon during July to September.

Geologically, the study area lies within the Ganga-Yamuna interfluve. The top stratum consists of approximately 1.3 km thick layer of quaternary alluvium. Alluvial deposits are sub-divided into older and younger alluvium. Younger alluvium is restrained to river passages and the surroundings of the low-lying areas which is generally flooded during the monsoon season. The alluvium in this area encompasses alternate beds of sand and clay with occasional inter-beds of calcareous concretions. The granular zones consist of various sand grades varying from fine through medium to coarse sands (Singh 2004; Umar et al. 2008).

For the present study, 27 monitoring locations on river Kali-East were selected starting from its origin in Khatauli (Muzaffarnagar) to its confluence with river Ganga in Kannauj. During its course, 26 drains with different sources (domestic/industrial/mixed) meet with the river. At two locations, freshwater Ganga canals (upper and lower Ganga canals) meet with the river which decreases the pollution load in the river. The sampling locations on river Kali-East were selected in such a way so that the effect of the receiving wastewater from drains on the river can be assessed. The sampling locations on the river, drains and freshwater canals are shown in Fig. 1 and **Supplementary Figure S1**.

2.2. Collection of river and drain samples

Surface river water samples were collected from 27 selected locations during the pre-monsoon season (March-May) of 2019. The detail of sampling locations on the river is presented in Table 1.

Table 1
Detail of sampling locations on river Kali-East

District	Sampling Code	Location	Geographical coordinates	
			Latitude	**Longitude**
Muzaffarnagar	S1	Before confluence of Sugar mill drain at Khatauli	29.279192	77.788599
	S2	After confluence of Sugar mill drain	29.278181	77.787853
	S3	Downstream of Muzaffarnagar-Khatauli near Khadli Village	29.197999	77.799431
Meerut	S4	Upstream of village Saini	29.056165	77.767262
	S5	Downstream of village Saini	29.028941	77.792795
	S6	Upstream of Abu drain-1	28.969660	77.774254
	S7	Downstream of Abu drain-1	28.960122	77.765603
	S8	After confluence of Abu drain-2	28.9318893	77.756765
	S9	Downstream of Odean Nala	28.921457	77.756156
Hapur	S10	Upstream of Hapur drain-1	28.726175	77.831318
	S11	Downstream of Hapur drain-1	28.695226	77.848477
	S12	Downstream of Chhoiya drain	28.694523	77.850791
Ghaziabad	S13	Downstream of Hapur drain	28.63685	77.814130
	S14	Downstream of Kadrabad drain	28.625799	77.816904
	S15	Downstream of Gulaothi drain	28.591529	77.824883
Bulandshahar	S16	Upstream of Bulandshahar drains	28.420485	77.851609
	S17	Upstream of Bulandshahar Devipura drain	28.413062	77.858749
	S18	Downstream of Bulandshahar Devipura drain	28.412494	77.858969
	S19	Downstream of Bulandshahar drains	28.39207	77.864000
Aligarh	S20	Upstream of M/s Wave Distilleries and Breweries Ltd.	27.980513	78.199289
	S21	Downstream of M/s Wave Distilleries and Breweries Ltd.	27.974796	78.207298
Kasganj	S22	Downstream of Neem Nala	27.807538	78.543141
	S23	Upstream of Kasganj drain	27.787246	78.627322
	S24	Downstream of Kasganj drain	27.787246	78.627322
Kannauj	S25	At Khudaganj bridge	27.177500	79.676667
	S26	Upstream of Patta Nala	27.081433	79.927073
	S27	Downstream of Patta Nala	27.080855	79.931004

Grab-samples were collected for physico-chemical (color, pH, DO, BOD, COD, TSS, TDS, Cl^-, NH_3-N, NO_3-N and PO_4^{2-}) and biological (total and fecal coliform) properties of river water. Samples for color, pH, COD, TSS, TDS, Cl^-, NH_3-N, NO_3-N, and PO_4^{2-} were collected in polyethylene bottles. Samples for DO, BOD, total and fecal coliform were collected in glass bottles. Sampling bottles for total and fecal coliform bacteria analysis were pre-sterilized with 70 % v/v ethanol before use. Samples for NH_3-N were preserved with H_2SO_4, and DO & BOD samples were preserved with $MnSO_4$ and NaN_3. After collection, samples were transferred to the laboratory in an ice-box.

Wastewater samples were collected from 26 drains discharging into the river Kali-East. The detail of drains is shown in Table 2.

Table 2
List of drains discharging wastewater in to river Kali-East in India

Catchment area	Sampling Code	Drains	Source of pollution	Coordinates of the sampling point	
				Latitude	Longitude
Muzaffarnagar	D1	Sugar mill drain	Mixed	29.277512	77.771723
Meerut	D2	Village Saini drain	Mixed	29.045227	77.785281
	D3	Abu Nala-1	Mixed	28.974999	77.760229
	D4	Abu Nala-2	Mixed	28.938786	77.753759
	D5	Odean Nala	Mixed	28.932410	77.749792
	D6	Chhoiya drain	Mixed	28.712963	77.862721
Hapur	D7	Hapur drain	Mixed	28.642790	77.804845
	D8	Hapur city drain	Domestic	28.726201	77.829546
Ghaziabad	D9	Kadrabad drain	Mixed	28.635293	77.804746
Gulaothi	D10	Gulaothi drain	Mixed	28.591294	77.803061
Bulandshahar	D11	DM colony drain	Domestic	28.419883	77.85176
	D12	Behind chamunda mandir drain	Domestic	28.417103	77.853463
	D13	Devipura drain	Domestic	28.412642	77.858481
	D14	Behind shanidev mandir drain	Domestic	28.409911	77.860892
	D15	Faisalabad drain	Mixed	28.409000	77.864000
	D16	Kasaiwada drain	Domestic	28.407526	77.862330
	D17	Nahsal ghat drain	Domestic	28.404597	77.866333
	D18	Cheel ghat drain	Domestic	28.400653	77.866675
	D19	Chandbhari road Nala	Domestic	28.399883	77.865031
	D20	Adil Nala	Domestic	28.396225	77.862753
	D21	Maman road drain	Mixed	28.392665	77.863288
Kasganj	D22	Neem Nala	Domestic	27.808402	78.540834
	D23	Kasganj drain	Domestic	27.796154	78.652609
Kannauj	D24	Patta Nala	Mixed	27.080536	79.927143
	D25	Adanga Nala	Domestic	27.063611	79.944722
	D26	Tammi Nala	Domestic	27.051085	79.929433

Wastewater samples from drains were collected before the confluence point of the drain with the river Kali-East. Samples were collected using grab sampling technique for the determination of physico-chemical (color, pH, BOD, COD, TSS, TDS, NH_3-N and NO_3-N) and biological (total and fecal coliform) properties of river water. Samples for color, pH, BOD, COD, TSS, TDS, NH_3-N and NO_3-N were collected in polyethylene bottles. Samples for DO, total and fecal coliform were collected in glass bottles. Samples for NH_3-N were preserved with H_2SO_4, and DO samples were preserved with $MnSO_4$ and NaN_3. After collection, samples were transferred to the laboratory in an ice-box.

For metal analysis, grab samples of water/wastewater from the river and drains in polypropylene bottles were also collected. The samples were immediately acidified with HNO_3 after collection to avoid precipitation.

2.3. Analysis of river and drain samples

After reaching the laboratory, river/drain samples were analyzed for physico-chemical and biological parameters following standard methods (APHA 2017). Metal (As, Cd, Cr, Cu, Fe, Pb, Mn, Ni, Hg, Zn, Sb, Co, Se, and V) concentration in water/wastewater samples of river and drains was measured using atomic absorption spectrophotometer following standard protocols (APHA 2017).

2.4. Calculations

2.4.1. Flow measurement in drains

The flow of wastewater in drains was measured using Ball-float method (CPHEEO 2013). Instantaneous flow in drains was calculated as

$$Flow\,(Q) = A \times V$$

Where Q was measured in m^3/sec; A is the average cross-sectional area of flow in m^2; V is the average velocity of flow in m/sec.

The average cross-sectional area of flow was calculated as

$$Averagecross - sectionalareaofflow\,(A) = W \times D$$

where the average cross-sectional area of flow was measured in m^3/sec; W and D are width and depth of the flow measured in m.

Width, Depth, and average surface velocity are measured thrice and average values were considered for further calculation of flow.

As flow velocity is not identical in the entire cross-section of the drain, suitable correction factors were applied so that flow is not exaggerated/over-estimated (Subramanya 2009). A factor of 0.8 was used for averaging velocity and flow width. Therefore, the resulting factor (0.8 × 0.8) ~ 0.65 was considered for flow calculation in natural drains.

2.4.2. Organic load of drains

Organic load in drains was calculated as

$$Organicload\,(inTPD) = \frac{Flow\,(inMLD) \times BOD(inmg/l)}{1000}$$

where TPD is tonnes per day and MLD is million litres per day.

1.1. Quality assurance and quality control

Reliable results were guaranteed by following appropriate quality assurance protocols and procedures during sample collection, preservation, and analysis. Bottles were acid washed before the collection of samples. Samples were transported in ice-boxes to ensure data representativeness. The analytical quality was assured by using duplicate samples, reagent, and procedural blanks. The atomic absorption spectrophotometer was calibrated after every five readings using blank and drift reagents. High calibration coefficients were maintained ($r^2 \geq 0.99$) during the analysis of metals. For each metal, the limit of detection was calculated as thrice the standard deviation of blank samples.

3. Results And Discussion

3.1. River water quality

3.1.1. Physico-chemical properties of surface water of river

The river Kali-East originates in Khatauli town in the Muzaffarnagar district of Uttar Pradesh. The river flows for approximately 550 km before meeting river Ganga in Kannauj. During the time of sampling (March-May), the river was not receiving any water due to precipitation and the river Kali-East primarily carried sewage and industrial discharge. The physico-chemical properties of the river water are driven by the discharge of sewage and industrial effluents from sugar, distillery, chemical, food & dairy, pulp & paper, slaughter house and textile industries in the catchment area. The sugar industries only operate seasonally however, other industries run throughout the year.

In river water, the color varied as 20–200 Hazen, DO as 0-8.16 mg/l, BOD as 6.6–410 mg/l, COD as 22-1409 mg/l, TSS as 38-4368 mg/l, TDS as 180–2536 mg/l, Cl^- as 27–845 mg/l, NH_3-N as 1.5–77.4 mg/l, NO_3-N as 0.1–5.8 mg/l and PO_4-P as 0.2–5.2 mg/l. The physico-chemical properties of river water at 27 selected monitoring locations are presented in Table 3.

Table 3
Physico-chemical properties of surface water of river Kali-East in India

Sampling code	Monitoring location on river	Parameter												
		Color	pH	DO	BOD	COD	TSS	TDS	Cl^-	NH_3-N	NO_3-N	PO_4-P	TC	FC
S1	Before confluence of Sugar mill drain at Khatauli	Dry											-	-
S2	After confluence of Sugar mill drain	30	4.9	0	410	1070	259	1094	142	3.9	1.6	2.2	7×10^5	22×10^4
S3	Downstream of Muzaffarnagar-Khatauli near Khadli Village	51	7.3	0	78	167	88	1120	199	13.5	4.4	4.2	28×10^3	14×10^3
S4	Upstream of Saini village	Dry											-	-
S5	Downstream of Saini village	bdl	6.7	0	132	421	254	2536	845	13.4	2.2	1	46×10^5	31×10^5
S6	Upstream of Abu drain-1	bdl	7.2	0	80	246	132	2376	781	12.6	1.4	1.1	22×10^4	45×10^3
S7	Downstream of Abu drain-1	bdl	7.6	0	146	289	177	1176	316	77.4	3.9	3.4	16×10^6	92×10^5
S8	After confluence of Abu drain-2	bdl	7.1	0	130	375	411	708	113	27.2	0.8	3.4	54×10^7	22×10^7
S9	Downstream of Odean Nala	bdl	7.0	0	154	474	765	608	96	29.7	0.6	3.8	2×10^9	17×10^7
S10	Upstream of Hapur drain-1	200	7.3	0	80	778	466	804	121	54.2	1.4	4.9	13×10^8	34×10^7
S11	Downstream of Hapur drain-1	143	7.2	0	49	555	280	752	126	64	2.5	4.5	49×10^6	49×10^6
S12	Downstream of Chhoiya drain	178	7.2	0	86	1074	226	752	118	49	2.4	4.1	11×10^6	11×10^6
S13	Downstream of Hapur drain	154	7.2	0	92	469	265	836	146	55.8	2.6	5.2	33×10^5	33×10^5

DO dissolved oxygen, BOD biochemical oxygen demand, COD chemical oxygen demand, TSS total suspended solids, TDS total dissolved solids, Cl^- chloride, NH_3-N ammoniacal nitrogen, NO_3-N nitrate, PO_4-P phosphate, TC total coliform, FC fecal coliform

All parameters are presented in mg/l except colour (Hazen), pH, TC (MPN/100 ml), and FC (MPN/100 ml)

bdl below detection limit

Sampling code	Monitoring location on river	Parameter												
		Color	pH	DO	BOD	COD	TSS	TDS	Cl^-	NH_3-N	NO_3-N	PO_4-P	TC	FC
S14	Downstream of Kadrabad drain	173	7.3	0	73	567	384	960	165	47.8	2.8	5	78×10^5	2×10^6
S15	Downstream of Gulaothi drain	bdl	7.5	0	78	209	206	828	146	30.8	1.5	3.2	94×10^5	94×10^5
S16	Upstream of Bulandshahar drains	bdl	7.4	0	33	114	92	844	171	29.5	1	3.4	22×10^5	13×10^5
S17	Upstream of Bulandshahar Devipura drain	bdl	7.4	0	45	219	308	816	156	26.7	1.5	3.3	22×10^5	79×10^4
S18	Downstream of Bulandshahar Devipura drain	bdl	7.4	0	52	135	72	820	142	37.6	1.5	3.6	38×10^6	12×10^6
S19	Downstream of Bulandshahar drains	bdl	7.3	0	186	1409	4368	870	127	32.6	1.5	3.8	16×10^6	54×10^5
S20	Upstream of M/s Wave Distilleries and Breweries Ltd.	bdl	7.6	0.8	22	76	48	870	160	33.3	0.1	4.4	35×10^3	17×10^3
S21	Downstream of M/s Wave Distilleries and Breweries Ltd.	bdl	7.6	0.6	23	67	38	848	158	31.7	0.2	4.4	24×10^4	24×10^4
S22	Downstream of Neem drain	bdl	6.6	5.7	28	111	98	1108	394	27.1	5.8	1.6	13×10^3	34×10^2
S23	Upstream of Kasganj drain	bdl	7.2	5.9	27	43	72	294	59	6.2	0.4	0.4	790	490
S24	Downstream of Kasganj drain	bdl	7	8.2	6.9	22	74	180	27	2.6	0.3	0.2	13×10^3	93×10^2
S25	At Khudaganj bridge	80	8.6	7.7	15.7	61.9	-	316	40.4	1.5	3.4	0.6	3.3×10^4	2×10^3
S26	Upstream of Patta drain	70	8.3	7.6	8.2	50.3	-	415	75	3.3	3.9	0.7	3.3×10^5	3.3×10^4
S27	Downstream of Patta drain	60	8.1	7.7	15.6	57.2	-	504	75	2.2	3.1	0.7	1.6×10^7	2.4×10^6

DO dissolved oxygen, BOD biochemical oxygen demand, COD chemical oxygen demand, TSS total suspended solids, TDS total dissolved solids, Cl^- chloride, NH_3-N ammoniacal nitrogen, NO_3-N nitrate, PO_4-P phosphate, TC total coliform, FC fecal coliform

All parameters are presented in mg/l except colour (Hazen), pH, TC (MPN/100 ml), and FC (MPN/100 ml)

bdl below detection limit

The color of water influences the photosynthesis process due to differential penetration of light, energy budget, stratification due to thermal gradients, and the aesthetic appearance of the aquatic ecosystems (Branco and Torgersen 2009). Color is a prominent feature of natural water when good quality water is produced from it for domestic and industrial purposes (Chow et al. 2007). In filtered water, the color chiefly arises from the dissolved organic carbon (fraction of total organic carbon) and ferric iron (Fe (III)) bound on it (Weyhenmeyer et al. 2014). The temperature drives certain chemical and biological reactions taking place in water and aquatic organisms (Shrivastava and Patil 2002). The pH rigorously affects the water quality by changing the alkalinity, the solubility of metals and hardness of the water (Osibanjo et al. 2011; Sener et al. 2017). The pH is driven by several factors such as aerosol and dust particles, dissolved materials, human-made wastes as well as wastes from plants through photosynthesis (Mitra et al. 2018).

The dissolved oxygen governs the metabolism of the biological community in an aquatic ecosystem and indicates the trophic status of a water body (Saksena et al. 2008). The dissolved oxygen reduces in the water due to respiration of biota, decomposition of organic matter, rise in temperature, oxygen demanding wastes and inorganic reductants such as hydrogen sulfide, ammonia, nitrates, ferrous iron, etc. (Sahu et al. 2000). Dissolved oxygen is frequently used to evaluate the water quality in reservoirs, bays, and rivers (Sanchez et al. 2007). In a study conducted by Rudolf et al. (2002) on water quality of San Vicente Bay (Chile), the dissolved oxygen content was considered as an index of water quality to assess the influence of industrial and municipal effluents on aquatic ecosystems.

Dissolved oxygen content and biochemical oxygen demand are greatly influenced by a combination of physical, chemical, and biological properties of oxygen demanding substances, encompassing algal biomass, dissolved organic matter, ammonia, volatile suspended solids, and sediment oxygen demand (Quinn et al. 2005; Kannel et al. 2007). Biochemical oxygen demand accounts for the extent of organic pollution in aquatic ecosystems (Khan et al. 2016). The oxygen requirement during the decomposition of organic matter and oxidation of inorganic chemicals is predicted through COD tests. Theoretically, if COD concentration is higher, then the water is considered polluted (Amneera et al. 2013).

Nitrates are the most thermodynamically stable and non-toxic form of inorganic nitrogen as it is the end product of the aerobic decomposition of the organic nitrogenous compound (Jaji et al. 2007). The nitrate concentration in the surface water is normally low (0–18 mg/l) however it may reach to elevated levels due to agricultural runoff (excess application of nitrogenous fertilizers and manures), oxidation of nitrogenous waste products in human and animal excreta and refuse dump runoff (Pillay and Olaniran 2016; Mitra et al. 2018). The excess nitrogen transported as nitrate-nitrogen to rivers leads to eutrophication and episodic and persistent hypoxia (dissolved oxygen < 2 mg/l) (Mitsch et al. 2005). The existence of chloride in river water is due to the organic waste in water, primarily of animal origin. Also, major sources of phosphate in river water are domestic sewage, agricultural effluents and industrial wastewaters (Saksena et al. 2008). The properties of surface water in Indian rivers are shown in Table 4.

Table 4
Properties of surface water in rivers in India and in the present study

Location	River	Year	Parameter							Reference
			pH	DO	BOD	COD	TDS	Cl^-	NO_3^-	
Rishikesh (India)	Ganga	2008	9-10.5	7.8–16.1	4.3–19.5	-	18–85	10-32.5	-	Haritash et al. (2014)
Haridwar (India)	Ganga	2012-13	6.9-8	-	2.1–2.9	4.6–6.8	-	-	0.02–0.04	Matta et al. (2017)
Haridwar to Garh Mukteshwar (India)	Ganga	2014-15	7.1–8.9	1.2–9.3	2–87	19–791	108.6–1743	-	1.7–15.8	Chaudhary et al. (2017)
Kolkata (India)	Ganga	2005-06	6.7–7.3	-	35.1–121	129–342	40–78	-	-	Aktar et al. (2010)
Uttarakhand and Uttar Pradesh (India)	Ramganga	2014	7.3	-	15	29.4	22.2	8.6	4.7	Khan et al. (2016)
Ramganga (India)	Ramganga	2014-15	7.2–8.3	0.2–9.2	0.6–46.3	3-229	27.2-619.1	3.7–27.8	-	Gurjar and Tare (2019)
Gomti (India)	Gomti	2002-03	7.5–8.9	0.5-9	1.8–19	8.7–54	213–275	5–14	-	Singh et al. (2005)
Uttar Pradesh (India)	Gandak	2006	6.2–8.6	-	-	-	60.1-192.6	3.5–121	14–38	Bhardwaj et al. (2010)
Uttar Pradesh (India)	**Kali-East**	**2019**	**4.9–8.6**	**0-8.2**	**6.9–410**	**22-1409**	**180–2536**	**27–845**	**0.1–4.4**	**Present study**

DO dissolved oxygen, BOD biochemical oxygen demand, COD chemical oxygen demand, TDS total dissolved solids, Cl^- chloride, NO_3 nitrate

All parameters are expressed in mg/l except pH

In the present study, the river was highly polluted until approximately 143 km downstream from the origin of the river. In this stretch (Muzaffarnagar to Bulandshahar district), DO was NIL and BOD was high (up to 410 mg/l). However, after the mixing of the upper and lower Ganga canal in the polluted water of the river Kali-East, the water quality improved (DO increased and BOD decreased). The DO level increased to 7.7 mg/l and BOD decreased to 15.6 mg/l before meeting the river Ganga.

In Muzaffarnagar district, high BOD (410 mg/l), COD (1070 mg/l) and TDS (1094 mg/l) in the river water downstream sugar mill drain were observed. Also, low pH (4.9) in river water indicates industrial discharge from near-by industries. In Meerut district, pronounced foul smell around the river was observed D/s Chhoiya drain and Hapur drain. The color of the river water at these locations varied as 154–178 Hazen. The foul smell in the river water may be attributed to anaerobic decomposition of organic matter present in the river. Also, it was observed that river water U/s Chhoiya drain, D/s Chhoiya drain, and D/s Hapur drain is being utilized for irrigation of adjoining agricultural fields. Irrigation of agricultural fields with the polluted river water may deteriorate human health due to the bio-amplification of pollutants to the human food chain. In Bulandshahar district, the river water quality (BOD-186 mg/l, COD-1409 mg/l) deteriorated after the discharge of 11 drains into the river. Till Bulandshahar, there is no DO in the river. However, after traversing a distance of approximately 143 km, the river meets upper Ganga canal and the river water quality improved substantially (DO-0.8 mg/l, BOD-22 mg/l, and COD-76 mg/l) at U/s Wave Distilleries and Breweries Ltd., Aligarh after meeting the canal. In Aligarh district, the river further meets another canal i.e. lower Ganga canal and the river water quality after meeting the canal improved further (DO-5.9 mg/l and fecal coliform-490 MPN/100 ml) at U/s Kasganj drain. In Kannauj district, the DO in the river Kali-East increased to 7.7 mg/l before the confluence with river Ganga.

3.1.2 DO-sag curve

The DO-sag curve in the river Kali-East is presented in Fig. 2. Considering bathing water quality criteria (pH 6.5–8.5, DO ≥ 5 mg/l, BOD ≤ 3 mg/l, and FC < 500 MPN/100 ml), the water quality of the river Kali-East was found complying with bathing water standards w.r.t. pH except for one location namely, U/s Sugar mill drain in Muzaffarnagar. Low pH (4.9) in the river at this location may be attributed to the discharge of untreated effluent from near-by sugar industries. With respect to DO, no location in the stretch from Muzaffarnagar to Aligarh was found suitable for bathing. Due to the mixing of freshwater from the Ganga canal in the river Kali-East, the water quality in Kasganj and Kannauj before meeting the river Ganga was meeting the primary water quality criteria w.r.t. DO. Also, no location in the whole stretch of the river meets bathing water quality w.r.t. BOD. High BOD in the river is due to the discharge of untreated domestic sewage and industrial effluents from the catchment area.

For fecal coliform, only two locations, namely, (i) U/s Kasganj drain in Kasganj and (ii) at Khudaganj bridge in Kannauj were meeting bathing water quality standards.

3.1.3 Biological properties of surface water of river

Total coliform (TC) and fecal coliform (FC) levels in surface water of the river were estimated (Table 3). In river water, the total coliform varied from 790 to 2×10^9 MPN/100 ml and fecal coliform varied from 490 to 34×10^7 MPN/100 ml. Fecal pollution in river water could be caused by untreated sewage, fecal bacteria remaining in the treated wastewater, and feces of wild and farmed animals. Moreover, open defecation along the banks of the river could also be the reason for elevated fecal coliform concentrations in river water (Bravo et al. 2017; Singh and Saxena 2018; Haque et al. 2019). The stretch of river from Muzaffarnagar to Bulandshahar contained high total and fecal coliform levels due to the discharge of untreated domestic sewage from the drains. However, after meeting the upper Ganga canal and lower Ganga canal in Aligarh, the total coliform and fecal coliform levels in river water at U/s Kasganj drain reached 790 and 490 MPN/100 ml, respectively. The total and fecal coliform concentration in surface water of the river Kali-East before the confluence with river Ganga were 2.8×10^8 and 9.4×10^6 MPN/100 ml. The discharge of high levels of coliforms by the river Kali-East into the river Ganga increases the fecal pollution load in river Ganga which could have adverse effects on the population dependent on the water of the river Ganga for drinking and cooking purposes.

3.1.4 Metals concentration in surface water of river

Metals (As, Cd, Cr, Cu, Fe, Pb, Mn, Ni, Hg, Zn, Sb, Co, Se, and V) concentration in surface river water samples are shown in Table 5.

Table 5
Metal concentration (mg/l) in surface river water collected from different locations on river Kali-East in India

Location	Metals													
	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Hg	Zn	Sb	Co	Se	V
S1	Dry													
S2	bdl	bdl	0.02	0.08	15.70	0.11	0.28	0.01	bdl	0.14	bdl	bdl	bdl	bdl
S3	bdl	bdl	bdl	bdl	1.96	bdl	0.25	bdl	bdl	0.02	bdl	bdl	bdl	bdl
S4	Dry													
S5	bdl	bdl	bdl	0.02	1.75	0.01	0.21	bdl	bdl	0.07	bdl	bdl	bdl	bdl
S6	bdl	bdl	bdl	0.01	0.73	bdl	0.13	bdl	bdl	0.06	bdl	bdl	bdl	bdl
S7	bdl	bdl	bdl	0.13	2.87	0.02	0.17	bdl	bdl	0.10	bdl	bdl	bdl	bdl
S8	bdl	0.15	0.09	0.36	10.52	0.09	0.32	0.11	bdl	1.02	bdl	bdl	bdl	bdl
S9	bdl	0.05	0.05	0.25	11.32	0.07	0.29	0.05	bdl	0.65	bdl	bdl	bdl	0.06
S10	bdl	0.03	0.04	0.13	5.17	0.03	0.25	0.04	bdl	0.42	bdl	bdl	bdl	bdl
S11	bdl	0.04	0.06	0.17	7.44	0.05	0.28	0.05	bdl	0.5	bdl	bdl	bdl	bdl
S12	bdl	0.02	0.03	0.09	3.46	0.03	0.24	0.03	bdl	0.28	bdl	bdl	bdl	bdl
S13	bdl	0.02	0.03	0.1	4.19	0.03	0.25	0.03	bdl	0.3	bdl	bdl	bdl	bdl
S14	bdl	0.02	0.03	0.08	3.89	0.02	0.26	0.02	bdl	bdl	bdl	bdl	bdl	0.06
S15	bdl	0.02	0.02	0.07	3.63	0.02	0.22	0.02	bdl	0.22	bdl	bdl	bdl	bdl
S16	bdl	bdl	bdl	0.03	1.82	bdl	0.21	bdl	bdl	0.13	bdl	bdl	bdl	bdl
S17	bdl	0.02	0.03	0.11	7.31	0.03	0.29	0.03	bdl	0.32	bdl	bdl	bdl	0.05
S18	bdl	bdl	bdl	0.03	1.15	0.01	0.21	bdl	0.11	bdl	bdl	bdl	bdl	bdl
S19	bdl	0.10	0.19	0.77	67.6	0.32	0.89	0.17	bdl	1.96	bdl	0.03	bdl	0.17
S20	bdl	bdl	bdl	bdl	1.16	bdl	0.26	bdl	bdl	0.03	bdl	bdl	bdl	bdl
S21	bdl	bdl	bdl	bdl	1.08	bdl	0.33	bdl	bdl	0.04	bdl	bdl	bdl	bdl
S22	bdl	bdl	bdl	bdl	2.38	bdl	0.31	bdl	bdl	BDL	0.01	bdl	bdl	bdl
S23	bdl	bdl	bdl	bdl	1.69	bdl	0.09	bdl	bdl	0.01	bdl	bdl	bdl	bdl
S24	bdl	bdl	bdl	bdl	3.33	bdl	0.10	bdl	bdl	0.02	bdl	bdl	bdl	bdl
S25	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.08	bdl	bdl	bdl	bdl	bdl	bdl
S26	bdl	0.01	bdl	bdl	bdl	bdl	bdl	0.08	bdl	bdl	bdl	bdl	bdl	bdl
S27	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.12	bdl	bdl	bdl	bdl	bdl	bdl

bdl below detection limit

Metals concentrations (mg/l) ranged as Cd bdl (below detection limit)-0.15, Cr bdl-0.19, Cu bdl-0.77, Fe bdl-15.7, Pb bdl-0.32, Mn bdl-0.89, Ni bdl-0.17, Hg bdl-0.11, Zn bdl-1.96, Sb bdl-0.01, Co bdl-0.03 and V bdl-0.17. Arsenic and Selenium were not found in river water. Metals in river water may be attributed to the discharge of untreated sewage from the catchment areas into the river. Also, the discharge of untreated/improperly treated industrial wastewater could also release toxic metals into the river water. The sources of metals such as Cd, Cr, and Cu are reported to be domestic as well as commercial (ATSDR 2012; Masood and Malik 2011). Apart from domestic wastewater, the catchment area of the river Kali-East comprises of several industries pertaining to sugar, textile, pulp & paper, dairy & food, distillery, and chemical sectors. These industries may also contribute to metal pollution in the river Kali-East. For e.g., textile wastewater consists of Cu, Fe, Mn, Pb, Zn, Cd, and Cr (Fenta 2014; Oyebamiji et al. 2019), and distillery wastewater contains Cu, Cr, Zn, Fe, Ni, Mn, and Pb (Chowdhary et al. 2018). The composition of wastewater generated by food and dairy and chemical industries depends upon the product-specific raw materials.

3.2 Pollution load due to drains

Twenty-six drains (domestic and industrial) discharge wastewater into the river Kali-East accounting for total flow and an organic load of 803 MLD and 148 tonnes per day, respectively. Odean Nala is the major contributor in terms of pollution load (42%). Two drains namely the Odean Nala (25%) and Abu Nala-2 (25%) accounted for 50% of the total wastewater being discharged into the river. The district-wise distribution of drains contributing pollution load into the river Kali-East is presented in Fig. 3. Out of the eight districts, the maximum number of drains are observed in Bulandshahar i.e. 11, however, the maximum pollution load was contributed by Meerut i.e. 67.7 % of the total pollution load on the river Kali-East.

[Insert Fig. 3 **here]**

In drains, the color varied as 37–317 Hazen, pH as 5.1–8.2, BOD as 21.8–1067 mg/l, COD as 104–1752 mg/l, TSS as 48–946 mg/l, TDS as 552–2572 mg/l, NH3-N as 5–82 mg/l and NO3-N as 0.7–4.6 mg/l. The physico-chemical properties of wastewater in drains meeting river Kali-East are shown in Table 6.

Table 6
Physico-chemical properties of wastewater in drains meeting river Kali-East in India

Sampling code	Name of drain	Parameter											
		Flow	Organic load	Colour	pH	BOD	COD	TSS	TDS	NH_3-N	NO_3-N	TC	FC
D1	Sugar mill drain	20.6	22	52	5.1	1067	1752	946	1296	5	1.9	45×10^4	45×10^4
D2	Village Saini drain	33.4	12.9	317	7.8	385	893	346	2572	6	3.2	17×10^5	61×10^4
D3	Abu drain-1	82.5	7.7	120	7.9	93	405	215	1248	82	4.6	16×10^6	92×10^5
D4	Abu drain-2	199.2	17.7	87	6.5	89	401	265	780	39	1.5	94×10^6	26×10^6
D5	Odean drain	200	62.2	120	7.2	311	721	498	1008	14	2.9	17×10^7	17×10^7
D6	Chhoiya drain	21.8	0.6	70	7.9	27	119	48	1132	23	1.4	46×10^4	24×10^4
D7	Hapur drain	34.6	2.3	226	7.6	67	251	129	1136	35	2.5	54×10^5	35×10^5
D8	Hapur city drain	1.2	0.1	102	7.6	75	210	51	1004	28	3.7	16×10^6	54×10^5
D9	Kadrabad drain	35.5	3.1	166	7.6	88	226	54	1204	26	2.3	7×10^6	33×10^5
D10	Gulaothi drain	54	8.1	75	7.3	150	498	654	872	36	1.5	92×10^7	92×10^7
D11	Maman road drain	36	2.0	76	7.3	56	201	483	552	21	0.8	54×10^6	35×10^6
D12	Aadil nagar drain	11.4	1.7	81	7.3	146	411	463	848	20	1.9	54×10^6	35×10^6
D13	Chandbhari road drain	5.6	1.0	97	7.1	173	597	503	1016	26	2.7	16×10^{10}	94×10^8
D14	Cheel ghat drain	3.5	0.2	187	7.6	46	160	96	1012	24	1.0	22×10^7	11×10^7
D15	Nahsal ghat drain	2.5	0.4	87	7.7	178	575	478	828	12	1.9	54×10^{10}	54×10^{10}
D16	Kasaiwada drain	-	-	72	7.4	158	564	475	1104	17	1.6	17×10^7	6×10^7
D17	Faisalabad drain	16.2	3.4	114	7.1	207	482	227	1060	32	2.7	28×10^6	12×10^6

BOD biochemical oxygen demand, *COD* chemical oxygen demand, *TSS* total suspended solids, *TDS* total dissolved solids, NH_3-N ammoniacal nitrogen, NO_3-N nitrate, TC total coliform, FC Fecal coliform

All parameters are presented in mg/l except flow (million litres per day), organic load (tonnes per day), colour (Hazen), pH, TC (MPN/100 ml), and FC (MPN/100 ml)

Flow in drains D16 was very low (not measurable), D18 was covered with municipal solid waste, stagnant wastewater was present in D19 and D22 was dry

Sampling code	Name of drain	Parameter											
		Flow	Organic load	Colour	pH	BOD	COD	TSS	TDS	NH_3-N	NO_3-N	TC	FC
D18	Behind shanidev mandir drain	-	-	37	8.2	54	194	224	660	14	0.7	17×10^6	12×10^6
D19	Devipura drain	-	-	70	7.4	92	245	139	672	21	1.4	35×10^8	24×10^7
D20	Behind chamunda mandir drain	20.7	1.8	97	7.2	89	261	285	612	20	1.3	35×10^6	17×10^6
D21	DM colony drain	3.5	0.2	57	7.5	69	239	350	560	22	1.3	12×10^8	82×10^7
D22	Neem drain	-	-	-	-	-	-	-	-	-	-	-	-
D23	Kasganj drain	4.8	0.4	67	7.1	78	221	98	700	24	1.5	16×10^6	16×10^6
D24	Patta drain	11.5	0.3	50	7.7	21.8	104	58.1	780	23.3	1.8	4.5×10^5	2.0×10^5
D25	Adanga drain	4	0.2	40	7.2	50.4	207	437	666	12.6	1.4	2.2×10^8	9.4×10^7
D26	Tammi drain	1.2	0.1	50	7.4	53.2	183	376	702	20.3	1.6	2.8×10^8	9.4×10^6

BOD biochemical oxygen demand, *COD* chemical oxygen demand, *TSS* total suspended solids, *TDS* total dissolved solids, NH_3-N ammoniacal nitrogen, NO_3-N nitrate, TC total coliform, FC Fecal coliform

All parameters are presented in mg/l except flow (million litres per day), organic load (tonnes per day), colour (Hazen), pH, TC (MPN/100 ml), and FC (MPN/100 ml)

Flow in drains D16 was very low (not measurable), D18 was covered with municipal solid waste, stagnant wastewater was present in D19 and D22 was dry

High BOD (1067 mg/l), high COD (1752 mg/l), and acidic pH (5.1) were observed in the Sugar mill drain which indicated the untreated/partially treated industrial discharge into the river. Saini Village drain consisted of high BOD (385 mg/l) and high COD (893 mg/l) which may be attributed to the discharge of wastewater from paper industries in the catchment area. Also, Odean Nala comprised BOD-311 mg/l and COD-721 mg/l which may be due to industrial discharge from textile industries in the vicinity.

4. Pollution Mitigation Strategy

Illegal discharge of untreated domestic and industrial wastewater increases the pollution load in the river Kali-East. Consequently, the polluted water of the river Kali-East pollutes the river Ganges after meeting it in Kannauj (Uttar Pradesh). To mitigate the pollution load on the river due to domestic sewage and industrial effluent, eleven sewage treatment plants (STPs) and one common effluent treatment plant (CETP) are constructed to treat wastewater generated in the basin of the river. The total sewage treatment capacity in the basin of river Kali-East is 181 MLD, out of which 168 MLD is located in Meerut (12 STPs) and 13 MLD in Kannauj (01 STP). For treating industrial effluent, one CETP (2.1 MLD) is located in the Pilakhua town of Hapur district. In spite of the construction of STPs, there is a huge gap (46.9%) between sewage generation and sewage treatment capacity in the catchment area of the river Kali-East. The competent authority must ensure that all sewage treatment facilities operate at the designed capacities. Also, the up-gradation of STPs must be considered if possible. All stakeholders must ensure the treatment of sewage before being discharged into the river. Different types of industries (sugar, textile, pulp & paper, dairy & food, distillery, and chemical industries) in the catchment area of the river are a potential threat to the water quality. Timely inspection of industries regarding the compliance of discharge standards should be carried out by the competent authority to ensure the water quality of the river Kali-East. The river water is also used by farmers for irrigation of agricultural fields (Fig. 4). This must not be practiced by the farmers to avoid bio-accumulation and bio-amplification of pollutants into the food chain.

[Insert Fig. 4 **here]**

The Hon'ble NGT (Government of India) has ordered the construction of sufficient sewage treatment facilities for treating drains discharging urban sewage into the river (NGT 2019b). The Hon'ble NGT also suggested the application of phytoremediation/constructed wetlands to treat drains carrying municipal sewage. In compliance with the NGT order, a total of nine locations in the catchment area of the river Kali-East may be considered for the construction of treatment wetlands to treat domestic sewage and industrial effluent (Fig. 5).

[Insert Fig. 5 **here]**

Constructed wetlands are a viable treatment technology that encompasses the use of natural components (such as soil, gravel, and plants) to treat wastewater (Angassa et al. 2020). Researchers have recommended the use of constructed wetlands for the treatment of municipal and industrial wastewaters (Flores et al. 2019; Hussain et al. 2019; Maine et al. 2019; Rahi et al. 2020). Rana and Maiti (2018) used constructed wetlands planted with *Colocasia esculenta* (L.) Schott and *Typha latifolia* L. to removing COD (71.1%), total Kjeldahl nitrogen (72.3%), Cu (83.4%), Cd (83.1%), Mn (74.5%), Cr (73.6%), Co (84.2%), Zn (66.1%), Pb (77.9%), and Ni (80%) from municipal wastewater. Rai et al. (2015) reported removal of Pb (86%), Cu (84%), Zn (83.5%), As (83.2%), Cr (81.6%), Co (76.8%), Ni (68.1%), and Mn (62.2%) from urban sewage in Haridwar (India) by using constructed wetlands planted with *T. latifolia*, *Phragmites australis* (Cav.) Trin. ex Steud. and *C. esculenta*. Apart from metals, the average removal efficiency of physico-chemical characteristics, i.e., conductivity, TDS, BOD, TSS, NO_3-N, NH_4-N and PO_4-P in winter and summer season were observed from 55.3–91.61% to 64.8–94.1%, respectively. Phytoremediation could also prove successful for the treatment of industrial wastewaters. Rai and Tripathi (2009) reported the removal of Hg from wastewater by a free-floating water fern *Azolla pinnata* R.Br. (80–94%) and submerged aquatic macrophyte *Vallisneria spiralis* L. (70–84%).

5. Conclusion

The water quality of the river Kali-East was assessed from its origin to confluence with river Ganga. The surface water quality indicated that biochemical oxygen demand varied as 6.6–410 mg/l, chemical oxygen demand as 22-1409 mg/l, color as 20–200 Hazen, DO as 0-8.16 mg/l, total suspended solids as 38-4386 mg/l, total dissolved solids as 180–2536 mg/l and fecal coliform as 490 – 34 × 107 MPN/100 ml. This study revealed that the river was highly polluted until approximately 143 km downstream from the origin of the river. In this stretch (Muzaffarnagar to Bulandshahar district), DO was NIL and BOD was high (up to 410 mg/l). However, after the mixing of the upper and lower Ganga canal in the polluted water of the river Kali-East, the water quality improved (DO increased and BOD decreased). The DO level increased to 7.7 mg/l and BOD decreased to 15.6 mg/l before meeting the river Ganga. With respect to DO, no location in the stretch from Muzaffarnagar to Aligarh was found suitable for bathing. Also, no location in the whole stretch of the river meets bathing water quality w.r.t. BOD. High BOD and COD in the river revealed untreated/partially treated industrial discharge into the river and the self-purification capacity of the river Kali-East has been inhibited for a long distance by the heavy and undiminished influx of domestic sewage into the river. A total of 26 drains carrying sewage and industrial effluent discharge an organic load of 148 tonnes per day into the river. The maximum pollution load was contributed by Odean Nala (42%) in the Meerut district. This study recommends strict regulatory norms for industries in the catchment area of the river, reduction in sewage treatment gap and proper dilution of polluted river water to improve the overall quality of the river. The study also recommends the employment of constructed wetlands technology to treat the drains discharging wastewater into the river.

Declarations

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Figures

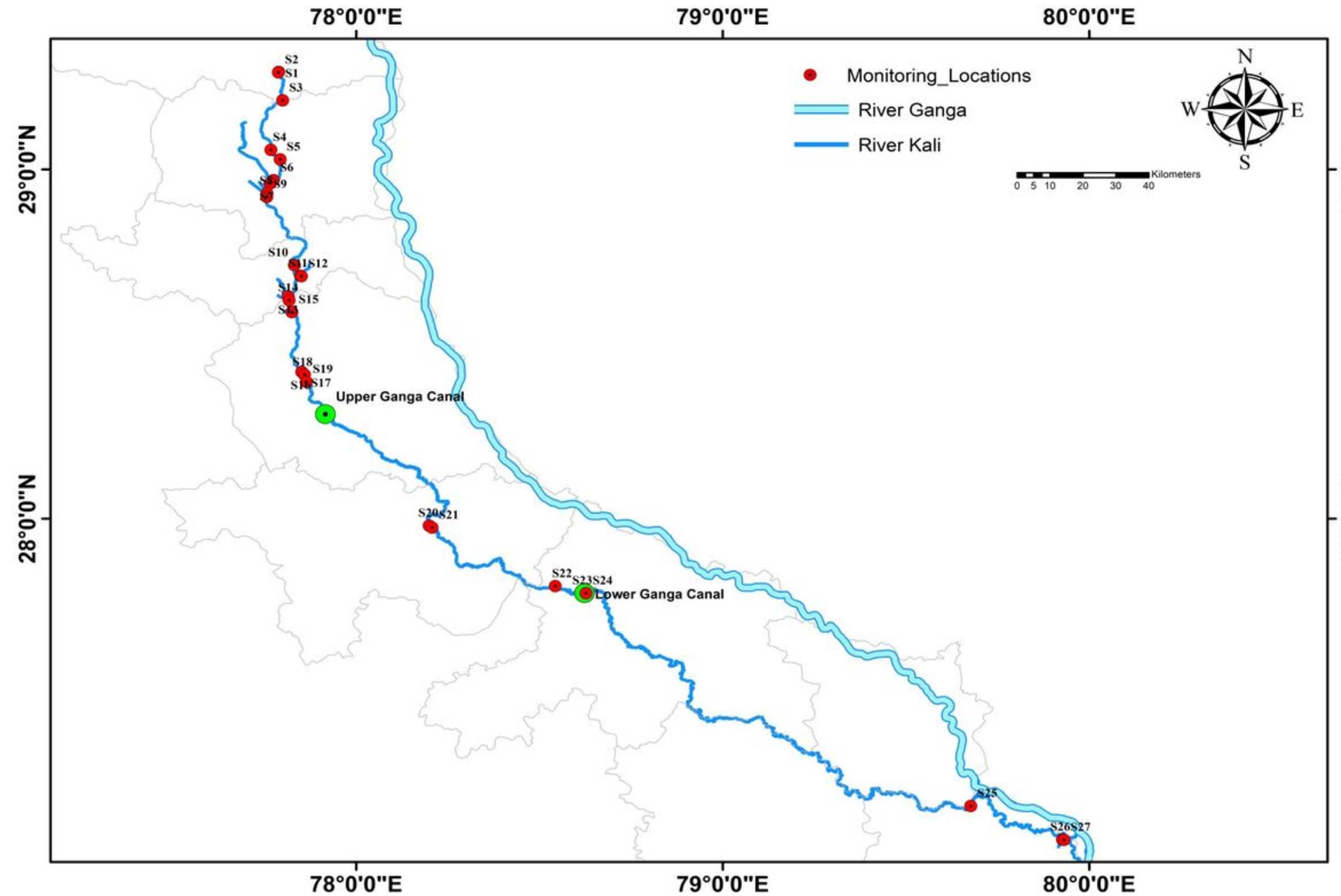

Figure 1

Map of water quality monitoring locations on river Kali-East in Uttar Pradesh state of India Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

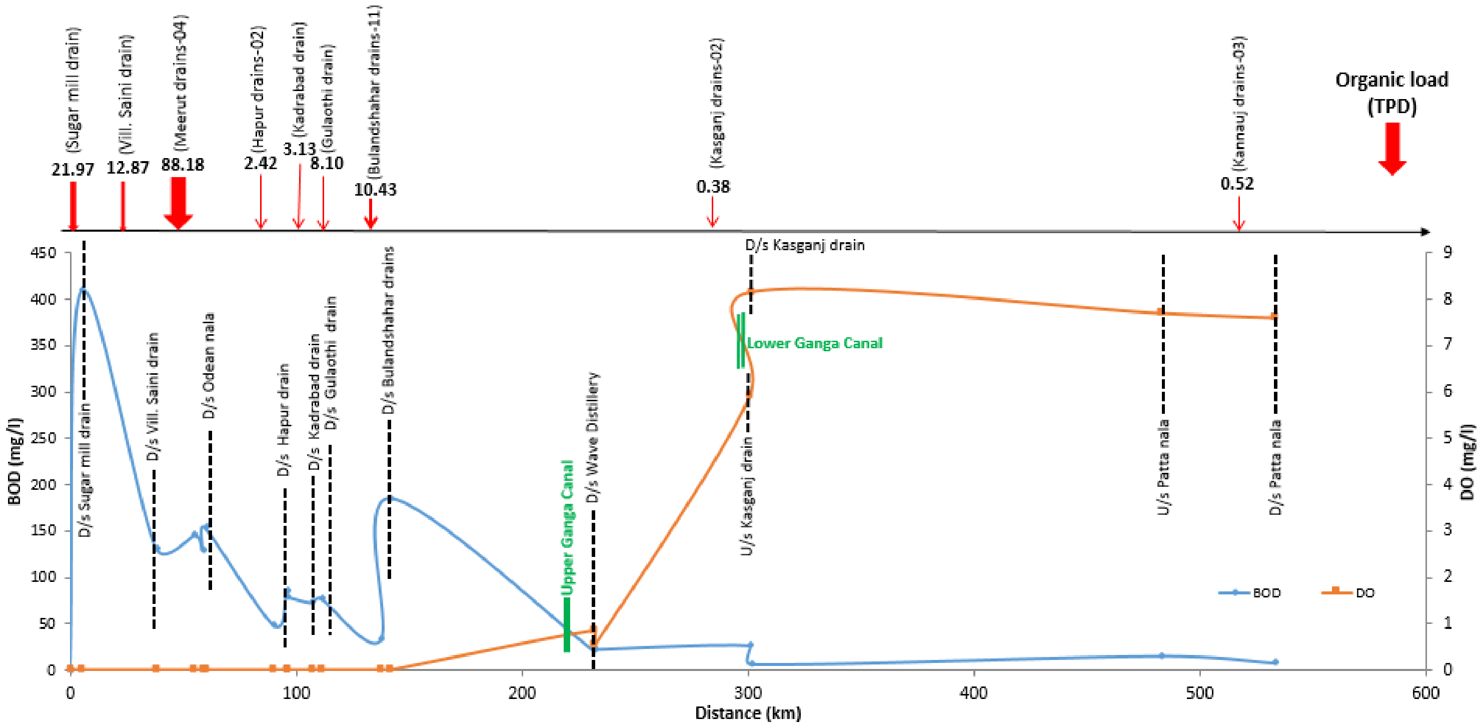

Figure 2

DO-sag curve of river Kali-East from origin to confluence with the river Ganga (Organic load discharged by drains in river Kali-East is expressed in tonnes per day (TPD))

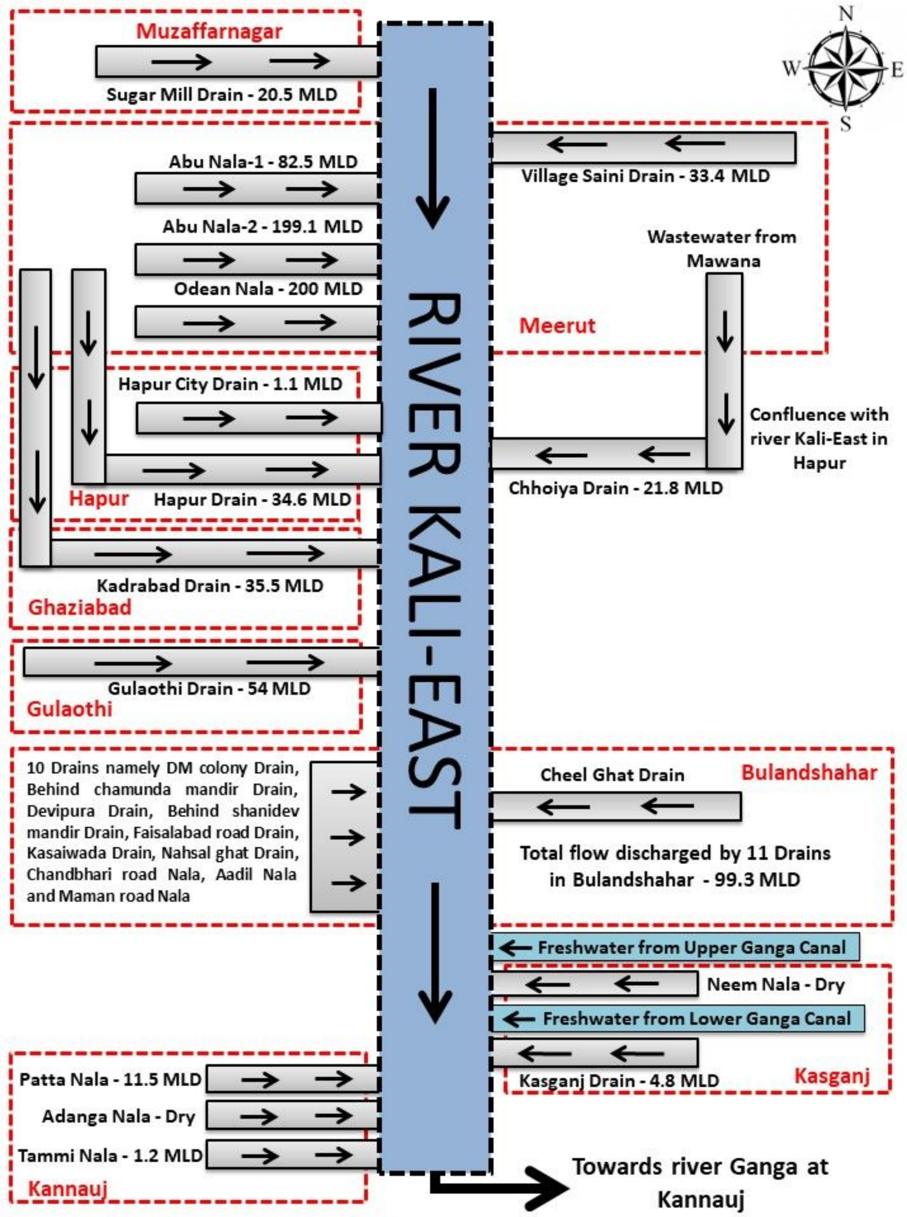

Figure 3

Schematic representation of drains and canals meeting river Kali-East in different districts of Uttar Pradesh (India) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 4

(a) River Kali-East upstream Wave Distilleries and Breweries, Aligarh (b) Extraction of river water downstream Neem Nala (or drain) for irrigation of adjacent agricultural fields

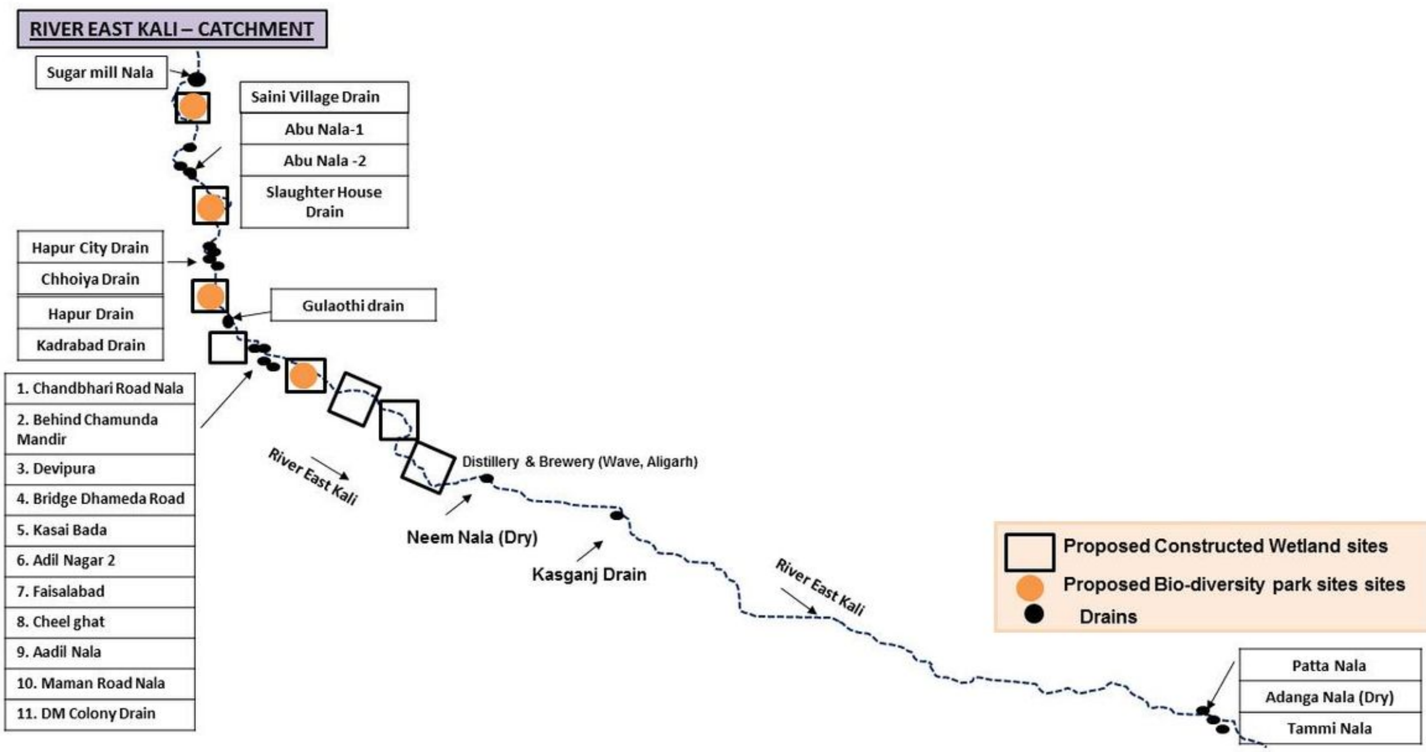

Figure 5

Proposed constructed wetland sites in the catchment area of river Kali-East Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

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