



Effective data convergence, mapping, and pollution categorization of ghats at Ganga River Front in Varanasi

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Abstract

Rivers support life of Indian population but water pollution threatens human health. There is no consensus data for water quality (WQ) of rivers in India including River Ganga. For robust stakeholder participation and community involvement and governance, a consolidation of WQ parameters for River Ganga from different data sources is essentially needed. The priority to combat environmental, economic, and social dislocations due to river pollution also necessitates WQ data convergence, its availability in public domain for policy makers, citizens, researchers, etc, and mapping with respect to the flowing river. Lack of real-time data limits civic involvement in river management. This paper is a novel attempt to consolidate the WQ data available in literature for River Ganga at Varanasi during 1992–2016. Results indicate water of River Ganga to have high coliform and BOD levels due to direct discharge of sewage waste from Varuna and that from Varanasi city. Categorization of ghats based on WQ parameters reveal pollution status of ghats to vary from low to highly polluted (coliform data excluded as it changes the category of all the ghats to highly polluted). More urban population with lack of readiness of authorities to follow the law appear to be major contributors towards failure of river management strategies. The consolidated information mapped with demographic data can be used as data management tools for sustenance of River Ganga. A need for change in policy framework and publicizing the real-time data seem key solutions for improving water quality of River Ganga at Varanasi.

Keywords Map · Population · River Ganga · Pollution · Varanasi · Water quality

Introduction

Water scarcity is the one of the major issues affecting more than half of the global population (Mekonnen and Hoekstra 2016). Nearly 844 million people strive for basic drinking

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water services, and the pollution degradation of 40% is reported for available water sources (Onda et al. 2012; WHO and UNICEF 2017; Daniel et al. 2018). In recent times, there has been a tremendous increase in the water scarcity levels owing to pollution of its sources (Clarke 2013; Kummur et al. 2016). Furthermore, consumption of polluted water results in several forms of health hazards (UNICEF 2010). Nearly 80% of Indian population suffer from water-borne diseases with death from diarrhea cases tolling to as high as about 600,000 persons annually (Wohl 2010; Conaway 2015). Increased rate of water pollution can be attributed to direct discharge of untreated wastewater into its rivers (Girija et al. 2007; Narain 2014; Marathe et al. 2017). Ganga Basin supports nearly 42% of Indian population where total water potential including surface and groundwater accounts to 695.02 km³ of water (Misra 2011). Being the largest river in India, Ganga drainage area covers 30 cities, 70 towns, and thousands of villages (Narain 2014; Nandi et al. 2016). This indicates dependence of large population on River Ganga for its daily water use. Expanding urbanization has increased the pace of degradation of surface and groundwater resources affecting infiltration and thereby

resulting in cases of urban flooding specially in basin areas (Misra 2011). Apart from affecting the hydrological cycle it also causes quality degradation of river and groundwater resources with further degradation due to global warming (Almeida and Dias 2016). In addition to urbanization, excess exploitation of water resource, deforestation in the local regions, and criminal discharge of untreated industrial waste which is against Indian law have made the problem of pollution in River Ganga much grave. Ganga with its largest drainage area is worst affected by direct discharge of untreated wastewater (Nandi et al. 2016). Each day, more than 1 billion liters of untreated wastewater comprising of toxic chemicals and raw sewage are dumped directly into the River Ganga (CPCB 2013a).

There exists a good administrative set-up to deal with the water resource sector in India yet water remains a matter of state. The Ministry of Jal Shakti, Department of Water Resources, River Development, and Ganga Rejuvenation (formerly Ministry of Water Resources, River Development, and Ganga Rejuvenation) is the authority for the water of the nation and from time-to-time lays down necessary regulations and policies. Merely creating authorities is not sufficient, effective management of water resources predominantly depends upon satisfactory functioning of the institution and the treatment of water on the public trust doctrine (Bhatt and Bhatt 2017). The governing actions towards management of River Ganga have a long history. In 1980, an extensive survey was conducted by Central Board for Prevention and Control of Water Pollution, New Delhi (now known as Central Pollution Control Board), on the recommendation of Department of Environment of the Indian Government. It resulted in the birth of Ganga Action Plan I (GAP-I) for cleaning of river in 1985. The same year also witnessed public outrage and case file by M.C. Mehta resulting in pollution fines and closure of various environmentally non-complying industries (Das and Tamminga 2012). This year was also the birth of the Central Ganga Authority (CGA) under the supervision of Department of Environment (Tare et al. 2003). Attainment of this goal was formulated on the premise of different objectives like development of various sewage treatment plants in urban areas, renovation of existing treatment plant, expansion of sewer systems to mouth of open drains, and unserved areas as well as construction of electric crematorium for the cremation activities at the river banks (Das and Tamminga 2012). Evaluation reports by various agencies stated fair results of GAP-I with reduction of discharge of organic pollution and improvement in water quality but still water was found unfit even for bathing purpose (Baker et al. 2000; Tare et al. 2003). Ganga Action Plan-II (GAP-II) with a focus of change in the funding arrangement with an equal share between center and state

was introduced by CGA during running of GAP-I between 1993 and 1996 (Jaiswal 2007; Das and Tamminga 2012). GAP-II targeted for the pollution management of three main tributaries of Ganga (Yamuna, Damodar, and Gomti) and 25 Class I towns (with a population of more than 100,000) remaining from the GAP I (Jaiswal 2007; Das and Tamminga 2012). The GAP phase II is still in process but the success rate is reported to be only 12% (Ching and Mukherjee 2015). Moreover, several river restoration programs designed for River Ganga like GAP-I and GAP-II met with an utter failure due to lack of proper planning and stakeholder participation (Das and Tamminga 2012). Planning of any restoration strategy requires access to large scale real-time data. Planners for restoration of River Ganga are stuck with the notion of uniform existence of source of pollution along its entire stretch. However, there exists a regional variation in its source characteristics of contaminant polluting River Ganga (Joshi et al. 2009; Singh 2010; Das 2011; Paul 2017). In recent years, there has been a change in the river health assessment paradigm using components of catchment, channel, floodplain, biotic, and water quality (Nandi et al. 2016). Component of water quality is generally assessed on three most common parameters, namely, physicochemical parameters, heavy metal level, and microbial load (Fig. 1).

Varanasi is an oldest continually inhabited city recognized as a holy pilgrimage site for Hindus (Singh 2011). Religious significance of Varanasi makes it an attractive tourist spot for various activities like bathing, temple visit, and cremation (Rana and Singh 2011). An estimated 230–410 million liters per day (MLD) of raw sewage is discharged into River Ganga at Varanasi (CPCB 2013a, b). Deteriorating condition of the river causes threat to its aquatic biodiversity, livelihood of locals, and various health ailments (Sarkar et al. 2012; Chaudhary et al. 2017). Restoration strategies fail due to lack of real-time data and civic participation (Das and Tamminga 2012). Access to real-time data suffers with several limitations such as sporadic data; discontinuous monitoring; and lack of consensus among researchers and lack of uniformity among selected parameters. In preview of all the above, the present article is an attempt to explore the existing literature pertaining to pollution of River Ganga with an objective to converge them and draw a consensus out of all these data. The novelty of the paper is that, for the first time, a comprehensive water quality data for the period 1992–2016 for River Ganga at Varanasi is converged to obtain a common baseline data set. This data set has been further utilized for developing maps for categorization of pollution levels at various ghats of River Ganga at Varanasi. Apart from mapping of ghats to various levels of pollution, the data is also plotted with total population of Varanasi to understand the relationship between population vs. pollution therein.

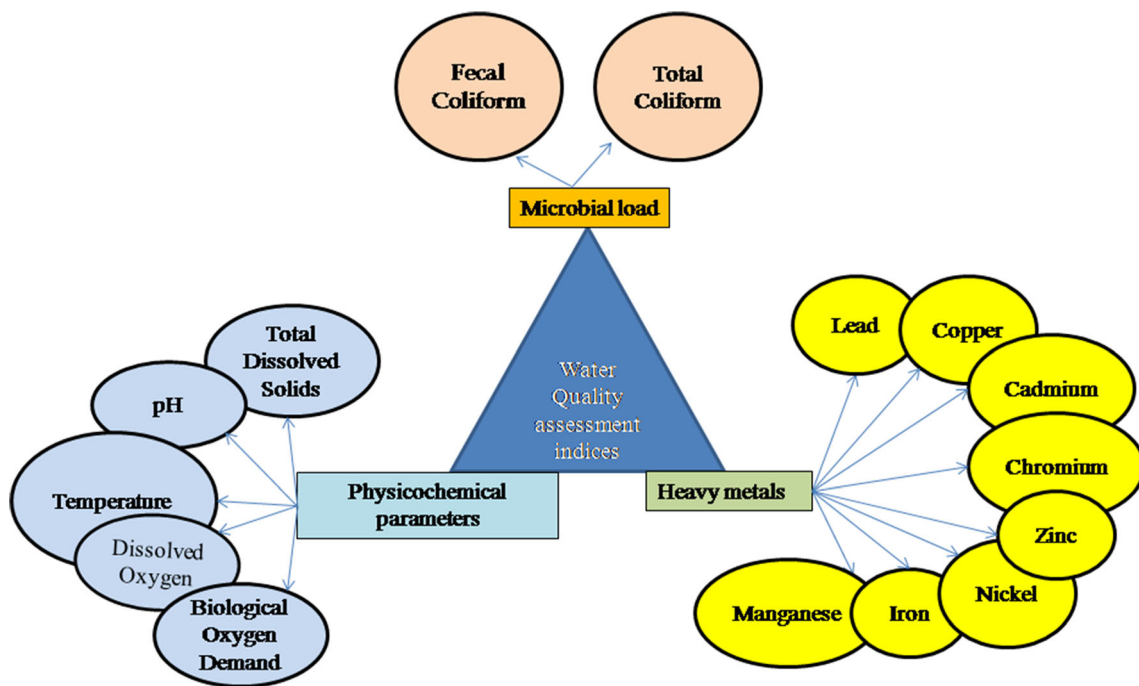


Fig. 1 Three most commonly studied parameters being used for water quality assessment as in literature

Materials and methods

Study site

Varanasi is situated along the left crescent-shaped bank of the River Ganga at 25° 16' N latitude and 83° 1' E longitude at 80.71 meters (264.8 ft) above sea level in the middle of Ganga valley of North India, a part of Eastern Uttar Pradesh (Fig. 2). The city bears a humid subtropical climate with extreme summer and winter temperatures. The dry summer starts in April

and lasts until June, followed by the monsoon season from July to October experiencing periodic flood in the monsoon (July–September). Varanasi is covered by ghats (banks) at a stretch of 6.8 km between Varuna and Asi, built in the 17th century as a structure for flood control (Singh 1993). River Ganga receives water from River Varuna that originates near Phoolpur in Allahabad and flows east-to-southeast direction for approximately 100 km, and confluences with River Ganga near Adikeshwar Ghat at downstream in Varanasi. The River Varuna receives domestic wastewater every day from the industries and the sewage system flows from a part of municipal area of Varanasi which contributes to its deteriorating water quality and that of Ganga as well. Each ghat of Varanasi is attached with some religious significance either as a spot for temples or for cremation place (Singh 2011) thereby attracting pilgrims from all over world. The changing physiochemical characteristics including biochemical oxygen demand (BOD), chemical oxygen demand (COD), acidity, chlorides, nitrates, fecal coliform, and heavy metals exceed far above the permissible limits (Sharma et al. 2007; Mishra et al. 2009; Singh 2010) suggesting the deteriorating condition of the River Ganga. The data for various water quality assessment reported in literature show large variations in their criteria of assessment highlighting the need of a comprehensive water quality data.

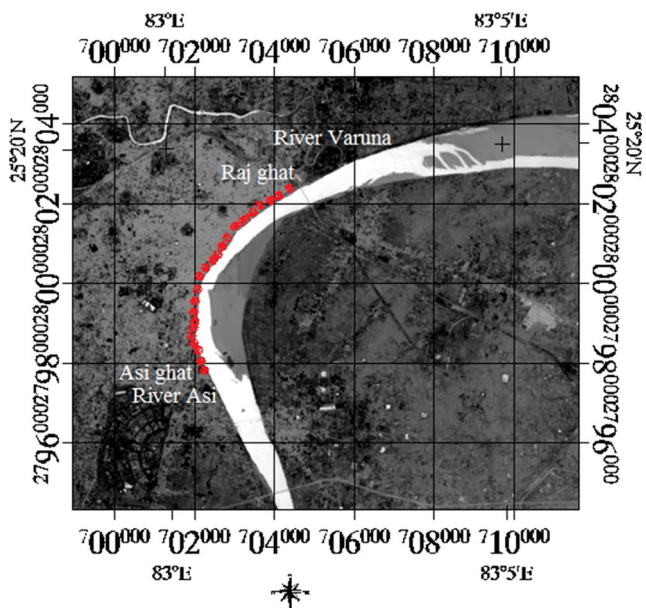


Fig. 2 The stretch of River Ganga at Varanasi showing the ghats

Methodology

Site visits were conducted to identify major sewage infrastructure sites, proposed sewage treatment plants (STPs) locations

and to the ghats of Varanasi. Coordinates for each ghat and all major sewage infrastructure such as major drains, sewage pumping stations, and STPs were recorded using global positioning system (GPS) (Trimble Juno SC model). An extensive literature review of peer-reviewed journals was conducted for water pollution at ghats of Varanasi. Literature with an assessment time of more than 3 months was selected for this study. In total, 52 research articles, government reports, and news articles published during 2001–2016 were critically analyzed. Average annual value for each parameter were taken to avoid seasonal variations including a range of average values between highest and lowest values taken into account. Literature was also reviewed to compile data for effluent discharge from three STPs (Dinapur, Bhagwanpur, and DLW) and was compared with the standard discharge values (Sawal 1986). Interviews were conducted with state water professionals, primarily water quality agencies and experts to fill the gap of missing data in literature. Data were statistically analyzed for STPs and water quality data. The census (2011) data for Varanasi was used to obtain the total population of each ward and associated drains (Supplementary Table 1) and choropleth maps were created in ArcGIS 10.1.

Results

Water quality of River Ganga at Varanasi (1992–2016)

Based on literature, water quality data were obtained for 21 prominent ghats of Varanasi for the study period of 1992–2016. The data primarily emphasizes upon assessment of basic physicochemical parameters and heavy metals. Water quality data thus obtained was then classified following Indian standards for water quality (BIS 2012) (Table 1) into four categories (Table 2). From Table 2, the water quality of River Ganga at Varanasi ranged from very less polluted to highly polluted. Water classified as very less polluted can be considered suitable for 5 different types of water use, whereas less polluted and moderately polluted water was found suitable for 4 and single water use, respectively (Table 2). The category highly polluted shows water quality characteristics similar to a drain and therefore was found unsuitable for any type of water use (Table 2).

Largely, the literature reported water quality measurements for temperature, pH, DO, BOD, total coliform (TC), fecal coliform (FC), and total dissolved solids (TDS); however, very few sources tested for heavy metals, namely, lead (Pb), copper (Cu), zinc (Zn), chromium (Cr), cadmium (Cd), nickel (Ni), iron (Fe), and manganese (Mn). Details of water quality data for last 26 years (1992–2016) for River Ganga at Varanasi as categorized under various categories are listed in Table 3. The percentage of ghats in this study falling under very less, less, moderately and highly polluted categories is illustrated as

Table 1 Water quality standards for classes of water for various purposes as per BIS 2012. Units for TC and FC are given in MPN/100 ml. For all other parameters except pH, the values are in mg/l

Class of water use	pH	DO	BOD	Total coliform	TDS	Lead	Zinc	Chromium	Cadmium	Manganese	Nickel	Copper	Iron
A Drinking water source without conventional treatment but after disinfection	6.5–8.5	6.0	2.0	50	500	0.1	1.5	0.05	0.01	0.5	–	1.5	0.3
B Outdoor bathing	6.5–8.5	5.0	3.0	500	500	–	–	1.0	–	–	–	–	–
C Drinking water source with conventional treatment followed by disinfection	6.5–8.5	4.0	3.0	5000	1500	0.1	1.5	0.05	0.01	0.5	–	1.5	50
D Fish culture and wildlife propagation	6.5–8.5	4.0	3.0	–	–	–	–	–	–	–	–	–	–
E Irrigation, industrial cooling, or controlled waste disposal	6.5–8.5	4.0	3.0	–	2100	–	–	–	–	–	–	–	–

Table 2 Ranking of water quality for River Ganga at Varanasi based on the data obtained from different researches (1992–2017)

Ranking	Type	pH	DO (mg/L)	BOD (mg/L)	Total coliform (MPN/100 ml)	Fecal coliform (MPN/100 ml)	TDS (mg/L)	Lead (mg/L)	Zinc (mg/L)	Chromium (mg/L)	Cadmium (mg/L)	Manganese (mg/L)	Nickel (mg/L)	Copper (mg/L)	Iron (mg/L)
Highly polluted	Drain	1–12.5	0–1.9	above 30	above 5000	above 5000	above 2100	above 1	above 30	above 2	above 2.0	above 2.0	above 3	above 3	above 50
Moderately polluted	E	6.5–8.5	2–3.9	3.1–30	500.1–5000	500.1–5000	1500–2100	0.11–1	15.1–30	1.1–2	0.015–2.0	0.51–2.0	0.071–3	1.5–3	3.1–50
Less polluted	B, C, D, E	7.5–8.5	4–5.9	2.1–3	50.1–500	50.1–500	500.1–1500	0.011–0.1	5.1–15	0.051–1	0.004–0.014	0.11–0.5	0.021–0.07	0.055–1.5	0.31–3
Very less polluted	All (A–E)	6.5–7.0	6 or above	0–2	0–50	0–50	0–500	0–0.01	0–5	0–0.05	0–0.003	0–0.1	0–0.02	0–0.05	0–0.3

Fig. 3. Majority of the ghats (43%) were found to be highly polluted followed by less polluted ghats (33%). 19% ghats were moderately polluted and only 5% of the ghats were found to be very less polluted. Total coliform and fecal coliform are secondary criteria for assessing the quality of water and have not been used for water quality assessment in the literature. These two parameters were not considered for the categorization of the ghats as these values far exceed the standard value for all the ghats. Inclusion of these two parameters for classification will change the category of all the ghats to be highly polluted. Heavy metal concentration for majority of the ghats was found to be in either less or moderately polluted category. Levels of DO, BOD, TC, and FC exceeded limits for drinking and bathing as per standards given by Central Pollution Control Board at almost all ghat locations (Table 3). The TC and FC levels ranged from as high as 1.06×10^8 MPN/100 ml and 6.40×10^8 MPN/100 ml at Varuna confluence and the lowest TC levels in the range ~ 310 MPN/100 ml is reported for Shivala and Samne ghats (Dataset 1992–2011) whereas the lowest FC of 58 MPN/100 ml was associated with Samne ghat (Hamner et al. 2006, 2007, 2013; Dataset 1992–2011). Levels of DO were beyond the permissible limit for bathing at several of the ghats including major ghats as Asi ghat (3.6–8.3 mg/L), RJP ghat (4.75–9.37 mg/L), and Varuna confluence (1.4–5.66 mg/L) (Dataset 1992–2011; Singh and Singh 2010; CPCB 2013a, b, 2014; Hamner et al. 2006, 2013; Vaseem and Banerjee 2013; Abed and Jazie 2014; Singh et al. 2016). BOD values showed large range variations and were reported to be above drinking and bathing standards for almost every ghat including Asi (2.8–36.89 mg/L), Dashashwamedh (7.4–27.77 mg/L), and RJP ghat (4.23–59.96) (Dataset 1992–2011; Singh 2010; CPCB 2013a, b, 2014; Hamner et al. 2006, 2007, 2013; Vaseem and Banerjee 2013; Abed and Jazie 2014; Singh et al. 2014, 2016). Altered pH levels compared to standards were reported for most of the locations with large variations at Asi ghat (7.6–9.3) and Raj Ghat (8.01–10.3) (Dataset 1992–2011; Singh and Singh 2010; CPCB 2013a, 2014; Hamner et al. 2006, 2013; Vaseem and Banerjee 2013; Abed and Jazie 2014; Singh et al. 2015, 2016; CWC 2011) (Table 3).

The data for heavy metal from the literature were reported for only 11 ghats. The level of lead, cadmium, and chromium exceeded the limit of water quality standards (Table 3). Only specific ghats showed values higher than standard limits for zinc and manganese (Table 3). Value for iron and copper was found within the standard limit for all of the reported ghats (Table 3). Levels of Pb at Asi ghat ranged from 0.09–0.84 mg/L (Singh 2011; Vaseem and Banerjee 2013; Singh et al. 2016), at RJP ghat from 0.19–0.2 mg/L (Singh 2011; Singh et al. 2016), and was 0.24 mg/L for Raj Ghat (Vaseem and Banerjee 2013). Copper levels were also shown to be high at

most locations including Asi ghat (0.08–0.29 mg/L) (Singh 2011; Vaseem and Banerjee 2013; Singh et al. 2016) and Raj ghat (0.305 mg/L) (Vaseem and Banerjee 2013). Chromium levels ranged at Asi and Harishchandra ghat ranged between 0.05–0.26 mg/L, 0.03–0.07 mg/L respectively and were as high as 0.48 mg/L at Raj ghat (Singh et al. 2016; Singh 2011; Vaseem and Banerjee 2013). Cadmium levels at Harishchandra ghat ranged from 0.02–0.023 mg/L (Singh et al. 2016; Singh 2011) and at Dashashwamedh from 0.02–0.06 mg/L (Singh 2011; Singh et al. 2014, 2016). Iron levels in Ganga water also varied widely at ghats such as Asi ghat (0.27–3.27 mg/L) (Singh 2011; Vaseem and Banerjee 2013; Singh et al. 2016) and Raj ghat (0.1–6.87 mg/L) (CWC 2011; Vaseem and Banerjee 2013) (Table 3).

Water quality data for effluent from STP (1992–2016)

Site visit revealed treatment capacity of 80 MLD, 8 MLD, and 12 MLD for Dinapur, Bhagwanpur, and DLW STPs, respectively. Literature suggests daily sewage generation of 230–410 MLD far exceeded the treating capacity of the STPs in Varanasi (CPCB 2013a, b). Moreover, 1.8 MLD of trickling filter at Bhagwanpur STP was non-functional further reducing its treatment capacity (Table 4). The upper limit of TSS, BOD, COD, ammonia, and phosphate at all three STPs exceeded water quality standards for surface water discharge (Table 4). TSS ranged between 13–153 mg/L, 45–157 mg/L, and 140–142 mg/L respectively for Bhagwanpur, Dinapur, and DLW STPs (Singh et al. 2004; CPCB 2013b, Mishra 2015). The COD values at Dinapur, Bhagwanpur, and DLW STPs ranged from 39 to 880 mg/L, 15.7–204.0 mg/L, 157–478 mg/L, respectively (Singh et al. 2004; Rai et al. 2010; CPCB 2013b; Mishra 2015). Similarly, the BOD values at Dinapur ranged from 14–340 mg/L, at Bhagwanpur from 9.6–107.0 mg/L, and at DLW from 26–156 mg/L (Rai et al. 2010; CPCB 2013b; Mishra 2015). Phosphate levels ranged from 0.19–9.37 mg/L, 0.85–10.39 mg/L, and 0.76–58.28 mg/L at Bhagwanpur, Dinapur, and DLW, respectively (CPCB 2013b; Mishra 2015; Rai et al. 2010). Ammonia levels ranged from 11.9–15.5 mg/L at Dinapur (Singh et al. 2004; Dataset 1992–2011), recorded as 6.2 mg/L for Bhagwanpur (WHO and UNICEF 2017) and 9 mg/L for DLW (WHO and UNICEF 2017). Presence of heavy metals such as zinc (Zn), copper (Cu), cadmium (Cd), lead (Pb), chromium (Cr), and nickel (Ni) were demonstrated in the effluent of all three STPs (Table 4). Except for Cd and Pb, the levels of all the heavy metals (Zn, Cu, Cr, Ni) at the three STPs were well below the permissible limits for surface water discharge (Table 4). The upper limits of cadmium and lead exceeded the water quality standards for surface water discharge at all three STPs (Table 4). Pb ranges were between 0.12–0.22 mg/L, 0.05–0.80 mg/L, and 0.08 to 0.62 mg/L at Bhagwanpur, Dinapur, and DLW respectively (Singh et al. 2004; Sharma et al. 2007;

Rai et al. 2010; Mishra 2015). Cadmium levels were reported to be between 0.08–2.65 mg/L at Bhagwanpur, 0.02–2.25 mg/L at Dinapur, and 0.01–2.23 mg/L at DLW (Singh et al. 2004; Sharma et al. 2007; Mishra 2015; Rai et al. 2010) (Table 4). It is evident from Table 4 that all the three functional STPs in this study partially comply to the standards for STP discharge, especially for pH, Zn, Cu, Cr, and Ni in particular but do not comply for physicochemical properties.

Sewage discharge and its effect on population of Varanasi

Visit to the study site revealed presence of 25 drain discharges into River Ganga at Varanasi which comply with the data range of 5–30 major drains reported in literature (CPCB 2013a; Hamner et al. 2013). Choropleth maps created using location and spread of drains, STPs, and pumping stations; severity of heavy metal and physicochemical pollution to the population of Varanasi gave major insight to the study (Fig. 4). All the major drains opening into River Ganga, their major pumping stations, and all the STPs (new and old) of Varanasi are shown in Fig. 4a. There are 6 sewage treatment plants in Varanasi, 3 of which are currently functional, while other 3 are under construction (GIZ ASEM 2011). Currently, functional STPs include Bhagwanpur, DLW, and Dinapur which all utilize activated sludge processing (ASP) technology. The new STPs are at Goitha, Ramana, and Dinapur extension with a capacity of 120 MLD, 50 MLD, and 140 MLDs, respectively (BIS 2012; CPCB 2013b; Samir 2017; Ganga Action Plan Project Phase II 2018). The Dinapur extension plant shall utilize ASP while the Goitha plant and the Ramana plant are proposed to utilize both sequencing batch reactor technology (BIS 2012; CPCB 2013b; Samir 2017; Ganga Action Plan Project Phase II 2018). Goitha and Dinapur are proposed to open within the year (2018) while Ramana is proposed for November 2019 (Ganga Action Plan Project Phase II 2018). The Goitha plant will treat sewage from trans-Varuna area, new Dinapur will treat sewage coming from the main city, and Ramana STP will treat sewage currently flowing from Asi Nala (GIZ ASEM 2011) (Fig. 4a). It can be noted that there are 11 pumping stations to move sewage around the city. Of these 7 pumping stations are along the 6.5–7.0 km stretch of River Ganga at Varanasi (Nandi et al. 2017) while the remaining 4 are along the banks of the Varuna River (GIZ ASEM 2011) (Fig. 4a). Major drains present in the 90 wards of the city of Varanasi have been illustrated as Fig. 4b. It is observed that among 90 wards of Varanasi, 04 wards have more than 28 drains, 09 wards have drains between 15–28, and 63 wards have the number of drains between 0–14 (Fig. 4b). Furthermore, among these 63 wards, sixteen of them (1, 14, 40, 51, 52, 59, 60, 62, 63, 67, 68, 69, 74, 78, 80, and 83) do not have presence of any major drains (Fig. 4b). Ward no. 16 has 42 drains (maximum number) discharging directly on the

Table 3 Water quality data for different ghats of River Ganga at Varanasi compiled from literature for the period 1992–2016 and the categorization of each ghat based upon pollution level

Location (no. of sources)	Period	Temp. (°C)	pH	DO (mg/L)	BOD (mg/L)	TC (MPN/100 ml)	FC (MPN/100 ml)	TDS (mg/L)	Pb (mg/L)	Cu (mg/L)
Samne Ghat (5)	2001–2016	16.50–27.80	*7.70	5.20–8.60	3.42–9.9	*307.45	58–27611	291.33–459.00	0.17–0.18	0.030–0.057
Aghoreshwar Ghat (2)	2001–2013	16.33–27.53	nd	7.07–8.40	3.48–4.2	nd	18200–21333	***230.00–340.00	nd	nd
Narayan Ghat (2)	2001–2013	16.33–27.53	nd	7.08–8.33	3.75–3.80	nd	17,059–20,600	***230.00–340.00	nd	nd
Assi Nala (6)	2001–2015	16.00–30.33	7.46–8.00	3.90–7.00	6.20–6.11	***500,000–4,500,000	235,000–48,800,000	294,790–608.40	nd	nd
Assi Ghat (10)	2001–2016	17.56–28.00	7.60–9.30	3.60–8.30	2.8–3.689	488.65–173,500	888–150,000	80.00–457.00	0.09–0.84	0.080–0.290
Tulsi Ghat (5)	2001–2013	15.50–30.00	7.89–8.11	5.30–8.90	3.67–9.00	48,705.88–88,500.00	29,059–620,000	208.81–350.00	*0.45	*0.102
Shivala Ghat (5)	2001–2013	16.50–30.00	7.70–8.23	5.67–8.59	4.20–17.63	301.68–810,000.00	601–386,000	230.00–408.00	*0.04	*0.120
Harishchandra Ghat (5)	2001–2016	16.00–27.80	7.60–8.10	4.17–8.00	6.2–4.698	*532.95	97–66,000	250.00–439.00	0.04–0.06	0.020–0.081
Chauki Ghat (2)	2010–2011	***21.00–33.70	***7.00–7.90	***7.40–9.70	***22.10–33.10	nd	nd	nd	*0.06	*0.071
Kchemeshwar Ghat (3)	2001–2013	19.00–30.00	7.80–8.17	5.80–7.32	5.72–9.07	*48000.00	21,000–71,000	205.00–406.00	*0.29	*0.071
Dashashwamedh Ghat (4)	2011–2016	19.27–27.90	7.56–8.60	5.90–6.10	7.4–27.77	*62,342.00	nd	121.96–456.00	0.01–0.26	0.020–0.070
Rajendra Prasad Ghat(7)	2001–2016	16.75–30.00	7.40–8.22	4.75–9.37	4.23–59.96	52,000.00–66,875.00	27,512–1,200,000	167.80–439.00	0.19–0.20	0.030–0.070
Lalita Ghat (2)	2001–2011	19.00–28.00	7.80–8.06	6.08–7.40	4.90–10.00	*82,000.00	29,000–302,200	238.00–1278.00	*0.27	*0.131
Panchganga Ghat (3)	2001–2013	14.00–26.97	7.86–8.21	6.82–9.40	2.60–8.23	***17,000.00–44,000.00	11,500–47,759	224.15–320.00	nd	nd
Trilochan Ghat (1)	2001–2011	19.50–28.20	7.80–8.30	5.80–8.75	3.88–14.80	*112,000.00	43,000–910,800	210.00–416.00	nd	nd
Teliyanla Ghat (1)	2001–2011	20.00–29.25	7.78–8.20	4.35–9.00	5.14–17.80	*93,000.00	44,000–790,000	200.00–447.00	nd	nd
Gola Ghat (1)	2006–2007	*30.5	*8.00	*5.60	*4.30	nd	*42,000	*350.00	nd	nd
Raj Ghat (9)	2009–2015	19.55–30.20	8.01–10.30	4.27–8.70	2.5–77.78	619.10–58,000.00	300–40,000	135.11–603.33	*0.24	*0.305
Khirikhi Nala (3)	2001–2015	18.25–28.60	7.70–8.80	2.40–5.92	29.35–59.00	***12,100,000.00	168,000.00–47,500,000	310.00–454.00	nd	nd
Varuna Confluence (6)	2001–2013	15.50–30.50	6.80–8.09	1.40–5.66	12.4–64	5,025,000.00–106,000,000.00	2,737,255–640,000,000	299.51–552.40	nd	nd
Sarai Mohana (1)	2006–2007	*30.50	*8.00	*3.40	*32.00	nd	*620,000	*360.00	nd	nd

Location (no. of sources)	Zn (mg/L)	Cr (mg/L)	Cd (mg/L)	Ni (mg/L)	Fe (mg/L)	Mn (mg/L)	Category	Reference
Samne Ghat (5)	0.174–0.200	0.04–0.08	0.006–0.02	*0.22	0.42–0.68	*0.04	LP	Datasets 1992–2011; Hammer et al. 2009; Singh et al. 2016; Singh 2011
Aghoreshwar Ghat (2)	nd	nd	nd	nd	nd	nd	LP	Das and Tamminga 2012
Narayan Ghat (2)	nd	nd	nd	nd	nd	nd	VLP	Datasets 1992–2011; Hammer et al. 2013
Assi Nala (6)	nd	nd	nd	nd	nd	nd	HP	Datasets 1992–2011; Dubey et al. 2012; Hammer et al. 2007, 2013; Pandey et al. 2015; Nandi et al. 2016
Assi Ghat (10)	0.150–9.440	0.05–0.26	0–0.15	0.35–0.99	0.47–3.27	0.07–2.1	HP	Abed and Jazie 2014; CPCB 2014; Datasets 1992–2011; Hammer et al. 2007, 2013; Mishra et al. 2009; Nandi et al. 2016; Singh et al. 2016; Singh and Singh 2010; Singh 2011; Vaseem and Banerjee 2013
Tulsi Ghat (5)	*0.216	*0.066	*0.012	nd	*0.596	*0.041	LP	Abed and Jazie 2014; Datasets 1992–2011; Hammer et al., 2006, 2007; Singh 2011
Shivala Ghat (5)	*0.141	*0.02	*0.023	nd	*0.552	*0.023	MP	Datasets 1992–2011; Mishra et al. 2009; Hammer et al. 2013; Singh and Singh 2010; Singh 2011
Harishchandra Ghat (5)	0.130–0.210	0.03–0.07	0.02–0.023	*0.37	0.43–0.54	*0.05	HP	Datasets 1992–2011; Mishra et al. 2009; Singh et al. 2016; Singh and Singh 2010; Singh 2011
Chauki Ghat (2)	*0.194	*0.058	*0.016	nd	*0.36	*0.048	HP	Singh and Singh 2010; Singh 2011
Kchemeshwar Ghat (3)	*0.143	*0.047	*0.007	nd	*0.526	*0.039	LP	Datasets 1992–2011; Hammer et al. 2013; Singh 2011
Dashashwamedh Ghat (4)	0.160–0.250	0.02–0.06	0.04–0.08	0.31–0.55	0.55–0.59	*0.03	MP	Singh 2011
Rajendra Prasad Ghat(7)	0.160–0.250	0.02–0.05	*0.05	*0.31	0.42–0.59	*0.05	HP	Abed and Jazie 2014; Singh et al. 2016; Singh 2011; Singh et al. 2014
Lalita Ghat (2)	*0.178	*0.055	*0.008	*0.506	*0.042	nd	LP	Data Set 1992–2011; Hammer et al. 2006, 2007, 2013; Singh et al. 2016; Singh and Singh 2010; Singh 2011

Table 3 (continued)

Panchganga Ghat (3)	nd	nd	nd	nd	nd	nd	nd	nd	nd	LP	Data Set 1992–2011; Singh 2011
Trilochan Ghat (1)	nd	nd	nd	nd	nd	nd	nd	nd	nd	MP	Hammer et al. 2007, 2013; Data Set 1992–2011
Teliyanla Ghat (1)	nd	nd	nd	nd	nd	nd	nd	nd	nd	MP	Data Set 1992–2011
Gola Ghat (1)	nd	nd	nd	nd	nd	nd	nd	nd	nd	LP	Pandey et al. 2015
Raj Ghat (9)	*15.320	*0.48	nd	nd	*1.12	0.1–6.87	*2.8	nd	nd	HP	Hammer et al. 2006
Khirikki Nala (3)	nd	nd	nd	nd	nd	nd	nd	nd	nd	HP	Abed and Jazie 2014; CPCB 2014; CWC 2011; Data Set 1992–2011; Das and Tamminga 2012; Hammer et al. 2013; Nandi et al. 2016; Pandey et al. 2015; Singh and Singh 2010; Singh et al. 2015; Vaseem and Banerjee 2013
Varuna Confluence (6)	nd	nd	nd	nd	nd	nd	nd	nd	nd	HP	Data Set 1992–2011; Hammer et al. 2015
Sarai Mohana (1)	nd	nd	nd	nd	nd	nd	nd	nd	nd	HP	(Data Set 1992–2011; Dubey et al. 2012; Nandi et al. 2016; Hammer et al. 2006, 2007, 2013)

*Only one source available

**It must be noted that the values of TC and FCC of all the ghats are however ranged in the highly polluted category and inclusion of this value may change their category of classification to highly polluted

***Data is a range from a single year

nd no data available

HP highly polluted; MP moderately polluted; LP Less polluted; VLP Very less polluted

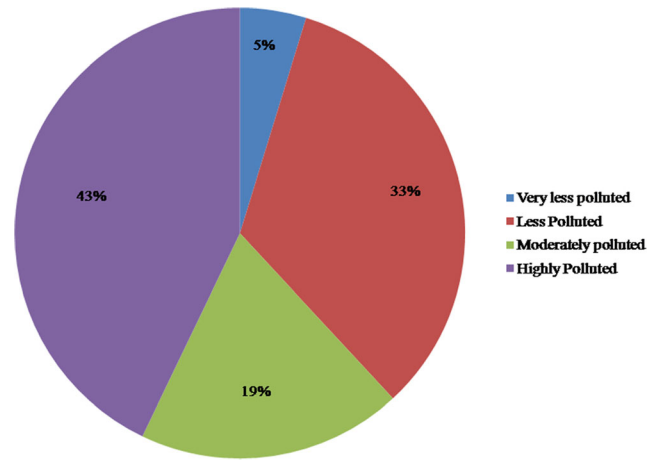


Fig. 3 Categorization of ghats of Varanasi into very less, less, moderately, and highly polluted levels based upon water quality data (1992–2016) excluding the coliform data

upstream of Dashashwamedh ghat thereby contributing to the pollution level downstream (GIZ ASEM 2011). Field visits also revealed presence of multiple drains in some wards such as ward 90 (3 drains) and ward 35 (6 drains), discharging near main bathing ghats, Asi and Dashashwamedh, respectively. To understand the severity of physicochemical pollution at ghats and its relation with the population of Varanasi, maps were drawn and ghats were categorized based on these properties (Fig. 4c) and considering levels of heavy metals (Fig. 4d). Choropleth maps of severity of physicochemical and heavy metal pollution to the population of Varanasi indicate existence of more number of individuals (highly populated) near River Varuna which is converted to a drain and has maximum pollution load (Fig. 4b, c). Maps also indicate more populated areas near highly polluted ghats like Asi confluence, Asi ghat, Varuna confluence, and Raj ghat (Fig. 4b, c).

Discussions

Though the literature sources revealed a large set of data differing in the range of values yet they clearly demonstrate that physicochemical and heavy metal pollutants in the River Ganga at Varanasi are above the standards required by the Indian government for drinking and bathing irrespective of the source of study. The astronomically high numbers recorded for TCC, FCC, and BOD along all ghats observed in the literature could be explained by the fact that the wastewater generated not only far exceeds the treatment capacity of STPs but also is contributed by direct discharge of untreated wastewater from River Varuna contaminated with organic-rich contaminants with high coliform levels which contributes towards 30% of microbial load in Ganga as reported by Singh and Singh (1994). This results in increased possibilities of water-borne diseases like cholera, typhoid, hepatitis A, and

Table 4 Comparison of water quality standards for surface water discharge as per India's Environmental (Protection) Act of 1986# and the measurements of effluent water from Bhagwanpur, Dinapur, and DLW sewage treatment plants as per literature (1992–2016)

Effluent type	Source publication date	Temp. (°C)	pH	TSS (mg/L)	BOD (mg/L)	COD (mg/L)	Ammonia (mg/L)	Phosphate (mg/L)	Zinc (mg/L)	Copper (mg/L)	Cadmium (mg/L)	Lead (mg/L)	Chromium (mg/L)	Nickel (mg/L)	Reference
#Standard surface water discharge	1986	Should not exceed 5 °C above the receiving water body	5.5–9.0	≤ 100	≤ 30	≤ 250	≤ 5	≤ 5	≤ 5	≤ 3	≤ 2	≤ 0.1	≤ 2	≤ 3	(Sawal 1986)
Bhagwanpur STP (8 MLD)	2010–2012	20.2–32.3	7.43–8.7	13–153	9.6–107	15.7–204	*6.2	0.19–9.37	1.57–2.1	0.11–0.13	0.08–2.65	0.12–0.22	0.01–0.76	*0.49	(CPCB 2013b; Mishra 2015; Rai et al. 2010; Dubey et al. 2012)
Dinapur STP (80 MLD)	2004–2015	23.8–36.3	7.13–7.97	45–157	14–340	39–880	11.9–15.5	0.85–10.39	0.09–3.4	0.03–1.2	0.02–2.55	0.05–0.8	0.02–0.25	0.05–0.3	(CPCB 2013b; Mishra 2015; Sharma et al. 2007; Rai and Tripathi 2007)
DLW STP (12 MLD)	2006–2015	22.58–33.2	7.17–7.89	*140	26–156	157–478	*9.0	0.76–58.28	0.17–1.2	0.06–1.5	0.01–2.234	0.08–0.62	0.09–0.414	0.03–0.318	(Mishra 2015; Rai et al. 2010; Sharma et al. 2007; Rai and Tripathi 2007)

*Only one source available

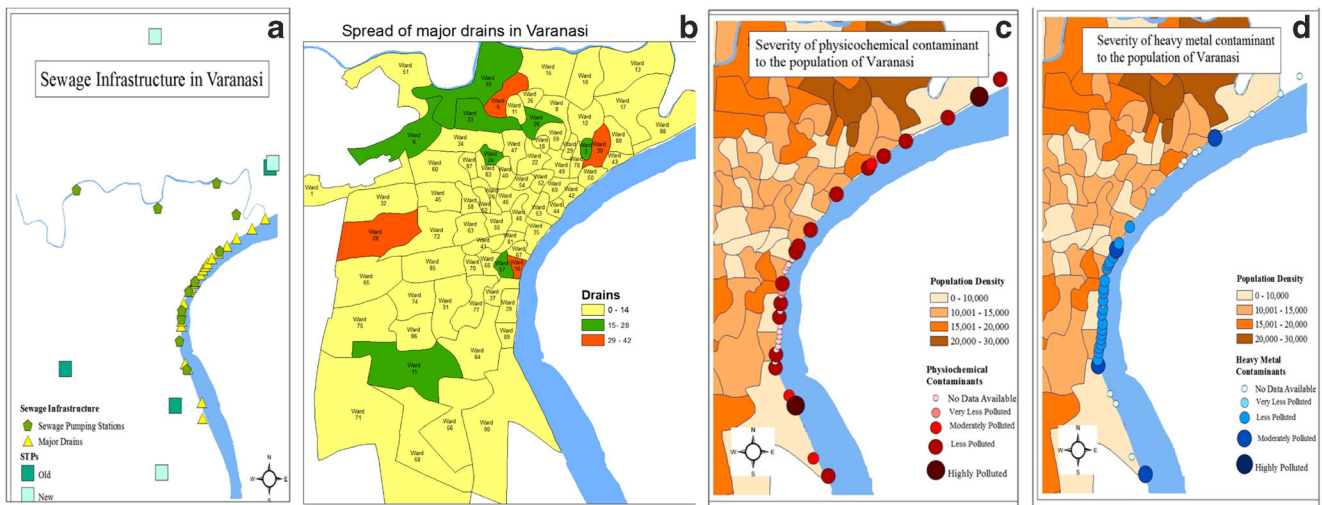


Fig. 4 Choropleth maps created in ArcGIS. **a** Sewage infrastructure in Varanasi showing, **b** spread of drains, **c** severity of physicochemical pollution and total population, **d** heavy metal pollution and total population at Varanasi

dysentery (Hamner et al. 2006, 2013) to locals and pilgrims using river water for drinking and bathing purpose. Further, the frequently visited ghats like Asi and Rajendra Prasad (RJP) ghat falls into the highly polluted category thereby exacerbating risks to human health. Presence of heavy metals was observed in water samples along the entire stretch of the ghats at Varanasi. Levels of lead, zinc, chromium, cadmium, and manganese exceeded drinking water standards in many locations adding up to the health issues for the locals of Varanasi. For example, lead ingestion is reported to cause birth defects and developmental disorders in children such as lowered IQ and behavioral problems (USEPA 2017). A continuous monitoring of heavy metals is therefore needed to be done to obtain real-time water quality data for River Ganga at Varanasi to avoid health risk to environment and locals of Varanasi.

Severely high levels of TC and FCC in water of River Ganga indicate need for efficient functioning of the STPs. This requires maintenance of the functional and repairing of the non-functional units of existing STPs. High levels of BOD and COD found in STP effluent at all three plants indicate that these STPs may not always function properly in their treatment of wastewater. This may be attributed to the increased rate of power cut problems existing in Varanasi resulting into functional discontinuity of STPs. Further presence of heavy metals in STP effluent indicates receiving of mixed wastewater by STPs. This may impact the functionality of the treatment plants, which are not designed to deal with such waste. This requires attention by the policy makers for separation of wastewater at the source. This can be easily taken into consideration with the upcoming STPs. These upcoming new STPs are designed to increase these waste treatment capacity in the city from 100 MLD to 410 MLD. This would enhance the efficiency of STPs and help in proper management of

sewage discharge into River Ganga. Use of latest sequencing batch reactor technology by the upcoming STPs is expected to further enhance the efficiency of their treatment capacity. There is also a need to deal with the heavy metals found in the treated effluent from STPs as it is often used for irrigation of crops in Varanasi and can lead to bioaccumulation of metals in soil and food (Singh et al. 2004). Monitoring of the proper functionality of the STPs with inputs from locals and stakeholders needs to be given utmost importance for their sustenance. This further needs to be substantiated with continuous monitoring and availability of the data with an open access to the public database.

High population along highly polluted ghats indicates a significant role of population in increasing pollution levels of River Ganga. The most populated area was observed near Varuna River that has the highest pollution load. This not only highlights the health risk to the population but also indicates role of various anthropogenic activities as one of the factors contributing to increased pollution load in Varuna. Moreover, the River Varuna faces tremendous pollution pressure owing to agricultural runoff, untreated domestic and industrial effluent, etc. Industries like textile, metals, food processing, and paints also discharge their effluent into River Varuna that enters River Ganga directly or indirectly (Kumar et al. 2015). Discharge of such highly polluted water severely increases the pollution level of River Ganga at Varanasi. In addition, excessive extraction of water of River Varuna has drastically reduced the flow of river thereby converting it to a drain (Kumar et al. 2015). This calls upon the necessity to look into restricted population growth and the river water management by controlling further settlements at Varanasi through local governing units to bring parity among all communities dependent upon the River Ganga at Varanasi. This also indicates prevailing exploiting nature as well as lack of awareness

among the population residing in Varanasi towards their vital water resources. It highlights the need of creating awareness among the locals and stakeholders as well as involving them in various management programs for River Ganga at Varanasi.

Although an apt organizational arrangement exists yet there appears a lack of a strong will for strict enforcement and monitoring of the regulating and developmental policies at the level of center and state. The central government does frame policies, work plans, legislations, regulations, and budget allocations, but the implementation at the local levels by the state government is subject to their adoption by the government of that state. However, it is not the law or law to be produced on the basis of analytical tool data but the readiness of responsible authorities to follow the law besides all obstacles. Present water policies suffer with limitations, *viz.*, lack of public participation in law-making process, lack of sufficient incentives promoting conservation, and use of water resources, water authorities happen to be politicians or bureaucrats with powers vested with former leaving vital decisions being guided by vote bank politics rather than situational demands, lack of transparency and accountability, and the recommendatory nature of central law, regulations, and policies (Bhatt and Bhatt 2017). The policies of the state must not only focus on regulations, licenses, restrictions, and penalties but also on knowledge dissemination to help, guide, influence, and coordinate the public water use. Therefore, public and stakeholders participation at all levels must be made integral to all water administration.

Conclusions

Overall, this study presents comprehensive and historical evidence demonstrating the severity and consistency of water pollution in the River Ganga at Varanasi over two decades. The work provides a mapping and data management tool for future research. It is clear that the River Ganga has been suffering from severe water pollution for decades, and for making it more vital now than ever, there is a need to collaborate and share information across groups in order to create viable and lasting solutions to this issue. Analysis of the data from literature (1992–2016) concludes that the data available in literature for water pollution in River Ganga at Varanasi is not uniform. The pollution in River Ganga has not one but several associated drivers. Water of River Ganga at Varanasi is characterized by high coliform and BOD levels. This may be attributed to the mixing of severely deteriorated water of River Varuna which contributes nearly 30% towards the microbial load of River Ganga at Varanasi. Generation of waste water beyond treating capacity of STPs, their poor maintenance, and use of old treating technologies are also main contributors towards discharge of untreated sewage waste into River Ganga at Varanasi. Degrading water quality of River Varuna

is associated with high pollution pressure, excessive water abstraction, and direct discharge of untreated sewage, agricultural and industrial waste. Industries largely contributing to pollution of River Varuna include textile, metal, food processing, and paints. Heavy metal contamination at certain sites is largely because of the inability of STPs to treat wastewater mixed with heavy metals that needs removal prior to treatment in STPs. Therefore a continuous monitoring of heavy metals and coliform levels in water of River Ganga is essentially required to reduce the health risk. Though a good governance setup exists for water management yet no improvement in water quality is observed for River Ganga at Varanasi. This may be because of the fact that water is a state affair and there exists a lack of coordination between central and state government leading to failure of regulating framework designed by central government for management of River Ganga. Moreover, lack of readiness of responsible authorities to follow the law besides all obstacles is also a major factor towards failure of river management strategies. Therefore, there also appears a need for change in policy framework from mere focus on regulations, licensing, restrictions and penalties towards inclusion of component of knowledge dissemination for a coordinated public use. A dissemination of power to local stakeholder for their increased participation in river management is required. Enforcement of strict settlement laws to reduce village immigrants to settle in Varanasi would help manage the population pressure, a primary contributor towards river pollution at Varanasi. Above all, it is important to publish the available data about River Ganga water quality from different sources at a common platform for citizens, water policy makers, researchers, NGOs, and government bodies which may help ensure proper planning based upon cohesiveness (convergence) in data for suitable river health management in a globally important city as Varanasi.

Recommendations

Adapting, adopting, and adjusting to population growth the following recommendations will set the basis for a shared secure future of River Ganga especially at Varanasi by cooperation, resilience, and sustainability.

1. Continuous, long-term monitoring of water quality and publication of data, creating comprehensive, historical datasets, and providing researchers with robust data to facilitate research on this topic and strategies for clean-up.
2. Increased investigation into heavy metal pollutants and their impacts.
3. Separation of wastewater or additional treatment mechanisms at existing STPs and their compliance to allow for treatment of heavy metals.

4. Increased sharing of information and collaboration among researchers, NGOs, and government bodies to create informed clean-up strategies.
5. Strict laws to restrict newer settlements and population density at Varanasi in particular.

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Compliance with ethical standards

Competing interest The authors declare that they have no competing interest.

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