Chapter 2
Story of the Ganga River: Its Pollution and Rejuvenation

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INTRODUCTION

Water is indispensable for the basic subsistence of human beings. No wonder, most of the civilisations have come upon the banks of rivers or in the river valleys as elsewhere in the world (Chaturvedi, 2019). India is a blessed country in terms of having numerous rivers in this regard (Hudda, 2011). Unfortunately, in 2017, the Ganga River, the National Legacy, and the life support of millions of people was classified as the world's highly polluted river (Mariya et al., 2019). Ganga, with over 2,525 km long main-stem along with her tributaries has constantly provided material, spiritual and cultural sustenance to millions of people living in and around its basin. The riverine water resources provide irrigation, drinking water, economical transportation, electricity, recreation and religious fulfilment, support to the aquatic ecosystem as well as livelihoods for many stakeholders. The myths and anecdotes about the river and its connection with the people and nature date back to ancient times (Kaushal et al., 2019).

India has rich water resources and roughly 45,000 km of riverine systems criss-crossing the country's length and breadth. It has 12 major river basins, 46 medium river basins and 14 minor river basins. The Ganga River Basin (22°30′ to 31°30′ N, 73°30′ to 89°00′ E) is the largest of these and approximately 43% of India's population lives in it, which extends over 860,000 km^2, making up 26% of the country's landmass; supporting 30 cities, 70 towns and thousands of villages in the areas of the fertile river basin (NRCD and MoEF, 2009; Trivedi, 2010; Nandi et al., 2016; Pathak et al., 2018; FAO, 2020). The Ganga stem covers the states of Uttarakhand, Himachal Pradesh, Haryana, Delhi, Uttar Pradesh, Bihar, Jharkhand, Rajasthan, Madhya Pradesh, Chhattisgarh and West Bengal (NRCD and MoEF,

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A. Mukherjee (ed.), *Riverine Systems*, https://doi.org/10.1007/978-3-030-87067-6_2

2009). It is one of the world's most agriculturally productive and populous regions. The Ganga encounters about 15 tributaries during its journey from Gomukh to the Bay of Bengal, which contribute to 60% of its total water, making it the third largest river in the world in terms of the volume of water released (Zhang et al., 2019). In 2008, Ganga River was professed as the 'National River' of India. There are more than 29 cities, 97 towns and thousands of villages along the stem of Ganga (Bhutiani et al., 2016).

Natural water resources have been exposed to an exponentially growing population, rising standards of living and accelerated industrialisation and urbanisation (Sharmila and Arockiarani, 2016). The Ganga is facing various human-induced risks across its basin. A wide range of pollutants falling in different categories like organic, inorganic, hazardous etc. emanating primarily from Municipal, Industrial and Agricultural sectors have severely affected its water quality, ecosystem and health of living beings dependent on it. Growing demands on the river water for irrigation, domestic, industrial use and hydroelectric projects exacerbate the challenges of ecosystem preservation. Due to the complexity of the issues facing Ganga, it has logically become the source of an intense discussion on benefits of river, ownership and even rights with an unclear line between use and misuse (Sanghi and Kaushal, 2014).

Considering that the river Ganga has a very special place in the collective consciousness of this country and recognising that the country's rivers were in a severe state of deterioration, an inception towards their rejuvenation was initiated with the introduction of the Ganga Action Plan-I (GAP-I) in 1985 with the support of several indigenous and international agencies (Hamner et al., 2006; IITs, 2013; Sharmila and Arockiarani, 2016). GAP-I was promoted to lessen the quantity of direct disposal of wastewater into the river, although the river water quality remained a challenging issue and was not even fit for bathing (Tare et al., 2003). GAP-II was consequently started in 1993 with the objective of managing the pollution load of the three main tributaries of the Ganga river (e.g. Yamuna, Gomti and Damodar) and the 25 towns that were not considered in GAP-I (Das and Tamminga, 2012). GAP-II had also been unable to decrease the pollution load, mainly due to a lack of strategic planning and less stakeholder engagement (Ching and Mukherjee, 2015). The National Ganga River Basin Authority (NGRBA) was established in 2009 for restoration and conservation, but even after nine years of the launch of NGRBA, the improvement in the river water quality was apparently less than desired and there still remained a paucity in the availability of systematic data on the status of various pollutants in the Ganga river. In 2015, the Integrated Ganga Conservation Mission was launched by the Union Government as a "Namami Gange" flagship scheme in order to integrate previous and current river rejuvenation initiatives with a budgetary provision, but the strategic goal could not be obtained due to long delays in execution (CAG, 2017).

Government of India has of late taken several steps and has made substantial investment for the conservation and improvement of the Ganga. Under the direction of various ministries, several actions have been undertaken viz. source control of sewage, industrial wastewater and solid waste; river catchment/basin management (controlled groundwater extraction, environmental flow management); along with other restoration measures such as riverfront development on the main stem and the tributaries, afforestation and biodiversity conservation, protection of flood plain zone and spreading community awareness.

STATUS AND IMPACT OF POLLUTION

The deterioration in the water quality of river Ganga has been of great concern for quite some time, as it has lost its fitness to be used for a variety of the designated uses in most of its stretches. Both point and non-point sources, including untreated and partially treated municipal and industrial wastewater, agricultural and urban runoff, leaching from dumping sites, open defecation in its basin, navigation, its use for recreational and religious purposes and last but not the least, severe depletion in its flow is adversely influencing its quality (NMCG, 2017; Dutta et al., 2020). The following sections discuss the nature of pollutants and various sources which are responsible for pollution.

Municipal Sewage and Open Defecation

The untreated sewage from urban and peri-urban areas is a significant cause of Ganga water quality deterioration. It contains constituents such as nutrients (N, P, K), toxic chemicals (heavy metal, pesticides), pathogens, organic and inorganic matter (FAO, 1992; Vega et al., 1998). The literature has revealed that Ganga water quality in the upper stretch is not even suitable for bathing and other nonportable purposes. The middle and lower stretch water are not even beneficial for livelihood activities (Mishra and Mohapatra, 2009; Tare, 2010; NMCG-NEERI, 2017). In the Ganga basin, around 12,000 Million Liters per day (MLD) of sewage is generated while the treatment capacity is only about 5,000 MLD (Sharmila and Arockiarani, 2016). The contribution of disposal of wastewater from municipal sewage and industries are 70-80% and 15-20%, respectively (Das, 2011; CPCB, 2013a; NMCG, 2017).

Inadequate and sub-optimal functioning of sewage treatment plants (STPs)

In India, a 50% difference between the sewage production and treatment has persisted for the last 4-5 years in spite of continuous augmentation in the capacity of treatment plants (CPCB, 2016a). It mainly occurs due to a rapid population growth, improper adoption of technology, and dearth of in-situ remediation of sewage carrying drains. In 2013, CPCB audited 51 out of 64 STPs along the main starches of the Ganga (CPCB, 2013b), and it was reported that only 60% of the installed volume of STP was operational while 30% of the STPs were non-functional. Thus, the actual treatment is although lesser, and raw sewage is flowing into the river. Such release of sewage results in an increase in the routinely analysed parameters like Biological Oxygen Demand (BOD) and coliform count, which is beyond the prescribed critical limit for outdoor bathing. A concern has also been raised that the conventional secondary treatment provided in the STPs is unable to bring the coliform count below the permissible limit, and the ensuing disinfection of the treated effluent has more issues than benefits. The water quality representing the Total and Faecal coliform (TC and FC) count, BOD and nutrients (nitrate and phosphate) has also been found poor in the downstream of Haridwar due to release of sewage (Dwivedi et al., 2018; Dutta et al., 2020) even after implementation of various federal schemes (Fig. 1). The dissolved oxygen (DO) trend has also depleted despite massive efforts and investment by the Indian government. However, clean water through the Yamuna at Allahabad somewhat improves water quality (CPCB, 2016a). Many STPs are observed to be "(a) overflowing during the wet period, (b) ineffective for the treatment of hazardous waste, (c) non-operational by recurrent electrical shortages, (d) often non-operational due to huge running cost". In the light of present treatment capacity (4994 MLD) and wastewater generation (11314 MLD) scenario in the riparian states have been represented in Fig. 2A, the difference in treatment capacity in these states is relatively huge which is about 6321 MLD (Dutta, 2019). It may also be noted that though we are at present generally concerned about the performance of our STPs in terms of reduction in the conventional water quality parameters, yet the current trends point towards a strong need to consider their efficiency in handling of the emerging pollutants also (Mathew and Kanmani, 2020).

Open defecation and unsatisfactory sanitation

Despite the continuous campaign towards control of open defecation, the reality remains that a huge portion of population still uses the flood plains as areas for defecation. Thus, resulting faeces finally reach the river water which leads to an increase in pathogenic bacterial and organic contamination during flood conditions (Chaturvedi, 2019). Prevalent open defecation considered to be a significant public health issue (Spears et al., 2013; Sahoo et al., 2015; O'Reilly et al., 2017). Approximately 524 million people defecate openly in India. Besides, unsatisfactory sanitation measures, social and religious activities also accelerate pathogenic pollution (Srinivas et al., 2020). As per the data of National Family Health Survey (NFHS, 2015), the status of sanitation facilities is unsatisfactory, particularly in the states of Uttar Pradesh, Bihar and West Bengal (Fig. 2B). Recently, 4465 villages situated alongside the Ganga river have been made open defecation free (ODF) under Swachh Bharat Mission (SBM) (SwachhindiaNDTV, 2019). Total 10,83,688 domestic toilets have been built by Ministry of Drinking Water and Sanitation (MoDWS). NMCG has funded Rs. 829 Cr to MoDWS for this work (PIB, 2018). 83 out of the 97 Ganga towns have already achieved ODF (open defecation free)

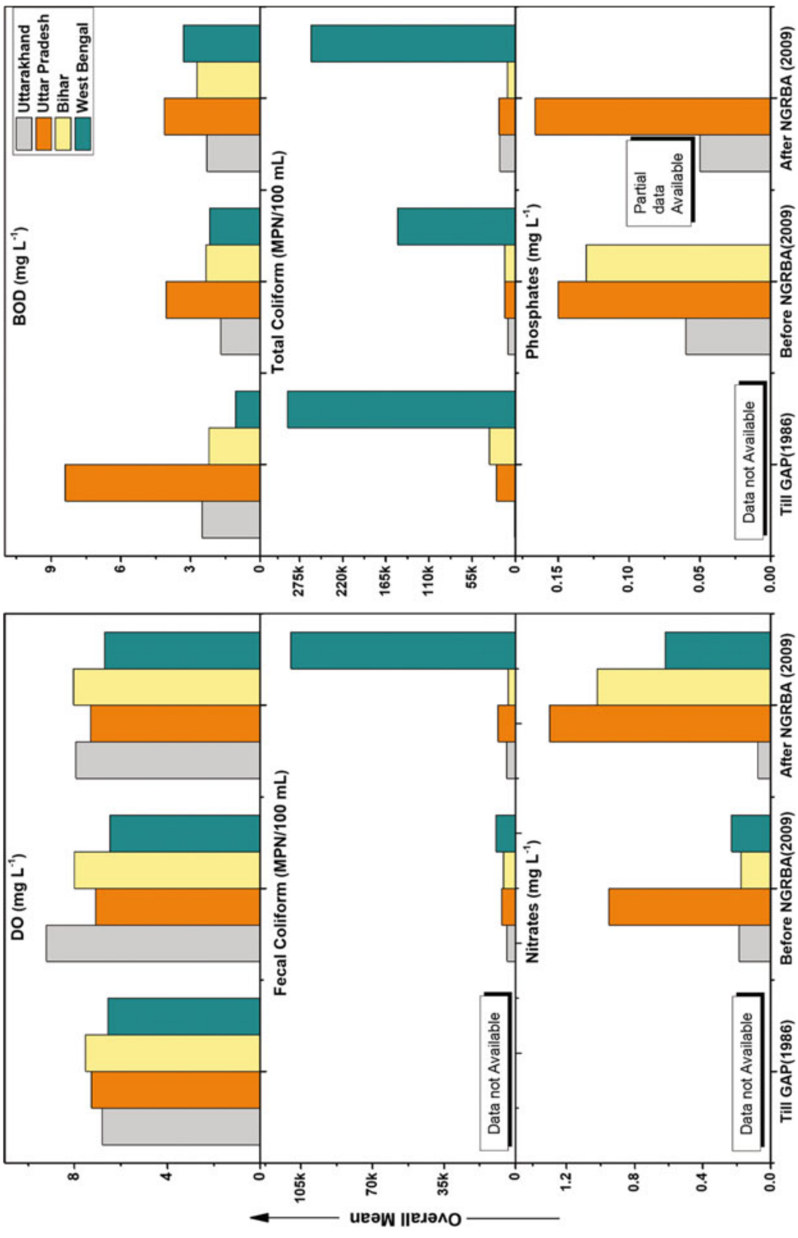

Figure 1. Water quality variation in the states of Ganga basin with the various federal schemes of Ganga (Dwivedi et al., 2018).

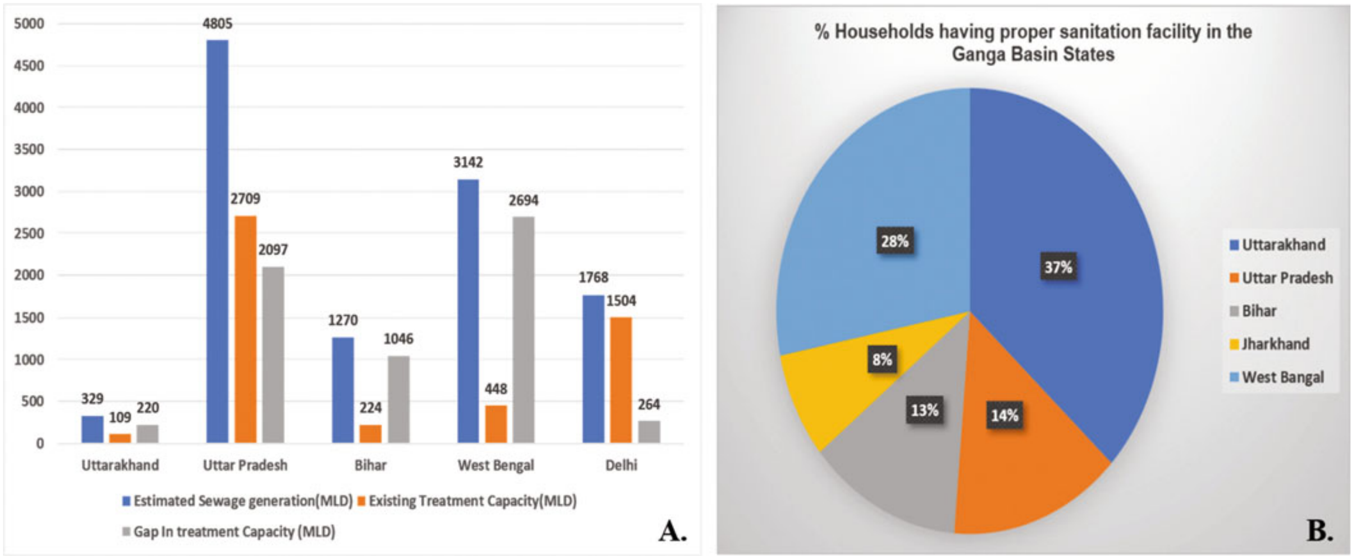

Figure 2. A. Scenario of sewage generation, existing treatment capacity and gap in the states along main stem of Ganga (Dutta et al., 2020). B. Status of households having proper sanitation facility in states under Ganga Basin (NFHS, 2015).

status, of which 44 have been certified ODF through third-party verification (SwachhindiaNDTV, 2019). Still, the type of twin-pit toilets employed and the way in which their construction has been reportedly implemented at many places raises doubts due to a strong possibility of contamination of groundwater and subsequently the river through river-aquifer interaction. The management of excreta is hence still a challenge. The total count of faecal coliform ranging from 2,500 to 2,40,000 per 100 ml depicts high pathogenic pollution along the Ganga basin of five states (Kaur, 2018). The consumption of water apparently polluted by these pathogens may cause a gastrointestinal contagion followed by restricted growth, undernourishment and diarrhoea. It is a known fact that approximately 0.2 million people die each year due to lack of proper access to safe drinking water (CWMI, 2018). Moreover, 2,000 children aged less than five die every year due to diarrhoea, as reported by WHO.

Industrial Wastewater Discharge

Discharge of industrial effluents to water bodies is one of the main cause of environmental poisoning that threatens the aquatic ecosystem and impairs the quality of water (Sinha and Paul, 2012). As per CPCB state and industry-wise waste consumption, wastewater generation and treatment have been illustrated in Fig. 3A. and B. (CPCB, 2013b). An increase in the industrialization and urbanization along the river Ganga has resulted in degraded water quality (MoEF, 2016). The effluents include the primary pollutants such as volatile, biodegradable, persistent organic compounds, hazardous metals, nutrients, suspended solids and microbial pathogens etc. (Paul, 2017). In the upper and middle stretch, industries present in the basin of Ramganga, Kali rivers and Kanpur city catchments have been reported as the main contributors to industrial pollution (MoEF, 2016; Pandey, 2019). The main industrial sectors responsible for Ganga's pollution reportedly include sugar, distillery, pulp and paper, tannery, textiles, thermal power plants, electro-processing industries and wood and jute mills, which are contributing 15-20% of the total effluent (NMCG, 2017; Dwivedi et al., 2018). These industries are responsible for the huge quantity of industrial wastewater also containing toxic compounds and heavy metals etc. (Tripathi et al., 2016; Mariya et al., 2019).

According to NMCG 1109, Grossly Polluting Industries (GPI) have been reported on the main stretches of the Ganga which contributes to about 669 MLD of industrial wastewater (NMCG, 2017). GPI from UP only are reportedly discharging over 100 kg/d of BOD load into the river Ganga (CPCB, 2016b; Chaudhary and Walker, 2019). Contribution of industrial wastewater has been reported at different times around 15-20% of the total quantity of wastewater discharged in the Ganga (Das, 2011; CPCB, 2013a; NMCG, 2017). Although their volume-wise contribution appears to be relatively low, still they are a serious cause of negative impact on river water due to their toxic and non-biodegradable nature (CPCB, 2013b; Pathak et al., 2018).

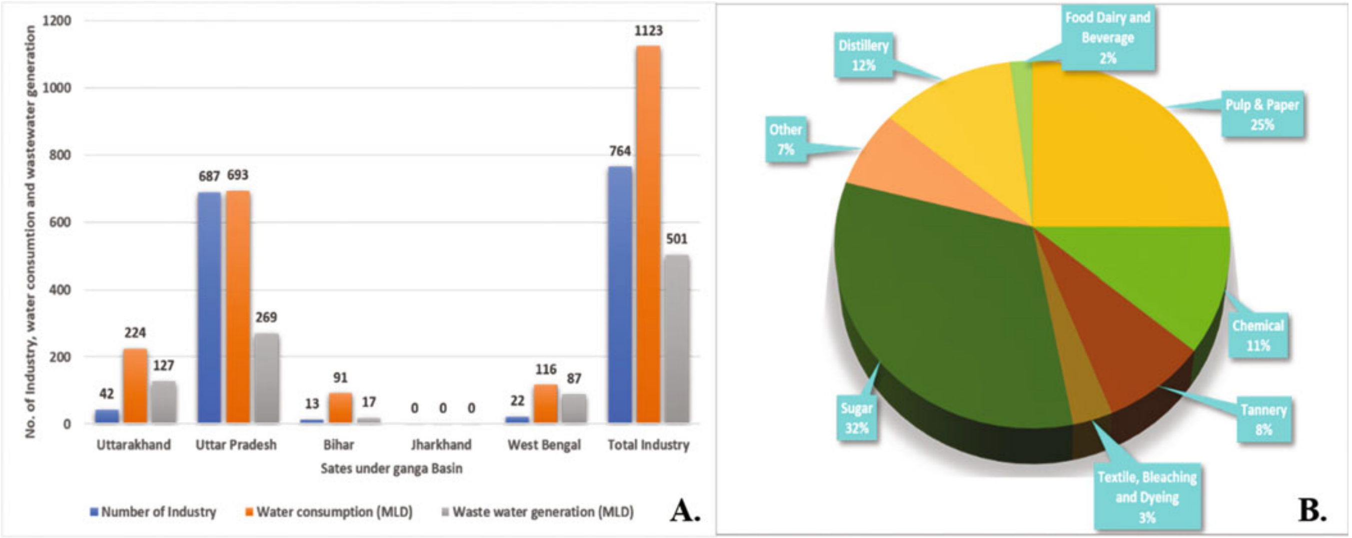

Figure 3. A. State wise status of industrial unit, water consumption and wastewater generation (CPCB, 2013b). B. Industry-wise wastewater generation in Uttar Pradesh (CPCB, 2013b).

A large volume of untreated water has been discharged into the river after the development of several industrial clusters along the bank of the Ganga in Kanpur, Prayagraj, Varanasi, and Patna (Chaturvedi, 2019). Besides, these point sources, its tributaries such as Yamuna, Kali, Ramganga, Damodar, Gomti, Ghaghra, and Son also have been responsible for further increasing the pollutant load in the river (Misra, 2010; Mishra et al., 2015). The Yamuna is Ganga's most polluted tributary. There are almost 359 industries in the Yamuna basin, that dump their wastewater directly or indirectly in the river Ganga (Misra, 2010). Approximately 400 tanneries reportedly contribute 8% of the total industrial effluent discharge along the river catchment of Unnao, causing severe chromium pollution and health hazard to the human population (CPCB, 2016a) (Homa et al., 2016). It is responsible for health problems such as cancer, diarrhoea, stomach, intestinal bleeding, cramps, liver, and kidney damage (Paul, 2017; Srinivas et al., 2020). The pulp and paper industries generate the largest amount of BOD load (65%) and account for 57% of wastewater flow and 44% of wastewater dumping in the river Ganga (CPCB, 2016b). A coal-based power plant on Pandu River burns 600 MT of coal every year generating 210 MT of fly ash, which leads to the addition of Pb and Cu into the river (Chaturvedi, 2019).

Agricultural Runoff and Soil Erosion

The agricultural runoff containing varying concentrations of pesticides, fertilisers and heavy metals is a primary non-point source that increases the pollutant load to water bodies at a large scale and their concentration found beyond the standard norms of WHO (Kumari et al., 2001; Guzzella et al., 2005; Singh et al., 2012; Mutiyar and Mittal, 2013; Srinivas et al., 2020). Extensive and improper utilization of fertilizers degrades the surface water by increasing the nitrate load (Agrawal et al., 2010). In Ganga Basin, the annual consumption of pesticides is about 60000 MT (Mohapatra et al., 1995; Ghose et al., 2009; Kumar et al., 2013). The runoff from arable land leads to an increase in the nutrient levels of nitrogen and phosphorous with the value of 70 and 0.05-1.1 mg/l, respectively (CPCB, 2016a; NMCG, 2017) (NMCG, 2017) and this further causes eutrophication (Zhang et al., 2017). The agricultural runoff resulting to eutrophication which in further causes a severe threat to riverine ecosystem and human lives. It leads to an imbalance in the river ecosystem that includes algal blooming, habitat destruction, and an decrement in self-purifying efficiency (Diaz and Rosenberg, 2008; Conley et al., 2009). In addition to the general agricultural activities in the Ganga Basin, the production of vegetables and fruits in the dry bed regions during summer also leads to pesticides in the riverine water. The maximum pesticide level has been observed in Ganga water of Uttar Pradesh before NGRBA, accompanied by West Bengal, Bihar and Uttarakhand, whereas Bihar was the highly polluted state with regard to pesticide content in Ganga water since NGRBA. A lack of data showing the pesticide contamination is reported in Bihar and West Bengal of Ganga Basin (Dwivedi et al., 2018). Organochlorine and organophosphorus pesticides are being widely utilized in India. However, some of them are still in practice even after the ban on highly hazardous pesticides such DDT, aldrin and hexachlorocyclohexane (Abhilash and Singh, 2009; Vijgen et al., 2011). These are potentially carcinogenic and mutagens and cause significant attention due to their harmful health impacts (Ejaz et al., 2004; Kumar et al., 2013). Thirteen banned organochlorine pesticides have been reported in the surface water of Ganga lower stem, causing critical ecological concerns (Sah et al., 2020). In another study, Varanasi's urban stretch has been identified as affected by high concentrations of heavy metals viz. Iron, followed by manganese, zinc, chromium, copper, nickel, lead, and cadmium, resulting from anthropogenic activities (Pandey and Singh, 2017). Non-judicious use of agrochemicals has reportedly led to massive damage of soil fertility, river ecosystem, destruction of conventional knowledge base, groundwater quality, and nutritive value of staple food (CPCB, 2016a).

Sediment load is also a crucial factor that causes pollution to Ganga Basin. It is prominent in the middle, and lower stretch, primarily covering the highly erodible alluvial plains (NRCD and MoEF, 2009; Sanghi and Kaushal, 2014) due to which floodplains and banks are more susceptible to erosion by run-off. Moreover, the massive deforestation to increase urbanisation and industrialization along the river banks has caused extreme flooded conditions (primarily in Bihar), also causing soil erosion on a large scale (Srinivas et al., 2020). Intense deforestation in the river catchment zone for the extension of agricultural lands, industries and residential areas causes river deterioration due to enhanced sediment loads. The anthropogenic activities along the Ganga have reportedly transformed the physicochemical characteristics of water and sediments and it also transformed the habitat distribution of several species (WII-GACMC, 2017).

Religious Activities and Inefficient Solid Waste Management

Religious Activities

Ganga Basin holds more than 300 million people, having an average density (persons/km^2) of 520, including the countries India, Bangladesh, and Nepal (Gopal, 2000; Das and Tamminga, 2012). The Ganga river basin is enriched with culture, heritage, and religious values from ancient times (Welcomme, 1985; Panigrahi and Pattnaik, 2019). Several ritualistic practices unfortunately contaminate the sacred Ganga water, leading to degradation in its limnological properties (Rani et al., 2014; Dwivedi et al., 2018; Chaudhary and Walker, 2019; Panigrahi and Pattnaik, 2019).

Several authors have evaluated the impacts of ritualistic activities occurred during the festive seasons of Kumbh, Maha Kumbh etc. and reported high deterioration in the Ganga water quality (Khanna et al., 2012; Srivastava et al., 2013; Tyagi et al., 2013; Sanghi and Kaushal, 2014; Dwivedi et al., 2018; Chaudhary and Walker, 2019; Panigrahi and Pattnaik, 2019). A high value of TSS, TDS, SPC, BOD, COD, and faecal counts were reported earlier during the period of Ardh Kumbh at Haridwar (Kulshrestha and Sharma, 2006); Tyagi et al., 2013; (Chauhan and Bhardwaj, 2018; Dwivedi et al., 2020).

The heavy metal/metalloid contamination, including As, Cd, Cr, Hg and Pb, is known to get released during the ritual of Idol immersion, which causes serious health problems like Cancer (WHO, 2003). The addition of gypsum, sulfur, phosphorus, and magnesium from the plaster of Paris which is used for making idols also increases the pollutant load of river. (Das et al., 2012; Kaur et al., 2013; Bhattacharya et al., 2014). A significant increase in temperature, pH, EC, BOD, COD, total alkalinity, Cl^-, Ca and Mg, and PO_4^{3-} has also been reported during the festival of Durga Pooja (Sarkar, 2013). High Pb and Cr content due to the addition of Sindhur (vermilion) in water bodies is also reported, and concentrations are found beyond the acceptable limit set by BIS, WHO, ICMR, and ISO 10500:1991 (Panigrahi and Pattnaik, 2019). Direct addition of offerings like milk adds to the organic load in the river. Further, heavy metal pollution due to these religious activities reportedly causes bioaccumulation and biomagnification issues across the food chain (Goswami et al., 2012; Dubey and Dubey, 2016).

Ineffective solid waste disposal and management

Solid waste management, treatment, and disposal in river basins are significant factors, which influence the quality of the receiving water bodies. A lack or inadequacy of proper management practices as well as processing facilities in especially the urban areas located along the Ganga Basin results in a significant increase in the pollutant loads. As per older estimates, Class I and II cities were generating around 14,000 TPD of municipal solid waste (CPCB, 2013b) along the main stretches of the River Ganga. According to the Ministry of Housing and Urban Affairs (MoH&UA), the solid waste generation in 97 towns along River Ganga is 11,428 TPD. Among these, in the states West Bengal, Uttar Pradesh, Bihar, Uttarakhand and Jharkhand, per day generation of solid waste (TPD) is 6001, 3282, 1771, and 347 respectively. Several SWM projects are being implemented to overcome the gap between solid waste generation and existing treatment capacity (UrbanUpdate, 2018). Plastic waste has also gained considerable attention as an emerging water pollutant. The Plastic Waste (management and handling) Rules 2011 was framed for combating the use of plastic bags below 40 microns (CPCB, 2016b). But this rustled in massive use of plastic bags of more than 40 microns. During anaerobic degradation of solid waste, a greenhouse gas methane (up to 50%) is produced from the solid processing sites (Alam and Ahmade, 2013).

Besides, uncollected solid waste may also inhibit stormwater runoff from reaching the receiving water bodies, which is likely to result in flash flooding. Solid waste management is an essential part of flood risk prevention. Floodwaters are also known to cause debris to flow to the river, which increases pollutant load by leaching out the hazardous compounds and also leads to groundwater pollution

(Lamond et al., 2012). Solid waste processing and disposal area also pose potential health threat to humans in neighbouring areas and groundwater pollution by leaching toxins (Srinivas et al., 2020).

Further, more than 100 MT of flowers, garlands, and earthen lamps are being reportedly thrown annually in the Ganga river. At Kashi Vishwanatha temple in Varanasi, floral waste per day is about 2 MT, whereas this limit increases to five times during the month of Shrawan (Dwivedi et al., 2018). An earlier study revealed that an average of 32,000 dead bodies is cremated (2009–2011) only at Harishchandra and Manikarnika Ghats in Varanasi and their half burnt ash is disposed into the river (Tripathi and Tripathi, 2014). Thus, all these activities continue contaminating water quality of Ganga.

Flow Obstructions and Water Abstractions

The ability of a river to self-purify and recharge itself is substantially damaged due to surface and groundwater over-extraction for irrigation, industrial and domestic utilisation. Mishandling of the Ganga water resources and inefficient utilisation has also resulted in increased levels of pollution in the river. Several hydropower projects have induced large stretches of the river to run dry and have resulted in many irretrievable environmental and social costs due to their cumulative impact (GAP, 2020). The barrages and dams have also impacted the ecological flow pattern and altered the habitat of riverine fauna, including Gangetic dolphins, wetland birds, several fish species, and freshwater turtles.

As river Ganga opens up to Gangetic plains (Bhimgoda barrage, Haridwar), an estimated volume of water (295 m^3/s) is allowed to divert into Upper Ganga Canal for irrigation purposes (Acharya et al., 2016). Additionally, during monsoon season, about 74 km from Haridwar, a barrage diverts the water into Madhya Ganga Canal at Bijnor. Further, a diversion of water into the lower Ganga Canal occurs downstream of the Bijnor barrage. About 492 major projects lead to the abstraction of water from the river for irrigation purpose. Among these, maximum projects have been implemented in Uttar Pradesh by forming 74,000 km canal systems (Shah and Rajan, 2019). It has been reported that around 30 diversion projects have been made along the main stem of Ganga and her tributaries which diverts 40-60% Ganga's yearly flow for the irrigation through the canal

This has resulted to a nominal quantity of water to flow into the river during the dry season, which is quite insufficient to provide adequate dilution to the added pollutant loads. Further, due to the excess extraction of groundwater in the river catchment, which has a significant impact on the quality of the river water, the river flow has also been seriously impacted in the recent past. If the dry period diversions from Ganga's major parts are blocked, there would be a 25% hike in base flows when the river reaches to Bihar (Khan et al., 2014).

OVERVIEW OF EFFORTS UNDERTAKEN FOR THE REJUVENATION FOR RIVER GANGA

Ganga rejuvenation has been attempted to restore the wholesomeness of the Ganga river in terms of ensuring pollution control (Nirmal Dhara) and river flow maintenance (Aviral Dhara). A holistic river basin approach has been adopted to rejuvenate the Ganga River, including its tributaries, under one framework. Pollution reduction is though the main objective, but not the only component; with the others being flow maintenance, rural sanitation, conservation of biodiversity, afforestation, environmental monitoring, ghats and crematoria development, enhancing public awareness, riverfront development in order to reinstate the magnificence of the Ganga river. For these activities, 254 projects with total cost of Rs. 24,672 cr have been approved under Namami Gange Programme (NGM) (PIB, 2018).

Source Control of Pollution

The principal source control includes treatment and disposal of domestic sewage, industrial pollution control and solid waste management as discussed below.

Channelization, treatment, utilization and disposal of treated domestic sewage

The Government of India has implemented several ambitious programmes to overcome the increasing problem of pollution in the Ganga water from GAP-I, and GAP-II to the Namami Gange project to restore the Ganga river (Fig. 4). The GAP-I with financial support of more than Rs. 462.04 cr focused to achieve the expansion of new and rehabilitation of existing STPs in urban settings, development of sewer networks in disjointed areas and installation of electric crematoria on the banks of the river (Birol and Das, 2010). GAP-I was promoted to lessen the quantity of direct disposal of wastewater into the river, although the river water quality remained a challenging issue and was not even fit for bathing (Tare et al., 2003).

GAP-II was consequently started in 1993 with the objective of managing the pollution load of the three major tributaries of the Ganga River (e.g. Yamuna, Gomti and Damodar) and the 25 towns that were not considered in GAP-II (Das and Tamminga, 2012). GAP-II had also been unable to decrease the pollution load, mainly due to a dearth of strategic planning and less stakeholder engagement (Ching and Mukherjee, 2015). The NGRBA was established in 2009 for restoration and conservation, but after nine years of the launch of NGRBA, the river water quality did not seem to improve and there is still a paucity of systematic data on the status of various pollutants in the Ganga river. Integrated Ganga Conservation Mission was launched in 2015 by the Union Government as a “Namami Gange” flagship scheme

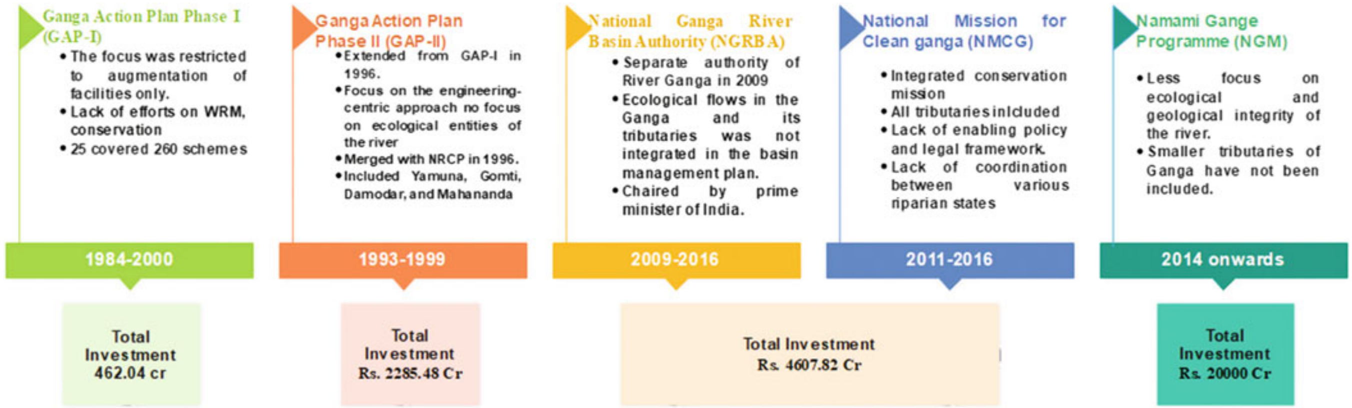

Figure 4. Various river rejuvenation schemes to clean river Ganga (Dutta et al., 2020; NMCG, 2020a).

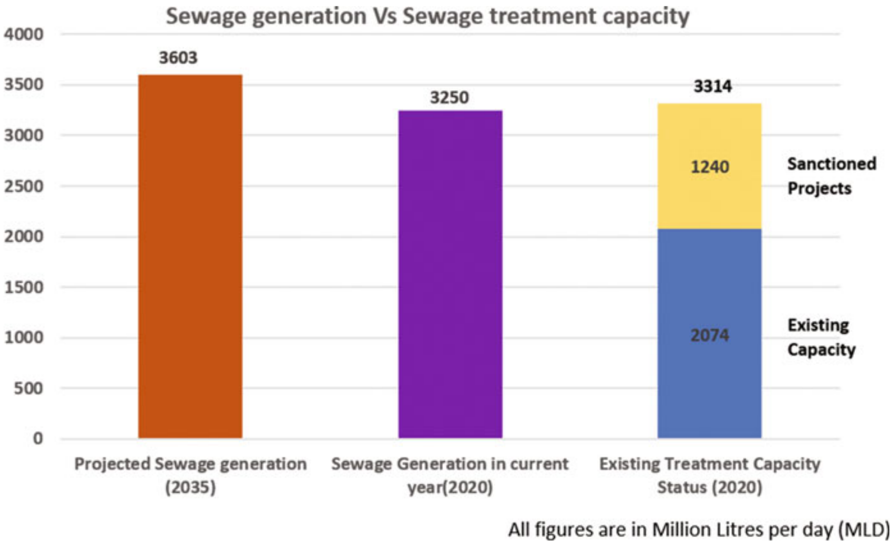

Figure 5. Status of existing infrastructure and interventions in 97 towns along Ganga main stem (Dutta et al., 2020; NMCG, 2020a).

in order to integrate previous and current river rejuvenation initiatives and their tributaries having a financial support of Rs. 20,000 Cr for the year 2015 to 2020, yet the strategic goal could not be obtained due to long delays in execution (CAG, 2017).

Nevertheless, in order to restore the glory of Ganga, the government has been constantly putting efforts. Since sewage pollution plays a prime role in the deterioration of the Ganga River, enormous investments and initiatives have been made to reduce this pollution. Under NGP, out of 254 projects 131 were approved for construction of new STPs with total capacity of 3076 MLD, refurbishment of existing STPs of total volume 887 MLD and laying/refurbishment of 4942 km sewer network for control of pollution load in river Ganga and Yamuna (TOI, 2017; UrbanUpdate, 2018). Recently, 97 towns have been identified along the major reaches of the river Ganga, contributing around 3250 MLD (current figure for the year 2020) and expected to generate 3603 MLD of sewage (projected for the year 2035). The current capacity for sewage treatment in these towns is 2074 MLD and the remaining 1176 MLD untreated sewage released into the Ganga. NMCG has approved several projects for construction of an extra 1240 MLD of STP which will enhance the capacity to 3314 MLD, and these projects are at various stages of execution (Fig. 5) (Dutta et al., 2020; NMCG, 2020a). All the sewage treatment infrastructure requirements in main towns that contribute around 64% of the current sewage generation of these 97 cities have been fully addressed (MoWRRD & GR, 2018; PIB, 2018). However, present treatment capacity (4994) and wastewater generation (11314) in the riparian states are very high and the difference in treatment volume (6321 MLD) in these states is also huge (Fig. 2A) (Dutta, 2019). The projects undertaken so far would address all the necessary interventions for main Ganga states; Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal in relation to the necessity for sewage treatment on the major reaches of the Ganga river until 2035.

In a paradigm shift in sewage sector in the past few years, several landmark projects have been completed intercepting major drains falling into the Ganga and diverting them to STPs. 80 major drains have been tapped, 120 years old Sisamau nala discharging 140 MLD in Ganga at Kanpur and kasawan Nala in Haridwar are some examples. All projects in Haridwar and Rishikesh—the main cities in Uttarakhand on Ganga, have been commissioned. Most of the other STPs in Ganga towns in Uttarakhand along Ganga are also completed. Almost entire Prayagraj now has a sewerage network and STPs. Varanasi saw the completion of 140 MLD STP at Dinapur and 120 MLD at Goitha. Another 50 MLD STP at Ramna would be ready this year to ensure that no untreated sewage flows from Varanasi. In Bihar, Namami Gange projects are increasing treatment capacity by 10 times from about 60 MLD to 650 MLD. In Jharkhand, Sahibganj STP is already functioning and the only other STP on Ganga at Rajmahal will be completed in a few months. Several projects in West Bengal too are making progress (Chakraborty, 2020).

Industrial Pollution Control

Due to accelerated Industrial development, the quantity of effluent discharged to the river has increased, resulting in different forms of deterioration, affecting the aquatic ecosystem and quality of life. There are several polluting industries, viz. pulp, distilleries, tanneries, sugar, fertilizers, textiles, automobiles, synthetic rubber and electro-processing industries along the Ganga tributaries which lead to the pollution load in the Ganga (CPCB, 2016b). Central Pollution Control Board (2019) has identified 1,072 Grossly Polluting Industries (GPIs) from Haridwar to Kanpur which discharge 219.18 MLD of effluents into river Ganga (TOI, 2017; NGM, 2020). Connection of online continuous effluent monitoring stations (OCEMS) to the CPCB server in 885 out of 1072 GPIs has been completed (NGM, 2020).

As far as industrial pollution abatement is concerned, it was noted that only 45% of the GPI units had effluent treatment plants (ETPs) and 18% did not work efficiently or comply with quality standards. These industries dispose wastewater into the Ganges River to the extent of 2667.16 MLD (NMCG, 2017; Srinivas et al., 2020). Nearly 11% (almost 275) units keep operating by violating country's pollution control norms. Approximately 50% of these non-complying GPIs are located in Uttar Pradesh and are liable for contaminating rivers such as Ganga (Pandey, 2019). Considerable improvement has been observed in few towns along Ganga stretch in Kanpur, where a significant amount of industrial wastewater is disposed into the Ganga. In 2019, under the Namami Gange project, the Sisamau drain in Kanpur, which used to release nearly 183.29 MLD of wastewater into the river, was stopped (Dutta et al., 2020). As per the latest report of NMCG, the improvement in compliance of industries was observed from 51.5% (in 2016-18) to 87.45% and construction of three common effluent treatment plant (CETP) having capacity 31.18 MLD is under process (NMCG, 2020a). The existing and future rejuvenation actions have been suggested to emphasise on source control using effective measures like wider use of CETPs, serious considerations in effective enforcement, regulation and even future socio-economic changes in long-term industrial expansion while utilising advanced eco-friendly technologies (Walker et al., 2015; Hoffman et al., 2017; Chaudhary and Walker, 2019). In view of the necessity of having an effective monitoring and evaluation framework, the NMCG plans to carry out Lidar mapping of 2525 km of the Ganga river, which will aid in precisely defining pollution and provide a more attentive method for long-term rejuvenation plans (Del Bello, 2018).

Proper enforcement, however, is necessary to restrict the known pollution point sources to control industrial pollution. In order to protect the future of the sacred Ganga, state and central government organisations are required to enforce the 'polluter pays' concept and also get harsher on violating industries. Enforcement of regulation of GPIs is conducted through periodic and surprise audits for compliance confirmation against specified pollution standards and process amendment, wherever mandated by third party technical organization. The first round of inspection of GPIs by the technical organization was conducted in 2017 and the second round of audit carried out in 2018. Out of 1072 GPIs, 961 were inspected, out of which 636 industries were observed adhering to the norms, 110 found noncomplying and 215 were shut.

Solid Waste Management

Solid Waste Management (SWM) is a significant part of Namami Gange Programme and Ganga river would not be fully clean unless the issue of SWM is addressed promptly. It is a domain of the province and the sole responsibility of the State Governments/Urban Local Bodies. This activity falls within the directive of the Ministry of Housing and Urban Affairs (MoHUA) at the Central level. The Namami Gange programme specifies that NMCG will fund STP projects whereas the other work will be carried out by ministries in accordance with their mandates. Thus, under the Swachh Bharat Mission, 97 towns along the main stem of Ganga have been identified and SWM projects have been implemented under the directives of MoHUA (UrbanUpdate, 2018). The total solid waste generation from these towns is 11428 tonnes per day (TPD). West Bengal produces 6001 TPD, the highest of the five main Ganga states, accompanied by Uttar Pradesh, where 3282 TPD solid wastes are produced every day while solid waste generation in Uttarakhand, Jharkhand and Bihar is 347 TPD, 27 TPD and 3282 TPD, respectively. The SWM programmes are being taken up on a high priority to fill the gap between the production of solid waste and the existing treatment capacity. Nearly 667 detailed project reports (DPRs) have now been sanctioned, while 413 are under review for approval in the five states of the Ganga basin. The SWM projects being carried out by MoHUA are in addition to several other initiatives undertaken by MNCG, such as river surface cleaning by trash skimmers in few Ganga towns and ghat cleaning in

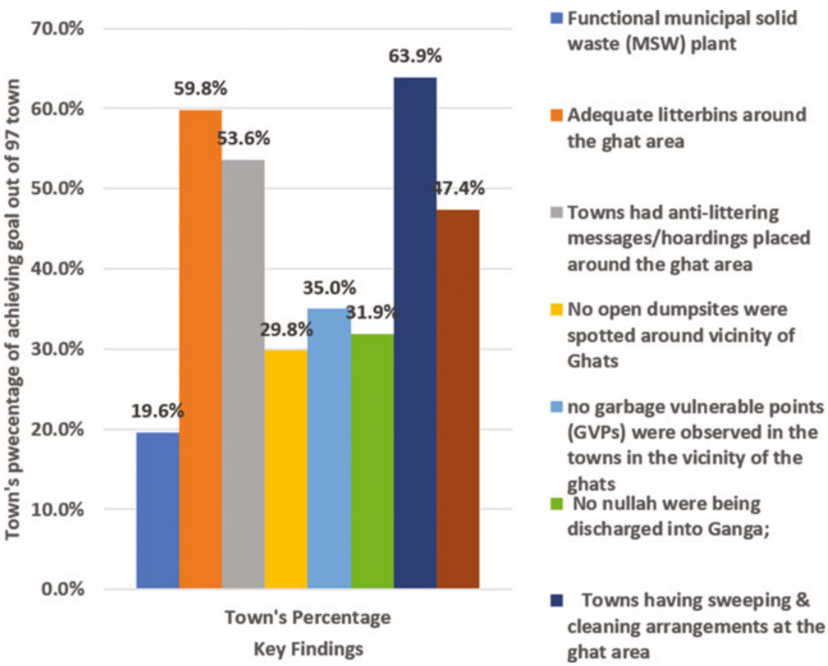

Figure 6. Results of Solid Waste Management Initiatives in the 97 main towns along the river Ganga (MoHUA, 2020).

Varanasi. Similar projects have been sanctioned by NMCG in Bithoor, Kanpur, Allahabad, Haridwar, and Mathura-Vrindavan, following the success of the ghat cleaning project in Varanasi (UrbanUpdate, 2018; NGM, 2020).

In addition, MoHUA has encouraged these states to install bar screens on drains falling into the river Ganga to avert the flowing solid waste into the river and to segregate waste at source and to ensure that process of recycling waste are carried out in productive and environmentally benign means (UrbanUpdate, 2018)**.** Solid waste from 243 ghats is being managed under NMCG and river surface cleaning has been done through trash skimmer at 11 locations. All states under the Ganga Basin have been directed to prevent solid waste dumping in drains with special attention on 1 km stretch from the river and ensure no garbage is dumped in the flood plains (NMCG, 2020a).

As a result of effective SWM projects implementation by MoHUA under the flagship of Namami Ganga programme, a substantial improvement has been observed in 97 main towns in the states of Ganga. The implemented project has reflected the cleanliness status of the surveyed towns. The key results of this projects are (Fig. 6) that 19 (19.6%) towns had functional municipal solid waste (MSW) plant within the town; 58 (59.8%) towns had adequate litter bins around the ghat area; 52 (53.6%) towns had anti-littering messages/hoardings placed around the ghat area; no open dumpsites were spotted around the vicinity of ghats in 29 (29.8%) towns; no garbage vulnerable points (GVPs) were observed in 34 (35%) towns in the vicinity of the ghats; no nullah was being discharged into Ganga in 31 (31.9%) towns; 62 (63.9%) towns had sweeping and cleaning arrangements at the ghat area; across 46 (47.4%) towns, no solid waste was found floating on river surface (MoHUA, 2020).

River Catchment/Basin Management

River basin management is a holistic approach and it has been adopted to restore the wholesomeness of the Ganga ecosystem and revive its ecological health, taking due account of the problem of competing water use in the river catchment. It includes environmental flow Management, periodic quality assessment and controlled groundwater extraction. These measures have been discussed in the subsequent heads.

Maintenances of environmental flows (e-flow)

The maintenance of uninterrupted and continuous river water flow (Aviral Dhara) in the natural course of the river is the backbone for river ecosystems and facilitates river self-rejuvenation. Sufficient e-flow in the river is needed to sustain aquatic ecosystems, transport of sediments, recharge of groundwater through aquifers and improve the quality of river water (MoEF, 2016). The ability of a river to self-purify and recharge itself is substantially damaged due to surface and groundwater over-extraction for irrigation, industrial and domestic utilisation. Mishandling of the Ganga water resources and inefficient utilisation has also resulted in increased levels of pollution in the river. Several hydropower projects have induced large stretches of the river to run dry and have resulted in many irretrievable environmental and social costs due to their cumulative impact (GAP, 2020).

A consortium of 7 IITs (Indian Institute of Technology) advised that the minimum e-flow need to maintain river integrity are less than one-third of virgin flow in the wet period while more than half of that in the lean (dry) period flows, the river flows being minimum in winter (IITs, 2013). In 2018, the Central Government of India mandated the minimum e-flows for the river Ganga that have to be maintained at different river locations even after the river flow is diverted by projects and structures for purposes such as hydropower, irrigation domestic and industrial utilization, etc. It was a significant move to maintain the continuous/uninterrupted (Aviral) flow of the river (PIB, 2018). It has been recommended recently to maintain an average flow of 51% of the river water in the natural stream bed of the Ganga throughout the year, to adequately support the rich biodiversity of the Ganga, to dilute hazardous waste and to allow users to access their inherent water rights. Besides, other measures such as restoration of all water bodies on the banks and in the vicinity of river Ganga; new water bodies to store rainwater, interlinking of various rivers and adoption of water-saving irrigation practice have been directed by concerned central agencies (GAP, 2020). According to the Central Water Commission (2020), 4 out of the 11 hydropower plants on the upper stretches of the river Ganga river still need to comply with ecological flow standards.

Moreover, high priority has been given to the Inter-Linking of Rivers (ILR) schemes to maintain the ecological flow of the river and to have a balancing act between water surplus and deficit basins. "It has been conducted in an advisory manner by the Government of India and four priority links under Peninsular River Component have been identified for preparation of DPR namely Ken-Betwa Link project (KBLP), Damanganga-Pinjal link project, Par-Tapi-Narmada link project and Mahanadi-Godavari link project". A large number of people or farmers are expected to be benefitted from the Ken-Betwa Interlinking Project, leading to additional irrigation advantages of around 8.98 lakh hectares yearly (MoWRRD & GR, 2018).

Water quality monitoring

Numerous water quality monitoring projects have been taken up by the Ministry of Water Resources, River Development and Ganga Rejuvenation and significant results have been achieved by the implementation of some of these projects (PIB, 2018). As per the latest report of NMCG 44, Real-Time Water Quality Monitoring Stations (RTWQMS) are operational and additional 44 RTWQMS stations being set up under Namami Gange programme (besides other manual monitoring stations). Improvement in water quality trends have been observed as compared to 2017 and monitoring at 138 sites (20 km interval) (MoWRRD & GR, 2018) of Ganga depicts that DO levels has improved at 39 sites, BOD improved at 42 sites and coliform count improved at 47 sites (PIB, 2018).

Ganga river bio-monitoring at different locations (Haridwar to West Bengal) is being also conducted on regular basis to investigate benthic macroinvertebrates which shows the biological health of the river. It was noticed that Ganga water maintains a diverse community composition and river reaches exhibit low to medium levels of pollution with relation to Biological Water Quality Criteria (BWQC), which is an indicative standard accepted by CPCB. At some of the locations of the Ganga stretch, the biological water quality has improved significantly (PIB, 2018).

Controlled groundwater extraction

Groundwater (GW) recharge is impeded by the construction and development along the banks of rivers. It is also affected by the disruption of the natural flow of water. The self-revival capacity of the river flow is affected by non-scientific and severe sand mining in select stretches, including in environmentally sensitive regions. An appropriate regulatory framework is a must to ensure that river banks are developed only in an environmentally sustainable way to support the coexistence of river flow and economic activities (MoEF, 2016). India is now the biggest user of groundwater for agriculture in the world. In some parts of Ganga, improper GW development initiatives have resulted to decline in GW levels, drying up of shallow wells, decreases in viability of wells, increased impairment GW quality and decreases in base flow in many small rivers etc. (PIB, 2017).

In 2012, with Central Ground Water Board (CGWB) as the executing body, a promising National Aquifer Mapping and Management Program (NAQUIM) was initiated with an aim to delineate and characterize the aquifers to develop plans for groundwater management. The total targeted area for NAQUIM is 12.91 lakh km^2 till March 2020 against 24 lakh km^2 area identified for mapping in the country (Downtoearth, 2019; PIB, 2019). Aquifer mapping and management plans prepared by the CGWB are finally provided to concerned state agencies in order to improve the groundwater situation by implementing the management plans (MoWRRD & GR, 2018; PIB, 2018). Aquifer mapping and management work performed under NAQUIM have been used to pursue successful projects, that will reduce wet season water dependence. For example, in the Tapi Mega Recharge (Managed Aquifer Recharge) plans for Chhatarpur basin, wells (18 Nos.) were drilled in water stressed villages in Tikamgarh district of Bundelkhand region for State PHED. In Latur, Maharashtra, 25 wells were drilled for drought mitigation in the Year 2016 and handed over to the state agency for water supply. Multi-layered aquifers were identified in intensely irrigated water scares areas of Haryana (MoWRRD & GR, 2018; PIB, 2018). For the tapping of arsenic-free water 72 innovative water wells have been created in Ballia and Gazipur districts (U.P), and 62 wells in Hugli districts, West Bengal. Additionally, two mobile apps "Jal Sanchayan" and "Mera Bhujal" commenced to enable and improve citizen's understanding to take up water conservation, groundwater recharge and quality measures (MoWRRD & GR, 2018).

Recently a comprehensive guideline has been released by Government of India under the purview of Jal Shakti Ministry (CGWA) to have sustainable management of groundwater resources. It has been prepared to control groundwater extraction and conserve the scarce groundwater resources in the country. This will regulate the groundwater abstraction from agricultural and commercial (industrial use, mining projects and infrastructure development projects sectors) (CGWA, 2020).

Other Restoration Measures

In addition to the major rejuvenation approaches discussed above, several other efforts have been initiated in order to revive the Ganga river in a holistic manner. Some of these efforts are discussed as follows.

Variety of Riverfront Development Projects on Ganga and its Tributaries

The ghats and river fronts-based interventions enable a better connection between citizens and pave the way for river-centred urban planning processes. The government has been proactive in taking up these projects of riverfront development and crematoria works. In selected cities, works for 151 ghats and 54 crematoria have been completed in 2019. In West Bengal (2011 to 2014), 24 ghats were also completed (MoWRRD & GR, 2018; PIB, 2018). Under the scheme of Namami Gange flagship programme, approximately 28 projects related to riverfront development and 33 entry level projects were reported to be launched for the infrastructural set-up of 182 ghats and 118 crematoria (NGM, 2020).

Afforestation and Biodiversity Conservation (BC)

Afforestation and BC interventions have been taken up with the objective to promote community driven sustainable land and ecosystem management of the riverscape, while improving and maintaining the forest/vegetation cover in the buffer zone along the course of river Ganga and its tributaries, and protection and conservation of the representative biodiversity of the Ganga riverscape (WWF et al., 2019). Wildlife Institute of India (WII), Central Inland Fisheries Research Institute (CIFRI) and Centre for Environment Education (CEE) have been already asked to take up the afforestation projects along the Ganga. They have been executed as per the DPR prepared by Forest Research Institute (FRI) for a duration of 5 years (2016-2021) at a worth of Rs. 2300 cr. Afforestation work has already been initiated in 7 districts of Uttarakhand for medicinal plants (NGM, 2020). Additionally, numerous integrated projects for medicinal plantation are being executed in 10 districts, 180 gram panchayats, 60 clusters of Uttar Pradesh and 800 Ha corridor of medicinal plantation along Ganga by National Medicinal Plant Board (NMPB) (NMCG, 2020a). According to NMCG, Rs.114 cr. have already been invested on afforestation.

In view of the biodiversity conservation of river Ganga, several interventions have already been commenced such as biodiversity conservation and Ganga rejuvenation, fish and fishery conservation in Ganga river, Ganges river dolphin conservation education programme etc. Five bio-diversity centres at various locations, viz. Dehradun, Narora, Allahabad, Varanasi and Barrackpore has been established for the protection of identified priority species (NGM, 2020). Furthermore, six projects related to the conservation and rehabilitation of river Ganga biodiversity with respect to ghariyal, fisheries, water birds, otter, and dolphin have been carried out. Among these, two rehabilitation projects have already been completed. For afforestation schemes in the Ganga basin, a funding of Rs. 190.3 cr has been provided to the state forest departments of Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West-Bengal for the year 2018-19 (PIB, 2018).

Protection of Flood Plains

Flood plains are an integral part of overall river ecology and their protection is important for the health of the river. The domain of flood management and flood zone protection along with erosion control comes under the control of the States. The state governments engage other concerned agencies to undertake projects related to river management, flood and erosion abatement, drainage expansion, flood proofing works and refurbishment of damaged flood management projects. These schemes are planned, investigated and executed as a primary consideration within the state by state governments with their own resource base. The central government provides technical direction and promotional monetary support in essential areas to supplement the work of the states (NMCG, 2020a).

"Flood Management Programme (FMP)" and "River Management Activities & Works related to Border Areas (RMBA)" schemes have now been integrated into the single scheme "Flood Management and Border Areas Programme (FMBAP)" for the 3 year duration from 2017-18 to 2019-20. Under this scheme monetary support worth of Rs. 5435.74 cr has been provided upto the year 2018 to the various states as grant-in-aid under FMBAP (PIB, 2018).

In-situ Bioremediation

Municipal sewage and industrial effluent control initiatives have been undertaken in towns along the major streaches of Ganga under the Namami Gange programme to target the main river and the tributaries, through the construction of STPs and ETPs/CETPs. These plants have a lengthy period of completion, and during this interim period, the effluents keep flowing into the water bodies, hence these pollution loads need to be addressed employing various available technological innovations. The NMCG is in the process of evaluating and promoting in-situ bioremediation technology.

In-situ bioremediation is the process of treating polluted wastewater at the site itself using microbial/phytoremediation technologies with no major structural modification of the site. In-situ bioremediation technologies can be implemented (with display of results) in a small time (few months only), are simple to operate and consumes less energy, unlike traditional treatment technologies. Primarily Microbial Bioremediation (Bacterial Inoculants, Nualgi, Ecobio Block, RENEU etc.), Phytoremediation (Constructed Wetland System and Root Zone Treatment, Green Bridge, Artificial Island and Phytorid technology etc) have been used for the treatment of these effluent carrying drains (CPCB, 2020).

The NMCG is proactively working towards the treatment of smaller Ganga tributaries and drains. After successful implementation of the in-situ bioremediation technology at Bakarganj drain in Patna, NMCG further executed two more pilot projects one each in Patna and Allahabad. Further, it was planned to scale it up by identifying 54 drains across the four states namely Uttar Pradesh, West Bengal, Bihar and Jharkhand where in-situ bioremediation technologies could be adopted to avert wastewater flowing directly into the Ganga (Mohan, 2017). So far, projects worth Rs.100.8 cr have been sanctioned for the in-situ bioremediation of 52 drains carrying 1369 MLD of wastewater along the main stem of Ganga, which are directly or indirectly impacting the river health. Out of these drains, 29 drains carrying 903 MLD of sewage have been identified in Uttar Pradesh, followed by 20 drains having 442 MLD of sewage in West Bengal, and 3 drains carrying 24 MLD sewage in Bihar (NMCG, 2020b). Recently, National Environmental Engineering Research Institute (NEERI) has successfully implemented an integrated in-situ bioremediation technology called RENEU (Restoration of Nallah with Ecological Units) for the treatment of 21 MLD of Sewage in drains at various locations in Prayagraj (NEERI, 2020). This technology has been found to be encouraging and is able to remove BOD up to 80-95%.

Public Awareness

Public awareness programmes play a vital role in the dissemination of information on river health and to take up the river conservation and rejuvenation initiatives at the local level. Awareness initiatives need to include stakeholders from diverse professions and levels that are from top of local representative bodies to municipal mayors, city/town planners, urban local officials and association of inhabitants. The main goal is to educate and train the community to make them more aware of their important responsibilities in restoring the deteriorated health scenario of rivers. The awareness programmes would not be so effective if carried out at a later stage of development, Thus, education concerning rivers has to therefore start at the level of primary education. Further, in any rejuvenation mission, governmental organisations, non-profit organisations, activists and society members must be welcomed.

For the awareness among various stakeholders in the Ganga Basin, several initiatives such as Ganga Manthan, Great Ganga Run, Ganga Utsav, Ganga Amantran, Ganga Quest, Ganga Cleanathon have been frequently organised by the Government of India through various stakeholders (NMCG, 2020a). These programmes have been implemented through numerous innovative awareness activities such as rallies, campaigns, exhibitions, shram daan, cleanliness drive, competitions, plantation drives and development and dispersal of resource materials. For large scale promotions, various media such as TV/radio, print media advertisements, advertorials, featured articles and advertorials are being used (NGM, 2020). In order to establish a successful pitch for public outreach and community involvement in this programme, a series of events like workshops, seminars and conferences and numerous IEC (Information, Education and Communication) activities has been regularly organised.

LESSONS FROM FEW GLOBAL RIVER REJUVENATION ATTEMPTS

Planning and management of river water at the basin level have been carried out for many decades on a global scale moving towards a more scientific and engineering-based approach during its gradual evolution over time in such a manner that the limited water resources of a river can be efficiently managed to achieve all possible requirements for the socio-economic development of a country.

In developed countries, the management of rivers and river basins has been fairly more holistic and exhaustive than in developing countries, (Newson, 1992; Shah et al., 2001). European Union, USA and Australia have been adopting well-structured advanced policies since the last few decades towards more holistic watershed management as governed by various social, environmental, political and economic factors (Newson, 1992; Heinz et al., 2007; Molle, 2009; Boon and Raven, 2012; Euler and Heldt, 2018). Appropriate policy execution at the national, local and regional level is also extremely essential for the sustainable management of the river basins which assures a fair dispersion of the gains of technological and other innovations in hydropower and water conservation etc. in the river catchment (Dourojeanni, 2001). Most of the river basin management committees across the world do have well-framed policies towards achieving the sustainable goals of basin management (Srinivas et al., 2020).

The Nile river basin has a legislative framework that includes educating the public about downstream and upstream rights, understanding the relationship between water quality and quantity, decreasing sedimentation, considering the impact of climate change on future development plans and focusing on reinstating biodiversity in the river basin (Hoag and Mohamoda, 2003; Misgan, 2013). Mississippi river basin management mainly encourages the perennial farming systems, reduction of nutrients, the management of chloride, the augmentation of fish research, the establishment of nitrate standards, the development of fertiliser management and the execution of tile drainage in agricultural watersheds (Hooper, 2012; Fang et al., 2017; MDEQ, 2020).

Thames river basin management plan focuses primarily on the innovative sewage treatment works including construction of the Thames tideway tunnel, artificial aquifer recharge, construction and management of wetlands, empowering communities through community modelling strategies and public awareness on eco-friendly agricultural practices (Environment Agency, 2015). Volga river basin authorities focus on management of flood plain, reviving ecosystem health, improving monitoring of biological parameters, advancement of wastewater treatment infrastructure and management of river channels (Schletterer et al., 2018). Amazon river basin management is designing a policy framework for integrated water and land management, conservation of biodiversity, evaluating the susceptibility of biodiversity and local communities to climate change, and improving mechanisms to recognise and address the root causes of river water pollution and community involvement in integrated water management (FAO, 2015; Souza-Filho et al., 2016). Similarly, Rio de la Plata river basin policy focuses on inland navigation, hydropower viability, exploring land-water interactions, introducing new management tools to riverine states and cross-border management (FAO, 2016; Villar et al., 2018).

CHALLENGES CONCERNING TO REJUVENATION STRATEGIES

Despite serious attempts at river rejuvenation, the level of alteration in river basins across the globe has often indicated that it is physically or financially unfeasible to restore rivers to the pre-development situation in most of the cases. Many rejuvenation projects have also been unsuccessful to address issues at the accurate spatial scale and even sometimes failed to properly understand basin level processes. It is also difficult to ensure that the rejuvenated rivers are perfectly suitable for the future world, because of the huge uncertainty about the future of river basins. Among many other aspects, uncertainties remain about climate change, land use and urbanization. Recently, a serious shortfall was reported by CAG of India in "Namami Gange" programme, when it was observed that even after years of NGRBA notification, the NMCG has no river basin management plan. The Ganga rejuvenation attempts were also queried by the National Green Tribunal, the Supreme Court of India and the state governments (SANDRP, 2018). Key challenges experienced during implementation of Ganga rejuvenation plans have been discussed further.

- Even after huge investment and efforts on implementing control measures for sewage pollution, Ganga rejuvenation has still not been able to reach the desired level due to several factors such as sewage infrastructure interventions limited in government schemes to Class I and Class II; Operation and maintenance issues and inadequate and sub-optimal functioning of STPs; Delay and poor quality DPRs; Inadequate citizen involvement and Ineffective data generation and analysis; Lack of Inter-Ministerial and Centre-State coordination and inadequately addressed non-point source pollution. It is also observed that efforts for expansion of sewage treatment infrastructure in order to achieve cleaner Ganga goals are not in line with rapid urbanization rate. Another issue with sewage treatment is the lack of sewerage networks in the many cities, they are not able to receive the designed volume of wastewater. There is also a discrepancy in sewage generation design consideration. "The estimation of sewage generation assumes that 80% of the water supplied is returned as wastewater. Some recent data compiled by CPCB shows that actual measured discharge of wastewater generation is 123% higher than the estimated discharge of wastewater (Kaur, 2018)."
- Ganga river basin have been made Open Defecation Free (ODF) now under rural sanitation mission, however, as per the FSSM (2017), household sewage management in rural areas will still pose a major challenge because most of the villages have twin-pit technology which is not recommended in low-lying areas surveyed by CSE (Kaur, 2018). Therefore, while the suppression of human waste

will be largely achieved, its safe disposal still remains an enormous challenging issue.

- Numerous comprehensive plans with fund allocation have been prepared in the past to regulate industrial pollution, so far it is found that water quality improvement due to Ganga rejuvenation initiatives are still transient as there is no major scheme to regulate the GPIs. There is an inefficient control of industrial wastewater discharge, even after the Namani Gange Programme, which shows week execution of pollution regulations and enforcement by central/state agencies (WWF et al., 2019). In addition, enforcement framework of small-scale industries is still weaker as compared to large and medium scale industries.
- The riverfront projects, when taken up in large stretches specially, though environmentally aesthetic, but are viewed by ecohydrologists as undesirable initiatives that are truly not able to reinstate the river to its original state in the manner executed. River engineers need to understand where to concretise the river banks and river fronts so that ecological well being can also be protected. Rivers naturally create their own water fronts and planners should invest in ecological health not creating ecosystems that are liable for their destruction (WWF et al., 2019). It is needed to sincerely integrate future ecological and sustainability goals, and cannot simply be a transient rightist step (Dutta, 2019).
- Maintenance of ecological flow is another critical issue, as the Ganga, except during monsoons, is unable to maintain the minimum required flow and, thus, it is not only a concern about the polluted Ganga but also about the existence of Ganga. It was also noticed that the water velocity tends to decrease and siltation increases due to reduction in the flow, and settling down of sediments at the river bottom leads to decrease in the flow cross-section area (WWF et al., 2019). In addition, dams are the primary cause of flow impediment in the upstream inducing large stretches of the river to run dry and result in many irretrievable environmental impacts; whereas on the other side, barrages divert huge amount of water for downstream irrigation and other purposes (Dutta et al., 2020; Trivedi, 2020).
- Mishandling and inefficient utilisation of the Ganga Basin water resources as a whole have also resulted to increased levels of pollution in the river. Appropriate policies for use of groundwater and treated/recycled effluents in agriculture are still not in place or lacking proper implementation.
- Seamless coordination within the existing institutional set-up for Ganga rejuvenation comprising various government organizations is still a major constraint in an efficient policy formulation and implementation. For instance, the Water Resources Ministry has MOUs with 10 other ministries for improved execution (Kaur, 2018). This is apparently leading to redundancy and ambiguity of tasks at both the federal and state levels and discourages centralised assessment of this limited resource. It does lead to several governance glitches such as lack of coordination, co-operation and accountability etc. among the various concerned agencies which ultimately affects the goal of Ganga river rejuvenation.

INTERVENTIONS RECOMMENDED

In order to strengthen the rejuvenation programme following interventions are recommended in order to restore pristine nature of the river Ganga.

- Regular assessment of all the implemented programmes should be done and programmes need to be decentralised as much as possible. In order to achieve the goals of the Ganga rejuvenation, all the stakeholders residing in the basin must be encouraged to participate. Unless it has a bottom-up approach, the programme cannot receive proper feedback at different stages from all relevant quarters, which is essential for its success.
- There is a need of good governance and seamless coordination among the various engaged agencies and the policy framework should be stringent while at the same time, sufficiently flexible to introduce changes with time. Pollution control schemes need to be more transparent, accountable and inclusive at every stage.
- In the light of non-compliance of wastewater treatment and discharge guidelines, more stringent regulation and enforcement are needed. For existing ETPs and STPs, there should be a requirement for strict third-party compliance audit to make the system more transparent and efficient. In order to protect the future of the sacred Ganga, state and central government organisations require to enforce the 'polluter pays' concept and also get harsher on violating industries. Additionally, enforcement framework for small-scale industries is also needed to be reviewed especially with respect to their connectivity to the Common Effluent Treatment Plants (CETPs) and the genuine problems faced by them. The effluent discharge standards need to be based on the concept of "Allowable Loads" rather than the independent parameter values as at present. Besides, for the design and monitoring of STPs, emerging contaminants needs to be duly considered as this has become a rising concern now.
- It seems that environmental flow standards have primarily been formulated with implicit reference to hydrological approaches primarily, and other crucial associated factors have been overlooked, like transported sediments, instream biota (ecosystem features), pollutants and other demands of water users. Thus, there is need to revisit the e-flow standards in a holistic manner.
- Agriculture sector should receive a lot of attention, considering its role in contributing non-point pollution on the one hand, as well as presenting an ever-increasing demand for surface and ground water. Rational employment of conjunctive use guidelines must be enforced, along with strictly adopting sustainable irrigation practises for achieving proper conservation of water. It should be ensured that the implementation of projects approved by NMCG is completed within stipulated time, while the monitoring and evaluation frameworks need to be more stringent.
- Although ODF problem has been completely eradicated but the problem of ensuing pollution has not been completely addressed because the field scale construction of toilets with lack of concern for safety protocols is raising concerns

regarding severe risk to the groundwater pollution and its adverse influence on the river quality also. These schemes need to be critically evaluated.

- Rejuvenation programmes should focus on the strengthening of capacity building by designing and providing novel learning and training tools for the scientific and efficient implementation of schemes. Moreover, collaborative frameworks should be developed for various sectors and at different stages between educational institutions, employer institutions (public, private, non-governmental organisations) and corporate sector, and appropriate incentives should be provided to encourage and retain staff.
- Regular and comprehensive monitoring of the river system should be ensured with further inclusion of the emerging pollutants, and all related information should be available on a common platform along with the information of all the ongoing or completed Ganga rejuvenation initiatives. The information should be regularly updated and arrangements should be made for a hassle-free access by stakeholders, taxpayers and research community.

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