Benchmark assessment of local water quality and quantity and existing infrastructures in the two case areas

Deliverable D4.1

WP4 Water monitoring, modelling and control
Task 4.1 Benchmark assessment of local water quality and quantity and existing infrastructures in the two case areas
&
Task 4.3 Regional water quantity and water quality modelling tools to assess the impact of adopted technologies / strategies and water resources allocation policies on water quantity/quality for the two case areas

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CO	Confidential, restricted under conditions set out in Model Grant Agreement	
CI	Classified information as referred to in Commission Decision 2001/844/EC)	
R	Document, report	X
DEM	Demonstrator, pilot, prototype	
DEC	Web sites, patent fillings, videos, etc.	
OTHER	Software, technical diagram, etc.	
ETHICS	ETHICS	

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SUMMARY

The benchmark assessment of quality and quantity of local surface and groundwater resources and the existing water infrastructures in the two case areas (Deliverable 4.1) – is the first deliverable of Work Package 4 – Water monitoring, modelling and control. WP4 has the overall objective of delivering robust, smart and comprehensive solutions for water quality and quantity monitoring, and management of water resources in the two case areas. In Task 4.1 the benchmark assessment was expected to be carried out on the basis of a historical analysis of existing secondary data and the baseline water quality data collected using mobile sensors with identified actors. Due to COVID-19 restrictions and the problems in procuring the hand-held water quality devices – the deliverable has largely depended on using the regional water quantity and water quality modelling tools established in Task 4.3. With the inclusion of citizen based water quality monitoring work carried out post COVID-19 Task 4.1 and Deliverable D4.1 is complete. The outcome of Task 4.1 is that it provides a framework for assessing the impact of improvements in wastewater treatment technologies and treatment infrastructure on regional water quality and water flows in the two case areas, but with more information from the modelling work (Task 4.3) than originally envisaged.

The Barapullah Drain catchment is situated on the western bank of the river Yamuna and is spread over five sub-districts of Delhi. The Barapullah catchment is 376 km^2 in area with a population of approximately 3.5 million as of the 2011 census (IIT New Delhi, 2018). The catchment is completely urbanized. The Barapullah, the major drain in the catchment (also referred to as Nizammuddin darya), was once a major stormwater drain. Due to limitations in urban sewage treatment infrastructure, the Barapullah currently discharges approximately 1.25 million litres (330 MGD) of wastewater per day into the Yamuna river, accounting for 80% of the stormwater which is transported to the Yamuna from the region (Bhaduri, 2017). The drain is approximately 100m wide at the outlet to the Yamuna and is 16km long (Trikannad, 2018).

Treatment capacity exists for treating nearly 53% of the total 330 MGD of wastewater generated in the Barapullah catchment area. A significant portion of untreated wastewater goes directly into the river. Domestic sources account for approximately 85% of pollution to the Yamuna river and include debris, untreated sewage and industrial effluents (Malik et al., 2014). Consequently, the outflow has high concentration of heavy metals [including lead (Pb), zinc (Zn), and copper (Cu)], high biochemical oxygen demand (BOD) and low values of dissolved oxygen (DO) which have historically not conformed to the recommended levels (Sehgal et al., 2012). More recent studies have highlighted the emergence of antibiotic resistant bacteria (ARB) originating from untreated sewage in the Yamuna river (Lamba et al., 2017).

Kanpur Metropolitan Area is located in the State of Uttar Pradesh and is the 10th most populous city in India with over 3 million people. The region is one of the major urban and industrial centers along the Ganges. Over the past 50 years, Kanpur has grown geographically by only four sq. km. However, the population has increased by more than three times from a mere 0.96 million in 1981 to 2.9 million in 2011. As a consequence, population density has increased from 3,243 persons/sq. km in 1961 to 9,666 persons/sq. km in 2011, thus putting more pressure on the existing natural resources in the city. Domestic water demand is estimated at 600 million liters per day (MLD). However, only 385 MLD is delivered to waste water treatment plants due to infrastructure limitations.

The estimated sewage generation in Kanpur city is about 339 MLD but only 50% is treated (Bassi et al., 2019). Apart from the use of a small quantity of treated wastewater in irrigation, the rest of the treated wastewater and the untreated wastewater is directly drained into the river Ganga in north and river Pandu

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in south of the Kanpur city. Sismau and Permiya Nalas (open drains) contribute to about 50 percent of total wastewater which is discharged into the River Ganga and River Pandu.

Both case areas therefore show similar waste water management issues, which reflect the general situation in India, whereby the current infrastructure is unable to deal with the waste generated by the growing population and industrial developments. However, an important difference between the two areas is that New Delhi meets about 50% of its water needs (913 million gallons per day (MGD) in 2018) from water imports whereas Kanpur uses water from the River Ganga and the local groundwater resources. Therefore, dealing with the pollution of surface water and groundwater bodies remains the management priority for the local self-governing bodies of both the cities.

The WEAP water balance model, developed by the Stockholm Institute of Environment, is set up for the two case areas to examine how the demand for water and quality of water in the river and the underlying aquifers change over time in accordance with various socio-economic and environmental drivers (population growth, growth in per capita demand, changes in climatic conditions, especially rainfall conditions and changes in wastewater treatment technologies and capacities) and how the supply of water in terms of quantity and quality to meet the requirements (demand) of water changes under various technological interventions.

The WEAP model has been fully developed for both case areas with the development of a baseline (reference) scenario and different future scenarios of the water balance. The configuration of the WEAP model was set up for the period beginning 2009 and ending 2040. The year 2009 was taken as the base year for the water balance (also referred to as 'current account') and the period 2010-2040 was considered for generating different future scenarios. Three scenarios, namely 'reference', 'high population growth', and 'high population growth and treatment efficiency improvement', were developed and the results obtained under them were compared.

Kanpur Metropolitan Area

The model predicts that under all the scenarios there will be an increase in the "unmet water demand" in Kanpur city and the peripheral areas. By 2040, the unmet water demand gap is expected to increase by 5.9 MCM in the urban sector, 1.3 MCM in agriculture sector, 1.1 MCM for industries (other than tanneries) and 0.2 MCM for tanneries. This gap will need to be filled by improved water use efficiencies, the uptake of water reuse measures, and augmenting the capacity of the existing water supply infrastructure (including adequate treatment), as there is no effective limit to getting additional water availability in the KMA even during the lean season, given its close proximity to Ganga River. The likely adverse impact of the expected increase in urban population and the resultant increase in wastewater generation on quality of local surface water (in the rivers) is expected to be offset by improvements in treatment efficiency of the WWT plants.

A more spatially explicit approach for the WEAP set up assesses the impact of the additional STPs being installed in the Kanpur Metropolitan Area. The generated future scenarios indicate that the planned sewerage treatment improvement in Kanpur is not yet adequate enough to achieve a substantial improvement. This indicates that the planned capacity improvement will not significantly improve water quality and more investments in STPs and sewerage network are required. This approach has allowed also the apportionment of effluent releases bto the Ganga and Pandu rivers and to quantify the different effects of the treatment infrastructure improvement on water quality in both rivers.

If the population grows as expected, the adopted and planned improvements will become insufficient. The increase in pollution generation, due to the increase in population and the expected improvement of the quality of life and, consequently, to the higher water footprint of the society, is likely to exceed the positive improvements brought by wastewater treatment technology enhancements. This means that an integrated approach is needed to reduce "unmet water demand". This includes decreasing the demand by improving

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the efficiency of water use, adopting appropriate reuse measures for treated wastewater and increasing supply by augmenting the capacity of the existing water supply infrastructure (including raw water treatment facilities), and improving wastewater treatment to safeguard water resources and the environment.

Barapullah Drain, New Delhi

The model predicts that until 2027, there would be no “unmet water demand” in the Barapullah catchment under the four scenarios. The groundwater reserves in the catchment would ensure the required water supplies. However, by 2028, there would be unmet water demand under the high population growth and high economic growth scenarios. For the other two scenarios (reference and the CETP improvement), water supply shortage will appear in 2037. By 2040, the annual unmet water demand at the aggregate level will be 54 MCM each under the reference and the CETP improvement scenarios , 92 MCM under the high population growth scenario, and 94 MCM under the high economic growth scenario. Under the four scenarios, urban domestic sector has the highest annual unmet water demand. By 2040, it will vary from 47 MCM under the reference scenario to 83 MCM under the high economic growth scenario, a difference of 36 MCM between the scenarios. For industries, the difference between the unmet water demand under the reference and high economic growth scenarios would be about 3 MCM by 2040.

The quality of water at the outfall of the Barapullah drain to river Yamuna for 2009-2030 under the reference scenario it shows that the monthly mean value of the three water quality parameters, i.e., TDS, BOD, and NH3-N are the lowest during the monsoon months of July, August, and September. During the monsoon, Barapullah drain receives fresh rain water which leads to dilution of the pollutants received in the drain and thus improves in the drain water quality. The monthly mean concentration in the reference scenario was highest in October (553 mg/l) for the TDS, in December (97.4 mg/l) for the BOD, and February (49.0 mg/l) for the NH3-N. Under the high population growth and high economic growth scenarios, the mean monthly values (2009-2040) for BOD and NH3-N increase (deterioration of the water quality) in comparison to the reference scenario (refer Figure 108 and Figure 110). The increase in the case of high economic growth scenario is the highest. However, the TDS decreases under both the scenarios in comparison to the reference scenario. But this is due to lack of data on the TDS of the effluents from the WWT plants. Nevertheless, as per the expected lines, the values of all the three parameters decrease (improvement in the water quality) under the CETP improvement scenario in comparison to the reference scenario.

Overall, the modelling results show that the impact of **climate variability on the water supply-demand** situation and **water quality** is likely to be quite large, and larger than the impact of many of the socioeconomic changes (increased water demand, increased waste generation, etc.) in both the regions. The potential impact of the probable future change in rainfall on runoff from Barahpullah catchment to Yamuna river is much less than the impact of rainfall variability. Non-point pollution of groundwater from agriculture in Kanpur appears to be significant and needs to receive more attention in future. The analysis is quite indicative of the role of water quantity management and water allocation in managing river water quality--on an annual basis. In Kanpu**r**, availability of sufficient quantity of water to meet the demand is not a concern. What is required is building of adequate infrastructure for augmenting the supply in response to the growing demand. However, in Delhi, water demand reduction in the municipal & industrial sectors has to receive great attention as availabilityof the resource to augment the supplies is a constraint.

Citizen based water quality monitoring

The citizen based water quality monitoring approach plan was devised for the two project case areas with the following broad objectives: demonstrate the efficacy of using mobile water quality tools (Akvo Caddisfly) to explore existing water quality issues at these sites; generate data using mobile water quality monitoring tools to assess ambient water quality along with contextual information on water resource use and flag up potential water quality issues; monitor the potential impact of wastewater on groundwater in

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project locations especially in Kanpur. The parameters ph, EC and Nitrates were measured in line with the GEMS/UNEP approach to monitor ambient water quality (UNEP, 2018) and assess the "Proportion of bodies of water with good ambient water quality" (SDG 6.3.2).

The 2023 monitoring campaigns in Delhi and Kanpur provide insights into the water quality and management challenges in the selected villages and case areas. The use of Akvo Caddisfly, with its simplified design and user support, facilitated the participation of individuals from Solidaridad in water quality testing. Individuals from Solidaridad had a strong background in community facilitation and outreach but limited expertise in monitoring and assessing local water resources effectively. The collaborative approach, engaging the community in selecting sampling points and sharing observations, enhanced the overall data gathering process. All information collected is organised and communicated via the Pavitra Ganga Dashboard - https://pavitra-ganga.eu/en/pavitra-ganga-dashboard.

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LIST OF ACRONYMS

ARB	Antibiotic Resistant Bacteria
BCM	Billion Cubic Metres
BOD	Biochemical Oxygen Demand
Cd	Cadmium
CETP	Common Effluent Treatment Plant
CFU	Colony-Forming Unit
CGWB	Central Ground Water Board
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board
Cr	Chromium
Cu	Copper
cumec	cubic metre per sec
CWC	Central Water Commission
DO	Dissolved Oxygen
ECMWF	European Centre for Medium-Range Weather Forecasts
FC	Fecal Coliform
Fe	Iron
GLDAS	Global Land Data Assimilation System
IIT	Indian Institute of Technology
IMD	Indian Meteorological Department
ISRO	Indian Space Research Organization
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
KMA	Kanupr Metropoitan Area
MCM	Million Cubic Metres
Mg	Magnesium
MLD	Million Liters per Day
OSM	OpenStreetMaps
Pb	Lead
ppm	parts per million
SPS	Sewer Pumping Stations
SRTM	Shuttle Radar Topography Mission
STP	Sewage Treatment Plant
SWAT	Soil and Water Assessment Tool
TC	Total Coliform
TDS	Total Dissolved Solids
UPJN	Uttar Pradesh Jal Nigam
WRIS	Water Resource Information System
Zn	Zinc

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INTRODUCTION OF THE TWO CASE STUDY AREAS

The original objective of Task 4.1 (as described in the Grant Agreement) was to deliver a benchmark assessment of the local water quality and quantity and existing infrastructure in the two case areas and establish citizen involvement and interest in waste water issues by engaging stakeholders to use low cost mobile monitoring tools. The work in Task 4.1 would pave the way for providing the necessary information for designing the stationary sensor network in the Barapullah Drain catchment area (Task 4.2) and collating essential information and context for the regional water quantity and water quality modelling (Task 4.3). Both the water quality data collected from the stationary sensor network (Task 4.2) and the regional modelling (Task 4.3) would then have provided additional information to enhance the benchmark assessment.

Due to the COVID-19 pandemic it has not been possible to implement the expected water quality monitoring in the two case areas. The approach has therefore changed to use water quality modelling approaches to provide the benchmark assessments, which will then be enhanced by the water quality monitoring information that is delivered later in the project. The outcome of Task 4.1 is therefore still to provide a framework for assessing the impact of improvements in wastewater treatment technologies on regional water quality and management of water resources in the two case areas, but the approach has been modified.

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CHAPTER 1 NEW DELHI - BARAPULLAH DRAIN

The Barapullah Drain is catchment is situated on the western bank of the river Yamuna and is spread over 5 sub-districts of Delhi. The Barapullah catchment is 376 km^2 with a population of approximately 3.5 million as of the 2011 census (IIT New Delhi, 2018). The catchment is completely urbanized. The Barapullah, the major drain in the catchment (also referred to as Nizammuddin darya), was once a major stormwater drain. Due to limitations in urban water sewage treatment infrastructure, the Barapullah currently discharges approximately 1.25 million litres (330 MGD) of wastewater per day into the Yamuna river, accounting for 80% of the stormwater which is transported to the Yamuna from the region (Bhaduri, 2017). The drain is approximately 100m wide at the outlet to the Yamuna and is 16km long (Trikannad, 2018).

The Barapullah catchment (in south and south-west direction along river Yamuna) has sewage treatment plants at seven locations. They are (including the treatment capacity as of March 2019): Okhla (140 MGD), Vasant Kunj (5.2 MGD), Sen Nursing Home Nalla (2.2 MGD), Delhi Gate Nalla (17.2 MGD), Mehrauli (5 MGD), Ghitorni (5 MGD), and Molarband (0.66 MGD). Most of the treated wastewater is discharged to the river Yamuna. The information pertaining to actual treatment of wastewater and reuse of treated water (as of March 2019) is provided in Table 1. The location of the seven STPs is presented in Figure 1.

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Table 1: Details of sewage treatment infrastructure in the Barapullah catchment

STP Location	Treatment Capacity (MGD)	Actual Treatment (MGD)	Amount of Treated Water Reused (MGD)	Remarks
Molarband	0.66	0.50	-	Treated WW discharged to Yamuna
Sen Nursing Home Nalla	2.2	2.32	4.8	To PPCL. The rest of the treated WW discharged to the Yamuna
Delhi Gate Nalla	17.2	17.61		
Ghitorni	5	0.39	-	
Mehrauli	5	3.84	3.4	To Garden of Seven Senses
Vasant Kunj	5.2	3.11	3.7	To park (Sanjay Van)
Okhla	140	108.80	37	To CPWD and Irrigation department for Horticulture and Irrigation purpose. The rest of the treated WW discharged to the Yamuna
Overall	**175.26**	**136.57**	**48.9**	

(Source: Government of NCT of Delhi, 2020)

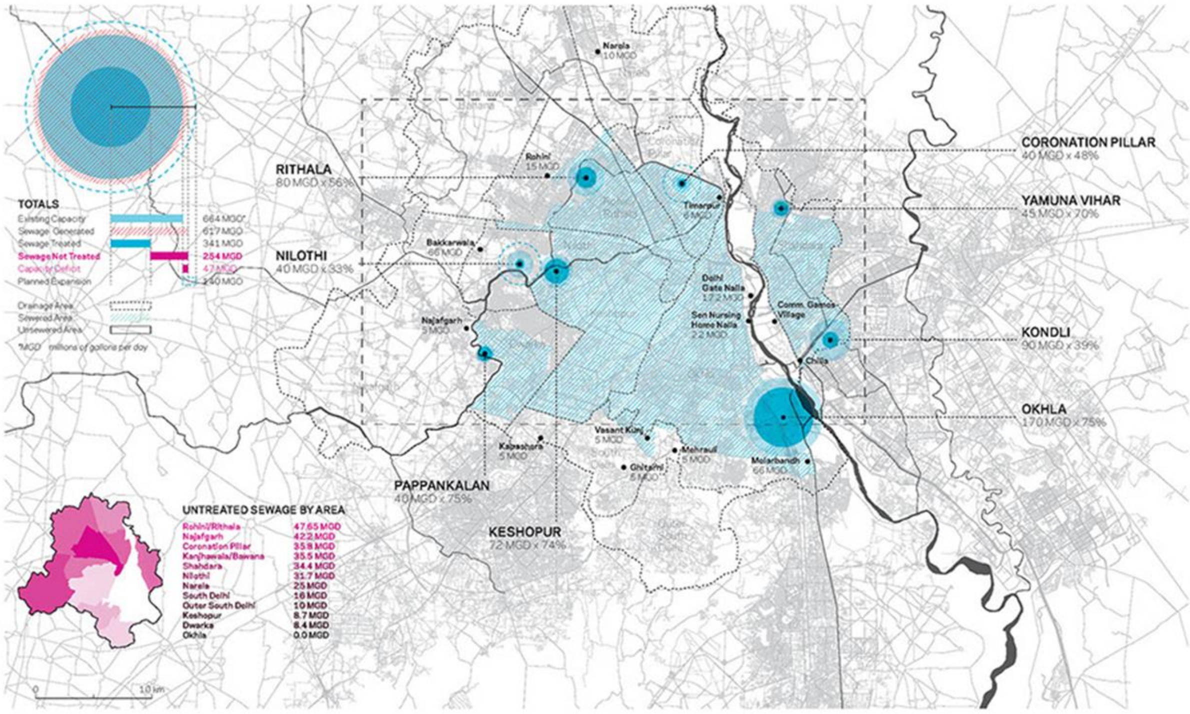

Figure 1: Sewage treatment infrastructure in the Barapullah catchment (highlighted in blue colour shade)
(Source: Yamuna River Project, University of Virginia, 2017)

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Thus, treatment capacity exists for 53% of the total 330 MGD wastewater generated in the Barapullah catchment area. A significant portion of untreated wastewater goes directly to the river Yamuna. Domestic sources account for approximately 85% of pollution to the Yamuna river and include debris, untreated sewage and industrial effluents (Malik et al., 2014). Consequently, outflows contain concentrations of heavy metals [including lead (Pb), zinc (Zn), and copper (Cu)], biochemical oxygen demand (BOD) and dissolved oxygen (DO) which have historically exceeded recommended levels (Sehgal et al., 2012). More recent studies have highlighted the emergence of antibiotic resistant bacteria (ARB) originating from untreated sewage in the Yamuna river (Lamba et al., 2017).

1.1. Kanpur Metropolitan Area

Kanpur Metropolitan Area is located in the State of Uttar Pradesh and is the 10th most populous city in India with over 3 million people. The region is one of the major urban and industrial centers along the Ganges. Over the past 50 years, Kanpur has grown by only 4 sq. km. However, the population has increased by more than three times from a mere 0.96 million in 1981 to 2.9 million in 2011 (Figure 2). As a consequence, population density has increased from 3,243 persons/sq. km in 1961 to 9,666 persons/sq. km in 2011, thus putting more pressure on the existing natural resources in the city. Domestic water demand is estimated at 600 million liters per day (MLD) however, only 385 MLD is delivered to waste water treatment plants due to infrastructure limitations.

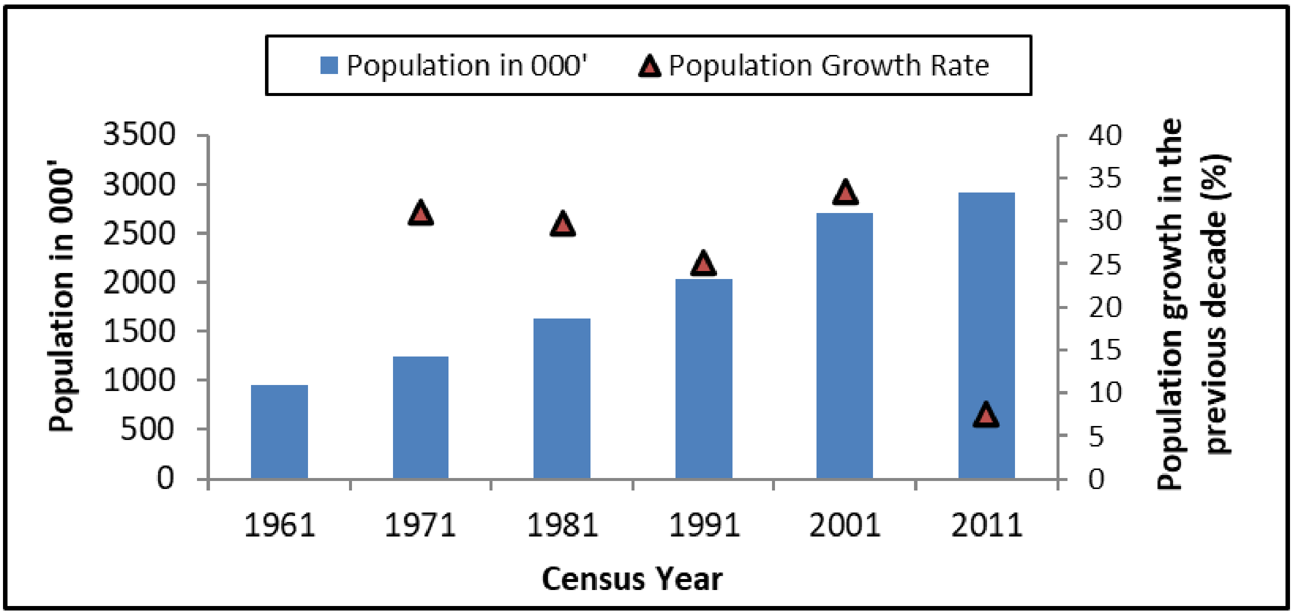

Figure 2: Population growth in Kanpur city
(Source: Analysis using data from the Census of India, 2011)

There are over 16,000 registered industrial units with a total investment of around US$ 138 million. Leather processing units having the highest fraction. The Jajmau cluster of tanneries in Kanpur consists of 400 sites and while it is mandatory for tanneries to have an effluent treatment plant within their premises, most of them discharge effluent with only primary treatment. In 1994, Uttar Pradesh Jal Nigam (UPJN) installed a 36 MLD common effluent treatment plant to treat the effluent from tanneries along with the domestic wastewater to make it more amenable to biological treatment. But since then effluent discharge from tanneries has increased from 9 MLD to 26 MLD, making the plant operation difficult. Additional studies have specifically monitored chromium (Cr) originating from these tanneries (CPCB, 2016). Other large

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industries include textile, jute and chemical manufacturers causing the prevalence of heavy metals similar to that in the Barapullah region, but additionally include cadmium (Cd), iron (Fe) and magnesium (Mg).

The estimated sewage generation in Kanpur city is about 339 MLD but only 50% is treated (Bassi et al., 2019). Apart from the use of a minor amount of treated wastewater in irrigation, the rest of it and the untreated wastewater is directly drained into the river Ganga in north and river Pandu in south of the Kanpur city. Table 2 presents details on wastewater (including industrial effluents) being generated from different regions in Kanpur Metropolitan Area (KMA). *Sismau* and *Permiya Nalas* contribute to about 50 percent of total wastewater which is discharged into the River Ganga and River Pandu.

Table 2: Amount of wastewater being contributed by different regions in KMA

Catchment Region	Discharge Point	Estimated Discharge (MLD)
Kanpur City	River Ganga	598.19
Unnao	River Ganga	77.76
Other Areas in KMA	River Pandu	91.27
Overall	-	767.22

(Source: Based on data presented in Kanpur City Development Plan, 2006 and CPCB, 2013)

As per the official estimates, the sewerage system covers only 29 percent of the city area which is being administered under four districts and five different zones. The total length of the main and trunk sewers is 74 km whereas branch sewer lines are 875 km. There are a total of 13 sewage pumping stations and 30,000 manholes. Sewer lines are cleaned by sewer jetting machines, sewer clearing machines and also manually as per requirement. Total numbers of regular employees are 517 whereas 178 are on the daily wage basis. In other regions of the KMA, sewerage system is non-existent.

Under the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) project, new sewerage works and renovation of existing works have been proposed in KMA. The works include construction of a new trunk sewers, two STPs (15 and 43 MLD), a sewage pumping station (SPS) and renovation of existing three STPs and 11 SPS in the inner old area of Kanpur city; construction of one new 210 MLD STP; and the construction of three SPS and one 42 MLD STP in District-IV (Figure 3). The total sanctioned cost for the works was around Rs 500 crore and all the proposed works were to be executed in three phases. The 43 MLD and 210 MLD STPs are now commissioned and operational.

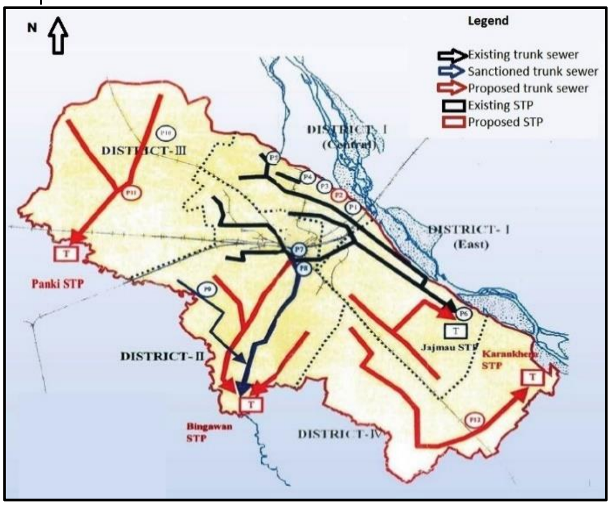

Figure 3: Existing and proposed sewerage works in KMA. Source: UP Jal Nigam

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Presently, there are six operational sewerage treatment plants (STPs) in Kanpur city, out of which three are located in Jajmau where tanneries are located (Figure 4; Table 3; Annex A). Also, one 36 MLD CETP is located in Jajmau. Further, there is one sewage treatment plant in Unnao town. The seven STPs in Kanpur metropolitan area together have a wastewater treatment capacity of 457 MLD, which is more than the total sewage generated (408 MLD) in the Kanpur Metropolitan Area (KMA). However, the actual treatment is only 75% of the sewage generated due to the operational constraints of the plants.

Figure 4: Layout plan of STPs and CETP in Jajmau, Kanpur.

Table 3: Details of sewerage treatment plants in Kanpur Metropolitan Area

Location of STP/ CETP	Year of Commissioning	Technology Used	Type of waste water fed	Installed Capacity (MLD)	Actual Treatment (MLD)	Use of treated water
Jajmau (STP)	1989	Up flow Anaerobic Sludge Blanket (UASB)	Domestic	5	4.5	Treated effluent flows into river ganga
Jajmau (CETP)	1994	UASB	Domestic and Industrial	36	36	Treated effluent irrigates 2200 ha of sewerage farm. Untreated wastewater is discharged into the river Ganga
Jajmau (STP)	1999	Activated Sludge Process (ASP)	Domestic and Industrial	130	105	
Bingawan (STP)	2016	UASB	Domestic	210	145	40 MLD treated effluent to be used for cooling Panki power plant
Sajari (STP)	2017	ASP	Domestic	42	30	
Jajmau (STP)	2018	ASP	Domestic	43	35	Irrigation

(Source: Based on data presented in CPCB, 2013 and latest information from the UPJN)

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1.2. Hydrology

Both the pilot locations, i.e., the Barapullah Drain, and the Kanpur Metropolitan Area are in the Ganges Basin. The Ganges is one of the most complex yet fascinating river systems in the world. The basin is characterized by a high degree of heterogeneity in terms of the physical environment--climate, hydrology, geology, geomorphology--, ecology and environment, and socio-economic systems. More than 500 million people are directly or indirectly dependent upon the Ganges River Basin, which spans China, Nepal, India and Bangladesh. Around 80% of them are from India (Kumar, 2017). The river basin has a total drainage area of 1,060,000 sq. km. Around 400 million people live in the Indian part of the basin, which has nearly 81.4% of the drainage area (862,769 sq. km). New Delhi, the second largest city of India, which is also India's capital, is located inside the basin on the banks of the River Yamuna. The Indian part of the river passes through many states (Uttarakhand, Uttar Pradesh, Delhi, Haryana, Bihar, West Bengal, Chhattisgarh, Jharkhand and Madhya Pradesh, and a very small stretch of Rajasthan and Himachal Pradesh) and the basin is a home to several thousands of small towns and cities.

The river has several tributaries. The major tributaries of Ganges are Yamuna, Ramganga, Gomati, Ghaghara, Sarda, Gandak River, Kosi River, Damodar River, and Mahananda River. The sub-basins of the Ganges are Upper Ganga, Middle Ganga and Lower Ganga. The Ganges has the second largest river discharge in the world. While the average rainfall is 1.089 MCM per sq. km (corresponding to an annual rainfall of 1089 mm), the average runoff for the basin as a whole is 0.562 MCM per sq. km. So, nearly 55% of the precipitation in the basin gets converted into runoff. These result in a total basin yield of 484.8 BCM per annum from within the Indian part of the basin (source: based on CWC, 2017).

The hydrology of the basin displays high spatial and temporal variation (Anand et al., 2018). The average annual rainfall varies from 760 mm at the western end of the basin to more than 2,290 mm at the eastern end. In the upper Gangetic Plain in Uttar Pradesh, rainfall averages about 760–1,020 mm; in the Middle Ganges Plain of Bihar, from 1,000 to 1,500 mm; and in the Delta Region, between 1,520 and 2,540 mm. The Delta Region experiences strong cyclonic storms both before the commencement of the monsoon season, from March to May, and at the end of it, from September to October. The climate varies from cold and humid mountain climate in parts of Uttarakhand to semi-arid climate in parts of the Yamuna sub-basin to hot and humid climate in the coastal areas of West Bengal.

Researchers have computed the stream runoff for the basin on annual and monthly time scales for the basin as a whole. The long-term monthly averages of surface runoff was also computed and analyzed (Anand *et al*., 2018). The analysis has shown sharp variations in flows between season with the highest monthly mean precipitation of 308.3 mm and 307.9 mm occurring in July and August respectively, and a minimum of 8.1 mm in November. Furthermore, mean monthly runoff was maximum during the month of August (159.8mm). During the monsoon months of June through to September the rainfall was found to be higher than the evapotranspiration rates and was able to meet most of the crop water requirements. However, during non-monsoon months, the evapotranspiration is higher than rainfall, meaning that additional water has to be supplied through storage and irrigation canals or shallow/deep aquifer withdrawal.

The basin hydrology varies drastically from the Upper Ganga to Lower Ganga. The upper basin area has dense forests, and is hilly and mountainous, whereas the middle and lower basin areas are largely flat. The upper basin area has the highest runoff generation potential (Anand *et al*., 2018). A study which assessed the variability of flows under present and 'naturalized' basin conditions in the Upper Ganges Basin (UGB) covering an area of over 87,000 sq. km showed that the annual average precipitation, actual evapotranspiration (ET) and net water yields of the whole basin were 1,192 mm, 416 mm and 615 mm, respectively. However, there were large variations in both temporal and spatial distribution of rainfall, runoff and Evapo-transpiration. Precipitation, ET and water yields were found to be higher in the forested and mountainous upper areas. On an annual average, present-day flows throughout the UGB are about 2-8%

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lower than in naturalized conditions. The percentage of flow reduction is the highest during the dry months as water is being withdrawn for irrigation (Bharati *et a*l., 2017).

The river basin has some of the most fertile lands in the entire country (Kumar, 2017). Given the high population density, and with good availability of water (flows in the river throughout the year due to the snowmelt in the Himalayas and the monsoon rains, and abundant groundwater resources in most parts in the thick alluvium), cultivation is mostly intensive.

Use of the Ganges water for irrigation, either when the river is in flood or by means of gravity canals, has been common since ancient times[1]. Irrigation was highly developed during the period of Muslim rule from the 12th century onwards, and the Mughal kings later constructed several canals. The canal system was further extended by the British. Over the past 50 years, groundwater development has picked up in the basin, with manually operated shallow open wells in the initial years to wells run by diesel engines and electric pumps, to shallow tube wells and deep tube wells later run by submersible pumps. As per some recent estimates, of the total mapped area of 102M ha in the Ganges basin (India, Nepal, Bangladesh and Bhutan), 44.7M ha is irrigated (Gumma *et al*., 2019). As per our estimates[2], a total of 30.77M ha of land within India is under irrigation in the Ganges basin.

The Ganges river has great religious importance. It has been revered from the earliest times and today is regarded as the holiest of rivers by Hindus. The places of Hindu pilgrimage, situated on the Ganges have particular significance. Among those are the confluence of the Ganges and the Yamuna near Allahabad, where Kumbh Mela is held once in every 12 years. During the ceremony, hundreds of thousands of pilgrims immerse themselves in the river. Other holy places for immersion are at Varanasi and at Haridwar.

The region being socioeconomically backward with some of the poorest states of the country located inside, most of the several thousands of small towns and cities located inside the basin (barring the large cities such as Delhi, Allahabad and Kolkata) do not have proper infrastructure for sewage collection and treatment. The effluent from the cities and towns with or without treatment is directly discharged into the river, and the estimated annual effluent discharge into the river and its tributaries is estimated to be 6,614 MLD. The Central Pollution Control Board (2013) also estimates that 3,200 MLD of this effluent is sewage from around 2014 towns[3] and cities located inside the basin, and nearly 85% of this is reported to be originating from around 50 cities. Of these only 1,208 MLD was treated as on 2013 (CPCB, 2013).

The river also receives large amount of agricultural runoff (Anand *et al*., 2018) containing ammonia, nitrates and phosphorous (Sandy *et al*., 2020). As a result, certain stretches of the Ganges river remained highly polluted for several decades. The heavily industrialised Kanpur region is the most polluted stretch of the Ganga river because of excessive pollutant discharge from the industries[4] and agricultural runoff (Sandy *et al*., 2020). Though the Ganga Action Plan to clean the river (to 'bathing' class) was launched by the government of India in 1986, the recent initiative of the Union government named Swachh Bharat Abhiyan and *Namami Gange* have given a fillip to the government investment for infrastructure building including construction of toilets, building of sewerage systems in cities and towns, and setting up of modern wastewater treatment plants along the river and its tributar[1]ies for collecting and treating effluent.

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[1] Such irrigation is described in scriptures and mythological books written more than 2,000 years ago. Megasthenes, a Greek historian and ambassador who was in India, recorded the use of irrigation in the 4th century BCE.

[2] Based on data from Directorate of Economics and Statistics, Ministry of Agriculture and Farmer Welfare, Govt. of India.

[3] Source: www. nmcg.nic.in/demography.aspx.

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1.2.1. SURFACE HYDROLOGY OF THE INDIA PART OF GANGES RIVER BASIN

The Ganges is one of the perennial rivers passing through India. Both rainfall and snowmelt contribute to the basin flows. While the monsoon rains contribute to the flows during from July to October, snowmelt contributes majorly to the flow during summer months from March to June in most parts. Baseflows or the discharge from groundwater and return flows from irrigation contribute to the flows during summer months (Anand *et al*., 2018). Variation in rainfall, climate, soil conditions and land cover cause significant variations in runoff generation potential in the basin. Runoff generation potential of rainfall is high in the hills of Uttarakhand due to the rocky terrain, excessively high rainfall and the cold and humid climate during larger parts of the years. Towards the middle Ganga basin, runoff generation potential of rainfall is low due to the sandy loam soils and the high aridity and the relatively lower rainfall.

Though the Ganges is a gauged river basin, with a large network of stream flow gauging stations, it is a classified river basin. As a result, access to data of stream-flows (river discharge) is restricted. Hence, the limited data that are available are based on studies using hydrological simulation models.

Anand *et al*. (2018) had undertaken such a modelling exercise for the entire basin up to Farakka barrage in the Indo-Bangladesh border. Analysis of results show that water yield has the maximum share of water balance with approximately 51 percent (601.6 mm) annually of total precipitation (1167.5 mm) with evapotranspiration having the next highest share (496.5 mm) followed by Groundwater recharge (274.8 mm). Significant long-term trends in runoff were also observed. While the streamflow from the snow fed areas has increased, the stream flow in the lower reaches and the non-perennial tributaries have declined significantly. While the estimated runoff in the upper catchment areas did not show any declining trend when compared to the virgin flows in those catchments, substantial reduction was noticed in the lower catchments, owing to large-scale water resources development in the form of diversion structures and reservoirs for meeting agricultural and industrial demands[5].

The Yamuna River Basin represents the North-Western part of the Ganga River Basin. The Yamuna River basin has an annual total precipitation of 900 mm. A total of five out of the seven gauging stations in this sub-basin had a significant downward trend in annual stream flow suggesting a reduction in the annual mean surface runoff. Two gauging stations in the upstream of the sub-basin namely, Yashwant Nagar and Tuini, showed no trend and were an exception to the dominant downward annual trend.

Rai *et al*. (2012) also showed a declining trend in the annual rainfall and monsoon rainfall values. The trend between observed rainfall and simulated surface runoff might not be opposite in this basin but huge difference between the overall mean Z-test value for the observed rainfall (−0.7) and stream flow (−3.066) suggest that overall, the impact of anthropogenic changes within the catchment offset the impacts of exogenous changes such as climate.

The Upper Ganga sub-basin is mostly snow fed and glacier dominated. A total of 11 stream gauge stations were analyzed, of which 4 stations namely Uttarkashi, Rudraprayag, Joshimath and Rishikesh had significant

[4] The major industries contributing to pollution of the Ganga river are tannery, sugar & distillery, pulp and paper mills. Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), solids, Total nitrogen (TN), Chromium, sulphide, sulphate and chloride are the major pollutants from these industries (CPCB, 2017; Kharayat, 2012; UNICO, 2011; IIT, 2011).

[5] The analysis of the virgin scenario and present scenario (with water resources development) showed that on an average the present annual water yield was 25%, 30%, 35% and 35% lower than in the virgin condition for Ganga basin (upstream of Allahabad), Yamuna basin (up to Agra), Chambal basin and Sindh basin, respectively (Anand et al., 2018).

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increasing trend while decreasing trend of streamflow at other seven stream gauge stations in the downstream areas of the river sub-basin was observed.

In the case of Gomti sub-basin, adjacent to Upper Ganga basin, significant downward trend in annual streamflow has also been observed at stream-gauges namely, Lucknow, Sultanpur, Jaunpur, Maighat and Raebareli with a single exception; Neemsar in the upstream part of the basin had significant increasing trend in annual streamflow. The analysis revealed significant differences in mean surface runoff between the periods prior to 1980 and post-1980 period. Abeysingha et al. (2016) also obtained significant decreasing trends for the surface runoff of the Gomti River basin, partly explained by variations in the rainfall and partly by anthropogenic activities.

Analysis of estimated stream-flows in the Ghaghra, Gandak and Kosi sub-basins also showed significant increasing trends in the annual runoff. Significant differences in mean surface runoff between two time periods, i.e., prior to 1990 and post-1990' was observed. The trend analysis of the stream-flows of Chambal, Sindh, Betwa, Ken, Tons and Son sub-basins showed a significant downward trend with a single exception of Maner station in the downstream part of Son sub-basin that has a significant increasing trend in the annual streamflow. A total of 24 stations have shown significant decreasing trends in annual streamflow. Anand et al. (2018) concluded that the decreasing trend in the rainfall coupled with increasing anthropogenic activities have resulted in decreasing trend of streamflow in these sub-basins (Anand *et al*., 2018).

1.2.2. GROUNDWATER HYDROLOGY

Both Kanpur and Delhi fall in the alluvial plains of the Ganges, underlain by rich aquifers, with shallow water table aquifer overlain by confined aquifers. A good part of Delhi is under young alluvium, followed by Yamuna flood plains, old alluvium and quaternary sediments (Source: groundwater year book 2015-16, CGWB) (see Figure 5). Earlier, groundwater was abstracted from the shallow aquifer using open wells with lifting of water either manually or using draught power. Subsequently, with the advent of energized pump sets, these open wells got energized, enabling farmers to increase groundwater draft for irrigation expansion, which caused lowering of water table. Consequently, shallow and deep tube wells, energized by submersible pump-sets were drilled in these areas. In both Delhi and Kanpur, groundwater pumping is for municipal uses, industrial use and irrigation, with the latter mostly confined to the peripheral areas.

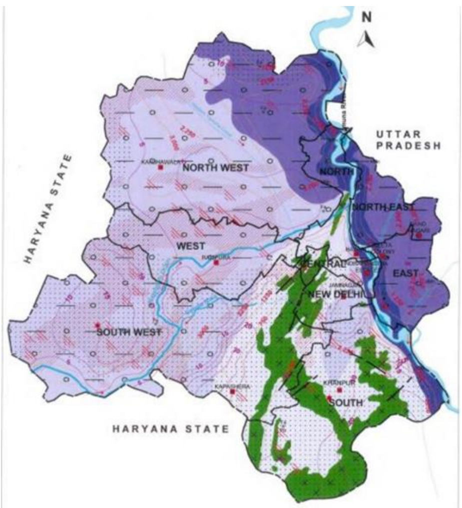

Figure 5: Hydrogeological Map of Delhi

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As per the estimates, groundwater abstraction in Delhi far exceeds annual recharge from direct precipitation (rainfall) and the infiltration of river water through Yamuna flood plains. As per four estimates available for 2009, 2011, 2013 and 2017, total groundwater abstraction in Delhi was in the range of 360 MCM and 400 MCM, and the gross recharge between 310 MCM (2009) and 340 MCM (2013). The stage of groundwater developed (based on estimated abstraction against the utilizable recharge) was 138% as per 2009 estimates and it came down to 119 % as per 2017 estimates. The summary of abstraction and recharge estimates for Delhi are presented in Table 4.

Table 4: Annual Groundwater Recharge and Extraction in Delhi (in MCM)

City/Town	Year							
	2009		2011		2013		2017	
	Annual GW recharge	Annual GW abstraction	Annual GW recharge	Annual GW abstraction	Annual GW recharge	Annual GW abstraction	Annual GW recharge	Annual GW abstraction
Delhi	310	400	310	390	340	390	320	360

(Source- Dynamic Groundwater Resources of India, CGWB; various reports)

In Kanpur, however, the situation is much better. The abstraction is found to be less than the recharge as per all the four estimates–from 2009 to 2017. While the recharge increased gradually from 1720 MCM in 2009 to 1860 MCM in 2017, abstraction also increased from 1160 MCM in 2009 to 1380 MCM in 2013, but came down to 1300 MCM in 2017. The stage of groundwater development stood at around 75% in 2017 in Kanpur, which consisted of two districts, viz., Kanpur Nagar and Kanpur Dehat. The summary of abstraction and recharge estimates for the two geographical units of Kanpur are presented in Table 5.

Table 5: Annual Groundwater Recharge and Extraction in Kanpur (in MCM)

City/Town	Year							
	2009		2011		2013		2017	
	Annual GW recharge	Annual GW abstraction	Annual GW recharge	Annual GW abstraction	Annual GW recharge	Annual GW abstraction	Annual GW recharge	Annual GW abstraction
Kanpur Dehat	890	550	910	590	870	610	960	630
Kanpur Nagar	830	610	830	670	930	770	900	670

(Source- Dynamic Groundwater Resources of India, CGWB; various reports)

The difference in recharge estimates for both Delhi and Kanpur could be due to the effect of rainfall. By virtue of the sandy loam soils, while higher rainfall can increase the recharge in over-exploited areas like Delhi, higher rainfall can also result in reduced abstraction of groundwater for irrigation.

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1.3. Surface Water Quality

Sources of surface water quality data varies by region. Water quality limits are dependent on the resulting use of the water, which is divided into five classes:
A: Drinking water without conventional treatment, but after disinfection
B: Water for outdoor bathing
C: Drinking water with conventional treatment followed by disinfection
D: Water for fish culture and wildlife propagation
E: Water for irrigation, industrial cooling and controlled waste disposal.

Surface water quality standards are as per international standards (IS) 2296 and drinking water quality standards as per IS 10500. Additionally, general standards for discharge effluents are provided for a range of parameters with limitation dependence on outflows categorized as into surface water, into public sewers, into irrigation water or into coastal waters. Precise thresholds and more detailed information can be found: https://elibrarywcl.files.wordpress.com/2015/02/surface-water-quality-standards-as-per-is-2296.pdf

Water quality data is readily available at monthly intervals on the WRIS website (http://indiawris.gov.in/wris/#/waterData) with a wide range of available parameters. Annual water quality data is also available at https://cpcb.nic.in/nwmp-data-2016/ and: http://mahenvis.nic.in/Pdf/Report/report_nrm2.pdf. Finally, pre and post-monsoon data is available along the Ganges at: https://cpcb.nic.in/water-quality-monitoring-of-drain/.

1.3.1. Barapullah Drain

The Delhi Railway Bridge monitoring station appears to be the closest point to the Barapullah drain with monthly data readily available (see example of data from the Delhi Raily Bridge in Annex B). CPCB annual water quality documents refer to the Barapullah drain as Nizammuddin, station number 1121 in the reports. Additionally, the CPCB conducted a study in 2014-2015 monitoring multiple points along the Yamuna (http://www.sulabhenvis.nic.in/Database/WaterQualityStatus_6984.aspx).

The laboratory of Professor Shaikh Ziauddin Ahammad from IIT Delhi has more consistently monitored the Barapullah drain water quality since October 2017, providing information on temperature, pH, conductivity, total dissolved solids (TDS), BOD, chemical oxygen demand (COD), total coliform (TC)/fecal coliform (FC), nitrates, phosphates and more (see Figures 6 to 9). Additional seasonal data is available for 2014 from Lamba et al., 2017, 2018.

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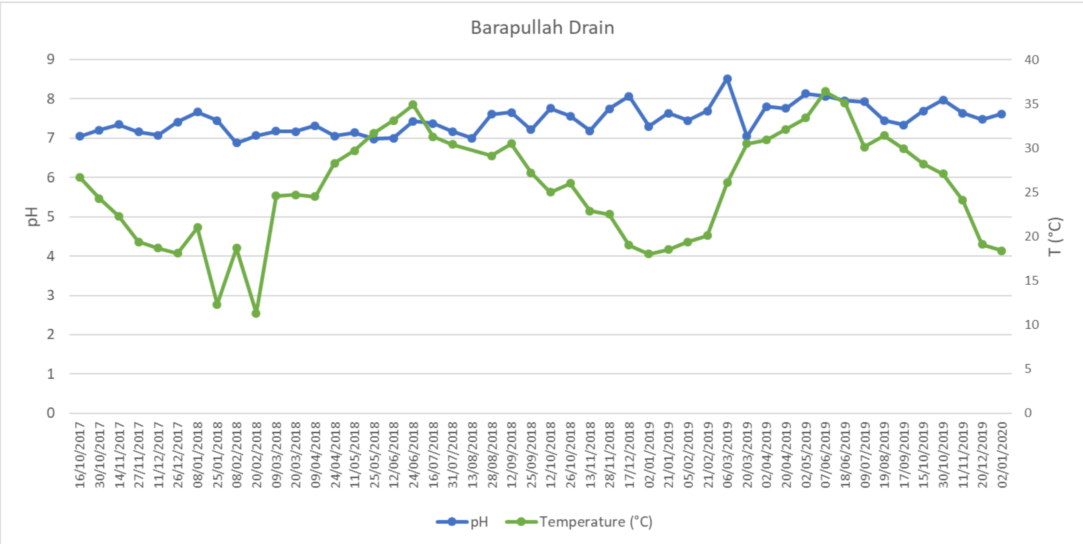

Figure 6: Monitoring data from IIT Delhi of temperature (C°) and pH at the Barapullah Drain.

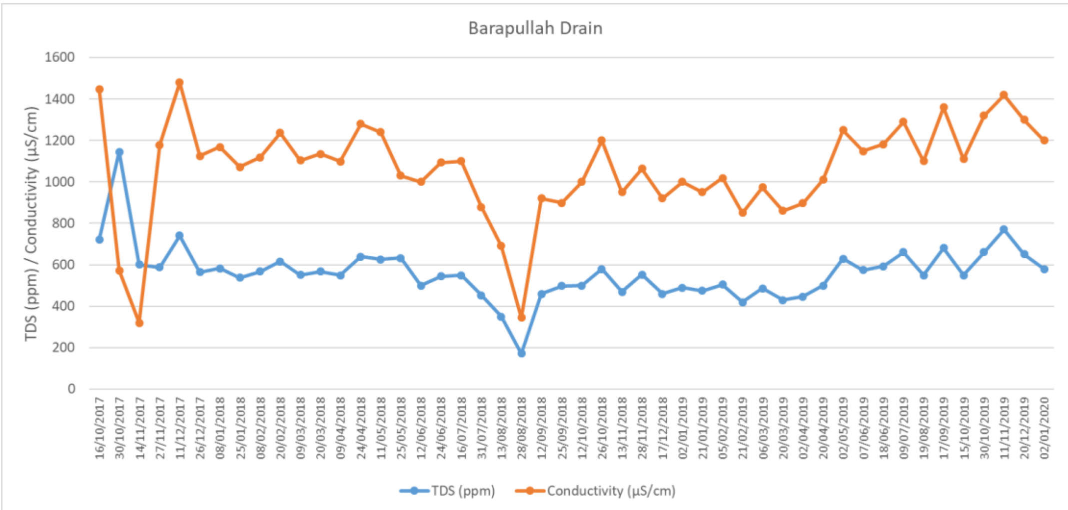

Figure 7: Monitoring data from IIT Delhi of TDS (ppm) and conductivity (µS/cm) at the Barapullah Drain.

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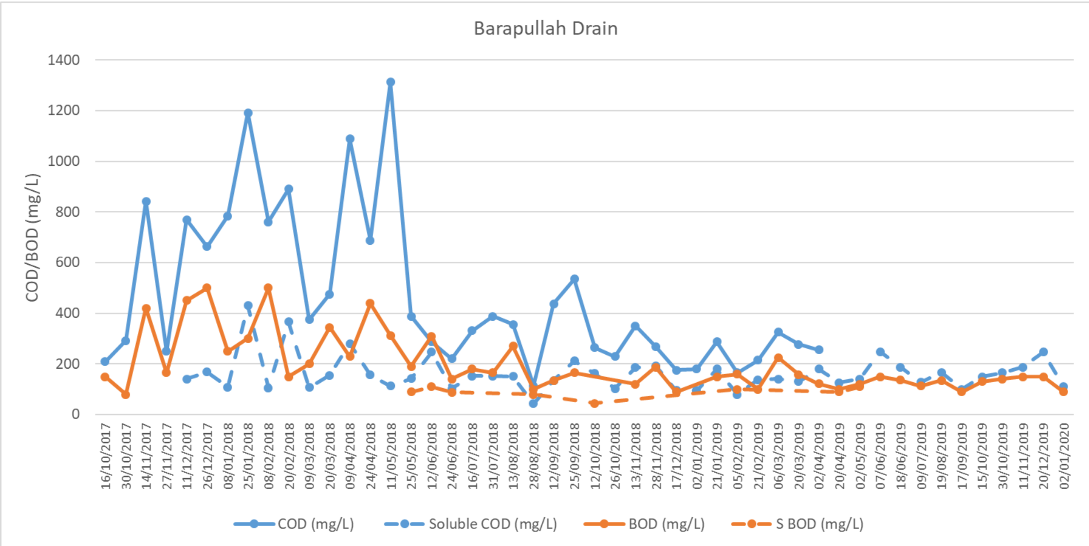

Figure 8: Monitoring data from IIT Delhi of COD (mg/L) and BOD (mg/L) at the Barapullah Drain.

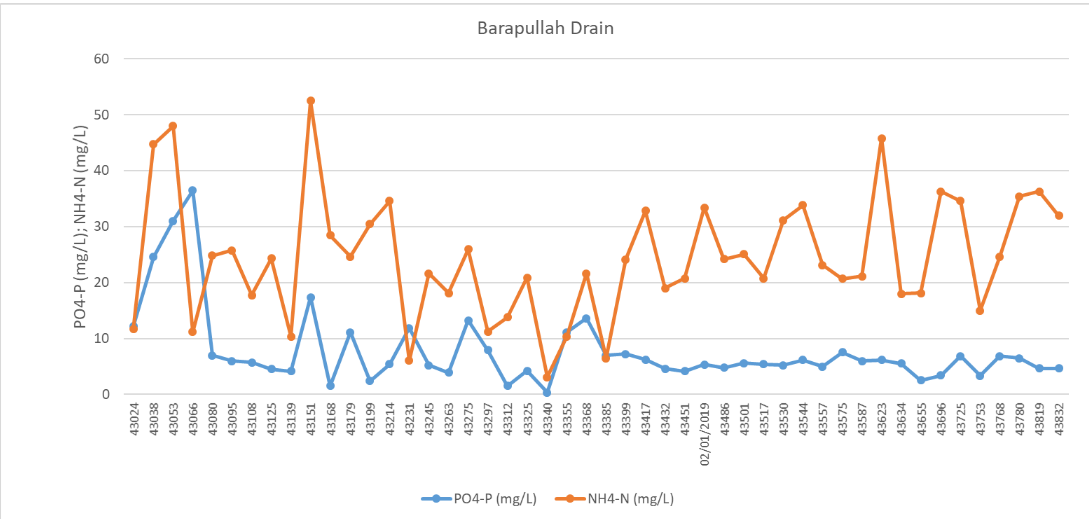

Figure 9: Monitoring data from IIT Delhi of PO4-P (mg/L) and NH4-N (mg/L) at the Barapullah Drain.

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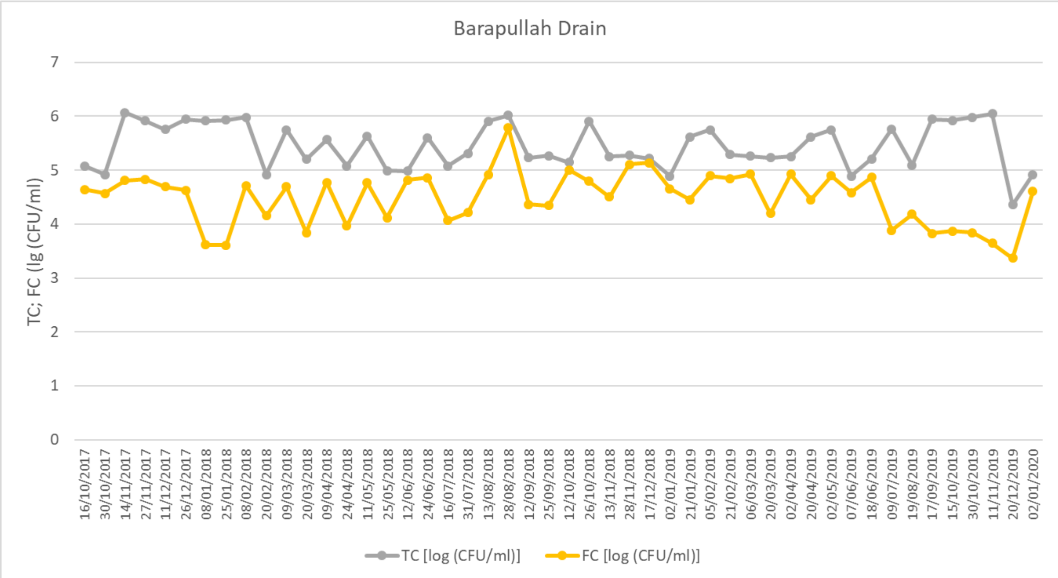

Figure 10: Monitoring data from IIT Delhi of TC (log CFU/ml) and FC (log CFU/ml) at the Barapullah Drain.

1.3.2. KANPUR

Similar to the Barapullah Drain, annual quality data is available via the CPCB for the Kanpur region, using station codes 1146, 1067, 1068. A gauge exists specifically at the Jajmau pumping station (1067). There are four major drains to the Jajmau area within Kanpur. The document provides more detailed water quality and some discharge estimates for single grab samples between 2015 and 2016 (starting page 35;(CPCB, 2016)). Monthly data is available at two gauges upstream and downstream of Kanpur.

It is difficult to make inferences using the water quality trend of a particular site due to the flow of Ganga being heavily altered by the several diversions in place. Nevertheless, from the analysis of CPCB monthly data (2000-2016) on the water quality from the two sites in the Kanpur city (Table 3), it can be concluded that the quality of water in river Ganges deteriorates significantly after passing through Kanpur city. The BOD and TDS increases in the downstream of Kanpur in comparison to the upstream stretch (Figure 11 and 12). This indicates that a greater amount of organic and inorganic effluents enter the river water while it passes through to the Kanpur city.

Table 6: Details of the two surface water quality monitoring sites on the river Ganga in Kanpur city

Particulars	**Name of the station**	
	Ranighat	*Jajmau Pumping Station*
Location	Upstream of Kanpur city	Downstream of Kanpur city
Latitude	26 30' 19.95''	26 26' 10.16''
Longitude	80 18' 51.64''	80 24' 34.87''
Parameters measured on a regular basis	Temperature, Turbidity, DO, pH, EC, BOD, Nitrate, FC, TC, Total Alkalinity, Chlorides, COD, Ammonia, Hardness, Calcium, Magnesium, Sulphate, Sodium, TDS, TSS, Phosphate	
Frequency of water quality testing	Monthly	
Data availability	2000-2016 with missing values for certain years	

(Source: CPCB)

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Further, faecal coliform at the upstream stretch (annual average) is above the permissible amount (< 2500MPN/100 ml), they increase to almost five times in the downstream stretch. The worsening of river water quality is mainly due to the untreated wastewater from the city which is drained into the river (Bassi et al., 2019). Thus the river water which leaves the city is heavily polluted and unusable for further use without treatment and poses a health hazard for the downstream users.

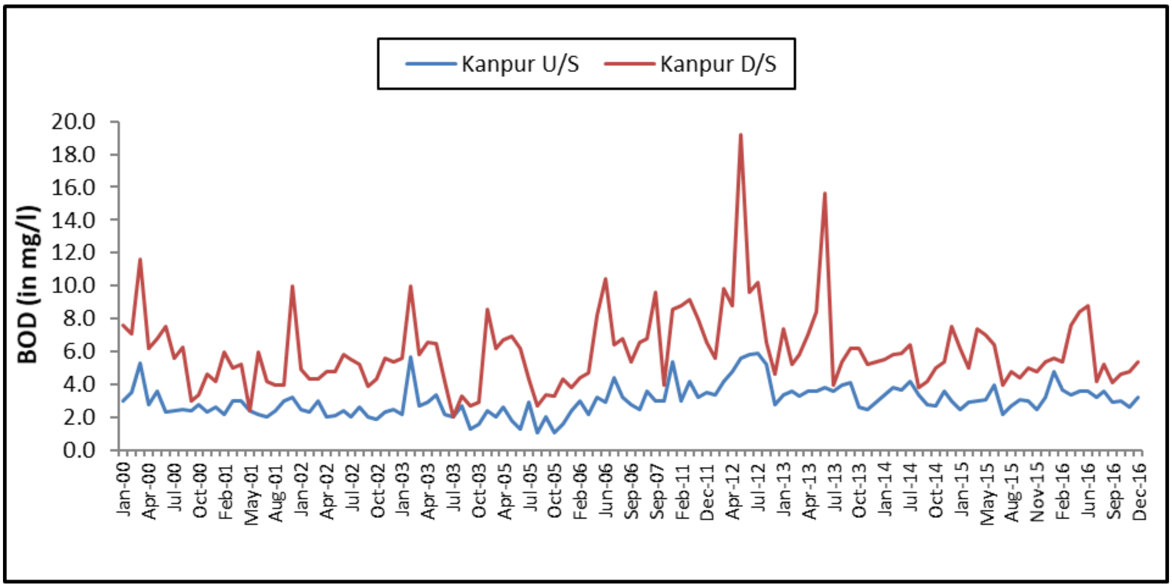

Figure 11: Estimated BOD on the Ganga River Monitoring Sites in the Kanpur City. Source: Authors' analysis using CPCB monthly water quality data (2000-2016)

Note: Monitoring data for the years 2004, and from 2008 to 2010 is unavailable

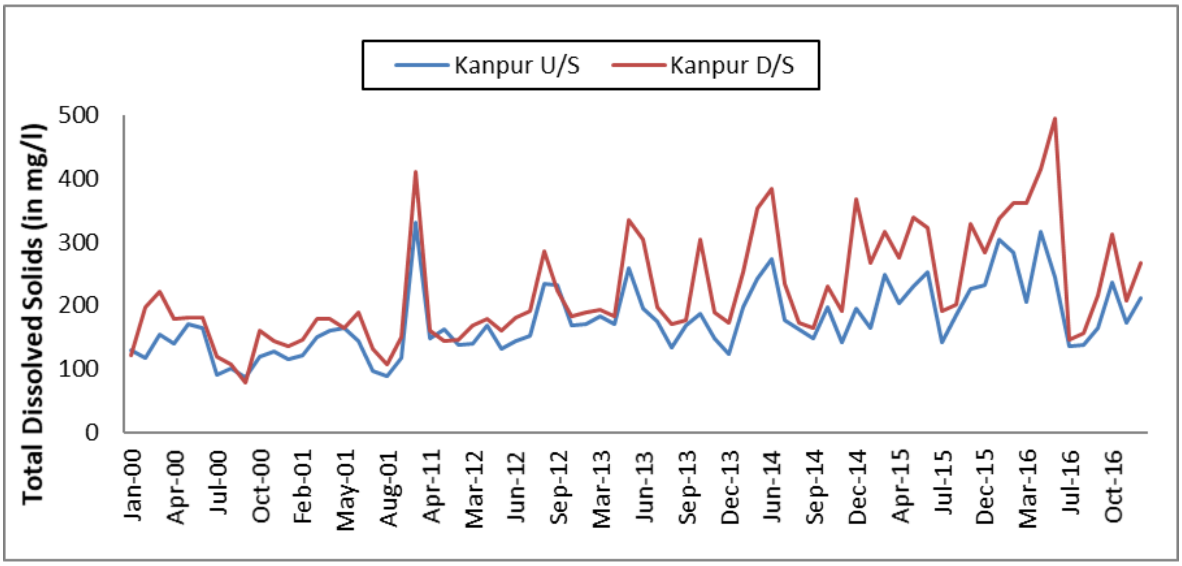

Figure 12: Observed TDS Values on the Ganga River Monitoring Sites in the Kanpur City. Source: Authors' analysis using CPCB monthly water quality data (2000-2016)

Note: Monitoring data for the years 2003, 2003 and 2004, and from 2006 to 2010 is unavailable

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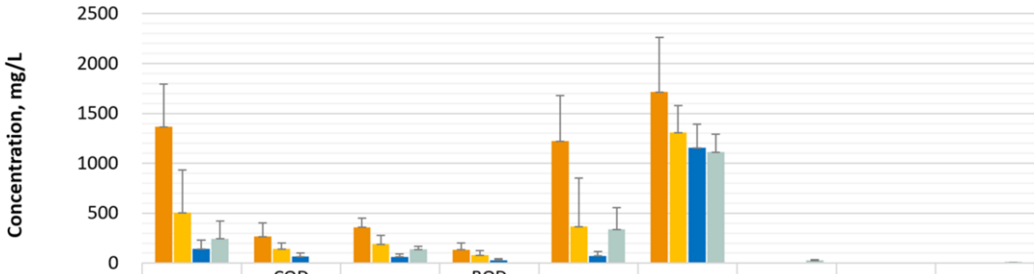
Water quality data of the Jajmau STP (130 MLD) for the period 2009 – 2013 (BOC, COD, TSS, TDS, total and fecal coliform) has made available by IIT Kanpur (see Figures). Additional data (sulfur and total chromium) of a limited number of samples is available for the period 2009-2012).



	COD total	COD filtered	BOD total	BOD filtered	TSS	TDS	NH4-N	NO3-N	PO4-P
STP: Influent	1366	265	360	134	1223	1716	N/A	N/A	N/A
STP: Primary effluent	504	141	188	78	365	1308	N/A	N/A	N/A
STP: Secondary effluent	143	64	63	29	72	1156	N/A	N/A	N/A

Figure 13: Overview water quality data STP Jajmau 130 MLD (2009 – 2013)

Table 7: Additional water quality data influent and effluent STP Jajmau 130 MLD

	COD (mg/L)	BOD (mg/L)	TSS (mg/L)	TDS (mg/L)	Sulphide (mg/L)	Total Cr (mg/L)
Influent 130 MLD						
17.02.2009		960	1692			7.3
08.01.2010	1800	580	1249	1425		8.96
31.08.2010	929	170	330	1388	32	
11.11.2010		278	1422			5.43
14.12.2010	1440	380	1190	1434	46	7.90
14.10.2011		346	1322	1574		9.20
28.02.2012	1420	292	1146	1524	48	22.4
08.07.2012	860	248	792	980	40	16.9
Average	**1397.3**	**429.4**	**1193.0**	**1469.0**	**42**	**10.2**
Std.-deviation	**357.7**	**265.4**	**421.9**	**77.1**	**8.7**	**6.1**
Effluent 130 MLD						
17.02.2009		48	44			0.04
08.01.2010	45	28	35	1010		0.22
31.08.2010	31	18	14	1065		
11.11.2010		46	58			0.33
14.12.2010	80	36	38	1052		0.27
14.10.2011		30	52	1056		0.18
28.02.2012	332	86	112	1348	12	1.6
08.07.2012	290	96	134	822	12	2.2
Average	**122.0**	**41.7**	**50.4**	**1106.2**	**12.0**	**0.4**
Std.-deviation	**141.5**	**22.1**	**30.6**	**136.8**		**0.6**
Removal Efficiencies						
17.02.2009		95.0%	97.4%			99.4%
08.01.2010	97.5%	95.2%	97.2%	29.1%		97.5%
31.08.2010	96.7%	89.4%	95.8%	23.3%		
11.11.2010		83.5%	95.9%			93.9%

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14.12.2010	94.4%	90.5%	96.8%	26.6%		96.6%
14.10.2011		91.3%	96.1%	32.9%		98.0%
28.02.2012	76.6%	70.5%	90.2%	11.5%	75.0%	92.9%
08.07.2012	66.3%	61.3%	83.1%	16.1%	70.0%	87.0%
Average	**91.3%**	**90.3%**	**95.8%**	**24.7%**	**71.4%**	**95.7%**

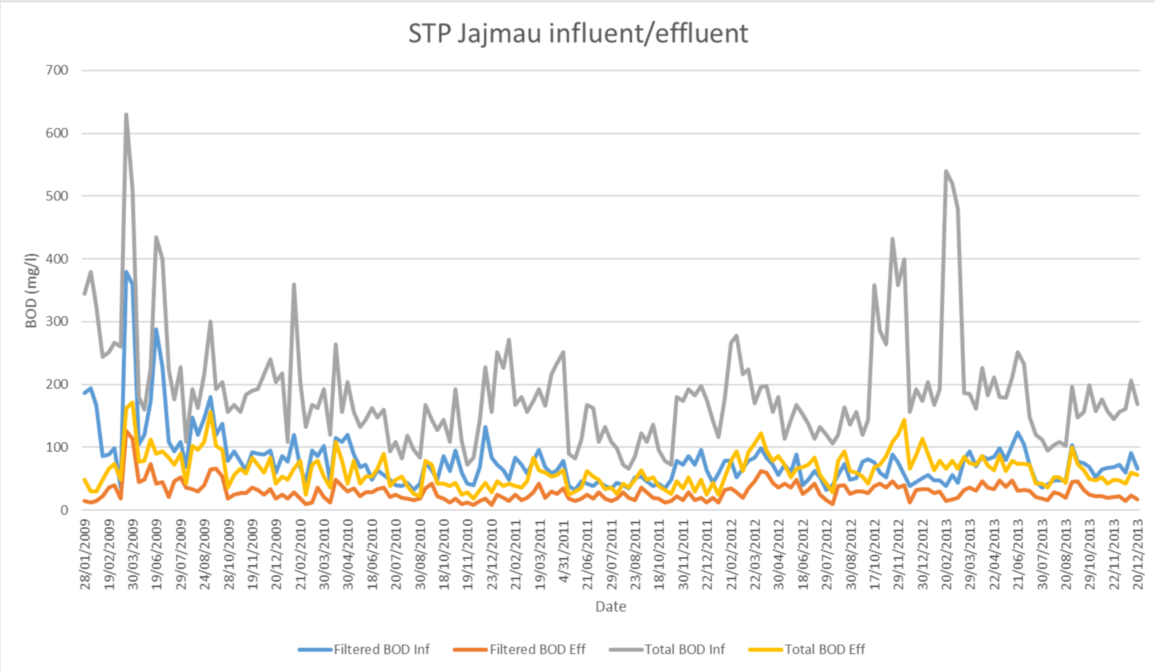

Figure 14: Monitoring data of filtered and total BOD (mg/l) at influent and effluent STP Jajmau

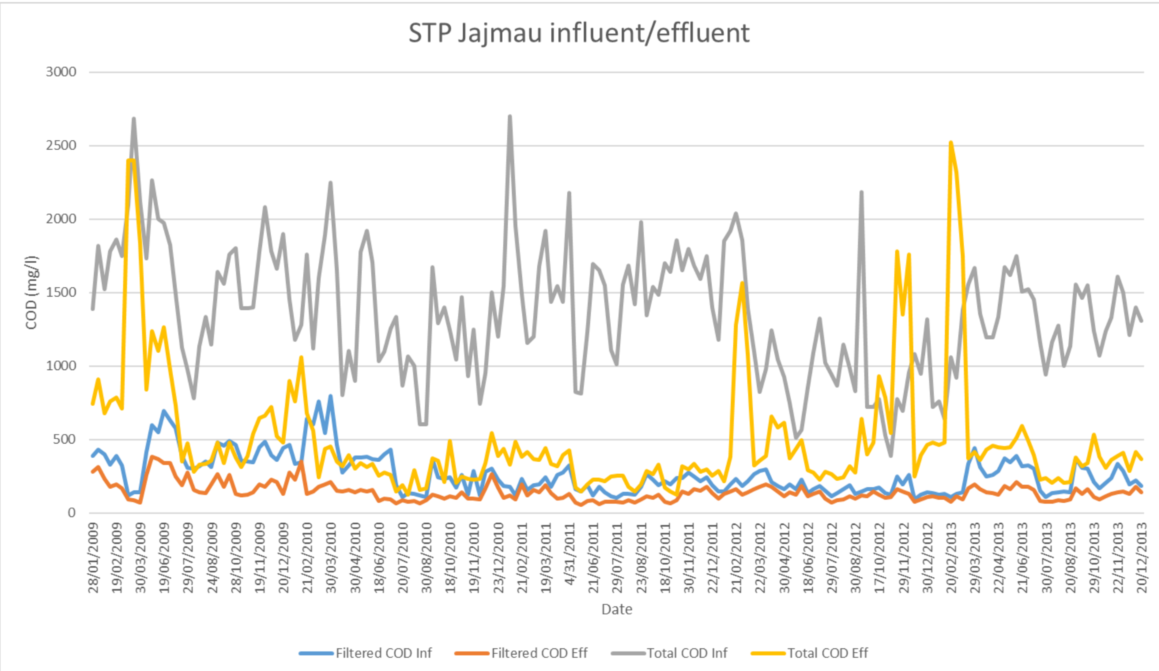

Figure 15: Monitoring data of filtered and total COD (mg/l) at influent and effluent STP Jajmau

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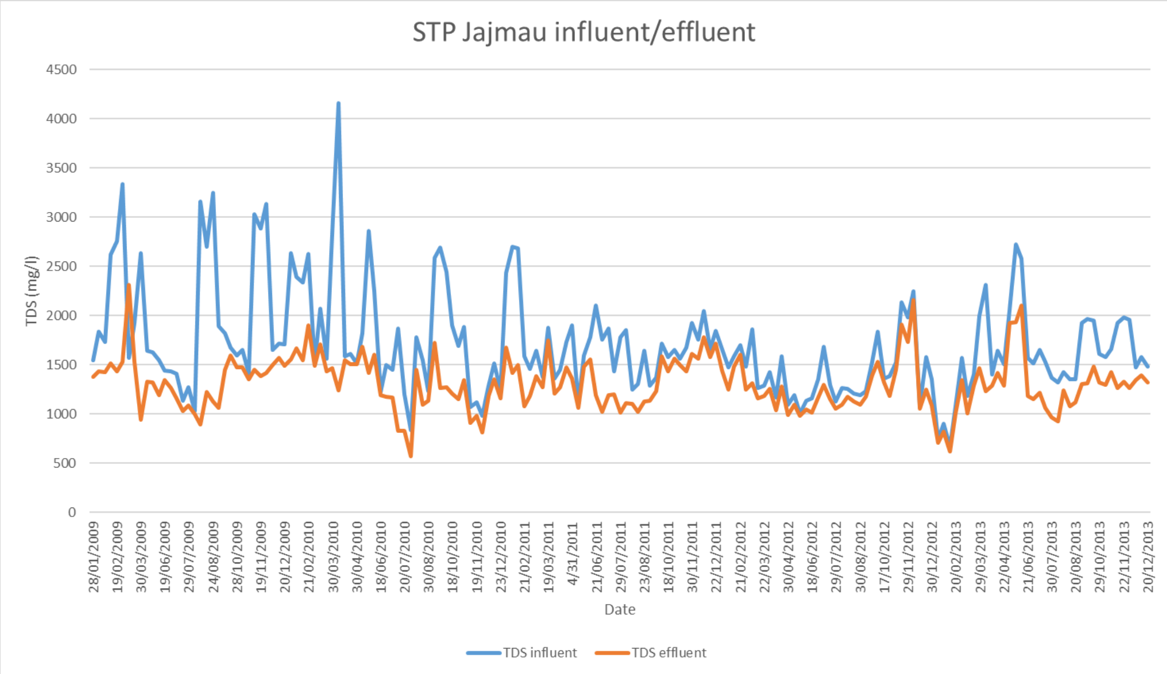

Figure 16: Monitoring data of TDS (mg/l) at influent and effluent STP Jajmau

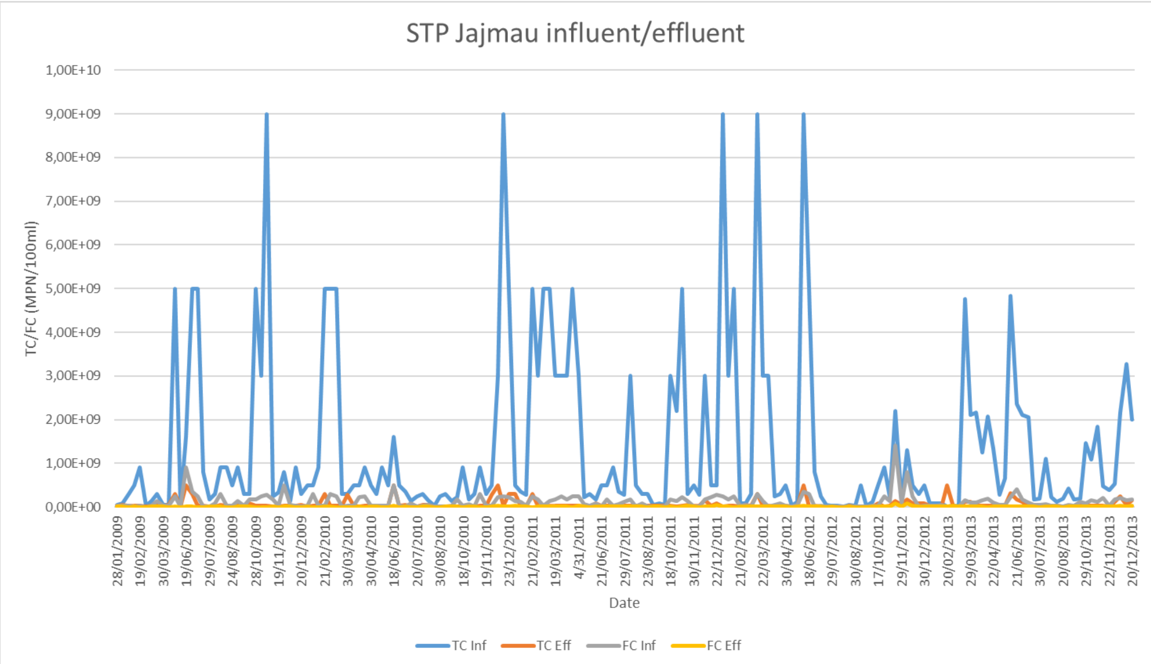

Figure 17: Monitoring data of total and fecal coliform (MPN/100 ml) at influent and effluent STP Jajmau

Water quality data of the Jajmau UASB (36 MLD) for the period 2009 – 2013 (BOC, COD, TSS, TDS, total and fecal coliform) has made available by IIT Kanpur (see Figures).

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Table 8: Overview monitoring data UASB Jajmau (2009-2013)

	Influent		**Effluent**	
	Average	St.-deviation	Average	St.-deviation
Filtered BOD (mg/L)	264	91	122	72
Total BOD (mg/L)	507	135	232	92
Filtered COD (mg/L)	469	133	225	75
Total COD (mg/L)	1598	426	593	209
TSS (mg/L)	1338	342	287	210
VSS (mg/L)	618	871	149	106
TDS (mg/L)	4893	1516	3587	1340
Total Coliform (MPN/100mL)	4.4E+09	4.7E+09	3.5E+07	5.9E+07
Faecal Coliform (MPN/100mL)	6.6E+08	4.0E+07	9.6E+06	1.9E+07

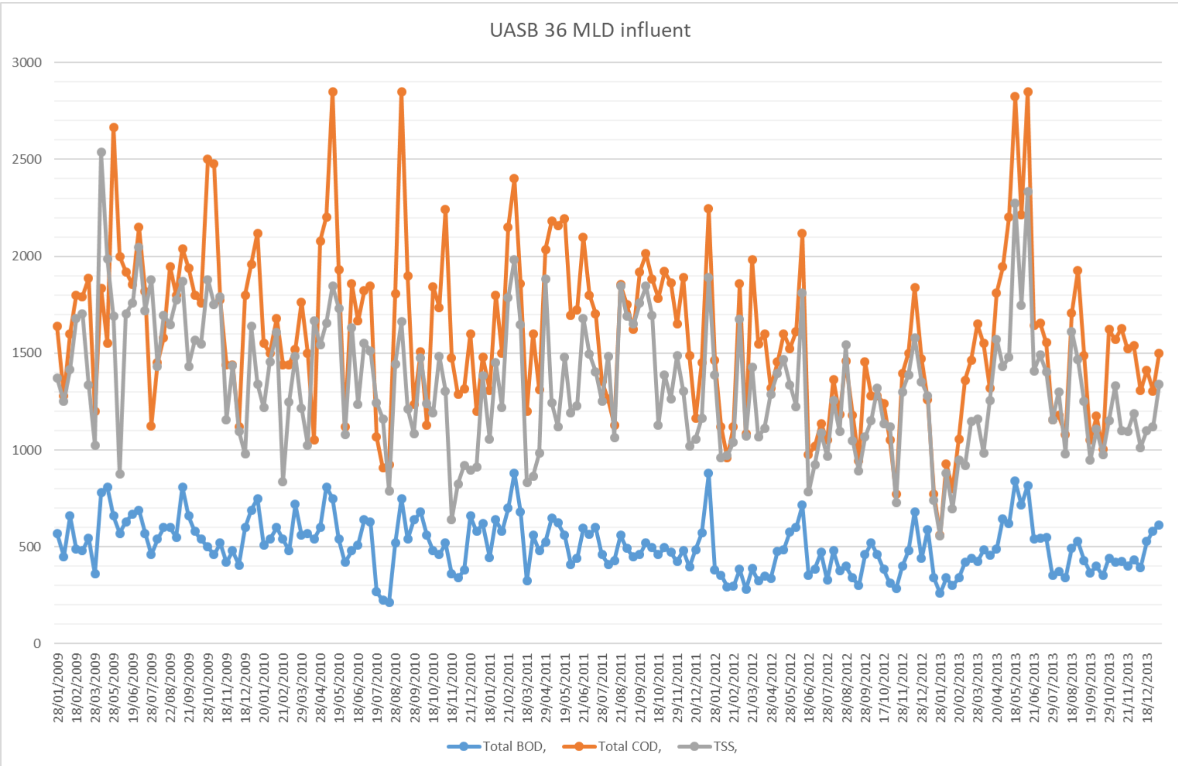

Figure 18: Monitoring data of BOD, COD and TSS (mg/l) at influent UASB Jajmau

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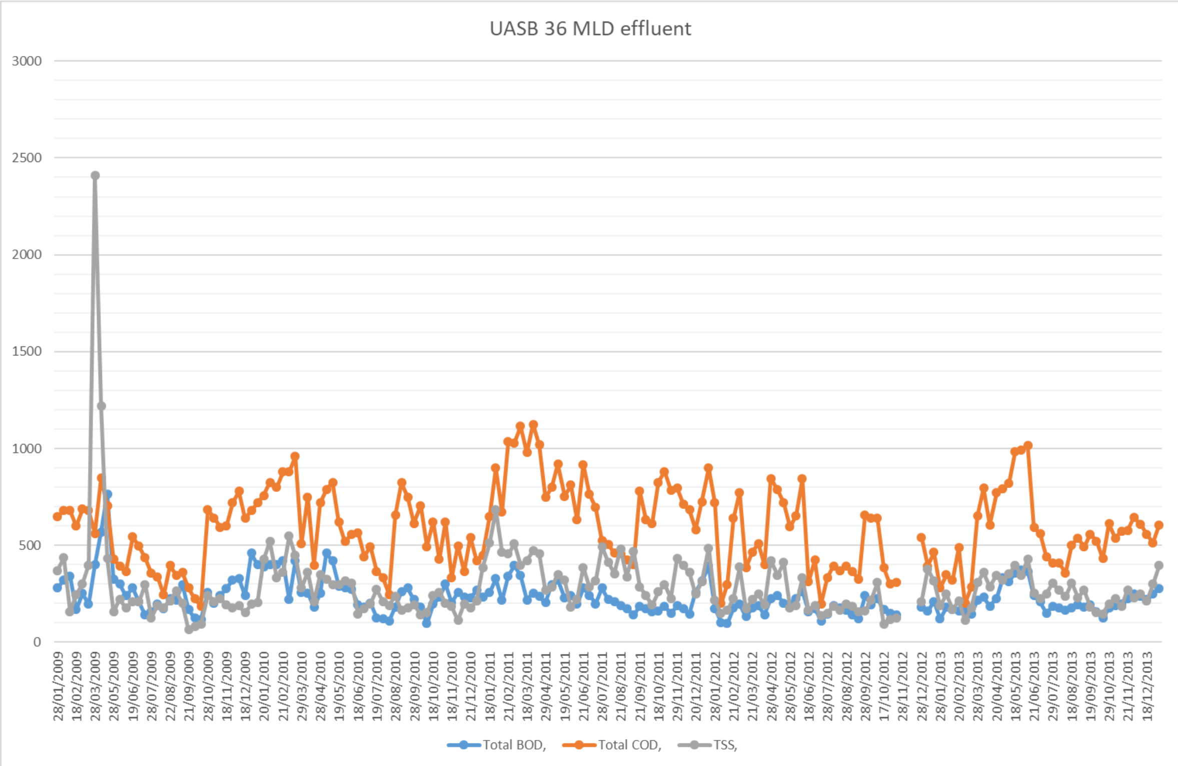

Figure 19: Monitoring data of BOD, COD and TSS (mg/l) at effluent UASB Jajmau

Water quality data of the Jajmau STP (5 MLD) for the period 2009 – 2013 (BOC, COD, TSS, TDS, total and fecal coliform) has made available by IIT Kanpur (see Figures).

Table 9: Overview monitoring data 5 MLD STP Jajmau (2009-2013)

	Influent		***Effluent***	
	Average	*St.-deviation*	*Average*	*St.-deviation*
Filtered BOD (mg/L)	*80*	*56*	*50*	*31*
Total BOD (mg/L)	*147*	*53*	*91*	*38*
Filtered COD (mg/L)	*138*	*45*	*96*	*34*
Total COD (mg/L)	*255*	*87*	*177*	*52*
TSS (mg/L)	*126*	*50*	*66*	*25*
VSS (mg/L)	*68*	*27*	*37*	*15*
TDS (mg/L)	*1320*	*241*	*1174*	*248*
Total Coliform (MPN/100mL)	*5.5E+07*	*1.2E+08*	*4.9E+06*	*1.1E+07*
Faecal Coliform (MPN/100mL)	*6.6E+06*	*7.0E+06*	*8.3E+05*	*1.4E+06*

A sample of specific information from the STPs was provided by IIT Kanpur for August 2017 and August 2018:

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Table 10: Comparison of water quality parameters before and after treatment in Kanpur for sample collected in August 2017.

Parameter	5 MLD		36 MLD		130 MLD	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
pH	7.68	7.9	8.26	7.91	7.65	7.69
TDS (mg/L)	1264	1151	11102	2520	1185	1170
TSS (mg/L)	1600	48	5292	181	547	72
TS (mg/L)	2864	1199	16394	2701	1732	1242
VSS (mg/L)	658	46	1098	162	313	63
COD (mg/L)	909	177	5558	695	707	152
BOD (mg/L)	280	60	870	180	230	60
TKN (mg/L)	17.04	0.87	172.31	37.08	16.50	0.82
Chloride (mg/L)	420	355	5598	1320	380	330
Total Phosphate (mg/L)	6.77	1.50	76.96	23	5.84	1.18
Chromium (mg/L)	11.79	6.63	110.27	65.92	18.49	3.56

Table 11: Comparison of water quality parameters before and after treatment in Kanpur for a sample collected in August 2018.

Parameter	36 MLD		130 MLD	
	Influent	Effluent	Influent	Effluent
COD (mg/L)	13500	750	600	75
BOD (mg/L)	1080	225	210	24
TSS (mg/L)	3866	208	554	34
TDS (mg/L)	13572	4192	1678	1474
Sulphate (mg/L)	3276	1018	666	454
Sulphide (mg/L)	31.2	102	8	0
Total Chromium (mg/L)	72.1	5.3	5.7	0.5

1.4. Discharges and Surface Water Quantity

Water level and stream discharge data exists from the CWC but is not publicly available. Measurement stations can be viewed on the WRIS website: http://indiawris.gov.in/wris/#/dataService.

Bassi et al. (2019) worked out average annual renewable surface water availability in Kanpur stretch of the river Ganga using the data presented in O Keeffe et al. (2012). As per the data collected from the hydrological station located at Kanpur, the long-term average annual discharge at Kanpur is about 1,679 cubic metre per sec (cumec) (O Keeffe et al., 2012). This means that the average annual renewable surface water availability in Kanpur stretch of the river is about 53 Billion Cubic Metres (BCM) per annum. However, there is a significant variation in water availability across seasons with average flow being less than 1000 cumec during the lean period (November to May).

Surface flows can be estimated from land surface and hydrological models. For example the Soil Water and Assessment Tool (SWAT) was used by IIT Delhi in the Drainage Masterplan (IIT New Delhi,

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2018).Additionally, reanalysis datasets may be useful to capture estimates of natural flows for example the Global Land Data Assimilation System (GLDAS; https://ldas.gsfc.nasa.gov/gldas). Under the Pavitra Ganga project, runoff from the catchment of the two pilot areas was estimated using the US curve number method. The method and the results are presented in Chapter 6.

For the Kanpur region, the STPs and CETP have known discharge capacities (Table 12). Other wastewater discharge data can be found: http://www.sulabhenvis.nic.in/Database/STST_wastewater_2090.aspx.

Table 12: Capacity limits of wastewater treatment plants in Kanpur.

S No	Capacity [MLD]	STP/CETP	Cost [Lac]	Year	Status
1	05 (UASB)	STP	94.66	1986	➢ 4.8 - 4.9 MLD wastewater is coming to the plant
2	130 (ASP)	STP	2348	1995	➢ Max flow is 110 MLD with average value is 95 MLD goes in plant. ➢ At present 60 – 70 MLD wastewater is coming to the plant
3	43 (ASP)	STP	1800	2018	➢ Under Commissioning
4	36 (UASB)	CETP	3102	1990	➢ 22- 25 MLD wastewater is coming to the plant

1.5. Imported Water

1.5.1. New Delhi

New Delhi is located in a semi-arid region and depends largely on imported surface water for meeting its water needs. New Delhi receives raw surface water from the Ganga basin, Yamuna sub-basin, and Indus-basin. Additionally, groundwater resources are tapped to meet leftover demand. The Delhi Jal Board (DJB) is responsible for the production and distribution of potable water in the city.

As of March 2018, out of 913 million gallons per day (MGD) of water supplied in Delhi, about 50% is imported surface water. The remaining 50% is sourced from the river Yamuna (375 MGD) and the local aquifers (80 MGD) in Delhi (Source: DJB). However, for the former, Delhi is dependent on its neighboring state Haryana for the release of its allocated share of Yamuna water. The basin-wise surface water contribution to Delhi water supply is presented in Figure 13.

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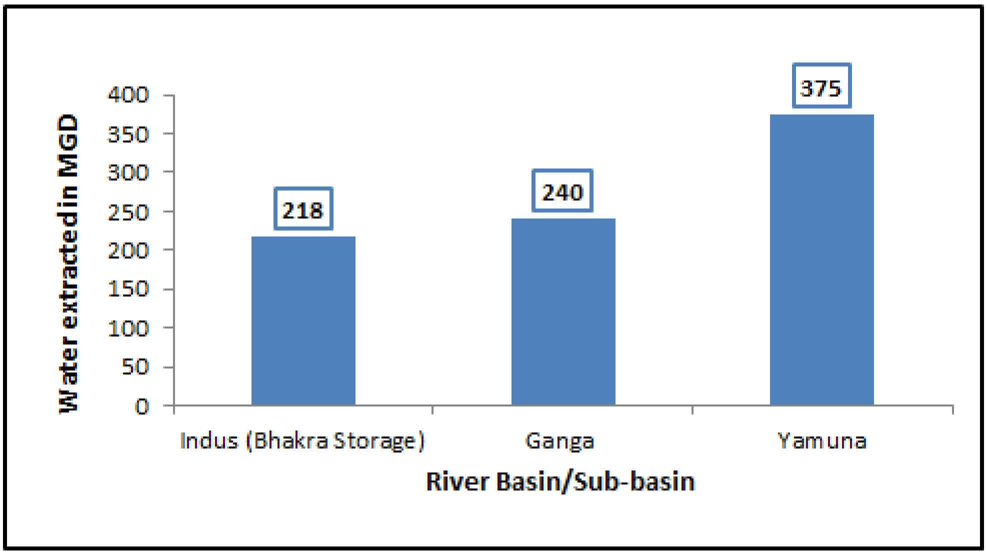

Figure 20: Basin-wise surface water contribution to Delhi water supply
Source: Based on DJB data

1.5.2. Kanpur Metropolitan Area

Kanpur does not receive imported water.

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CHAPTER 2 GEOHYDROLOGY

2.1. SOILS

Soil data including texture, depth and mean carbon density is available to download after registration at: https://bhuvan-app3.nrsc.gov.in/data/download/index.php#
Remaining more specific data can be extracted from SoilGrids: https://www.isric.org/explore/soilgrids

The soil types in the entire Barapullah catchment are sandy and clay. The soils are suitable for irrigating moderately salt-resistant crops such as wheat, barley, and mustard. The geological formations in the Barapullah catchment are mainly quartzite of the Alwar series of the Delhi Supergroup that are interbedded with thin micaceous schist bands.

In Kanpur city, the clay, silt, gravel, and sands of different grades are the main sedimentary constituents. The major part of the city consists of ordinary soils (locally known as *Bhur*) and sand on ridges, clay (locally known as *Matiyar*) in depressions, and Loam (known as *Domat*) in the Plains. Also, the '*Reh*' prevails in the clay dominant areas. The older alluvium occurs in the central part of the city, while newer alluvium mostly occurs along the course of the Ganga River.

2.2. GROUNDWATER

Seasonal monitoring of observation wells by CGWB follows assessments of groundwater resources, done periodically. District and block level data from 1996-2018 is readily available for pre and post monsoon in excel formats: http://59.179.19.250/GWL/GWL.html?UType=R2VuZXJhbA==?UName=. Water quality maps of groundwater are also readily available: http://cgwb.gov.in/wqmaps.html. Annualized data is available: http://mahenvis.nic.in/Pdf/Report/report_nrm2.pdf and https://cpcb.nic.in/wqm/2016/Water_Ground_Water_2016.pdf.

In the Barapullah region, groundwater occurs in the alluvial as well as hard rock aquifers. The general groundwater flow path is in the south-eastern direction. The analysis of the data using one of the dug (open) wells (near Safdarjung tomb) monitored by the CGWB in the Barapullah catchment shows that the depth to groundwater level varies from 7.8 to 18.4 m during pre-monsoon and 6.0 m to 16.8 m during the post-monsoon (1996-2018). The variation in depth to water levels across years can be due to the variation in annual rainfall that influences the quantum of recharge, and the variation in annual groundwater draft, owing to variation in rainfall that changes in agricultural water demand. Overall, the depth to water level is lower, post monsoon owing to the recharge from rainfall.

The analysis of the long term groundwater level for the same well shows a general declining trend with depth to groundwater level going down by 44 cm/year during both pre-monsoon and post-monsoon (Figure 21 and Figure 22). The mean annual groundwater level fluctuation during this period was 2.8 m.

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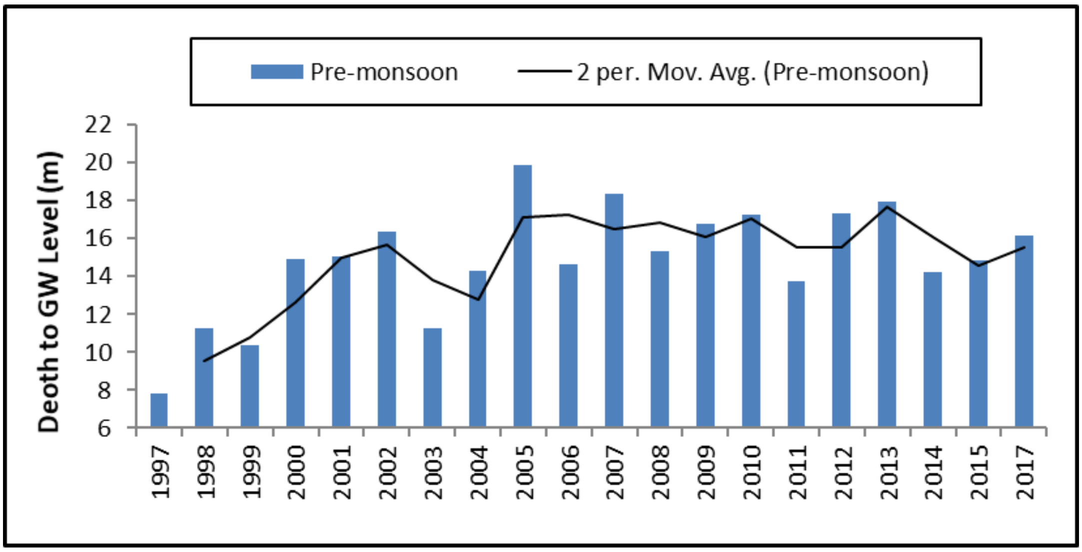

Figure 21: Pre-monsoon groundwater level trend for the Barapullah drainage area using CGWB data.

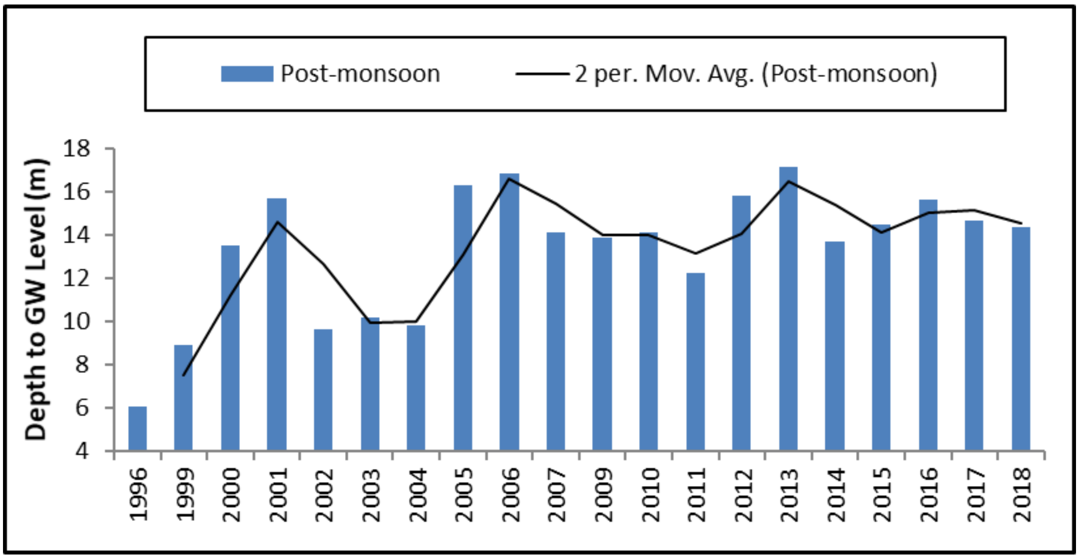

Figure 22: Post-monsoon groundwater level trend for the Barapullah drainage area using CGWB data.

Groundwater occurs under un-confined (in phreatic zones) to confined (in deeper zones) conditions. Groundwater flow is in the eastern direction of the city, confirming the effluent nature of river Ganga.

The analysis of the data using one dug (open) well monitored by the CGWB in Kanpur city shows that the depth to groundwater level varies from 14.9 to 18.7 m during pre-monsoon and 11.83 m to 18.7 during the post-monsoon (1996-2007). Like in the case of Barapullah drain, the depth to water levels during post monsoon period is lower than that of pre monsoon period. The analysis of the long-term groundwater levels in the city shows a general declining trend with depth to groundwater level going down by 45 cm/year during pre-monsoon (Figure 23) and 52 cm/year during post-monsoon (Figure 24), though there are inter-annual fluctuations. The average groundwater level fluctuation during monsoon for this period was 1.8 m.

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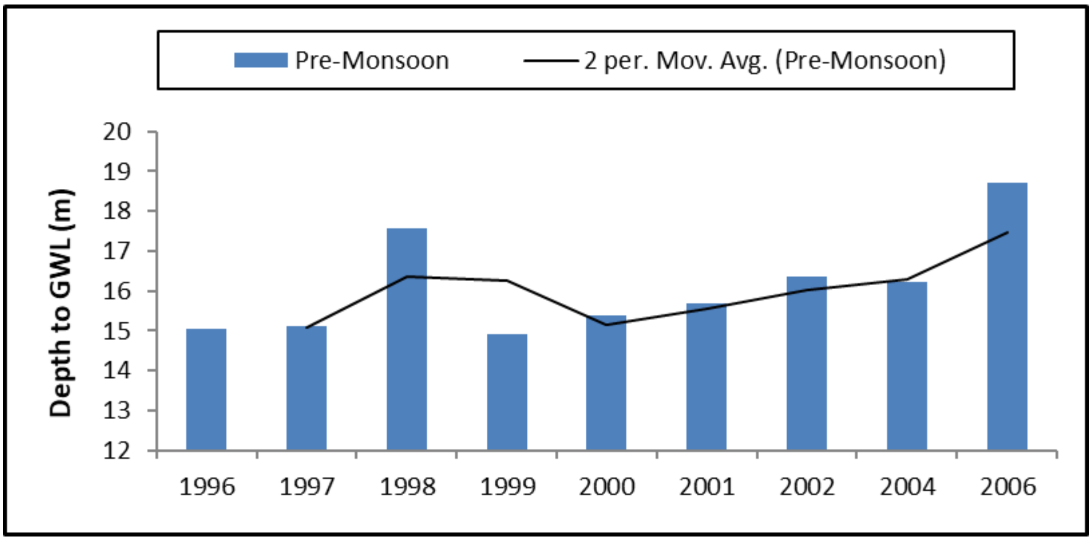

Figure 23: Pre-monsoon groundwater level trends for Kanpur city using CGWB data.

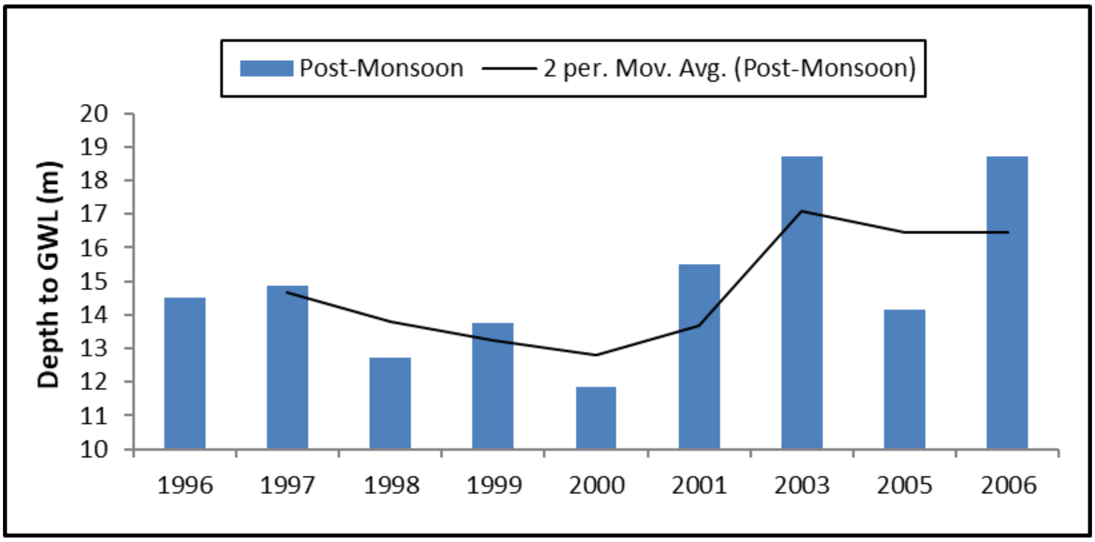

Figure 24: Post-monsoon groundwater level trends for Kanpur city using CGWB data.

Bassi et al. (2019) estimated annual groundwater availability in Kanpur city using the per unit area replenishable annual groundwater resources in the three districts of Kanpur (Kanpur Dehat, Kanpur Nagar and Unnao). Kanpur city is part of Kanpur Dehat district. As per the estimates, net annual groundwater availability is about 1475 million cubic metres (MCM) and the total annual draft (including for irrigation) is about 863 MCM. This indicates that annually, 612 MCM of groundwater is available for further use. It is highest in Unnao and Gangaghat region followed by Kanpur city and Akbarpur (Figure 25).

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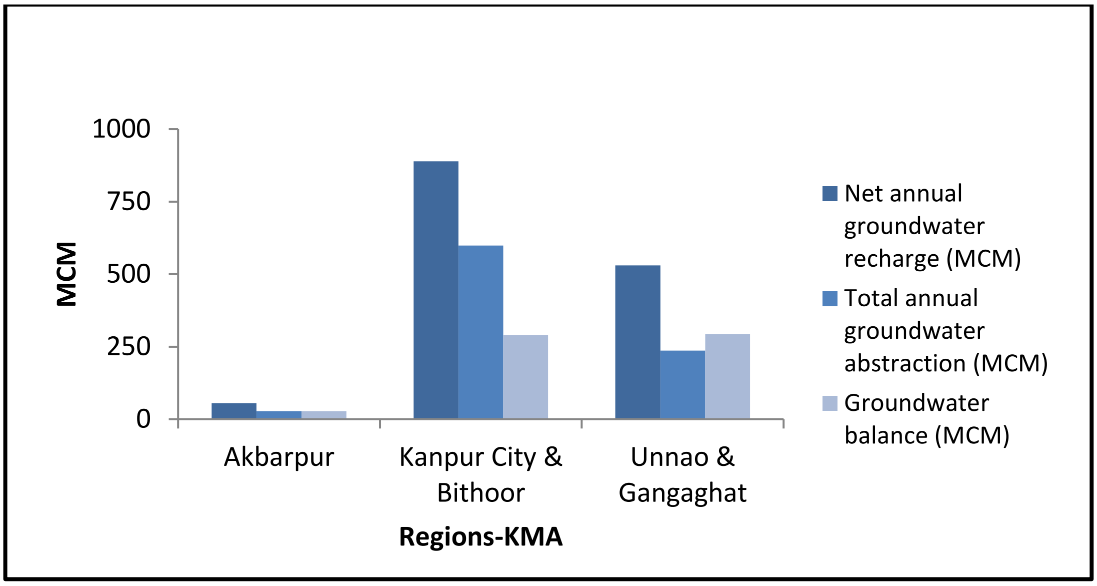

Figure 25: Estimated groundwater availability for the Kanpur Metropolitan area.
(source: estimates from Bassi et al., 2019)

Table 13 presents the groundwater quality in two industrial areas of Kanpur city. Electrical conductivity (EC) was found to be high in Jajmau industrial area where most of the tanneries are located and nitrate was found to be high in Panki industrial area. Apart from fluoride, other parameters were found to be within permissible limits. Fluoride content was found to be high in groundwater in Jajmau in comparison to the Panki industrial area.

Table 13: Groundwater quality in Kanpur city.

Parameter	**Location of Observation Wells**					
	Jajmau Industrial Area			**Panki Industrial Area**		
	Min	*Max*	*Mean*	*Min*	*Max*	*Mean*
Temperature (ºC)	27.0	27.0	27.0	27.0	27.0	27.0
pH	7.8	7.8	7.8	6.9	6.9	6.9
Electrical Conductivity (µmhos/cm)	796.4	796.4	796.0	548.2	548.2	548.0
BOD (mg/l)	2.4	2.4	2.4	0.8	0.8	0.8
Nitrate (mg/l)	2.5	3.2	2.9	34.5	34.5	34.5
Fluoride (mg/l)	3.0	3.0	3.0	1.2	1.2	1.2

(Source: CPCB, 2013)

2.3. Hydraulics

Information on more exact manmade channel geometry, weirs, sluices etc. is not readily available. Locations of dams can be derived from the Global Dam Watch database: http://globaldamwatch.org/grand/

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CHAPTER 3 CLIMATE AND RAINFALL

3.1. CLIMATE

Delhi has a humid sub-tropical climate with long and hot summers and cold winters. The normal annual rainfall is 794 mm, 81% of the annual rainfall is received during the monsoon months, i.e. from July to September. However, there is a high inter-annual variability in the rainfall. The month of January is the coldest with the mean daily maximum temperature at 21.3°C and the mean daily minimum at 7.3°C. The hottest months are May and June, when the maximum temperature reaches 46 or 47°C. The average annual relative humidity is 54%.

The climate in Kanpur is sub-tropical with average temperature varying from as low as 8°C during winters to 41°C during summers. The normal annual rainfall is about 846 mm and exhibit high inter-annual variability. About 90 percent of the rainfall is received during the monsoon months (June to September). The relative humidity ranges from less than 30 percent in the summer season (March to May) to about 70 percent during monsoon. The potential evaporation (PE) is 1660.9 mm.

The average monthly temperatures and rainfall show the seasonal nature of the climate in both New Delhi (Figure 26) and Kanpur (Figure 27): hot dry season (March to June); hot wet season (July to September); and the cold dry season (October to February).

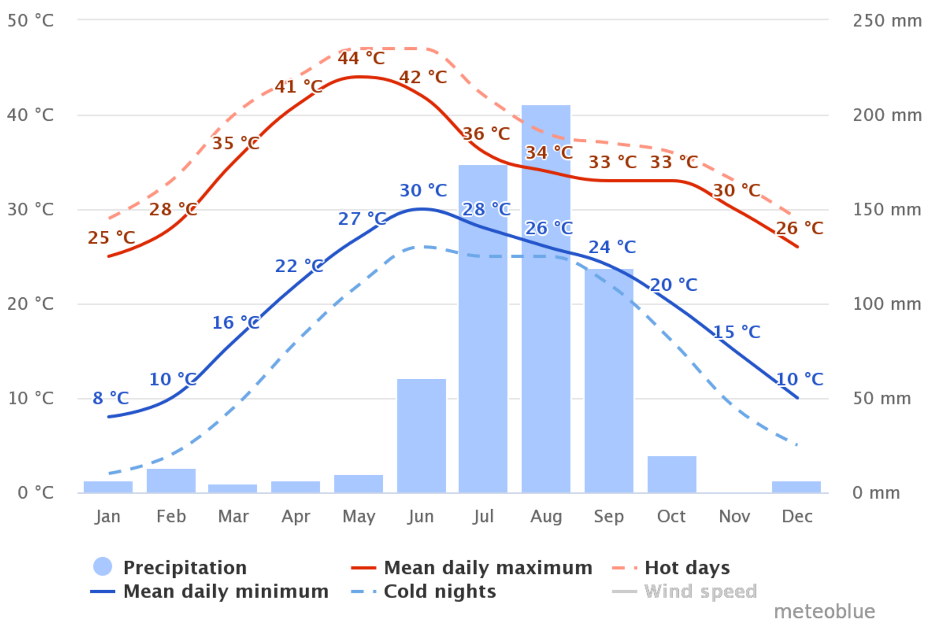

Figure 26: Average temperatures and precipitation in New Delhi, based on 30 years of hourly weather model (source MeteoBlue [Simulated historical climate & weather data for New Delhi - meteoblue])

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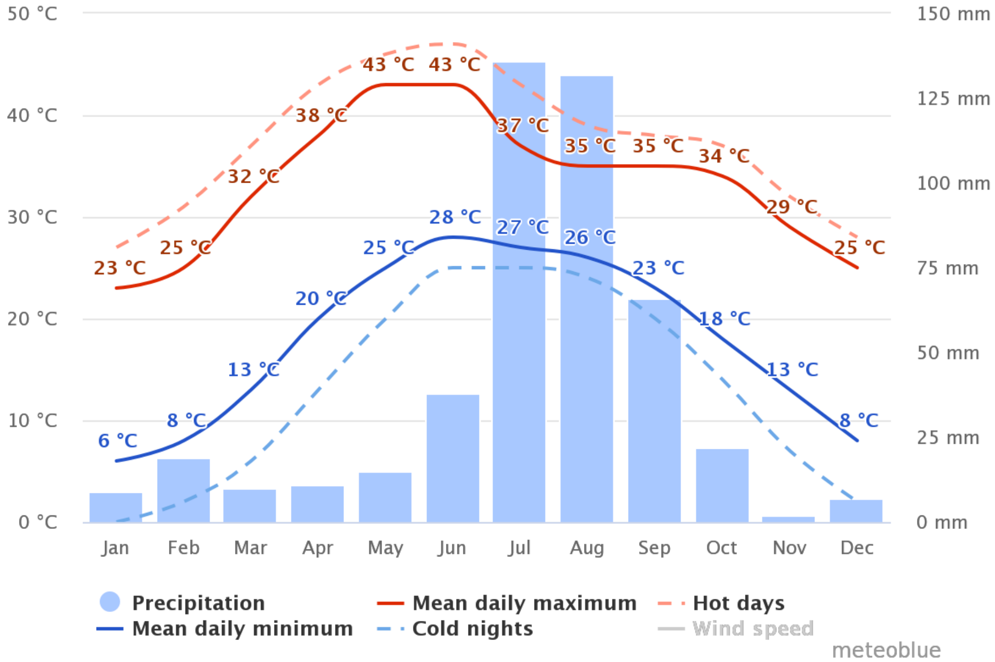

Figure 27 Average temperatures and precipitation in Kanpur, based on 30 years of hourly weather model (source: MeteoBlue *Simulated historical climate & weather data for Kanpur - meteoblue*)

3.2. Annual Rainfall

This section presents analysis of the rainfall trend in Delhi and Kanpur Nagar districts to gain insights into the characteristics, especially the incidence of occurrence of extreme events that will have implications for surface water flows and quality of water in the rivers. For this, the data of average annual rainfall for 52 years (1970-2021) were collected from India Water Resources Information System (IWRIS) for the two districts. From this, the Standard Precipitation Index (SPI) was calculated for both the locations for each year. The SPI measures the departure of the rainfall (in this case the annual rainfall) from the long-term mean expressed in terms of the number of standard deviations (SDs)[1]. Subsequently, the coefficient of variation in the rainfall (CV) was also estimated based on mean and standard deviation.

3.2.1. Analysis of Rainfall in Delhi

Figure 26 presents the spatial average annual rainfall receiv[2]ed during the 52 years from 1970 to 2021 and the mean annual rainfall. The mean of average annual rainfall in Delhi was estimated to be 794 mm for the 52 years. The actual average annual rainfall for the district varied from a minimum of 350 mm in 1989 to a maximum of 1182 mm in 1975. Figure 27 presents the year-to-year departure in the average annual rainfall from the mean value in percentage terms. Overall, the analysis shows high inter-annual variability in average rainfall with a coefficient of variation (CV) of about 32%.

[2] The SPI tool was developed by McKee et al. (1993) to determine drought conditions based on the long-term rainfall data and is a useful tool for comparing the intensity of extreme hydrological events (like dry and wet years) in two or more locations that experience different degrees of year to year variation in rainfall, but having same amount of mean annual rainfall.

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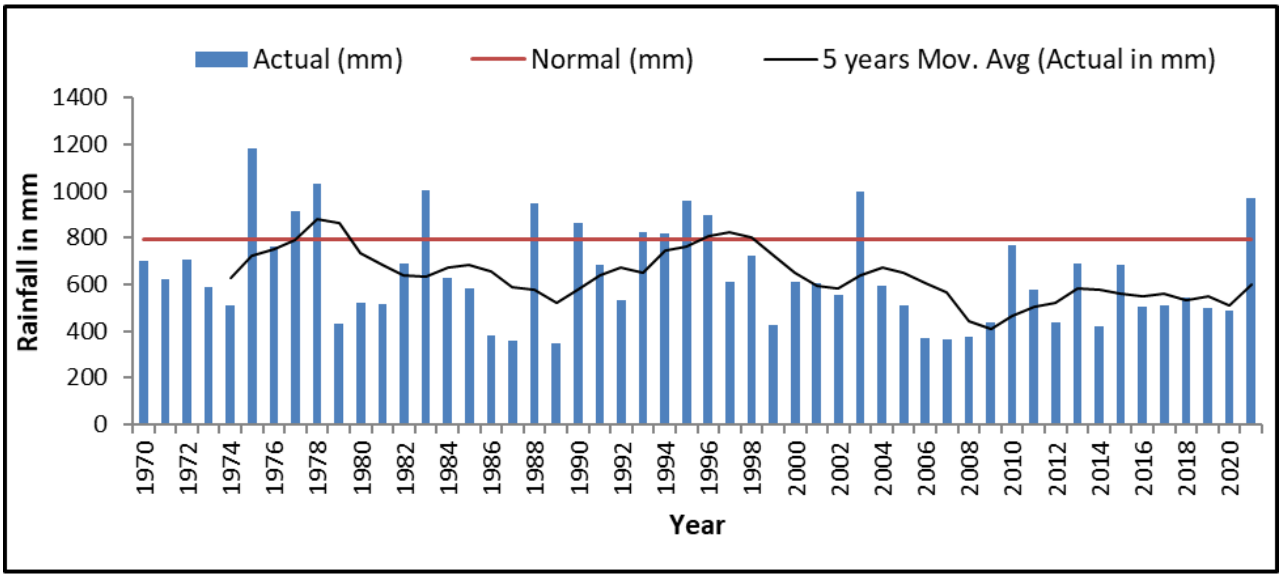

Figure 28: Average annual rainfall v/s mean annual rainfall in Delhi during 1970-2021
(Source: Based on analysis of rainfall data accessed from the India WRIS)

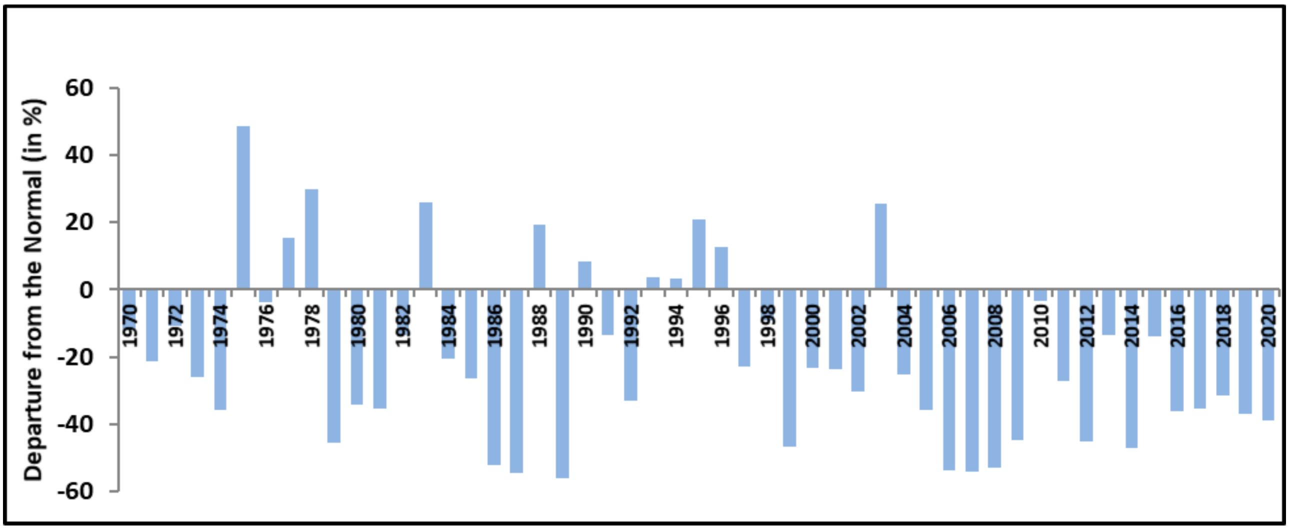

Figure 29: Departure of Average Annual Rainfall from the Mean (%) in Delhi
(Source: Based on analysis of rainfall data accessed from the India WRIS)

The SPI estimates for Delhi are summarized in Table 14 and Figure 28. The frequency analysis of the estimated SPI values shows that though a majority of the last 52 years were near normal (63% of the total), about 17% were moderately dry, and 8% were moderately wet. Further, six out of the total 52 years were 'very wet' to 'extremely wet'. However, there was no 'severely dry' or 'extremely dry' year.

Table 14: Frequency Analysis of Computed SPI Values for Delhi

SPI Classification	Number of Years	in %
Extremely wet	1	1.92
Very wet	5	9.62

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Moderately wet	4	7.69
Near Normal	33	63.46
Moderately dry	9	17.31
Severely dry	0	0.00
Extremely dry	0	0.00
Total number of years	52	100.00

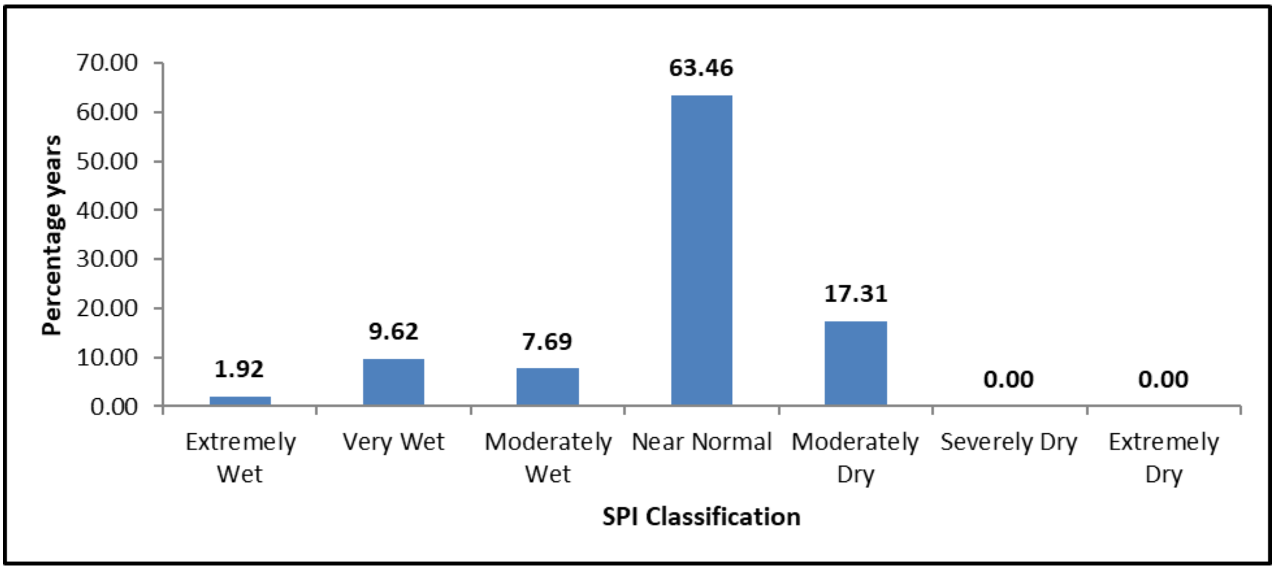

Figure 30: Frequency of Occurrence of Normal and Extreme Rainfall Events, Delhi

3.2.2. Analysis for Rainfall in Kanpur Nagar

Figure 29 presents the spatial average annual rainfall received in Kanpur Nagar during the 52 years from 1970 to 2021 and the mean annual rainfall. The mean of average annual rainfall in Kanpur Nagar was estimated to be 846 mm for the 52-year period. The actual average annual rainfall varied from a minimum of 187 mm in 1998 to a maximum of 1556 mm in 1980. Figure 30 presents the year-to-year departure in mean annual rainfall from the mean value in percentage terms. As was the case in Delhi, the spatial average rainfall in Kanpur Nagar district shows high inter-annual variability with a coefficient of variation (CV) of about 36%.

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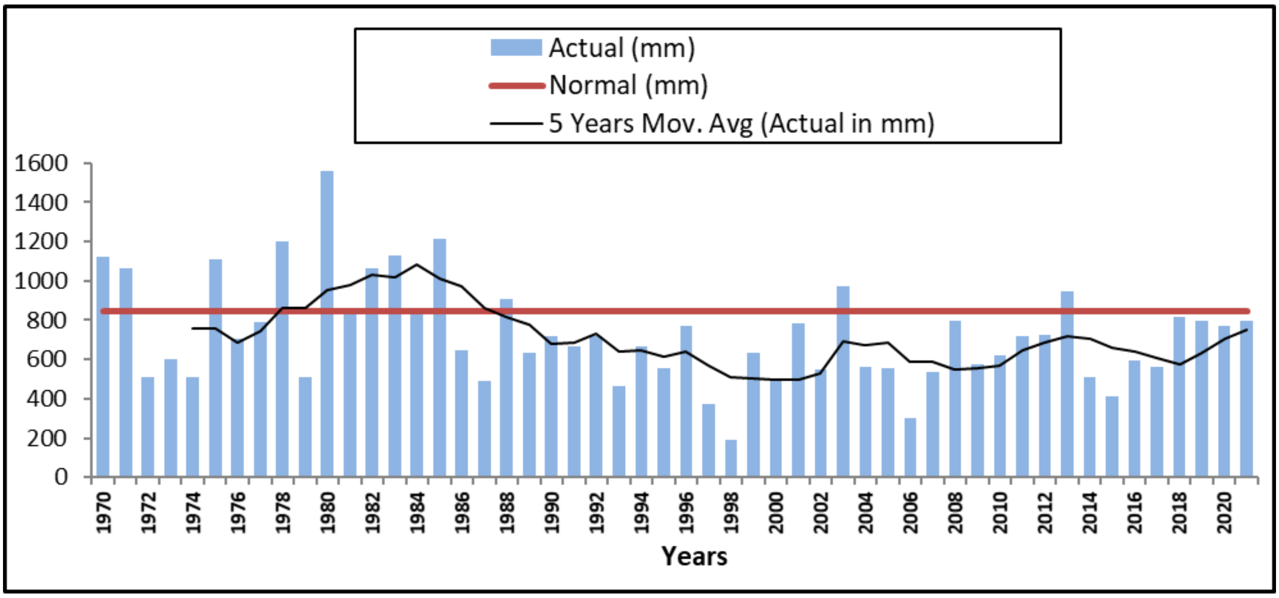

Figure 31: Kanpur Nagar Normal Rainfall v/s Actual Rainfall

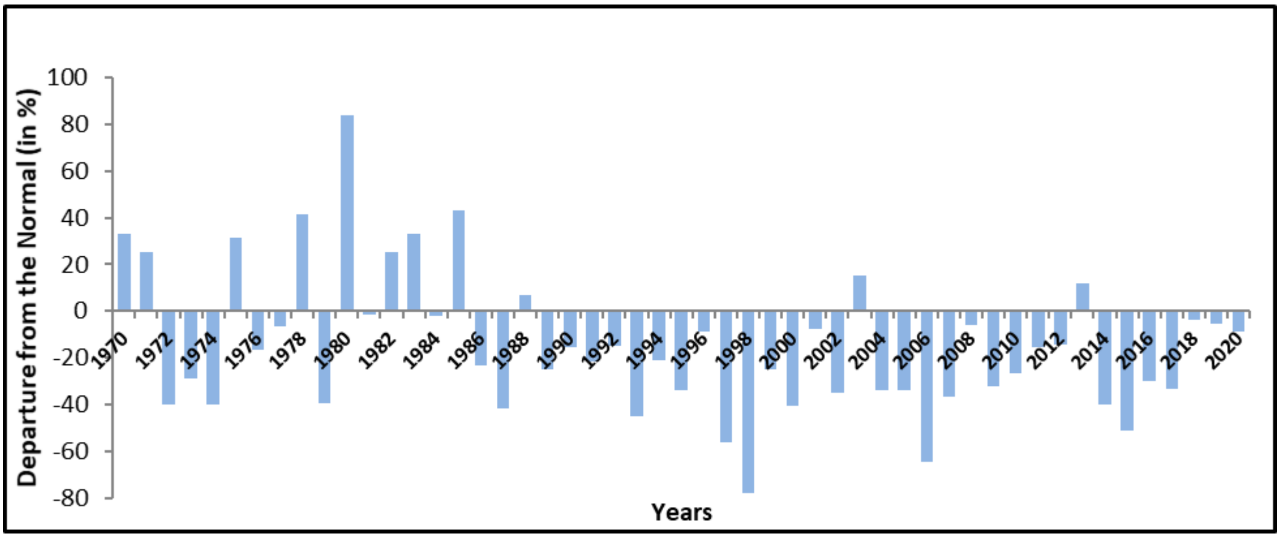

Figure 32: Departure in annual rainfall from normal (in %) Kanpur Nagar

The SPI estimates for different years for Kanpur Nagar district are summarised in Table 15 and Figure 31. The frequency analysis of estimated SPI values shows that a majority of the 52 years were near normal (73% of the total). About 4% were 'extremely wet' years, 9% 'very wet' years, 3% 'moderately wet' years, 6% 'moderately dry' years, and 2% each were 'severely dry' and 'extremely dry' years.

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Table 15: Frequency Analysis of Computed SPI Values for Kanpur Nagar

SPI Index	Number of Years	in %
Extremely wet	2	3.85
Very wet	5	9.62
Moderately wet	2	3.85
Near Normal	38	73.08
Moderately dry	3	5.77
Severely dry	1	1.92
Extremely dry	1	1.92
Total number of years	**52**	**100.00**

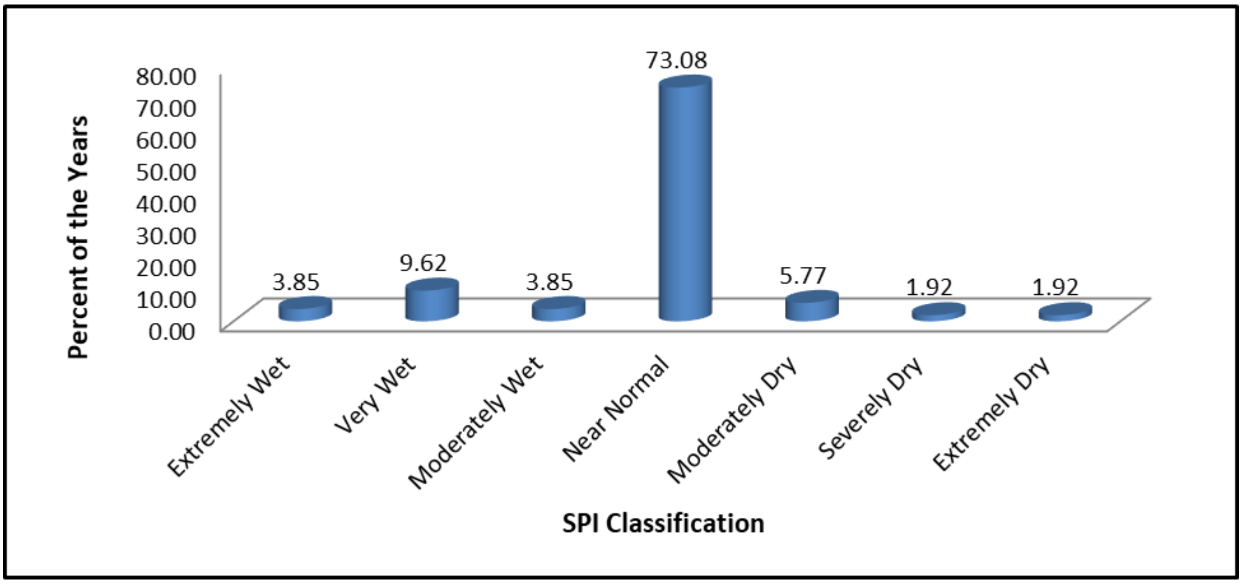

Figure 33: Frequency of Occurrence of Extreme Rainfall Events: Kanpur Nagar

3.2.3 Summary of Rainfall Analysis

A quick comparison of the outputs of the analysis of rainfall in Delhi and Kanpur shows that Kanpur, which witnesses a higher mean annual rainfall than Delhi, also witnesses a lower degree of climatic extremes, as indicated by the frequency analysis of the Standard Precipitation Index values. While Kanpur gets normal rainfall in a 73 per cent of the years, Delhi receives normal rainfall only in 63 per cent of the years. In Delhi, 17 per cent of the years were 'moderately dry' years, whereas in Kanpur, only less than 6 per cent of the years were 'moderately dry'.

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CHAPTER 4 LAND USE AND LAND COVER

4.1. Topographical Data

The Shuttle Radar Topography Mission (SRTM) provides digital elevation data at 30m: https://www2.jpl.nasa.gov/srtm/. In addition the Indian Geo-Platform from the Indian Space Research Organisation (ISRO) provides topographical information: https://bhuvan-app3.nrsc.gov.in/data/download/index.php.

4.2. Land Use

As per the Delhi Master Drainage Plan 2018 (IIT New Delhi, 2018), the land use of the Barapullah catchment is broadly divided into cropland, urban, river and water bodies, grass and fallow lands. The basin region is highly urbanized with nearly 30% of the total geographical area under built-up land use (Figure 17).

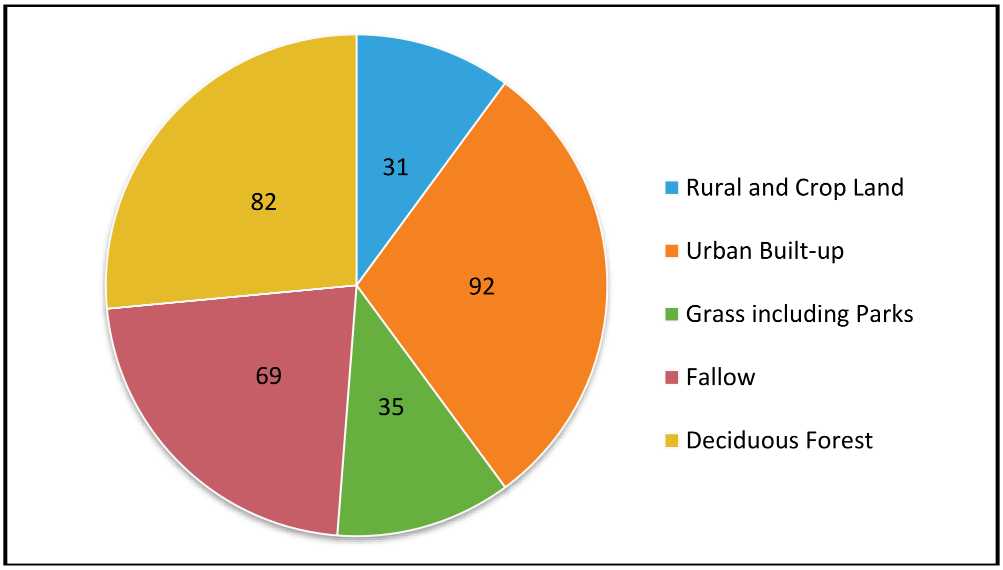

Figure 34: Land use area (km^2) in the Barapullah drainage catchment. Data from Bhuvan.

The total geographical area of Kanpur city is 1065 sq. Km. Out of this, nearly 71% of the area was under agricultural use which includes area under cropland, plantations and land kept fallow for that year (Figure 18).

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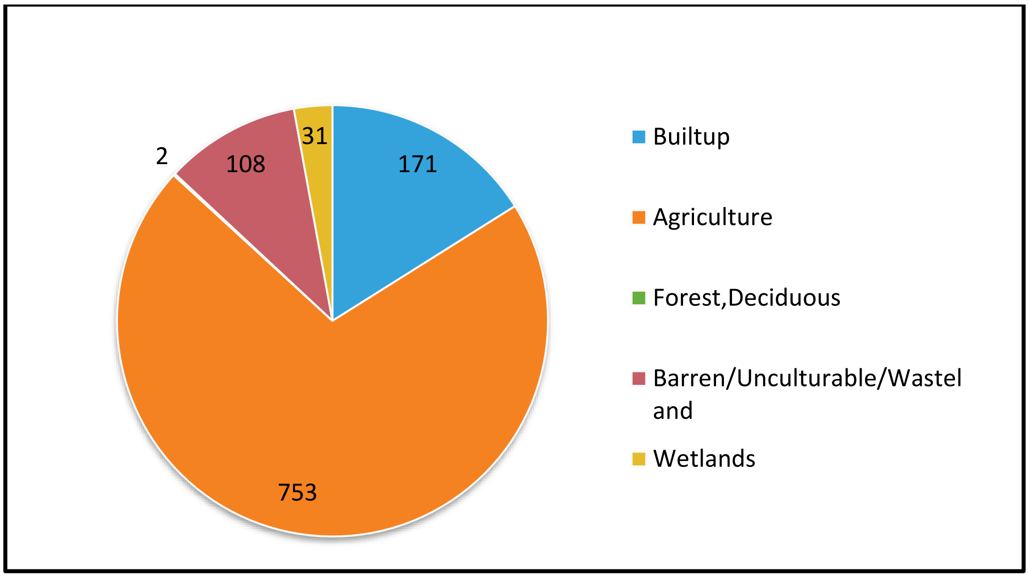

Figure 35: Land use area (km²) for Kanpur Metropolitan Area. Data from Bhuvan.

ISRO provides comprehensive but generalized land cover classifications over both regions: https://bhuvan-app1.nrsc.gov.in/state/UP# and https://bhuvan-app1.nrsc.gov.in/state/DL
OpenStreetMaps (OSM) provide more detailed classifications but is not comprehensive over both regions (see comparison in Figure 19).

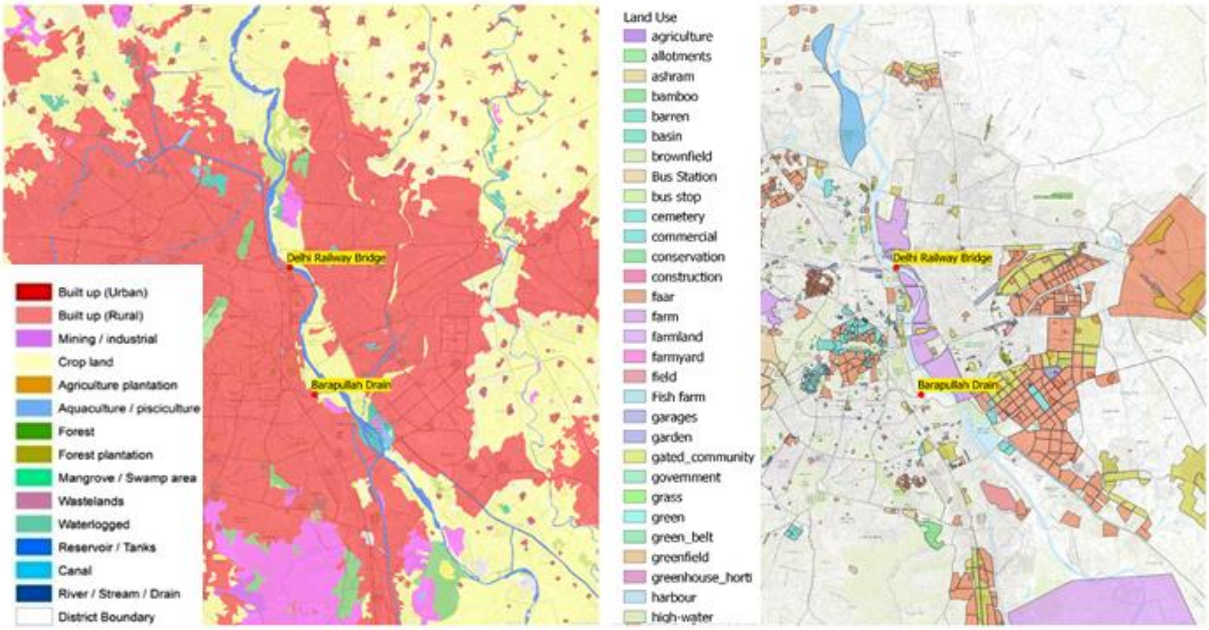

Figure 36: Comparison of coverage and level of detail in land use classes between ISRO and OMS classifications.

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CHAPTER 5 WATER QUALITY MODELLING ASSESSMENT OF THE TWO CASE AREAS

5.1. General Features of WEAP Model

WEAP is a water balance model, which can be set up for river basins, catchments and administrative units for assessing water supply potential of the units against the demands (Yates et.al., 2005). WEAP can be run on a time scale to examine how the demand for water within the analytical unit changes over time in accordance with various socio-economic and environmental drivers, how the supply of water to meet the requirements (demand) of water changes under various technological interventions and changes in water allocation priorities, and both can be compared under various future scenarios of water balance.

For analysing the water balance, the 'supply requirement' is estimated by the model by adding the conveyance losses in the networks linking the supply sources and demand sites to the estimated demands (at the demand sites) and compared with the supply potential of the system. For instance, if a canal has to carry water from the reservoir to the command area, which is the demand site, the conveyance losses in the canal will be factored in while estimating the supply requirement. The model also estimates the return flows to the supply sources from the demand sites such as irrigation return flows to groundwater and streams, and return flow of treated and untreated wastewater to streams.

The model has three components, viz., 1] a supply programme to simulate various sources of water supply with respect to space and time; 2] a demand programme to simulate various demand sites in quantitative and qualitative with respect to space and time; and, 3] a network programme, which handles the conveyance systems for taking water from the supply sources to various demand sites and also the return flows (domestic and industrial wastewater, irrigation return flows, etc.) from demand sites to various sinks and sources. The supply programme estimates the total amount of water that can be supplied from a node based on the water available (from stream-flows or groundwater recharge), the storage and release capacity of the reservoir headworks and canals/pipes, or diversion capacity of the weirs/barrages/pipelines/canals) or the discharge potential of the wells that tap the aquifers, depending on the nature of the source. If the supply node is a reservoir, the model would require data on the reservoir storage-elevation curve to compute the water level and water spread area. For estimating the water release, the carrying capacity of the canal or pipe will have to be defined. The streamflow data can be historical (annual and monthly) inflows gauged at various control points defined in the programme along the stream.

The demand programme estimates the requirement of water in various sectors (at the demand site) using a demand tree (with sectors such as agriculture, industry, municipal, urban domestic, etc. as its branches) with demand rates in each sector (like irrigation water requirement per unit area under different crops, water demand in the domestic sector per capita per day, water demand for industrial sector per unit volume of production for different categories of manufacturing outputs, etc.) and the size of the sector (irrigated area under different crops, size of population in rural and urban areas, and volume of industrial production under different industrial categories) using simple algorithms. The demand programme can also handle drivers of change in demand with respect to time (such as population growth rate, per capita domestic water demand) and also under different water use efficiency scenarios (irrigation water requirement per unit area, water intensity of industrial production, etc.). The complexity of the demand tree depends on the data availability for different demand sectors and sub-sectors.

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The network programme estimates the losses in the conveyance system constructed for transmitting water from the supply source to the demand site based on infiltration rate, canal seepage rate, distribution losses in the pipeline network, etc., as defined in the WEAP configuration, which is used to estimate the supply requirements at the source based on the estimated losses. The programme also estimates the return flows from the demand sites to various supply sources based on the defined rates of return flows from irrigated fields, and domestic and industrial sectors. These data will have to be provided in the programme for the model to run.

For running the model, the base year, the time period and the time scale will have to be defined (for instance, month, year). Several scenarios of water balance can be created in the model for different time periods depending on the time scale defined, and depending on the nature of scenarios, several of the input data files used in the base case scenario will have to be modified. For a high economic growth scenario, the per capita water demand in the domestic sector could change. So is the efficiency of water use for crop production, with large-scale use of efficient irrigation technologies, with result impact on irrigation return flows. Similarly, the annual and monthly runoff can get affected as a result of changes in rainfall (magnitude and intensity) and temperature.

5.2. Setting up the Water Balance Model for the Kanpur Metropolita Area (KMA)

The WEAP model was used to analyze the water balance of KMA, under the likely future changes in demand for water resulting from predicted socio-economic and environmental changes, and likely changes in water supplies resulting from climate variability and change. The configuration of the WEAP model set up to simulate the water supply-use and reuse system of the Kanpur Metropolitan Area (KMA) is presented in Figure 37. The various components of the system are explained below.

5.2.1. Supply Nodes

The supply nodes include aquifers, reservoirs, withdrawal points, tributary confluence points, and special locations (such as streamflow gauges, diversions, etc.). Nodes are linked by lines that represent the natural or man-made water conduits which include rivers, diversions, and transmission and return flow links. A river reach is defined as the section of a river or diversion between two river nodes or following the last river node.
In the configured WEAP system for the Kanpur Metropolitan Area (See Figure 37), there are two water supply sources. They are: [a] the river (surface water); and [b] a groundwater supply source. The Ganga main river stem is taken as the surface water source. For groundwater supply source, alluvial aquifer underlying Kanpur Metropolitan Area was considered.

A total of three supply nodes were defined for modelling, which include: [a] one water diversion node i.e., Kanpur barrage; and [b] two streamflow gauges which include Ranighat and Jajmau pumping station; and [c] one groundwater supply node. All the surface water supply nodes are on the Ganga main river stem.

Configuration of the WEAP system was set up for a study period beginning June 2009 and ending May 2040. The year 2009 was taken as the base year and the period 2010-2040 was considered for generating scenarios (also called reference years). The estimated monthly river discharge for the period 2000-2019 was used as streamflow data for the two gauging stations (shown as dark blue circles) defined on the Ganga river main stem. The streamflows were estimated using the SCS runoff curve number method and were extrapolated up to 2040 in the WEAP model. The water quality data for the two stream gauges for 2000-2016 was considered for the modeling and extrapolated up to 2040.

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The configuration also has one groundwater supply node (shown as a green rectangle). Data on initial storage capacity, annual natural recharge, and maximum withdrawal was provided for 2009. Groundwater quality data such as temperature, BOD concentration, conductivity, and pH has also been provided for 2011 -2019, for which data was available on these parameters, and were extrapolated up to 2040.

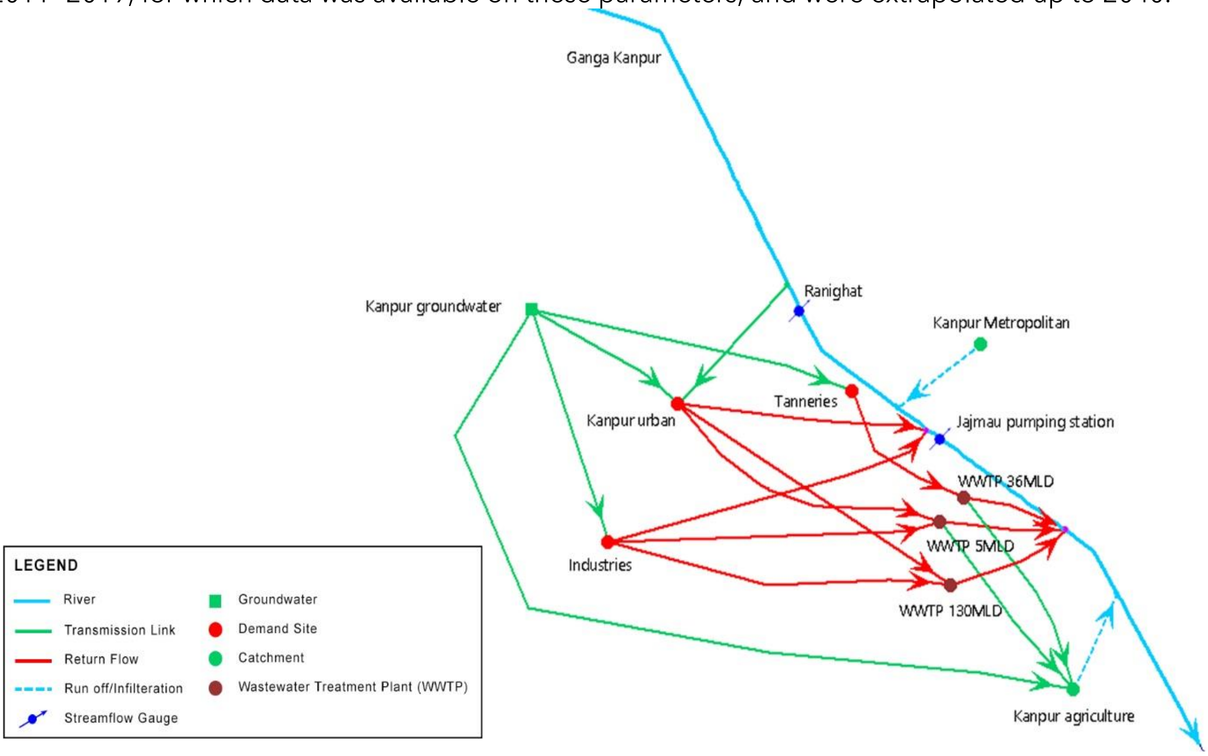

Figure 37: The WEAP Configuration for Kanpur Metropolitan Area

5.2.2. DEMAND SITES

A total of four demand sites were defined in the model. They are: Kanpur agriculture, Kanpur urban area, industries, and tanneries. Each of the demand sites comprises a demand tree consisting of annual activity level, annual water demand rate, actual consumption, and loss rate at the branch and sub branch. Table 16 presents the data that were entered for the four demand sites.

Table 16: Data used for the demand sites in the WEAP

Demand Site	Particulars		
	Annual Activity Level (units)	Annual Water Demand Rates (thousand litres/unit/year)	Actual Consumption
Kanpur urban (persons in million)	3.2	54.75	20%
Industries (production units)	3490	74,095.13	20%
Tanneries (production units)	2428	20,439.87	20%
Agriculture (area in square kilometres)	540	4,15,394.44	As estimated by the FAO CROPWAT Model

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5.2.3. Kanpur Catchments

Three catchments, i.e., Kanpur agriculture, Kanpur metropolitan area (KMA), and Kanpur regional catchment (KRC) were defined. The KMA and KRC were used for the estimation of the runoff from the Kanpur urban area and the catchment upstream of the city. The Kanpur agriculture catchment contributes to the river flows through irrigation returns. Further, the latter also acts as a demand site as it receives groundwater and the treated wastewater from the three plants.

→ **Kanpur Agriculture**

Kanpur agriculture is considered both as a catchment and a demand site. As a catchment, it is modeled to contribute to river flows through irrigation returns. Kanpur agriculture demand tree has two sub-branches, each representing an irrigated crop in the area i.e., wheat and paddy. Each sub-branch is further divided in terms of irrigated area and annual water use rate. The data on crop wise irrigated area and the irrigation water requirement for the individual crop (estimated using the FAO CROPWAT model) were used to work out the total irrigation water demand for each crop. The monthly climatic data of precipitation and reference ET, and the time of sowing and harvesting of the two crops were used as input for running the FAO CROPWAT model.

→ **Kanpur Metropolitan Area**

This part of the catchment Is the urban area of KMA having an area of 103 sq. km. The land use land cover map was prepared by using MODIS land cover data of the year 2016 and re-gridded to 250m. All soil data was downloaded from 'OpenLandMap' and re-gridded to 250m (Figure 38a). The description of soil texture classes and their numbering system is presented in Table 17.

Table 17: Soil Texture discrete numbering system

Value	Description
1	Cl
2	SiCl
3	SaCl
4	ClLo
5	SiClLo
6	SaClLo
7	Lo
8	SiLo
9	SaLo
10	Si
11	LoSa
12	Sa

The spatial data on KMA land use and soil type was used for the preparation of the Curve Number (CN) grid. For preparing the grid, the land use/land cover was reclassified to form four major categories: forest, agriculture, built-up, and water bodies (belowFigure 38b). For each soil type, the hydrologic soil group (HSG) was assigned using QGIS. Thereafter, the CN grid along with the daily rainfall data for the KMA was used to estimate the daily runoff from the catchment following the SCS curve number method.

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5.2.4. KANPUR REGIONAL CATCHMENT

The catchment is between the Kachla Bridge (50 km downstream of Narora barrage) and Kanpur Barrage (taken as the outlet of the catchment). This catchment has a dendrite drainage pattern with a total geographical area of 18,342 sq km. The SCS CN method was used for estimating runoff from the catchment using the rainfall data. The daily rainfall data of one location (Kannuaj) for 2000-2020 has been used for estimating runoff. Satellite data such as 'Global Land Service (CGLS) Dynamic Land Cover Layers' at 100 m resolution, 'HYSOGs250m' (for hydrologic soil groups), and digital elevation model (DEM) data of 'Cartosat-1' (NRSC, Hyderabad) at 30 m resolution has been used. The QGIS version 3.18 was used for preparing all the GIS layers. The following sub-sections provide the details on the various processes undertaken to estimate the runoff from the regional catchment.

A] Drainage map

The catchment was delineated and a drainage map (Figure 39a) was prepared using the 'Cartosat-1 DEM' data of 2015 from the NRSC, Hyderabad. A DEM map of the study area is also prepared (Figure 39b).

b] Land use land cover

A land use land cover map for Kanpur regional catchment was prepared using the 'Copernicus Global Land Service (CGLS) Dynamic Land Cover Layers' at 100 m resolution data of 2019. The data was processed and the land use classes were reclassified into four major classes, i.e. water bodies, urban, forest, and agriculture. The detailed classification map is shown in Figure 39c.

B] Hydrologic Soil Group (HSG)

The 'HYSOGs' 250 m spatial resolution data of 2017 was used to derive the HSG of the Kanpur regional catchment. The HSGs are a fundamental component of the USDA curve number (CN) method for estimation the runoff. The HSG map of the study area has 3 classes (B, C, and D) of soil and is presented in Figure 39d.

C] Antecedent Soil Moisture Condition (AMC)

The antecedent soil moisture condition (AMC) refers to the water content present in the soil at a given time. It is a very important factor for determining the final CN value. The SCS developed three antecedent soil moisture conditions (I, II, and III) according to soil conditions and rainfall limits for dormant and growing seasons. In this study, the average condition (AMC-II) is taken to determine the CN value for the study area. The developed CN grid map of the study area is presented in Figure 39e.

D] Area weighted curve number

A weighted average curve number based on the area assigned to different curve numbers is used for the entire watershed to study the runoff of a watershed. The weighted average curve number of the study area is 82.84 (taking CN II = 83). CN values for AMC-I (dry condition) and AMC-III (wet condition) conditions were also calculated using conversion equations. The value are CN (I) = 68 and CN (III) = 92. The runoff was calculated using the SCS method.

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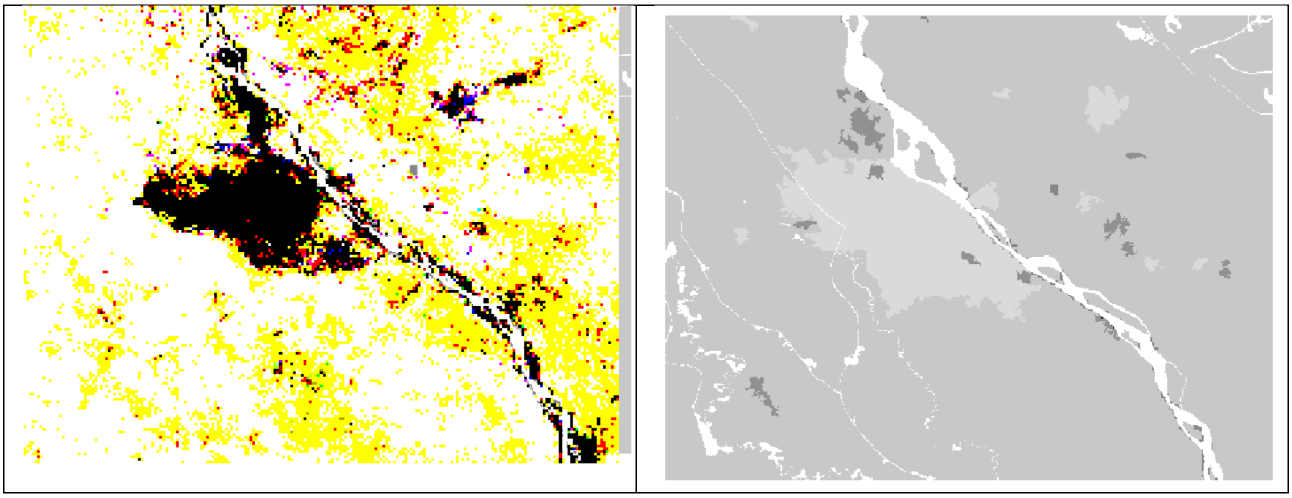
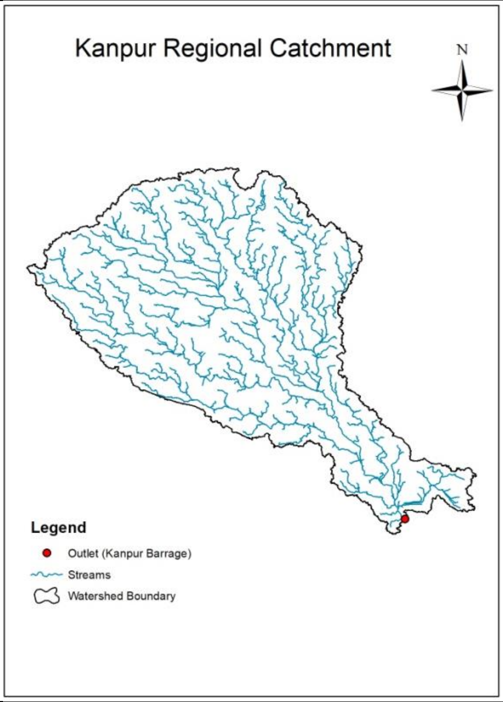
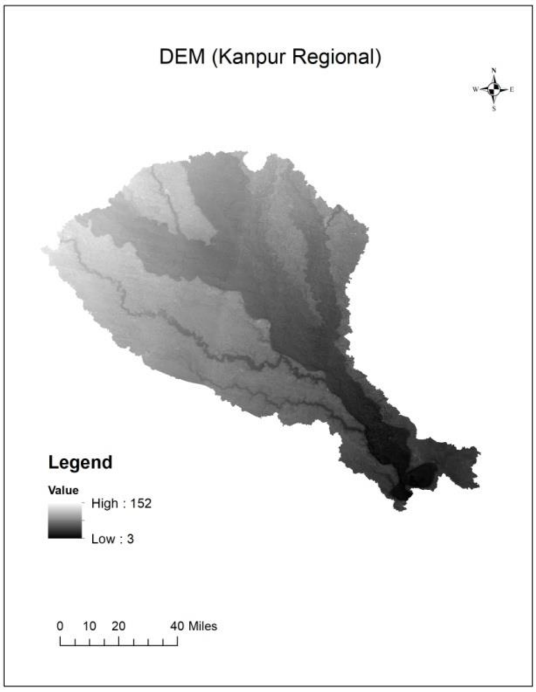


Figure 38: a) Soil Texture of Kanpur Metropolitan Area b) Curve Number Grid of Kanpur Metropolitan Area





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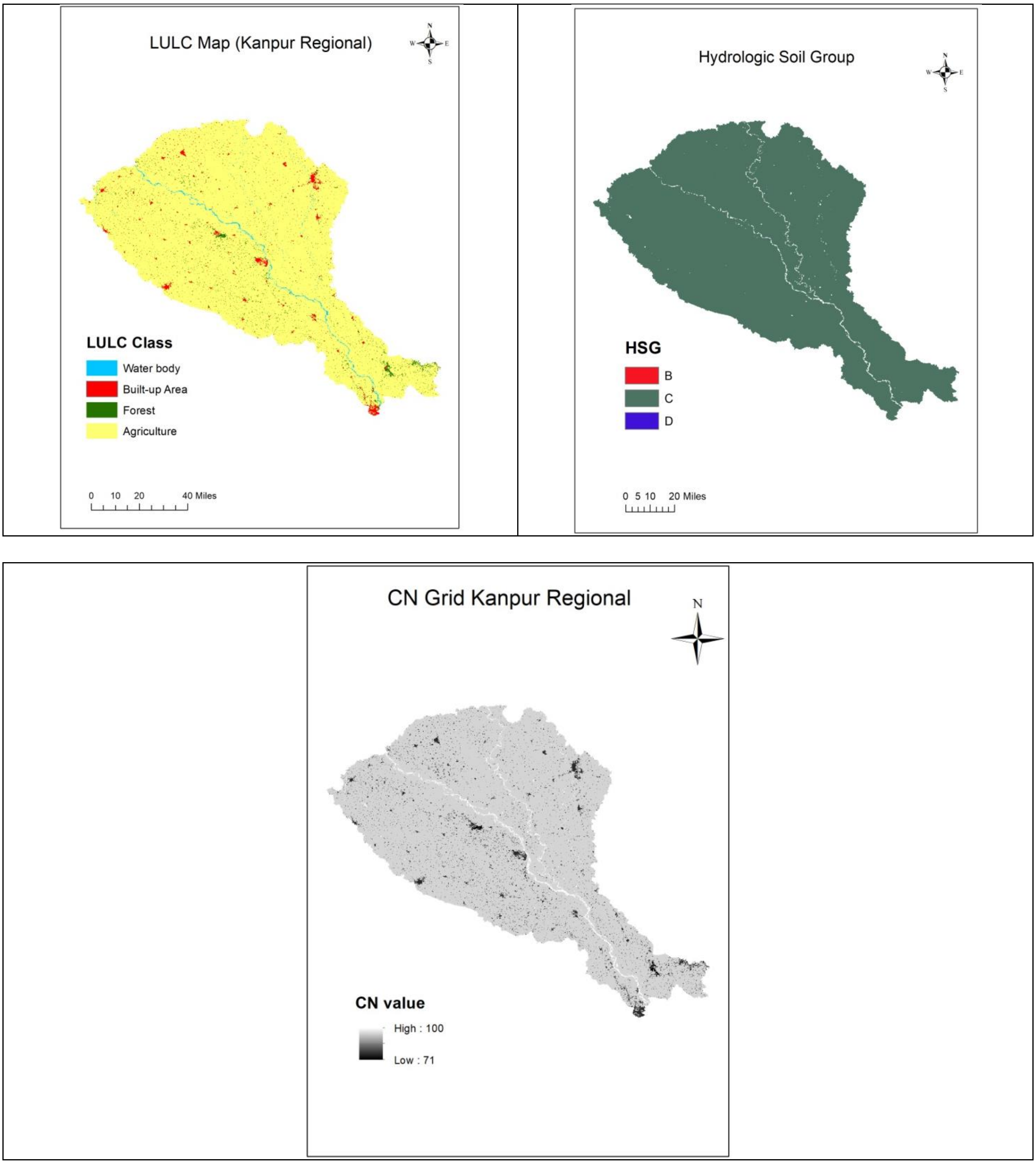

Figure 39: a) Drainage pattern of Kanpur regional catchment b) DEM of Kanpur regional catchment c) LULC of Kanpur regional catchment d) HSG of Kanpur regional catchment e) CN grid of Kanpur regional catchment

E] Rainfall-runoff regression for Kanpur regional catchment

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Using the estimated runoff as the dependent variable and the rainfall as an independent variable, a univariate regression analysis was performed which is presented in Figure 40. The analysis estimates an R-square value of 0.75 which is a good fit for the developed rainfall-runoff regression model.

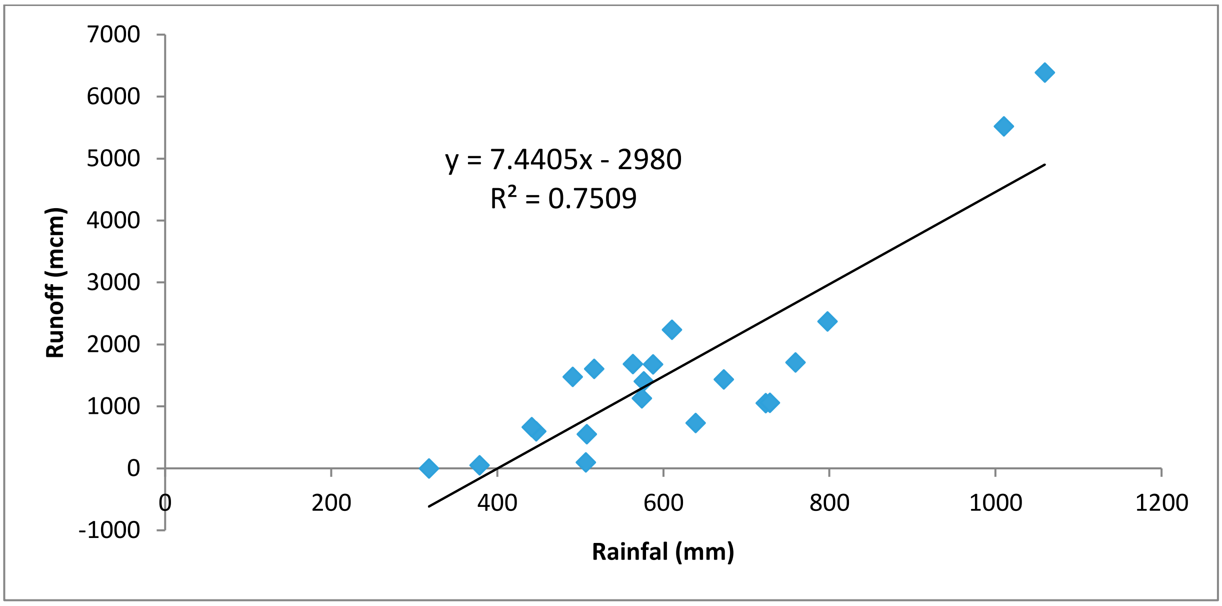

Figure 40: Rainfall - runoff regression plot

5.2.5. Wastewater Treatment Plants at STP Jajmau

Three wastewater treatment plants i.e., 5 MLD, 36 MLD, and 130 MLD, were considered for the modeling. While the 5 MLD and 130 MLD primarily serve the urban and industrial areas, the 36 MLD common effluent treatment plant (CETP) serves the tanneries in the KMA. Data on wastewater quality (influent and effluent) for 2010-2013 were used in the WEAP model and extrapolated up to 2040. These data were available for the following water quality parameters: BOD, COD, Total Coliform, Fecal Coliform, and TDS. The technology used for wastewater treatment along with the removal efficiency of various contaminants is provided in Table 18.

Table 18: Contaminant removal efficiency of the wastewater treatments plants

Nutrients	Nutrient removal efficiency (%)		
	5 MLD Plant (UASB)	36 MLD Plant (UASB + Polishing Unit)	130 MLD (Activated Sludge Process)
BOD	44.2	51.9	81.7
COD	36.9	70.3	87.8
Total Coliform	88.4	98.7	99.8
Faecal Coliform	74.8	97.7	99.3
TDS	12.0	37.0	42.3

5.2.6. Network Links

The WEAP system has the following network links:

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- One main river (Ganga),
- One river diversion (Kanpur barrage),
- Two runoff links,
- Seven transmission links (representing the conveyance of water from surface and groundwater supply sources to the demand sites) and
- Seven demand site return links representing the return flow from industrial and urban water use to the river, and
- Three return links from the wastewater treatment plants to the river.

The demand site return link simulates the return flows from the urban and industrial demand sites to the river. The return links from the wastewater treatment plants simulates the treated wastewater that returns to the river. The conveyance losses for the seven transmission links and all the return flow links were also defined. Of the 7 transmission links, four are from the aquifer to the urban, tanneries, and industrial demand site, and the agriculture catchment. One transmission link is from the river to the urban area and two transmission links are from wastewater treatment plants (WWTPs) to agriculture (as treated wastewater is used for irrigation).

In the case of the transmission link from the river to the urban area, a conveyance loss of 10 per cent was considered. Similarly, for the transmission links from WWTPs (5 mld and 36 mld) to the agriculture area, a transmission loss of 10 percent was considered. The conveyance loss for transmission from groundwater to the demand site was not considered.

Of the total 10 return links, three are from WWTP and one each from urban and industries to the main river. The remaining five return flow links are from the urban area, industries, and tanneries to WWTP. The treatment plant return-flow defines the fraction of the raw water, which goes back to the supply sources as treated water.

5.2.7. Input Data for the WEAP Programme

Table 19 provides details of the data sets that were used for setting up the WEAP system.

Table 19: Data sets used in the WEAP configuration

Particulars	Parameters	Time Period
Land Use Land Cover (KMA)	Four classes- Water bodies, Urban, Forest and Agriculture (Source: MODIS Land Cover Data)	2016
Land Use Land Cover (Kanpur Regional)	Four classes- Water bodies, Urban, Forest and Agriculture (Source: Copernicus Global Land Service Dynamic Land Cover Layers)	2019
DEM (Kanpur Regional)	Cartosat-1 DEM data	2015
Soil Data (KMA)	Three textural classes (Source: OpenLandMap)	2017
Soil Hydrological Group Data (Kanpur regional)	Three classes- B, C, and D (Source: Global Hydrologic Soil Groups HYSOGs250m, ORNL DAAC)	2017
Climate data	Rainfall, ET	2000-2019

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Streamflow gauges	Monthly discharge data	2000-2019
Runoff from the KMA and Kanpur Regional catchment	Estimated by developing the CN Grid	2000-2019
Urban water demand	Population, Water use rate, Consumption	2011
Irrigation water demand	Rainfall, Crop Coefficient, ET (using FAO CROPWAT)	Latest land use data
Tanneries	Production units, water use rate, consumption	2011
Industrial water demand	Production units, water use rates, consumption	2011
River water quality	BOD, Conductivity, pH, DO, COD, TC, FC, Nitrate, Nitrite	2000-2016
Quality of influent and the contaminant removal efficiency	BOD, COD, TC, FC, EC, BOD removal, COD removal, TC removal, FC removal, TDS removal	2010-2013
Groundwater quantity	Initial storage, groundwater recharge, withdrawal	2009
Groundwater quality	BOD, Conductivity, pH, Temperature	2011-2019

5.2.8. RUNNING THE WEAP MODEL FOR FUTURE WATER BALANCE OF KMA

Initially, WEAP was used to model three future water balance scenarios. The salient features of the three scenarios are as follows:

Scenario 1: Base Case Scenario

- It is the *business-as-usual* scenario where the human population continues to grow as per the past trend.
- The urban population is estimated to grow at 1.3 percent per annum
- The rainfall-runoff relationships, established on the basis of data of rainfall and runoff during 2000-2019, are assumed to remain the same for the regional and local (KMA) catchments.

Scenario 2: High Growth

- This scenario uses drivers that affect higher growth in demand for water for various consumptive uses in the basin.
- It is assumed that the human population will grow at a higher rate than under the *business-as-usual* scenario.
- The urban population is estimated to grow at 1.8 percent per annum.
- The rainfall-runoff relationship for the catchments remains the same as considered for the base case scenario.

Scenario 3: High Growth and Treatment Efficiency Improvement

- This scenario uses certain drivers/technologies which can improve the treatment efficiency of the wastewater treatment plants.
- The capacity of the treatment plants will remain the same for this scenario case

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- In this scenario, it is assumed that the wastewater treatment efficiency of the plants will be improved through the adoption of efficient technologies.
- It is assumed that the BOD removal efficiency of the 5 MLD, 36 MLD, and 130 MLD plants will be 60, 60, and 90 percent respectively.
- It is assumed that the COD removal efficiency of the 5 MLD, 36 MLD, and 130 MLD plants will be 50, 80, and 90 percent respectively.
- It is assumed that the Total Coliform removal efficiency of the 5 MLD, 36 MLD, and 130 MLD plants will be 84.7, 99.3, and 99.8 percent respectively.
- It is assumed that the Faecal Coliform removal efficiency of the 5 MLD, 36 MLD, and 130 MLD plants will be 77.3, 98.7, and 99.4 percent respectively.
- It is assumed that the TDS removal efficiency of the 5 MLD, 36 MLD, and 130 MLD plants will be 60, 50, and 60 percent respectively.
- The urban human population continues to grow at the same rate as in the case of the 'high growth scenario'.
- The rainfall-runoff relationship for the catchments remains the same as considered for the base case scenario.

5.2.9. RESULTS OF THE SCENARIO RUNS – IMPLICATIONS FOR THE BENCHMARK ASSESSMENT

Introduction

This section provides the results obtained from the WEAP model on the water availability, water demand and supply, river water quality, and wastewater quality in the Kanpur Metropolitan Area (KMA) for the present and the future years under different scenarios and compares them. The configuration of the WEAP model was set up for the period beginning 2009 and ending 2040. The year 2009 was taken as the base year (also referred to as 'current account') and the period 2010-2040 was considered for generating scenarios. Three scenarios, namely 'reference', 'high population growth', and 'high population growth and treatment efficiency improvement', were developed and the results obtained under them were compared. A brief description of each scenario is provided in *Table 20*.

Table 20: Scenarios developed for WEAP model of KMA

Scenario	Description
Reference	▪ It is the 'business-as-usual scenario' where the human population continues to grow as per the past trend, i.e., at 1.3% per annum. ▪ The three wastewater treatment plants (WWTPs) having a capacity of 5 MLD, 36 MLD, and 130 MLD are operating at a TDS removal efficiency of 10.6%, 24.1%, and 30% respectively. ▪ The BOD removal efficiency of the three plants is 35.1%, 54.9%, and 82.9% respectively. ▪ The Faecal Coliform (FC) removal efficiency of the three plants is 77.3%, 98.7%, and 99.4% respectively. ▪ The rainfall-runoff relationships, established based on data of rainfall and runoff during 2000-2019, are assumed to remain the same for the regional and local (KMA) catchments.
High Population Growth	▪ This scenario uses drivers that affect higher growth in water demand for consumptive use (domestic sector) in the KMA. ▪ It is assumed that the human population will grow at a higher rate than under the 'reference scenario'. ▪ The urban population is estimated to grow at 1.8% per annum.

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	▪ The three WWTPs are assumed to operate at the same removal efficiency for TDS, BOD, and FC as under the 'reference scenario'. ▪ The rainfall-runoff relationship for the catchments remains the same as considered for the 'reference scenario'.
High Population Growth and Treatment Efficiency Improvement	▪ This scenario uses certain drivers/technologies which can improve the treatment efficiency of the wastewater treatment plants (WWTPs). ▪ Though the capacity of the treatment plants will remain the same, it is assumed that the wastewater treatment efficiency of the plants will be improved through the adoption of efficient technologies. ▪ It is assumed that the TDS removal efficiency of the 5 MLD, 36 MLD, and 130 MLD plants will be 60%, 50%, and 60% respectively. ▪ It is assumed that the BOD removal efficiency of the 5 MLD, 36 MLD, and 130 MLD plants will be 60%, 60%, and 90% respectively. ▪ FC removal efficiency of all the plants is assumed to be the same as in the 'reference scenario'. ▪ The urban human population continues to grow at the same rate as in the case of the 'high population growth scenario'. ▪ The rainfall-runoff relationship for the catchments remains the same as considered for the 'reference scenario'.

Renewable Surface Water Availability in Kanpur Stretch of River Ganga

Figure 41 presents the annual renewable surface water availability in Kanpur stretch of river Ganga for the past, present, and future years during a 'reference scenario' (also called as 'business-as-usual scenario'). The estimated mean annual water availability for 32 years (2009-2040) is 81 billion cubic metres (BCM). The water availability will be the lowest (i.e., about 52 BCM) every eighth year. The highest renewable surface water availability for any year (a wet year) is about 136 billion cubic metres (BCM). During the same period, the estimated runoff contribution from the Kanpur Metropolitan Area (KMA) to the river Ganga varies from 99 MCM to 242 MCM per annum.

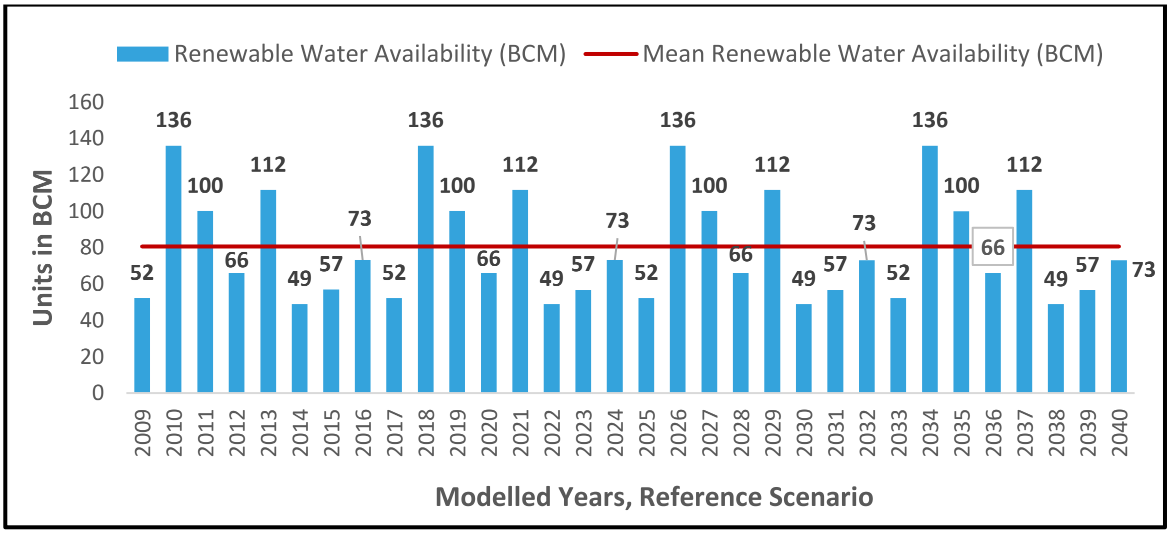

Figure 41: Renewable surface water availability in Kanpur stretch of river Ganga in 'reference scenario'

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Return Flows from KMA to River Ganga

Figure 42 presents the return flow from the domestic and industrial (including tanneries) sectors directly to the river and treated effluent from the wastewater treatment plants (WWTPs) under the 'reference' (population growth @ 1.3% per annum) and 'high population growth' (population growth @ 1.8% per annum) scenarios[3].

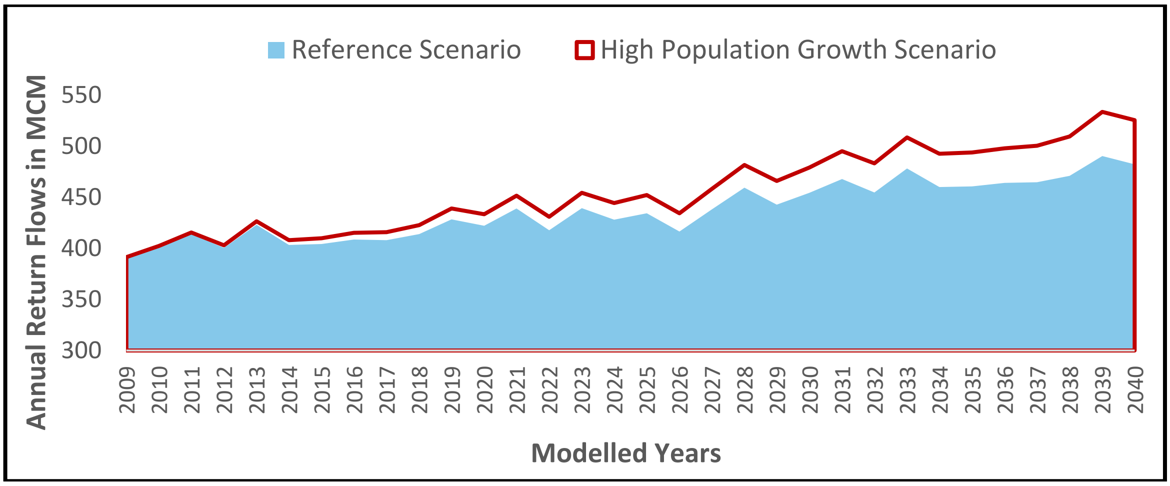

Figure 42: Return flow to river Ganga from the KMA under the 'reference scenario' and 'high population growth scenario'

The estimated mean annual return flow for 32 years (2009-2040) is 437 million cubic metres (MCM) under 'reference scenario' and 456 MCM under 'high population growth scenario'. Further, the results indicate that the annual return flows will increase by 44 MCM by the end of 2040 under the 'high population growth scenario' in comparison to the 'reference scenario'. Overall, the annual return flows to River Ganga in the former case will be about 526 MCM and in the latter about 482 MCM by 2040. About 86% of this increase will be the contribution of untreated sewage from the urban areas in the KMA.

Unmet Water Demand

The unmet water demand is the difference between the water supply requirement and the actual supply delivered (including conveyance losses) at the demand site. For this, urban, industrial (including tanneries), and agriculture sectors were considered. While, the urban sector taps both surface and groundwater, the other sectors fully depend on groundwater supplies.

By 2040, the annual unmet water demand at the aggregate level will be 74 MCM under the 'reference scenario' and 83 MCM under the 'high population growth scenario'[4]. During dry years, the annual unmet water demand would go up to 109 MCM under the 'reference scenario' and 115 MCM under the 'high population growth scenario' (refer to Figure 43). Though a minimum of 49 BCM of renewable water is available in the Kanpur Metropolitan Area (KMA) annually (refer to Figure 41), the annual water supply requirement which is a maximum of only 880 MCM under the 'reference scenario' is not delivered. One

[3] The assumed population growth rate under the 'high population growth scenario' and the 'high population growth and treatment efficiency improvement scenario' is the same. Hence, only the former case is presented.
[4] The unmet water demand under 'high population growth and treatment efficiency improvement scenario' is same as that of 'high population growth scenario'. Hence, only the latter case is presented.

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reason is that only about 278 MCM of the total water supply requirement will be met from the surface sources (River Ganga) by 2040 as per the 'reference scenario'.

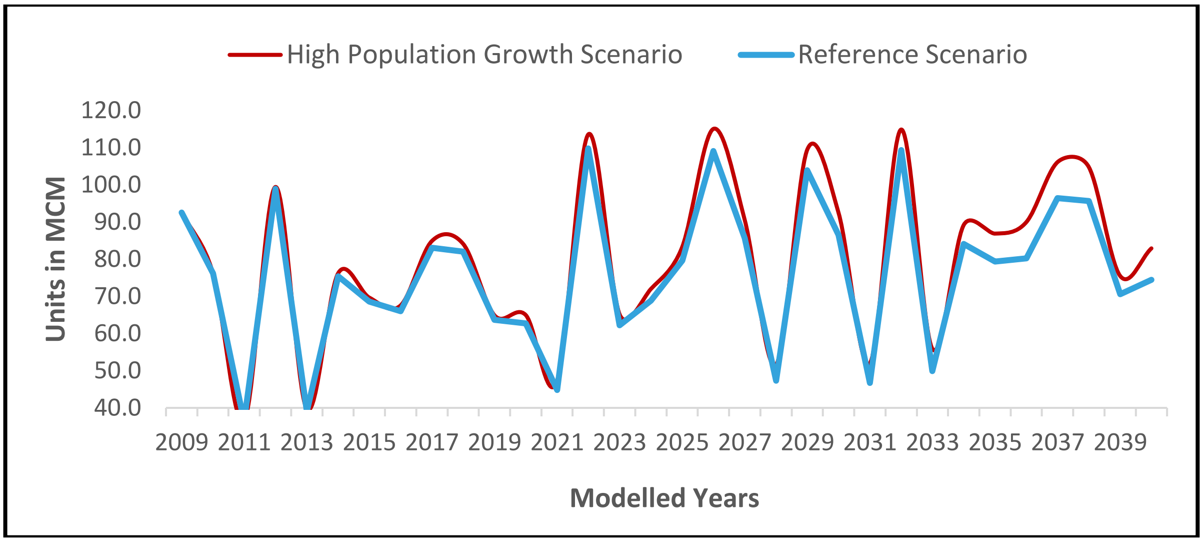

Figure 43: Unmet water demand at the aggregate level under different scenarios in KMA

Annual unmet water demand in urban, industrial (including tanneries), and agriculture sectors is provided in Figures 44a to 44d. Under both the scenarios ('reference' and 'high population growth'), agriculture has the largest annual unmet water demand, followed by industrial (other than tanneries), urban, and tannery sectors. However, the difference in the unmet water demand between the 'reference scenario' and 'high population growth scenario' is highest for the urban (municipal) sector. By 2040, the unmet water demand gap will increase by 5.9 MCM in urban sector, 1.3 MCM in agriculture sector, 1.1 MCM for industries (other than tanneries) and 0.2 MCM for tanneries.

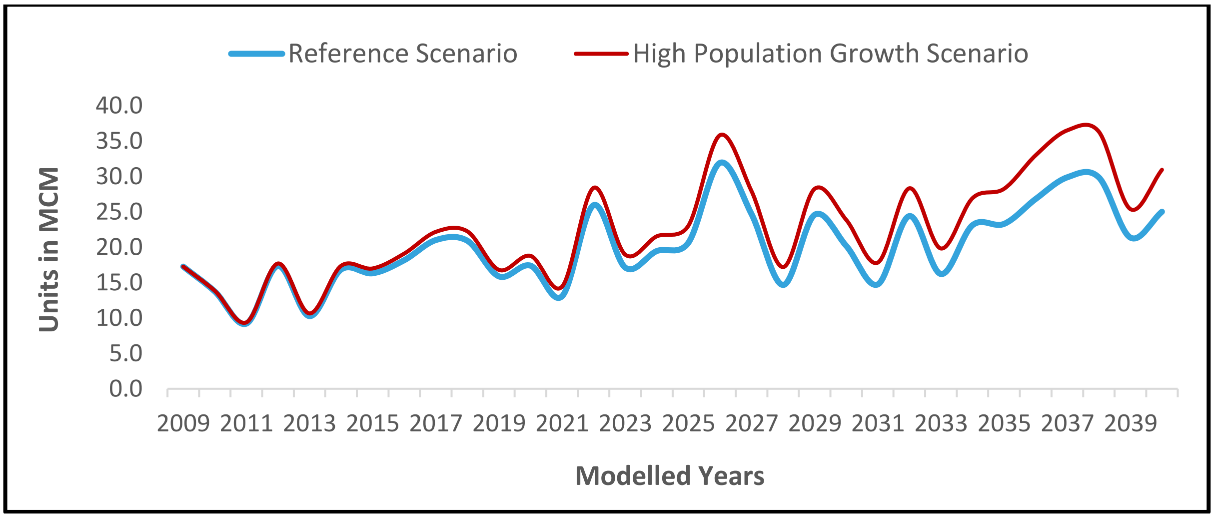

Figure 44: Unmet water demand in the urban sector under different scenarios in KMA

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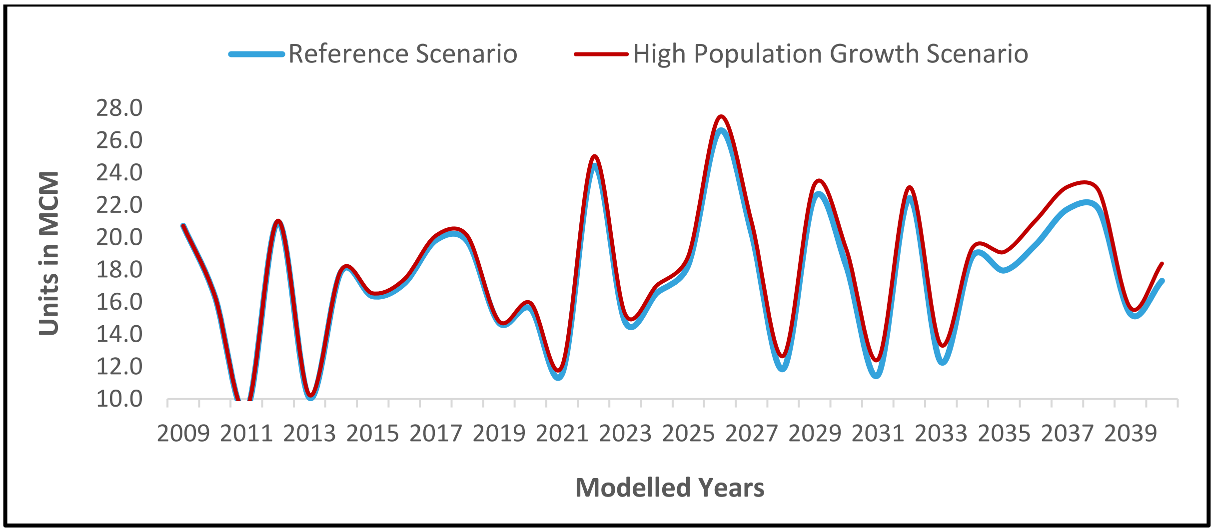

Figure 45: Unmet water demand in the industrial (other than tanneries) sector under different scenarios in KMA

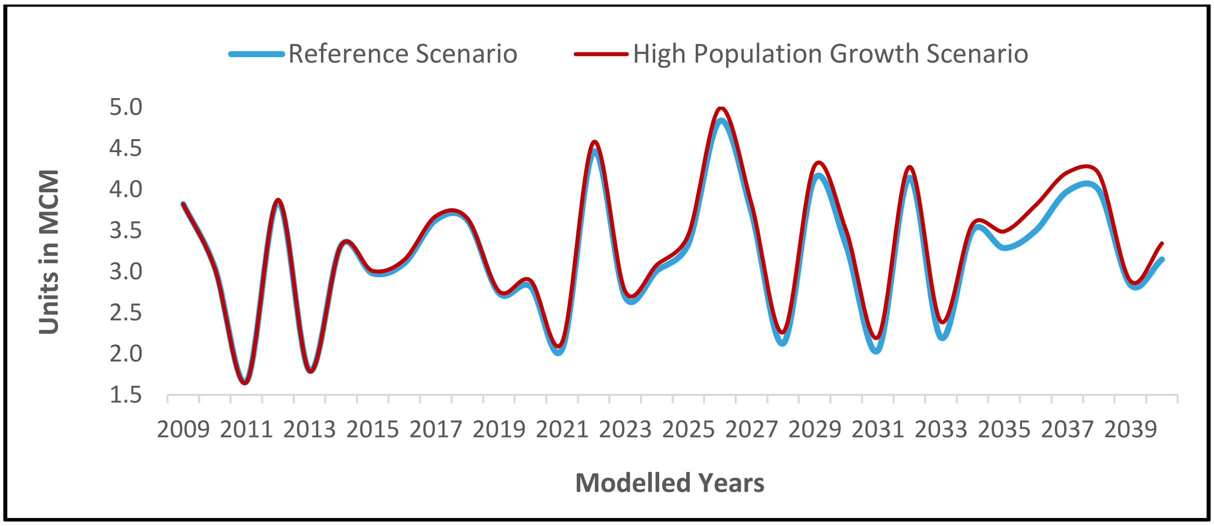

Figure 46: Unmet water demand in the tannery sector under different scenarios in KMA

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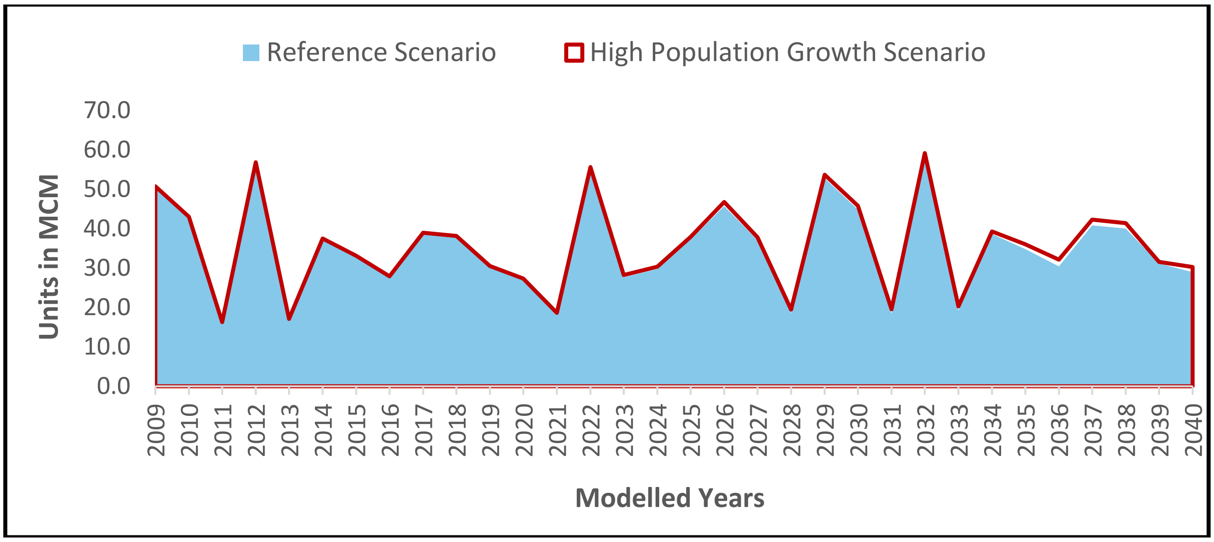

Figure 47: Unmet water demand in the agriculture sector under different scenarios in KMA

Pollutant Removal Efficiency of WWTPs in the KMA

The pollutant removal efficiency of all the WWTPs under different scenarios are summarised in Table 21.

Table 21: Pollutant removal efficiency of WWTPs under different scenarios

Parameter	WWTP	Removal efficiency (in %)			
		Base year (2009) under all scenarios	*Modelled years (2010-2040)*		
			Reference scenario	*High population growth scenario (HG)*	*HG and treatment efficiency improvement scenario'*
TDS	5 MLD	12.0	10.6	10.6	60.0
	36 MLD	37.0	24.1	24.1	50.0
	130 MLD	42.3	30.0	30.0	60.0
BOD	5 MLD	44.2	35.1	35.1	60.0
	36 MLD	51.9	54.9	54.9	60.0
	130 MLD	81.7	82.9	82.9	90.0
FC	5 MLD	74.8	77.3	77.3	77.3
	36 MLD	97.7	98.7	98.7	98.7
	130 MLD	99.3	99.4	99.4	99.4

Reference Scenario

Under the reference scenario, the TDS removal efficiency of all the WWTPs is below 50%. For the base year (2009), 130 MLD WWTP has the highest efficiency (42.3%) followed by 36 MLD (37%) and 5 MLD (12%) WWTPs. For 2010-40, it will be 10.6% for 5 MLD, 24.1% for 36 MLD, and 30% for 130 MLD WWTPs. Thus, treated wastewater discharged in River Ganga has a high salinity.

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Similarly, the BOD removal efficiency for the base year (2009) is highest for 130 MLD WWTP (81.7%), followed by 36 MLD (51.9%) and 5 MLD (44.2) WWTPs. Thus, the BOD removal efficiency of the 5 MLD WWTP is almost half of the 130 MLD WWTP. For 2010-40, it will be 35.1% for 5 MLD, 54.9% for 36 MLD, and 82.9% for 130 MLD WWTP.

For the base year (2009), the FC removal efficiency was above 95% for both the 36 MLD and 130 MLD WWTPs. For 5 MLD WWTP, it is only 74.8%. For 2010-40, it will be 77.3% for 5 MLD, 98.7% for 36 MLD, and 99.4% for 130 MLD WWTPs.

High Population Growth Scenario

Under the 'high population growth scenario', the pollutant removal efficiency of the WWTPs for the base year as well for 2010-40 will remain the same as that of the 'reference scenario'.

High Population Growth and Treatment Efficiency Improvement Scenario

Under the 'high population growth and treatment efficiency improvement scenario', though the pollutant efficiency of the WWTPs for the base year (2009) will remain the same as that of the 'reference scenario' and 'high population growth scenario', it will improve for 2010-40. The extent to which the removal efficiency can be improved for any technology is based on the optimal level of treatment that can be achieved with each such technology in different environmental conditions. The 5 MLD WWTP uses Upflow Anaerobic Sludge Blanket (UASB) reactor, 36 MLD uses UASB reactor and polishing unit, and the 130 MLD uses Activated Sludge Process (ASP) for treating wastewater.

Considering the optimal performance of each of such technology in different environmental conditions, the TDS removal efficiency was enhanced (in the WEAP model) to 60% for 5 MLD and 130 MLD, and 50% for 36 MLD WWTPs for 2010-40. For BOD, it was enhanced to 60% for 5 MLD and 36 MLD, and 90% for 130 MLD WWTP. And for the FC, it was considered as same as that of the 'reference scenario' for 2010-40.

Influent and Effluent Quality for WWTP: 5 MLD

The quality of influent and effluent for the 5 MLD wastewater treatment plant (WWTP) under the different scenarios is presented in Figures 5a to 5f. This WWTP receives a mix of domestic sewage and industrial (other than tanneries) wastewater. Total Dissolved Solids (TDS), Biological Oxygen Demand (BOD), and Faecal Coliforms (FC) were analysed.

For the 32 years (2009-2040), the monthly average TDS concentration in the influent will be highest in August (2,002 mg/l) for the 'reference scenario', and in March (1,517 mg/l) for the other two scenarios[5]. The lowest would be in July for all the scenarios. Overall, in 8 out of the 12 months, the value of monthly average TDS will be higher during the 'high population growth scenario' (refer to Figure 48).

[5] The value of TDS, BOD, and FC in the influent to 5MLD WWTP under 'high population growth scenario' and 'high population growth and treatment efficiency improvement scenario' is the same.

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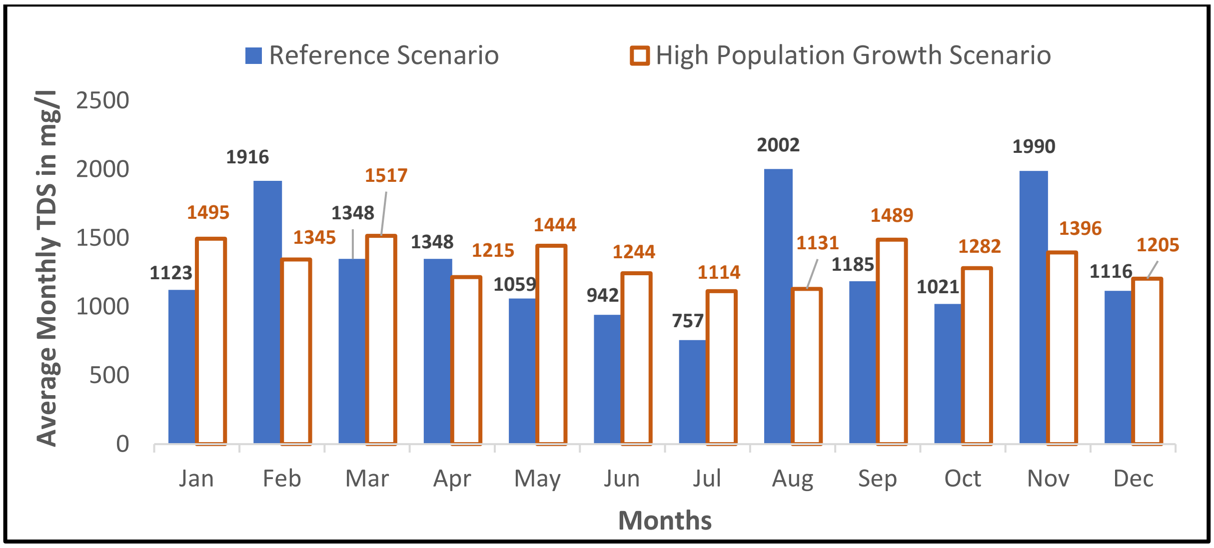

Figure 48: TDS concentrations in influent to 5 MLD WWTP in KMA under different scenarios

Though the TDS removal efficiency considered for the 5 MLD plant is low under all the scenarios, there will be a marked improvement (decrease) in the value of monthly average TDS under the 'high population growth and treatment efficiency improvement scenario' in comparison to the other two scenarios (except for the four months in the reference scenario) (refer to Figure 49). The monthly average value of TDS in the effluent will be highest in August (1,915 mg/l) for the 'reference scenario', in March (1,432 mg/l) for the 'high population growth scenario', and in January (1,147 mg/l) for the 'high population growth and treatment efficiency improvement scenario'. For the latter, the lowest will be in June (847 mg/l) and in July for the other two scenarios (724 mg/l in 'reference' and 1,067 mg/l in 'high population growth' scenarios).

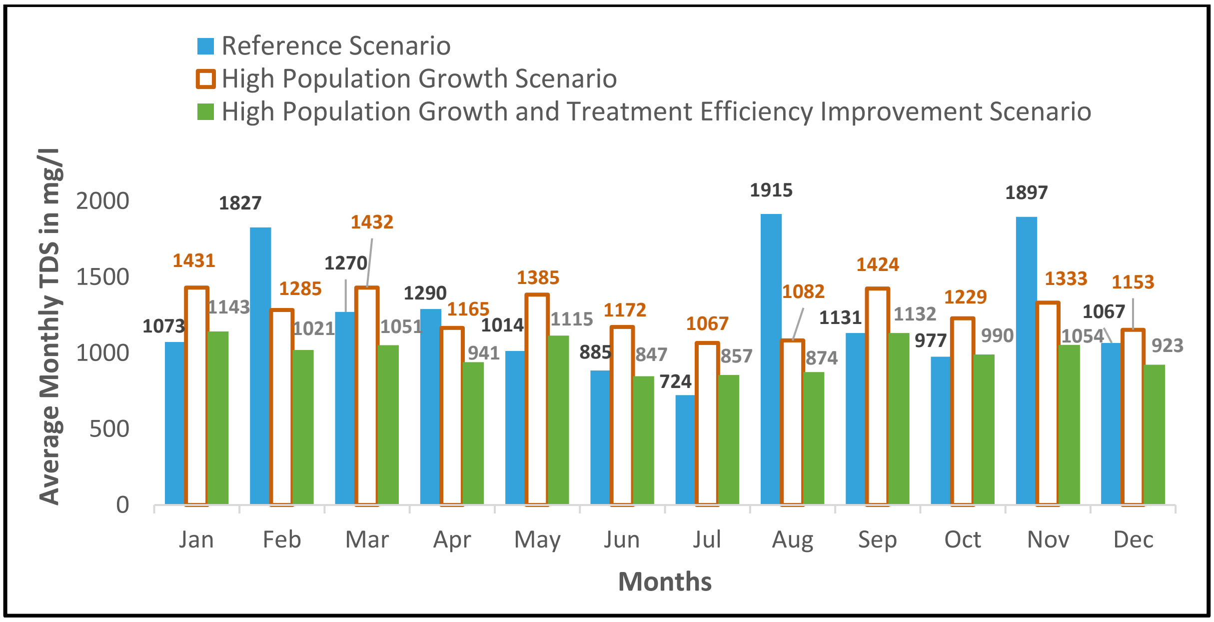

Figure 49: TDS concentrations in effluent from 5 MLD WWTP in KMA under different scenarios

Concerning BOD, the monthly average values in the influent will be higher in the 'reference scenario' as compared to the other two scenarios in all the months for 2009-2040. Thus, though the municipal usage of water will be more during the 'high population growth scenario', there will also be higher dilution of BOD

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(which is an indicator of organic pollution) in the sewage generated from the urban area. Overall, the monthly average BOD concentration in the influent will be highest in June and lowest in July for all the scenarios (refer to Figure 50).

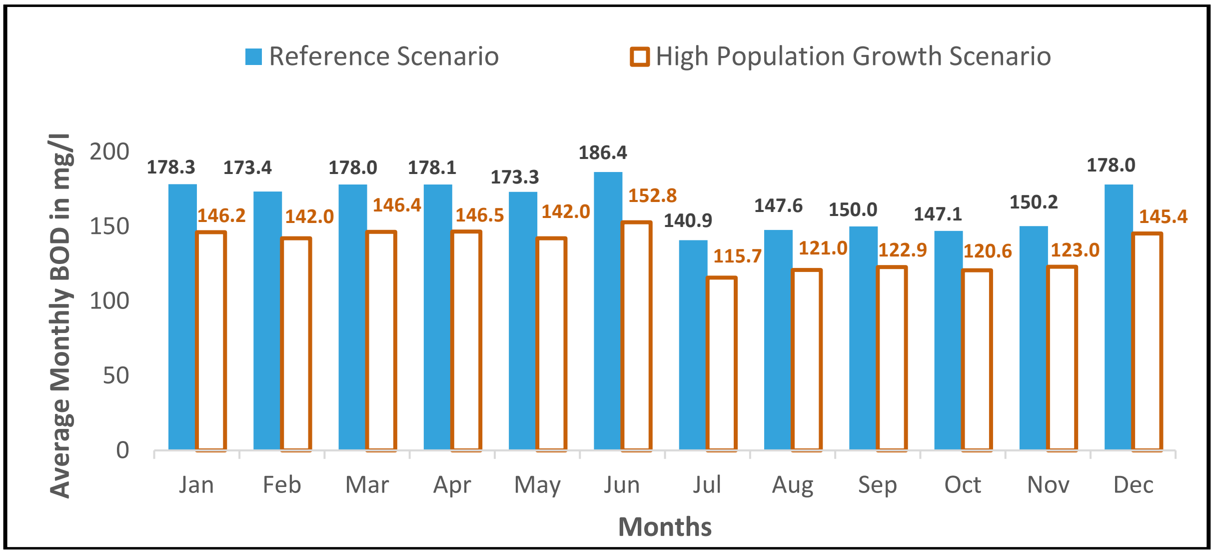

Figure 50: BOD concentrations in influent to 5 MLD WWTP in KMA under different scenarios

As was the case with the TDS, there will be a marked improvement in the value of monthly average BOD under the 'high population growth and treatment efficiency improvement scenario' in comparison to the other two scenarios. The monthly average value of BOD in the effluent will be highest in April and lowest in July for all the scenarios (refer to Figure 51).

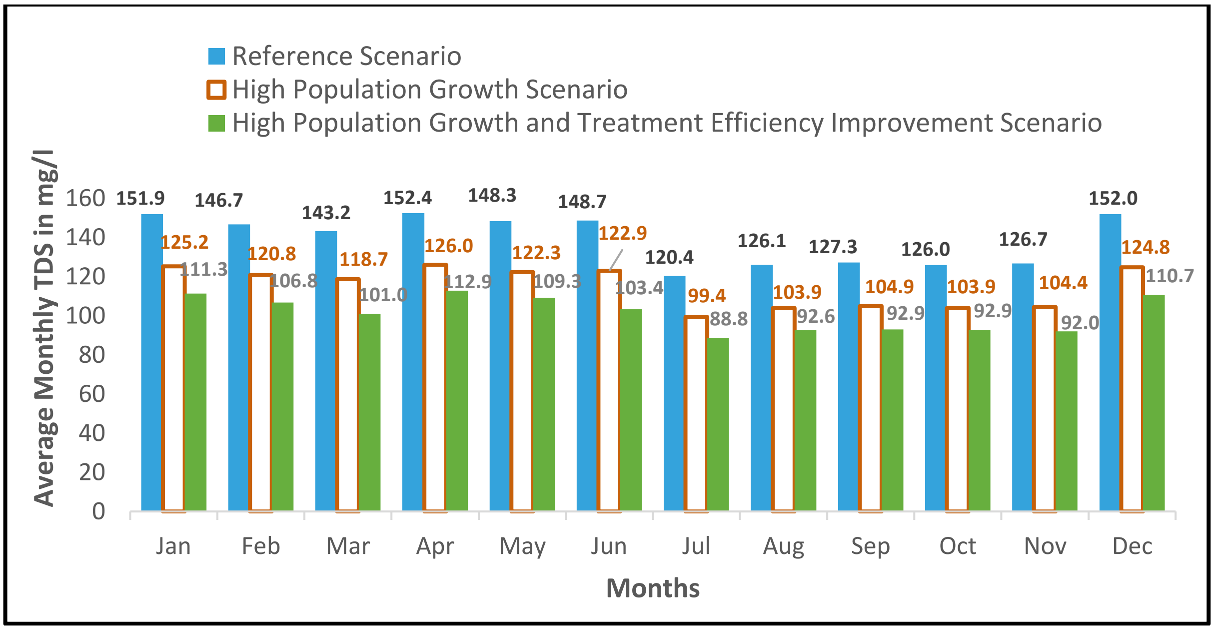

Figure 51: BOD concentrations in influent to 5 MLD WWTP in KMA under different scenarios

The monthly average count of FC in the influent is higher for 'high population growth scenario' and 'high population growth and treatment efficiency improvement scenario' than the 'reference scenario'. For the

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32 years (2009-2040), the monthly average FC count in the influent will be highest in November and lowest in August for all the three scenarios (refer to Figure 52).

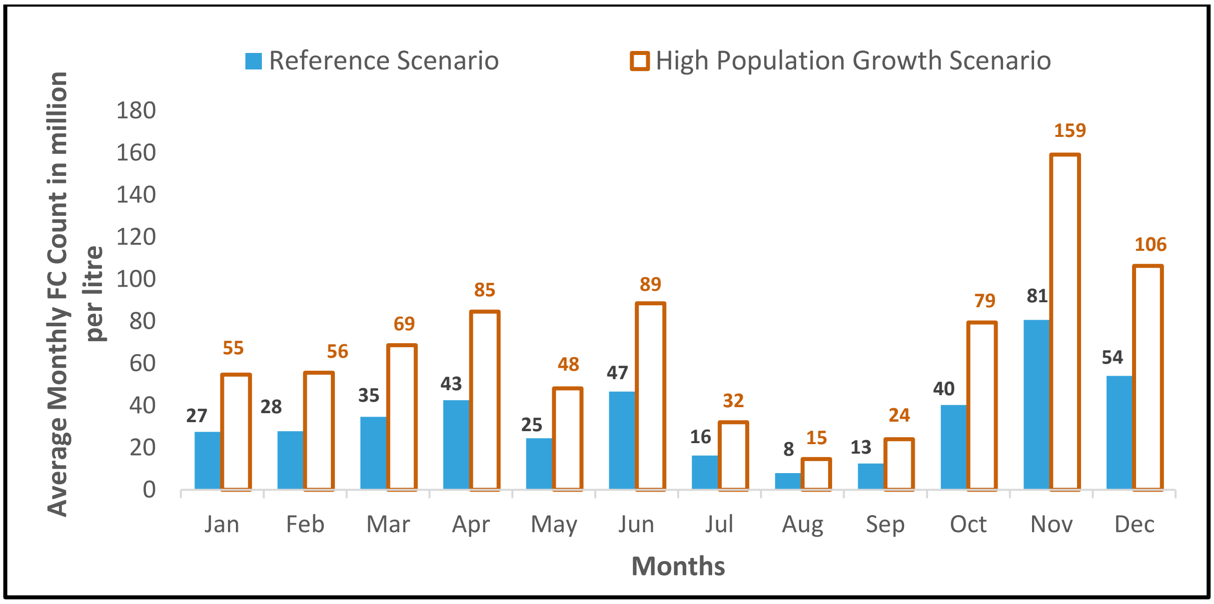

Figure 52: FC counts in influent to 5 MLD WWTP in KMA under different scenarios

Unlike, the TDS and BOD, there will be no improvement in the effluent quality with respect to FC count under the 'high population growth and treatment efficiency improvement scenario' (refer to *Figure 53*) in comparison to the 'reference scenario'. As the WTP is already operating on a high FC removal efficiency (77.3%) under the reference scenario, there is a low scope to improve it further with the existing technology (i.e., UASB) used in this WTP. Nevertheless, the monthly average FC count will be highest during November and lowest in August under all the scenarios.

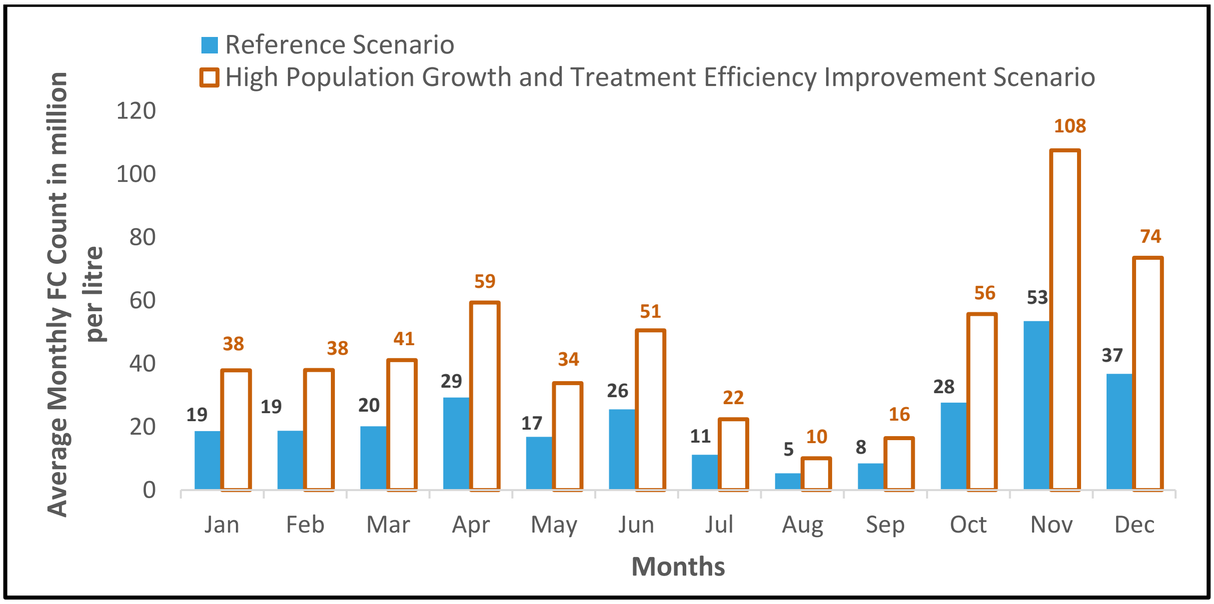

Figure 53: FC counts in effluent from 5 MLD WWTP in KMA under different scenarios

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Influent and Effluent Quality for WWTP: 36 MLD

The quality of influent and effluent for the 36 MLD wastewater treatment plant (WWTP) under the different scenarios is presented in Figures 6a to 6d. This WWTP receives wastewater from the tanneries. The value of TDS, BOD, and FC in the influent are substantially higher than the 5 MLD and 130 MLD WWTPs.

For the 32 years (2009-2040), the monthly average TDS concentration in the influent will be highest in May (5,673 mg/l) for the 'reference scenario', and in August (5,846 mg/l) for the other two scenarios[6]. The lowest would be in December (3,182 mg/l) for the 'reference scenario' and in July (3422 mg/l) for the other two scenarios. Overall, in 10 out of the 12 months, the value of monthly average TDS will be higher during the 'high population growth scenario' (refer to Figure 54).

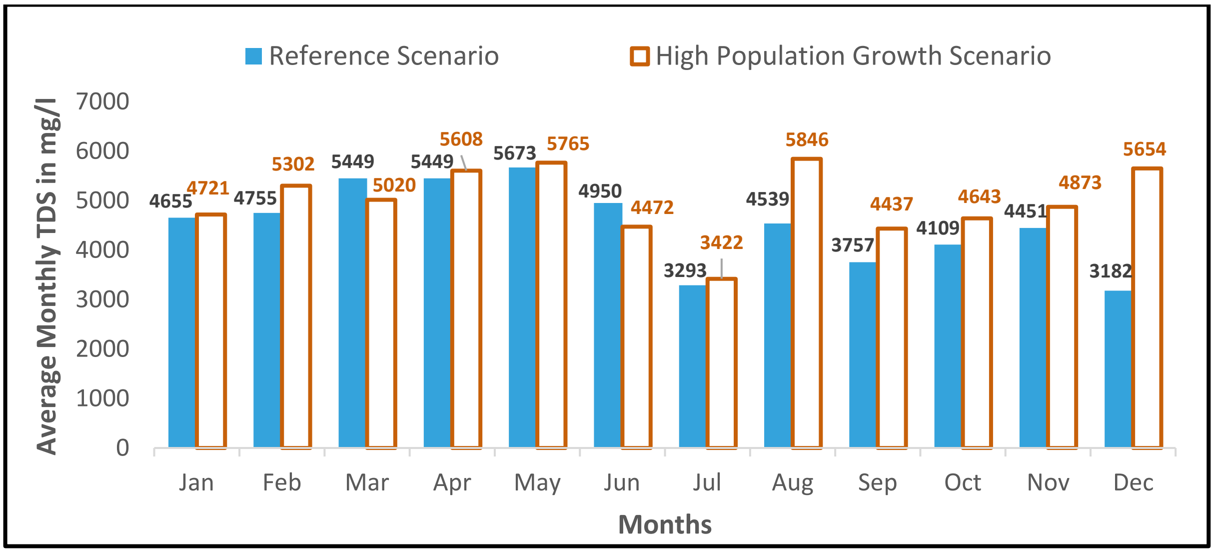

Figure 54: TDS concentrations in influent to 36 MLD WWTP in KMA under different scenarios

There will be a decrease in the value of monthly average TDS of effluent under the 'high population growth and treatment efficiency improvement scenario' in comparison to the other two scenarios (except for the five months in the reference scenario) (refer to Figure 55). The monthly average value of TDS in the effluent will be highest in May for the 'reference scenario' (5,213 mg/l). Whereas, for the 'high population growth scenario' and the 'high population growth and treatment efficiency improvement scenario', it will be in August (5,362 mg/l and 4,861 mg/l respectively). The lowest value will be in December (2,919 mg/l) for the 'reference scenario' and in July for other two scenarios (3,141 mg/l and 2,853 mg/l respectively).

[6] The value of TDS, BOD, and FC in the influent to 36 MLD WWTP under 'high population growth scenario' and 'high population growth and treatment efficiency improvement scenario' is the same.

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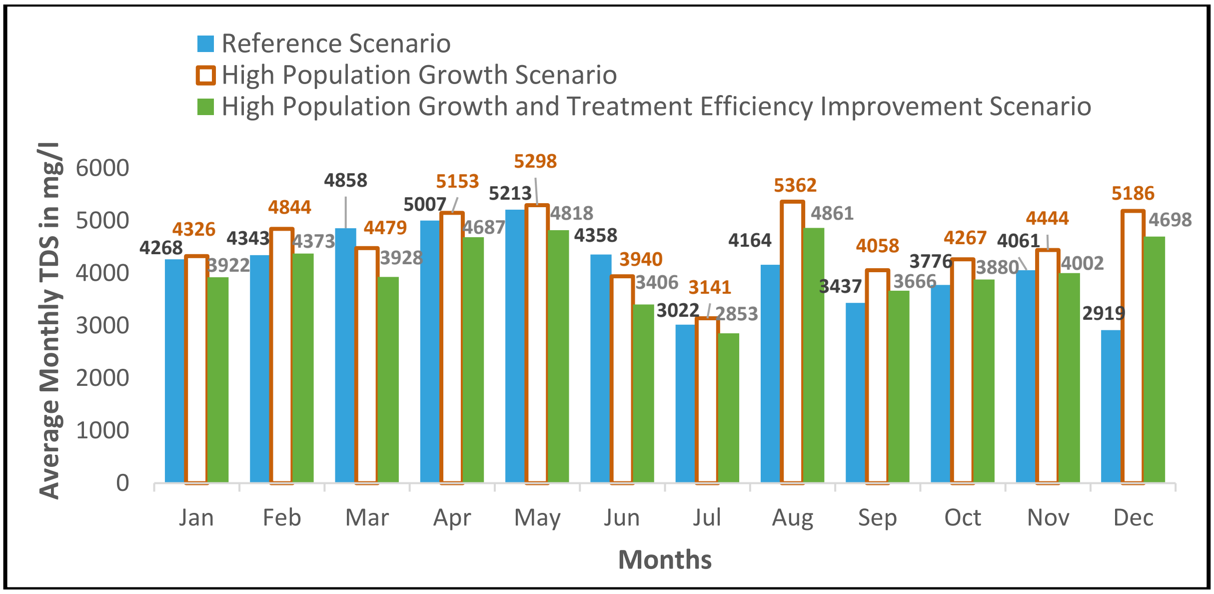

Figure 55: TDS concentrations in effluent from 36 MLD WWTP in KMA under different scenarios

The monthly average value of BOD for 2009-2040 is same for all the scenarios. As this WWTP receives wastewater mostly from the tanneries and the scenarios are built considering the potential changes in sewage received from the urban area, no difference in the BOD values were observed in the influent to this plant for different scenarios. Overall, the monthly average BOD value in the influent will be highest in May (587.7 mg/l) and lowest in July (355.4 mg/l).

As the case of TDS, there will be an improvement in the value of monthly average BOD under the 'high population growth and treatment efficiency improvement scenario' in comparison to the other two scenarios. The monthly average value of BOD in the effluent will be highest in May and lowest in July for all the scenarios (refer to Figure 56).

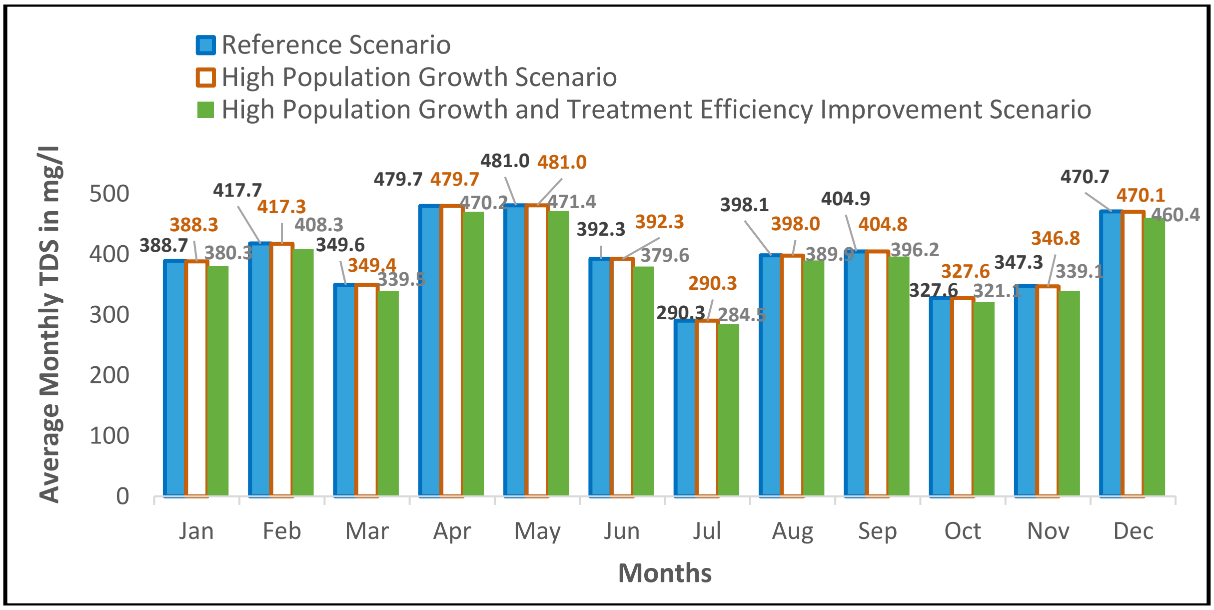

Figure 56: BOD concentrations in effluent from 36 MLD WWTP in KMA under different scenarios

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As in the case of BOD values, the monthly average count of FC for 2009-2040 is same for all the scenarios. For the 32 years (2009-2040), the monthly average FC count in the influent will be highest in April (12,464 million per litre) and lowest in June (1,793 million per litre) for the three scenarios.

There is only a marginal improvement in biological quality of the effluent under the 'high population growth and treatment efficiency improvement scenario' in comparison to the 'reference scenario' (refer to Figure 57). This is because no scope exists to increase the present FC removal efficiency (which is 98.7%) of the existing technologies (i.e., UASB reactor and the polishing unit) used in the 36 MLD WWTP. Nevertheless, the monthly average FC count will be highest during April and lowest in June for all the scenarios.

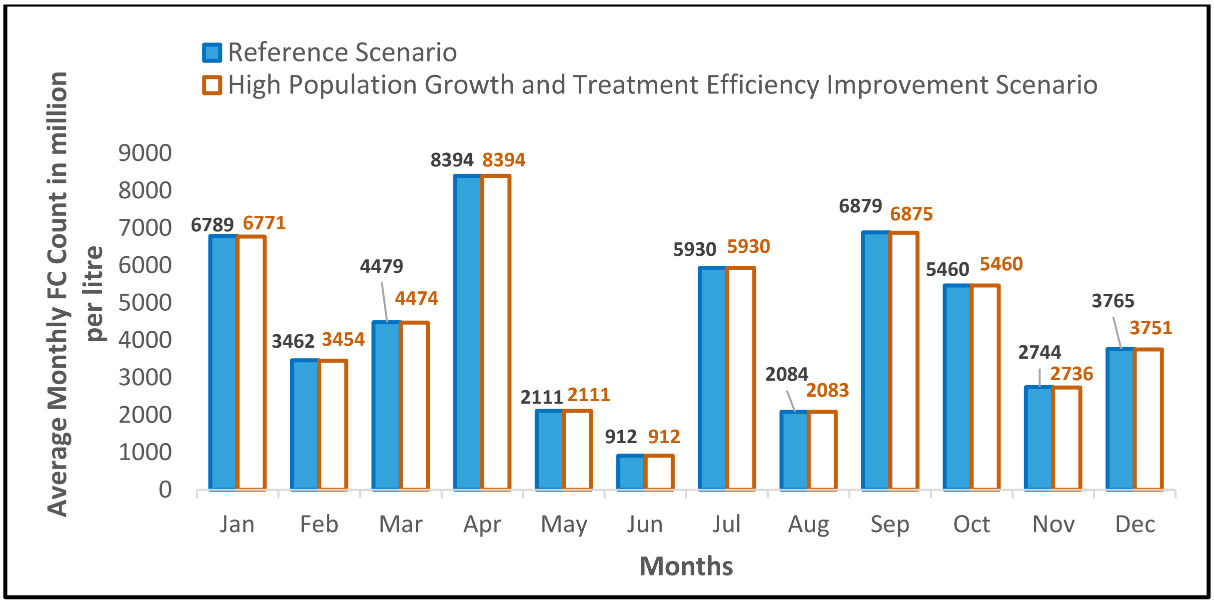

Figure 57: FC counts in effluent from 36 MLD WWTP in KMA under different scenarios

Influent and Effluent Quality for WWTP: 130 MLD

The quality of influent and effluent for the 130 MLD wastewater treatment plant (WWTP) under the different scenarios is presented in Figures 7a to 7d. As was the case with the 5 MLD WWTP, this WWTP receives a mix of domestic sewage and industrial (other than tanneries) wastewater.

For the 32 years (2009-2040), the monthly average TDS concentration in the influent will be highest in August (3,034 mg/l) for the 'reference scenario', and in March (1,907 mg/l) for the other two scenarios[7]. It will be lowest in July for all the scenarios. This trend is in line with the 5 MLD WWTP. Overall, in half of the months in a year, the value of monthly average TDS will be higher during the 'high population growth scenario' (refer to Figure 58).

[7] The value of TDS, BOD, and FC in the influent to 36 MLD WWTP under 'high population growth scenario' and 'high population growth and treatment efficiency improvement scenario' is the same.

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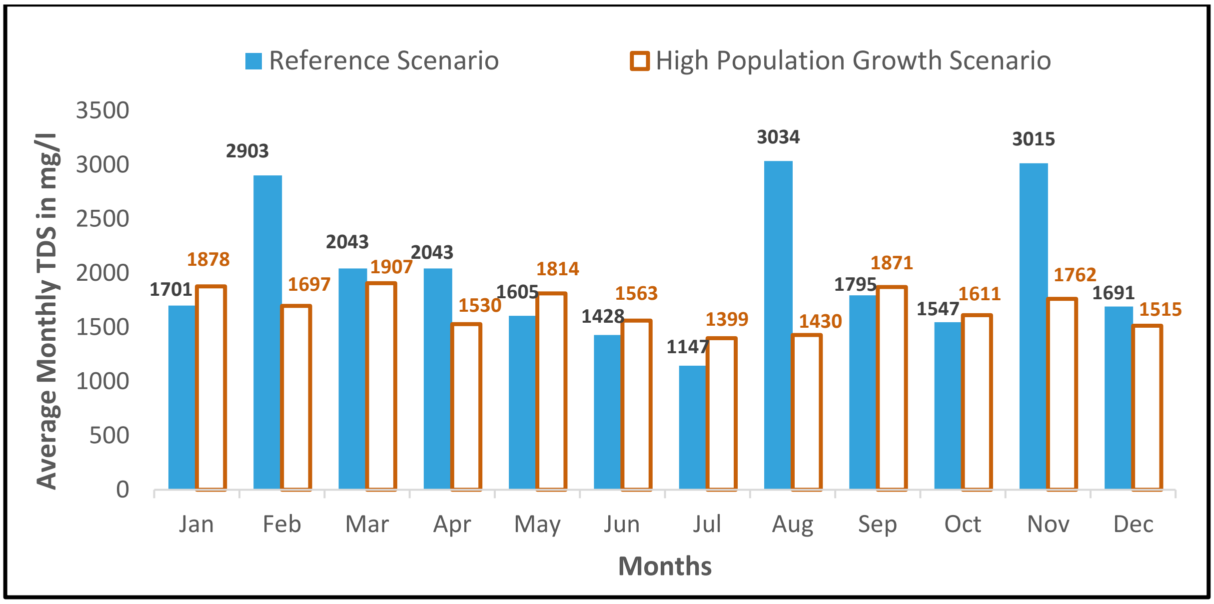

Figure 58: TDS concentrations in influent to 130 MLD WWTP in KMA under different scenarios

There will be a marked improvement (decrease) in the value of monthly average TDS under the 'high population growth and treatment efficiency improvement scenario' in comparison to the other two scenarios (refer to Figure 59). The monthly average value of TDS in the effluent will be highest in August for the 'reference scenario' (2,375 mg/l). The lowest would be in July (899 mg/l). Whereas, for the 'high population growth scenario' the highest will be in January (1,480 mg/l) and lowest in July (1,110 mg/l). For the 'high population growth and treatment efficiency improvement scenario', the highest will be in January (1,101 mg/l) and lowest in June (727 mg/l).

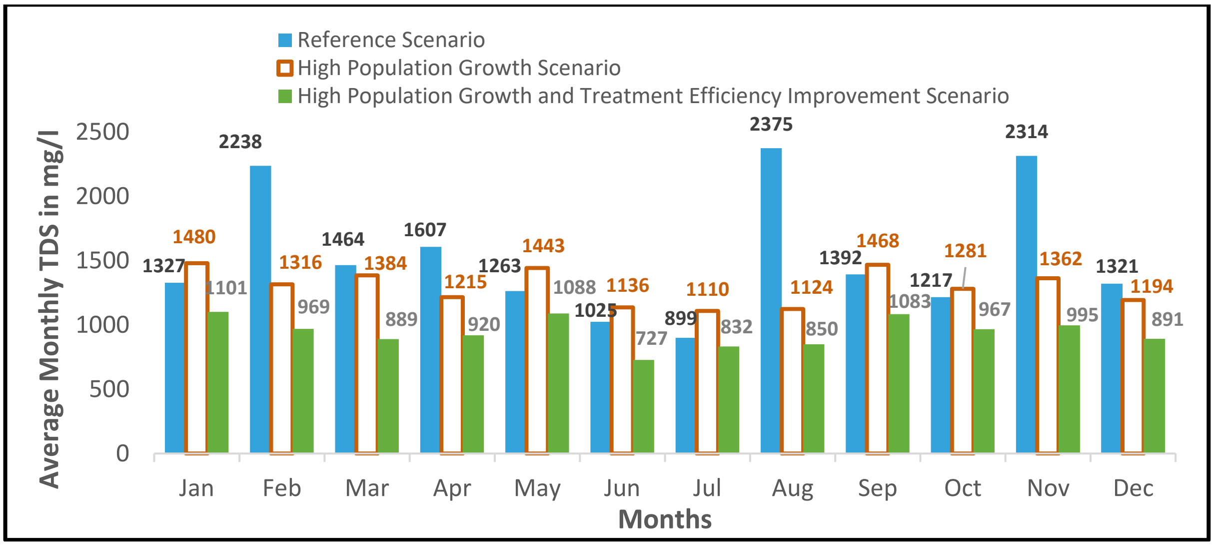

Figure 59: TDS concentrations in effluent from 130 MLD WWTP in KMA under different scenarios

The monthly average value of BOD in the influent for 2009-2040 is same for all the scenarios. As this WWTP receives a high proportion of wastewater from the industries and the scenarios are built considering the potential changes in sewage received from the urban area, no difference in the BOD values were observed

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in the influent for different scenarios. Overall, the monthly average BOD value in the influent will be highest in June (388.4 mg/l) and lowest in July (293.5 mg/l). This trend is in line with the 5 MLD WWTP.

Like in the case of TDS, there will be a marked improvement in the value of monthly average BOD under the 'high population growth and treatment efficiency improvement scenario' in comparison to the other two scenarios. The monthly average value of BOD in the effluent will be highest in April and lowest in March for all the scenarios (refer to Figure 60).

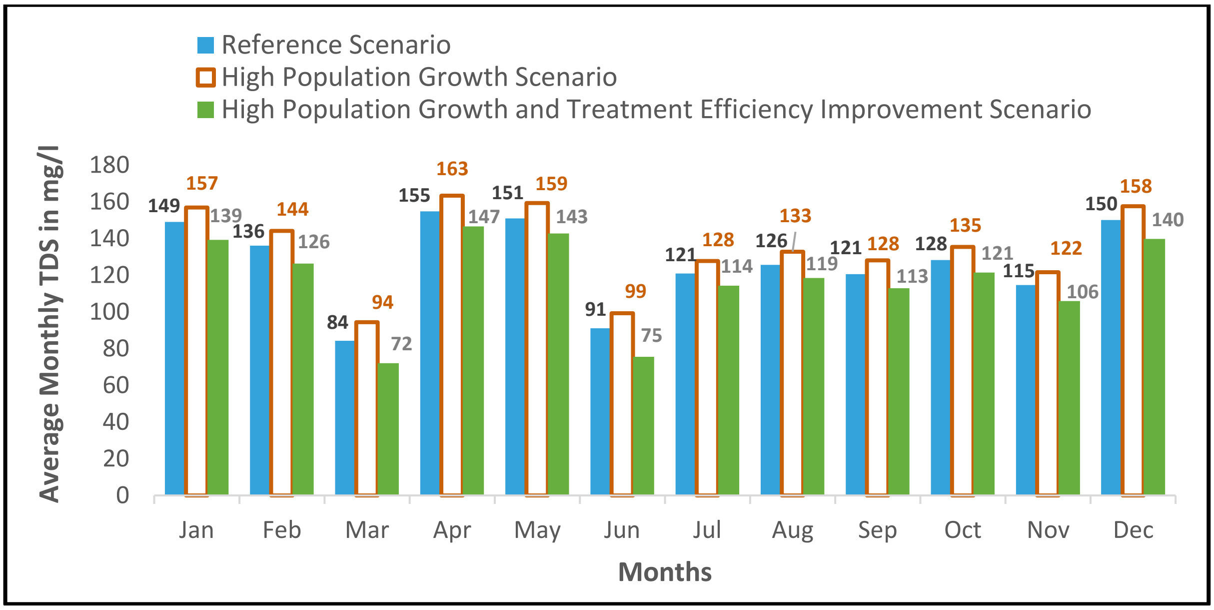

Figure 60: BOD concentrations in effluent from 130 MLD WWTP in KMA under different scenarios

Like in the case of BOD, the monthly average count of FC for 2009-2040 is same for all the scenarios. For the 32 years (2009-2040), the monthly average FC count in the influent will be highest in November (2,688 million per litre) and lowest in August (262 million per litre) for the three scenarios. This trend is in line with the 5 MLD WWTP.

Unlike, the TDS and BOD, there will be no improvement in the effluent quality with respect to FC count under the 'high population growth and treatment efficiency improvement scenario' (refer to Figure 61). As the WTP is already operating on a high FC removal efficiency (99.4%) under the reference scenario, there is a low scope to improve it further with the existing technology (i.e., ASP) used in this WTP. Nevertheless, the monthly average FC count will be highest during November and lowest in August for all the scenarios.

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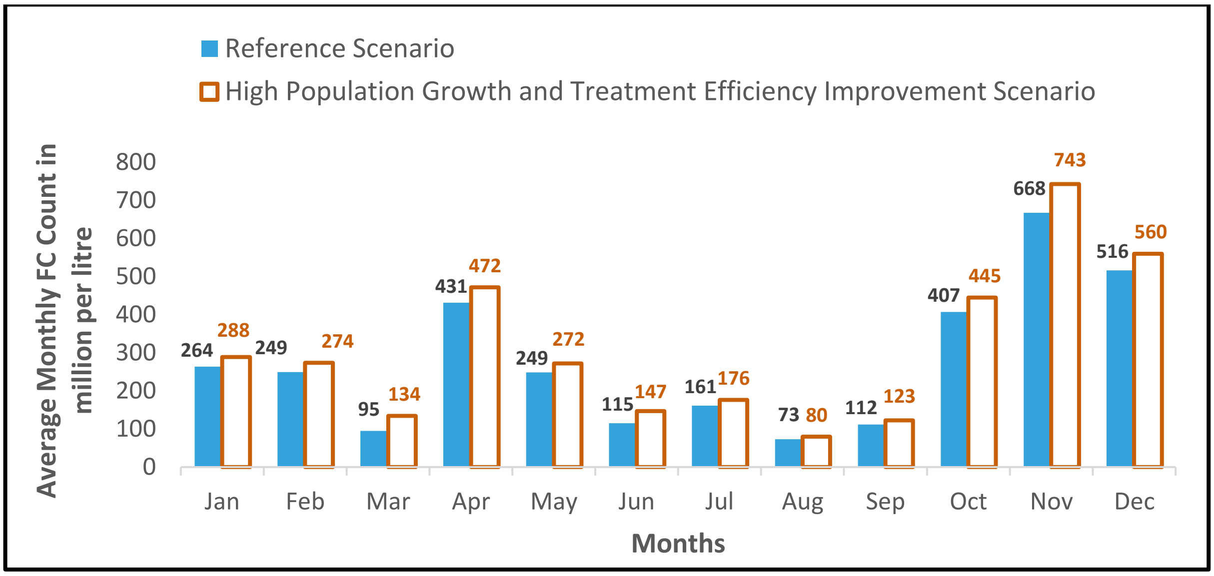

Figure 61: FC counts in effluent from 130 MLD WWTP in KMA under different scenarios

River Water Quality

The river water quality was compared for the two locations. One corresponds to the point where the untreated wastewater from the KMA is discharged to river Ganga (referred to as midstream), and the other where the treated wastewater is released in river Ganga (referred to as downstream).

Under all three scenarios[8], there is an increase in the monthly average value of TDS for 2009-40 between the midstream and the downstream points on river Ganga, indicating a slight increase in the salinity (refer to Figure 62 and *Figure 63*). The difference is noticeable during Jan-May (winter and summer months). Further, only in half of the months in a year, the monthly average value of TDS for 2009-40 is marginally higher for the 'high population growth scenario' in comparison to the 'reference scenario'.

[8] It must be noted that for the point after the release of wastewater from the KMA (midstream), the TDS, BOD and FC values under 'high population growth' and 'high population growth and treatment efficiency improvement' scenarios are the same. Hence only one of these scenarios is presented along with the reference scenario.

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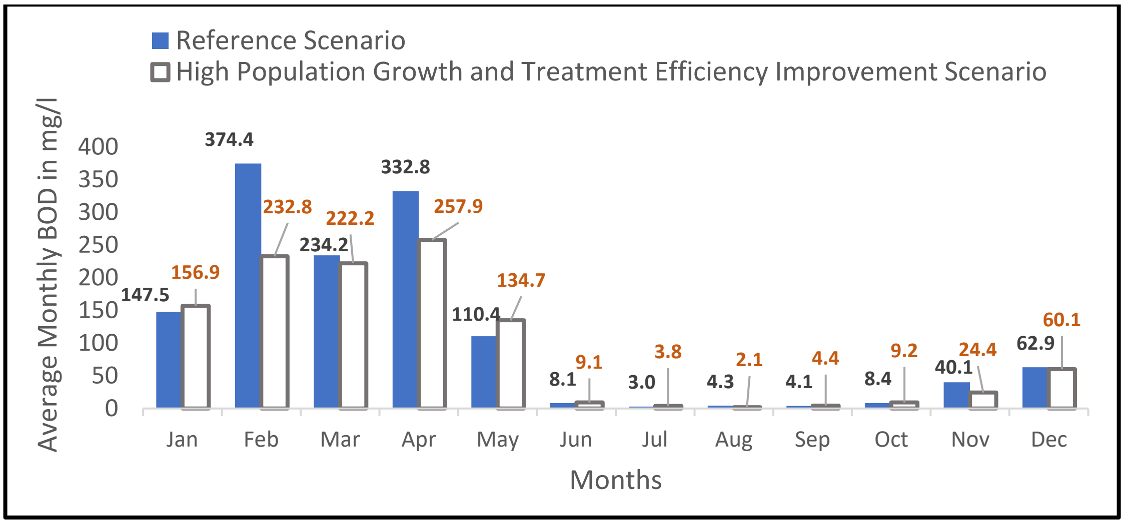

Figure 62: TDS concentrations at a point on River Ganga after the release of wastewater from the KMA, monthly average for 2009-2040

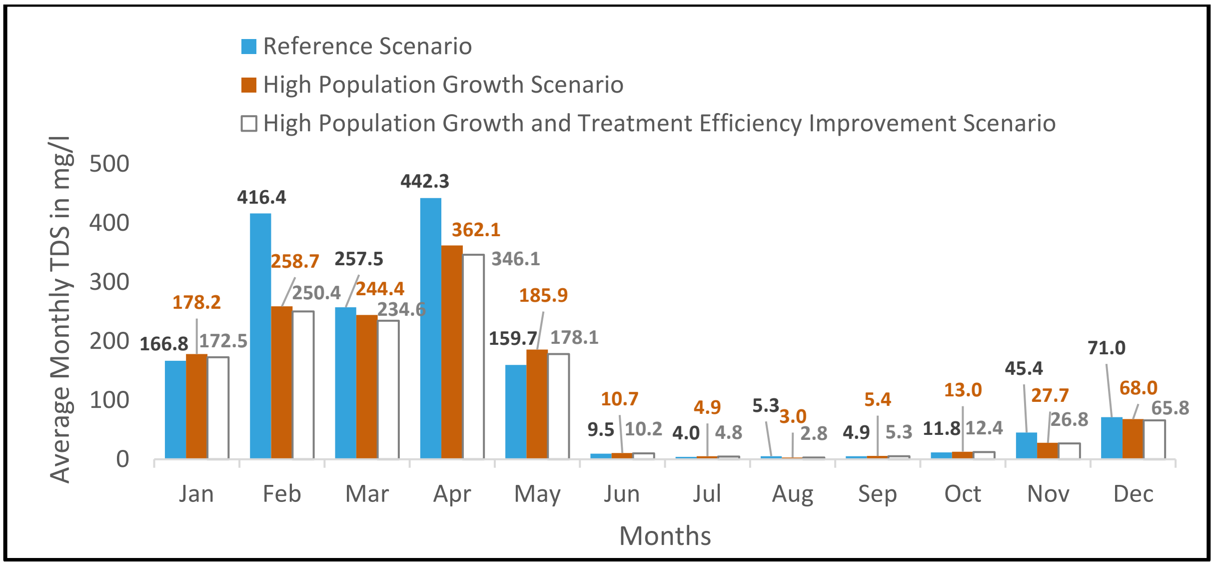

Figure 63: TDS concentrations at a point on River Ganga after the release of treated effluent from the WWTPs and the agricultural runoff, monthly average for 2009-2040

However, for the 2009-40, the monthly average value of BOD will reduce from the midstream to the downstream point on river Ganga under all the scenarios (refer to Figure 64 and Figure 65). Nevertheless, in all the scenarios, the monthly average value of BOD for 2009-40 is marginally higher for the 'high population growth' and 'high population growth and treatment efficiency improvement' scenarios in comparison to the reference scenario.

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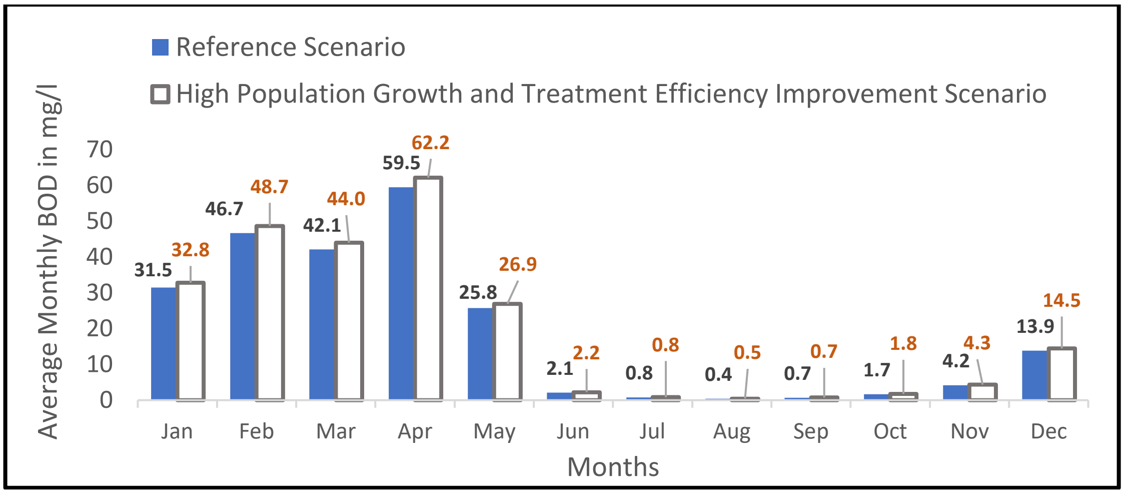

Figure 64: BOD concentrations at a point on River Ganga after the release of wastewater from the KMA, monthly average for 2009-2040

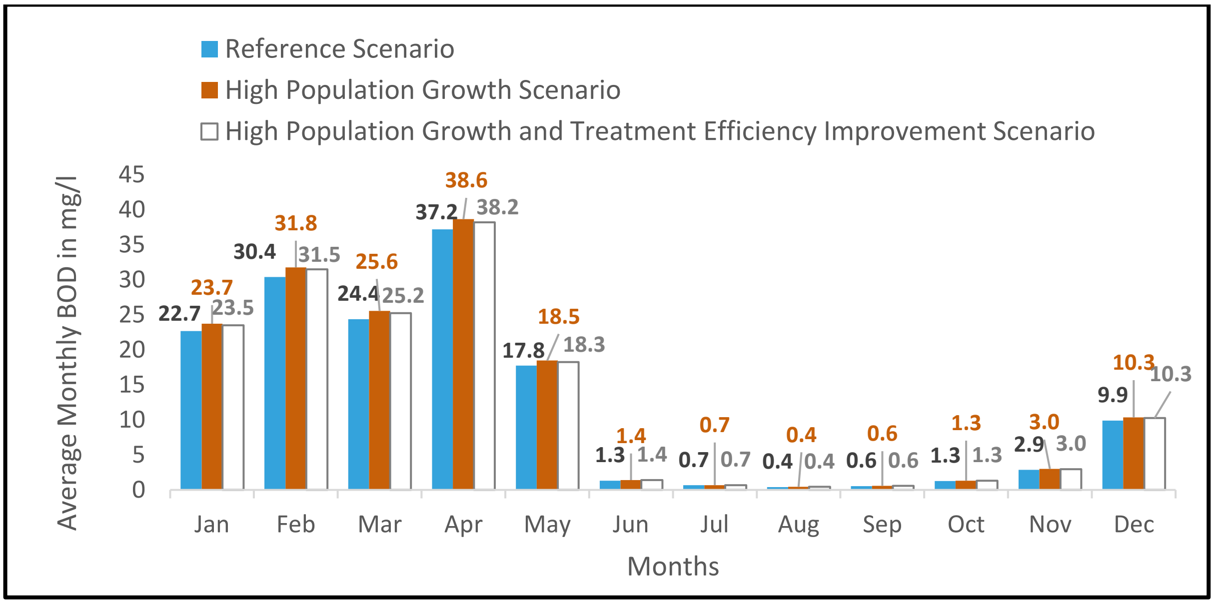

Figure 65: BOD concentrations at a point on River Ganga after the release of treated effluent from the WWTPs and the agricultural runoff, monthly average for 2009-2040

The monthly average count of FC for 2009-40 increased substantially from the midstream to the downstream point (refer to Figure 66 and Figure 67) under all the scenarios. As the case with the BOD, in all the scenarios, the monthly average count of TDS for 2009-40 is higher for the 'high population growth' and 'high population growth and treatment efficiency improvement' scenarios in comparison to the reference scenario.

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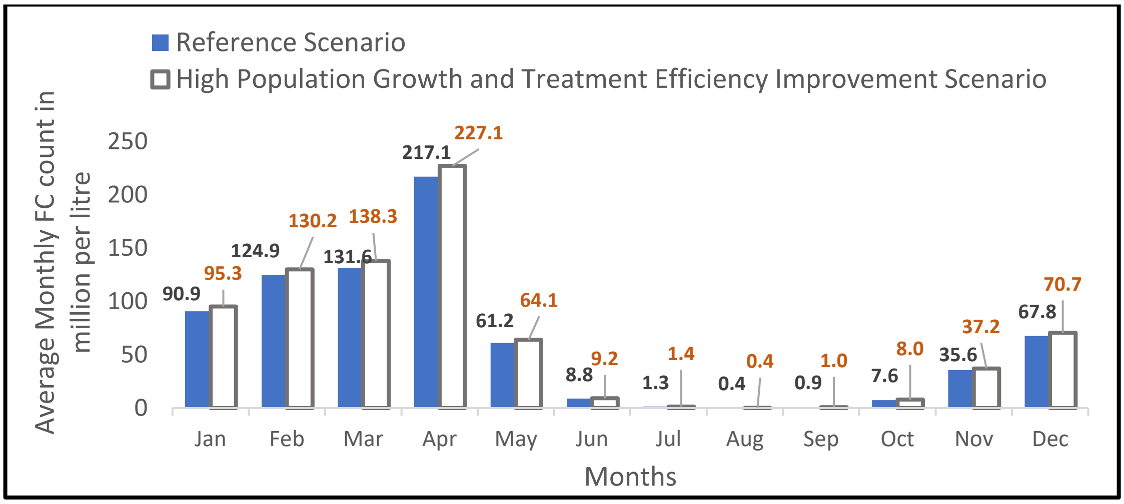

Figure 66: FCs at a point on River Ganga after the release of wastewater from the KMA, monthly average for 2009-2040

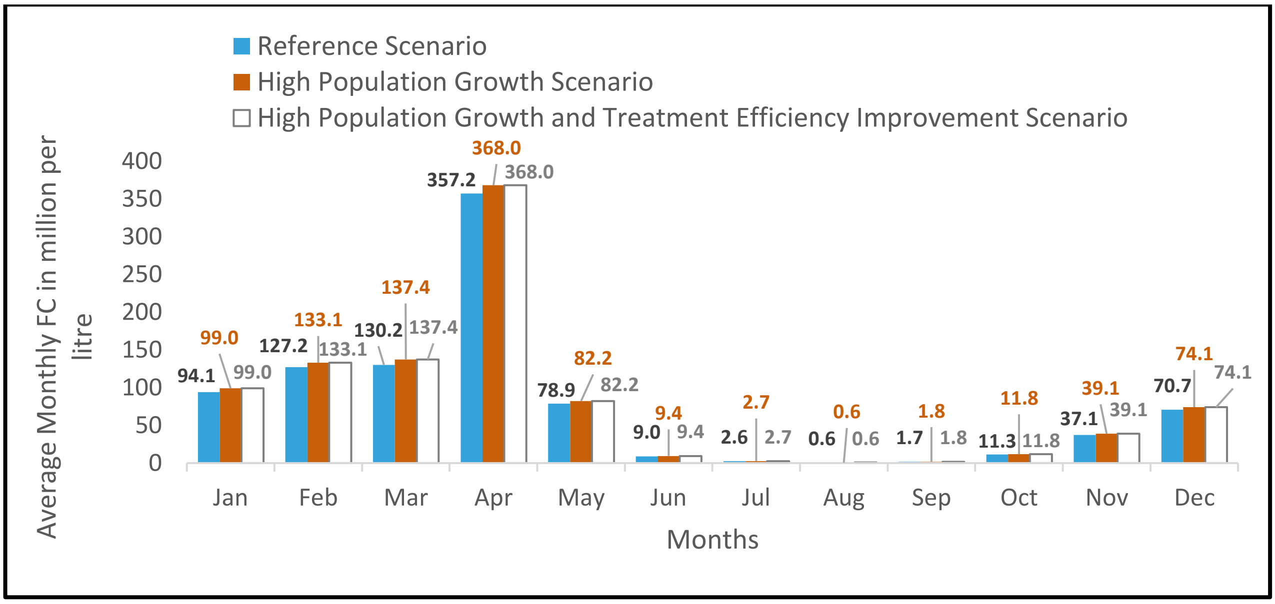

Figure 67: FCs at a point on River Ganga after the release of treated effluent from the WWTPs and the agricultural runoff

Overall, for the 32 years (2009-2040), the average monthly value of TDS, BOD and FC count will be highest in April for the downstream point under the three scenarios. For April, the average monthly TDS concentration will be 442 mg/l under the 'reference scenario', 362 mg/l under 'high population growth scenario', and 346 mg/l under 'high population growth and treatment efficiency improvement scenario'. For BOD, it will be 37.2 mg/l under 'reference scenario', 38.6 mg/l under the 'high population growth scenario', and 38.2 mg/l under the 'high population growth and treatment efficiency improvement scenario'. The average monthly FC count in April will be 357 million per litre in 'reference scenario' and 368 million per litre in the other two scenarios.

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Nevertheless, the monthly average values of TDS, BOD, and FC at the downstream point in river Ganga are much below their values in the treated effluent from the WWTPs. This indicates that the river Ganga has a very high pollution assimilation capacity.

5.2.10 Improvements in the WEAP Model Configuration for Kanpur

The model results discussed above for Kanpur Metropolitan Area (KMA) did not consider the return flows from irrigated area and therefore the impact it will have on groundwater quality. However, it was realied that non-point pollution from agriculture could be a major sourc of concern for Kanpur area given the ecohydrology of the region. The model was hence reconfigured to include the return flow from irrigated paddy fields and the nitrate loand that it will carry through leaching. The following assumptions were made for modelling. The total volume of water applied to the crop in excess of the evapo-transpirative demand was considered as the return flow to shallow groundwater. The total amount of fertilizer dosage considered was 170 kg/ha and the proportion of of nitrate that leaches to shallow groundwater is assumed as 58 per cent. Accordingly, the model was run for the period 2009-2040 and the outputs were generated vis-à-vis the total volume of irrigation return flow from the agricultural catchment and the total nitrate load. The results are presented in Figure 68 and Figure 69, respectively for return flows and nitrate load respectively. The results show that the recharge from irrigation return flows can be as highg as 102.8 MCM in some years, while it some other years it can be just nil (Figure 68). In the same way, the nitrate leaching can be as high as 531 ton in some years, while in some other years, it can be nil (Figure 69).

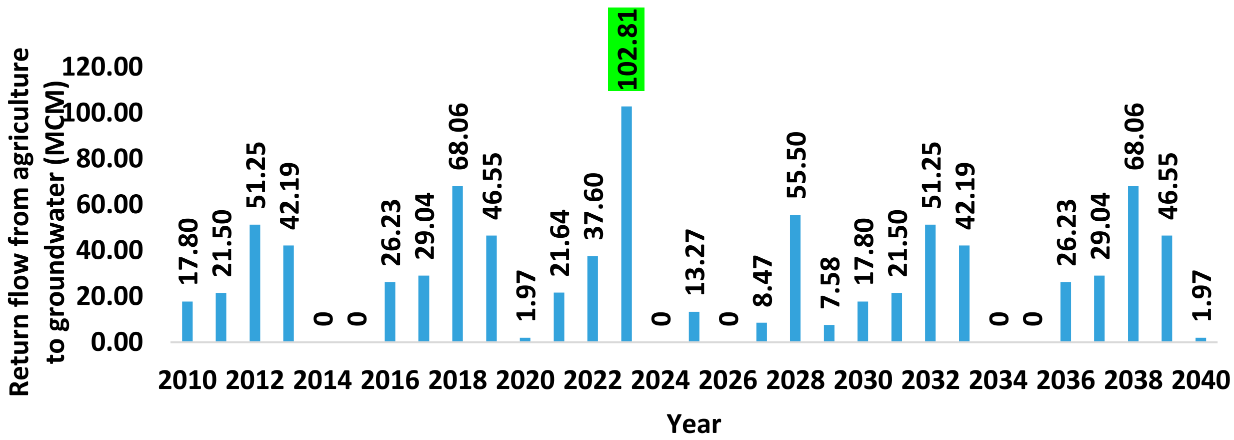

Figure 68: Recharge to Groundwater from Irrigation Return Flows

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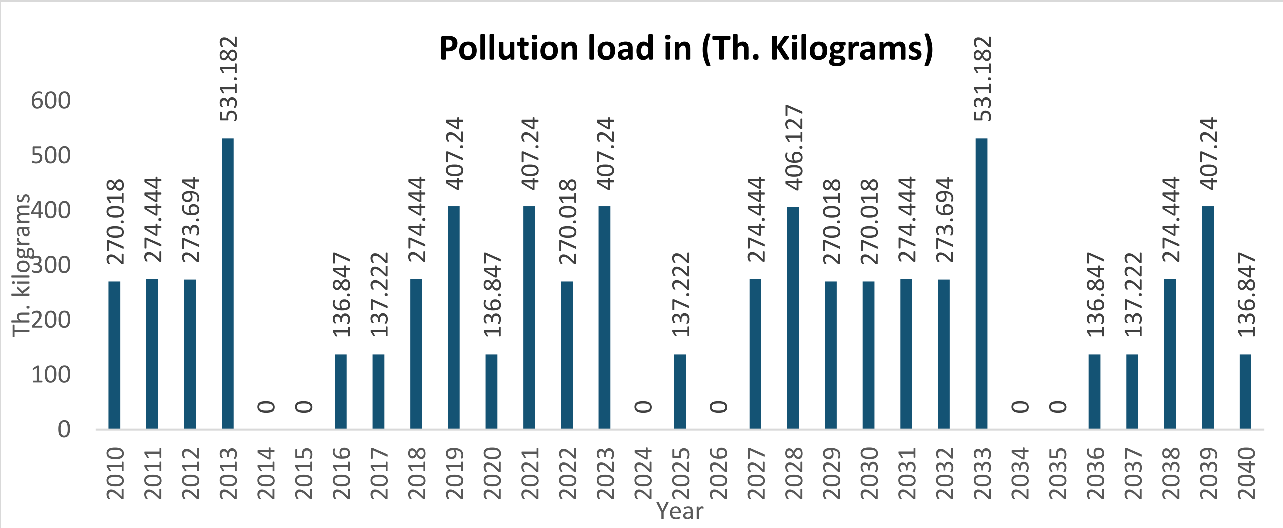

Figure 69: Nitrate Pollution of Groundwater from Irrigated Paddy

5.3. WEAP MODELLING APPROACH FOR KANPUR METROPOLITAN AREA – INCORPORATING MORE SPATIAL INFORMATION

The baseline model set up in section 6.2 (covering the years 2009-2040) includes the following assumptions:

- all the Kanpur urban area contributes to the Ganges river through 3 existing treatment plants discharging into the river and (indirectly) through discharge to a number of drains;
- all the tanneries existing in the urban area convey their wastewater to the 36MLD treatment plant; and,
- all the "other" industries discharge directly to the Ganges river.

However, on the basis of additional information gathered from scientific papers and from official information collected from technical services in the Kanpur Municipality (Figure 70), it has been decided to incorporate more spatial detail into the model. In particular it became evident that the following facts were of a fundamental importance in order to achieve a complete understanding of the Kanpur case study and to build a meaningful model:

- a large part of the town and of the population produces wastewater that is delivered to the Pandu River, a small very polluted stream flowing NW to SE, more or less parallel to the Ganges, on the southern side of Kanpur, before flowing into the Ganges, downstream of Kanpur;
- the pollutant load carried by the Pandu River plays a big role in creating the overall load of the Ganges;
- the water managers in Kanpur have planned a large effort in order to improve the existing 3 STPs, build 6 new STPs, build or improve a large number of drains (some of which to be routed to STPs), eliminating the direct discharge to the rivers.

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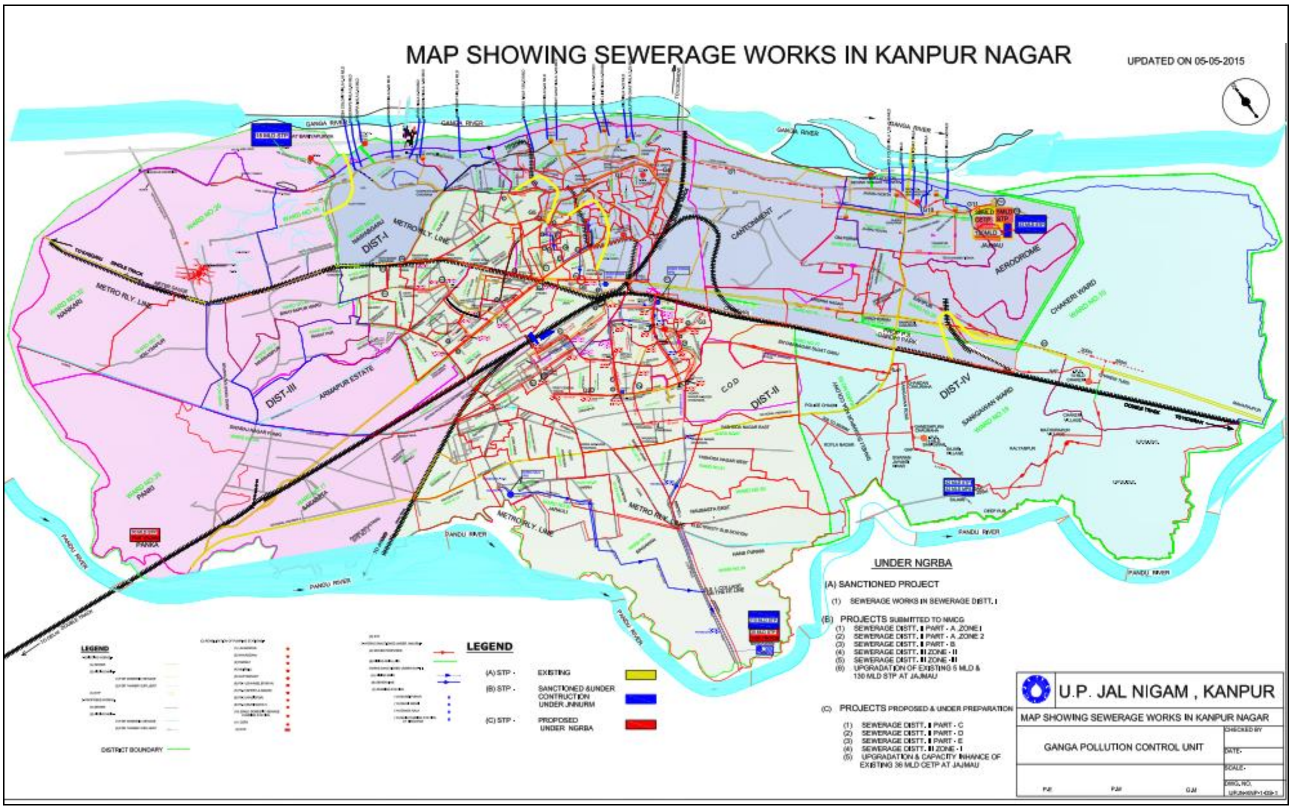

Figure 70: Planned sewage works in Kanpur

5.3.1. SETUP OF WEAP USING MORE SPATIALLY EXPLICIT DATA

The borders of the four Districts have been digitized on the basis of the “Kanpur Sewage Map” drafted by the U.P Jal Nigam (Kanpur), Ganga Pollution Control Unit. The same map has been used to locate the planned STPs. The Pandu River has also been added to the WEAP schematization. The area of each District has been calculated in a GIS environment as a portion of the whole Kanpur urban settlement. The calculated portion has been used also as a base to calculate a rough population estimates for each District. This, in turn, has allowed to allocate the water use for each District. This is obviously something that can be improved using more spatial information from 2011 population Census data. Pollution load production in each part of the town has been calculated on the basis of the concept of “inhabitant equivalent” (see references).

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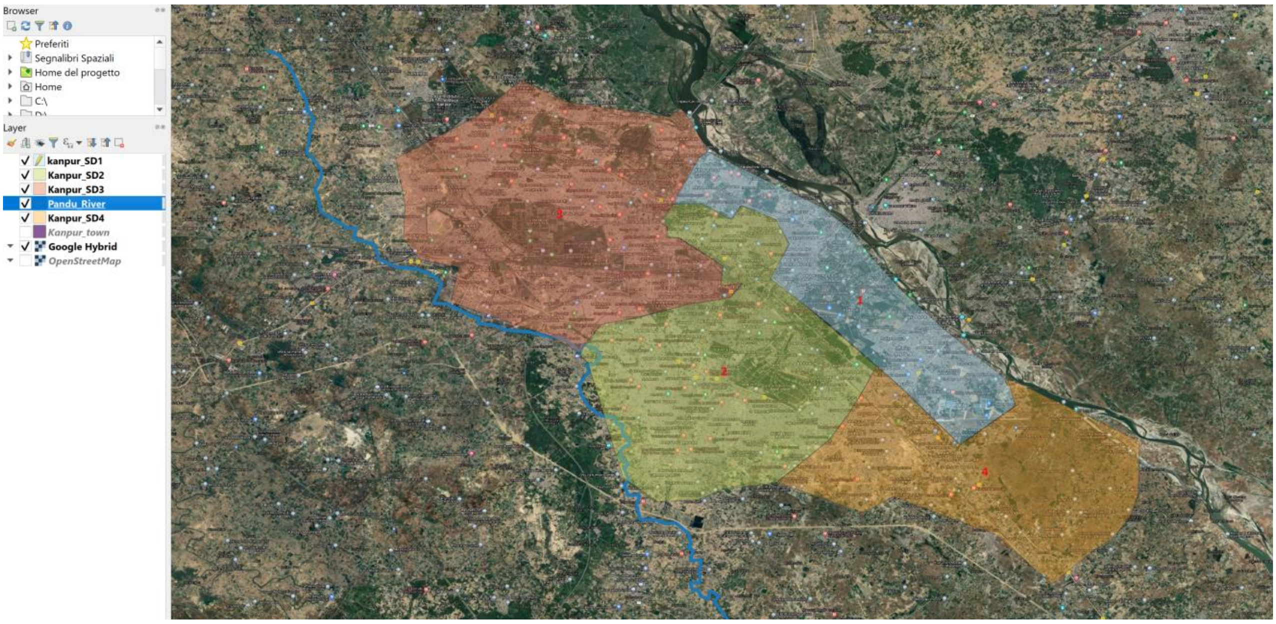

Figure 71: Wastewater treatment Districs in Kanpur and River Pandu location

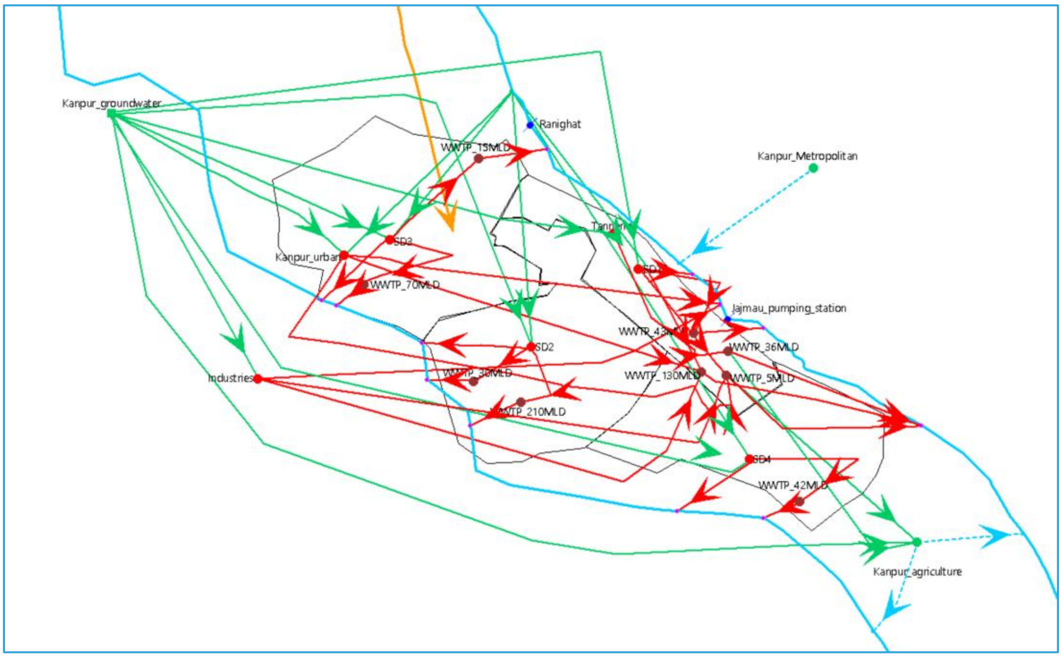

Figure 72: WEAP Model – using more spatially explicit information

5.3.2. ASSUMPTIONS ADOPTED FOR WEAP USING MORE SPATIALLY EXPLICIT DATA

Some assumptions have been made, in a somehow arbitrary way, on topics in which more refined information is for the moment not available:

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- equal population density in the 4 Districts (District 4 seems having a lower population density than others) - this has been improved.
- STP 43MLD operational in 2018 (on the base of historical satellite imagery)
- planned STPs become operational in 2023 – can be improved based on information from the Jal Nigam Director ppt (6 March 2020)
- location of SSTPs outlets to rivers have been arbitrarily placed to the closest reach
- tanneries/Industries keep the same level of activity by 2040
- tanneries keep discharging to CETP 35MLD
- treatment efficiency improvement set at +20% upon new technologies adoption
- Pandu instream water quality characterization done from one-time sampling campaign (article from IIT K Earth Sciences – Sen et al., 2018) - the assumption is that this is representative of the long-term situation.
- Pandu flow estimated by charted flow (Sen et al., 2018, **Error! Reference source not found.**) - the a ssumption is the same as above .
- Tapping of drains to STPs not accounted for (but the drains flow either to the Pandu River or the Ganges)

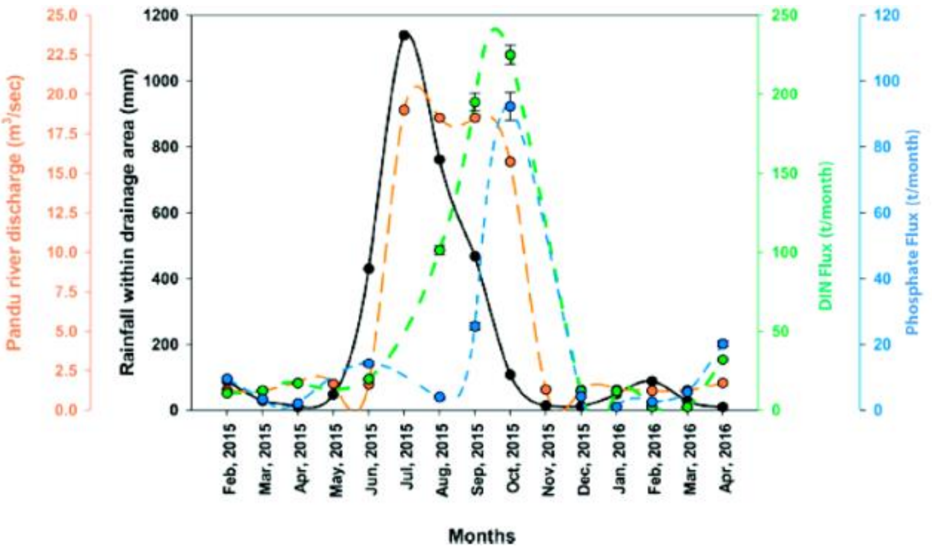

Figure 73: Pandu River; chart used to gather flow data for the WEAP model

Key to figure:
Orange curve – monthly variations in river discharge
Black curve – rainall
Green curve – DIN flux
Blue curve – Phosphate flux

5.3.3. SCENARIOS USED FOR WEAP USING MORE SPATIALLY EXPLICIT DATA

The scenarios that have been implemented into the WEAP model using more spatially explicit data are the following

CHAPTER 1 Baseline (input data from Section 6.2 has been implemented in Section 6.3)
CHAPTER 2 High growth

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CHAPTER 3 Treatment technology improvement
CHAPTER 4 High growth – Technology improvement
CHAPTER 5 (Climate change) - see below

The parameter set used to populate the scenarios are summarized in the attached reports (Appendix 1 to 4).
In general the adopted scenarios had the following characteristics:

- High growth
  - population increase set at 1.8%/year, higher than in the reference (1.3%)
  - water use per capita set as slowly increasing from 54750 L/year (2009) to 60000 L/year (2040)
- Treatment technology improvement
  - pollutant concentration decrease in return flow to the STPs set at slightly higher values
  - treatment efficiency in STPs set at slightly higher values
  - new STPs set as becoming operational in 2023
- High growth and Treatment Technology improvement
  - the scenarios 2) and 3) have been combined

The scenario 5) has not yet been implemented (work in progress). Downscaled modelled weather data have been obtained from CCCR – Centre for Climate Change Research (Indian Institute for Tropical Metereology, Pune, India). The data set consists in a subset of the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset over India shared during the Workshop on Development and Applications of Downscaling Climate Projections, 07 - 09, March, 2017 at IITM, Pune, India. The NEX-GDDP dataset is comprised of downscaled climate scenarios for the globe that are derived from the General Circulation Model (GCM) runs conducted under the Coupled Model Intercomparison Project Phase 5 (CMIP5) and across two of the four greenhouse gas emissions scenarios known as Representative Concentration Pathways (RCPs). The CMIP5 GCM runs were developed in support of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5). The NEX-GDDP dataset includes downscaled projections for RCP 4.5 and RCP 8.5 from the 21 models and scenarios for which daily scenarios were produced and distributed under CMIP5. Each of the climate projections includes daily maximum temperature, minimum temperature, and precipitation for the periods from 1950 through 2100. The spatial resolution of the dataset is 0.25 degrees (~25 km x 25 km).

5.3.4. PRELIMINARY RESULTS FROM THE WEAP MODELLING USING MORE SPATIALLY EXPLICIT DATA

The Pandu River receives the major part of the Kanpur discharge (Figure 70 and Figure 71): this is the motivation on the basis of the decision of adopting a more spatially explicit model which includes the Pandu river (in addition to the Ganges river) and a scheme of STPs and respective discharge outlets close to the real situation/plans.

The Pandu river plays a great role in pollutant load to the Ganges, notwithstanding the huge differences in flow (Figure 74 to Figure 78). The concentration of chemical species indicating pollution from urban wastewater discharge (namely nitrite, ammonia and phosphorus) in the Ganges river downstream of the Pandu confluence is largely higher than upstream such confluence, in some case reaching the double of the annual average. This does not happen to nitrate, suggesting that the major contribution from this pollutant is not from urban wastewaters. Furthermore, the presence of nitrite and ammonium in downstream water confirms that the efficiency of the existing STP is largely insufficient to adequately treat Kanpur wastewater.

The modelled effect of STP numbers and technology improvement on the Ganges is visible (Figure 79 to Figure 87). The improvement introduced in the scenario "Improved Treatment Efficiency" (together with

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the development of new STPs) has a positive impact on the pollutant load discharge in the rivers and, consequently, on the pollutant concentration in the rivers. However, this positive effect is rather moderate: expected percent change in COD and BOD load in the Pandu River is expected to reach (at the end of the modelled period) respectively about -10% and -6% as annual average, while expected changes for the same parameters in the Ganges River are even lower (respectively -4% and -5%). This conclusion is more evident for BOD than for COD. This can lead to the conclusion that the planned sewerage treatment improvement in Kanpur is not yet sufficiently in order to achieve a substantial advantage. This indicates that the planned capacity improvement will not significantly improve water quality and more investments in STPs and sewage network are required.

If the population grows as expected, the adopted and planned improvements results to be even less than sufficient. The increase in pollution generation, due to the increase in population and the expected improvement of the quality of life and, consequently, to the higher water footprint of the society, seems to be able to exceed the positive improvement brought by the technology enhancement (Figure 79, Figure 80).

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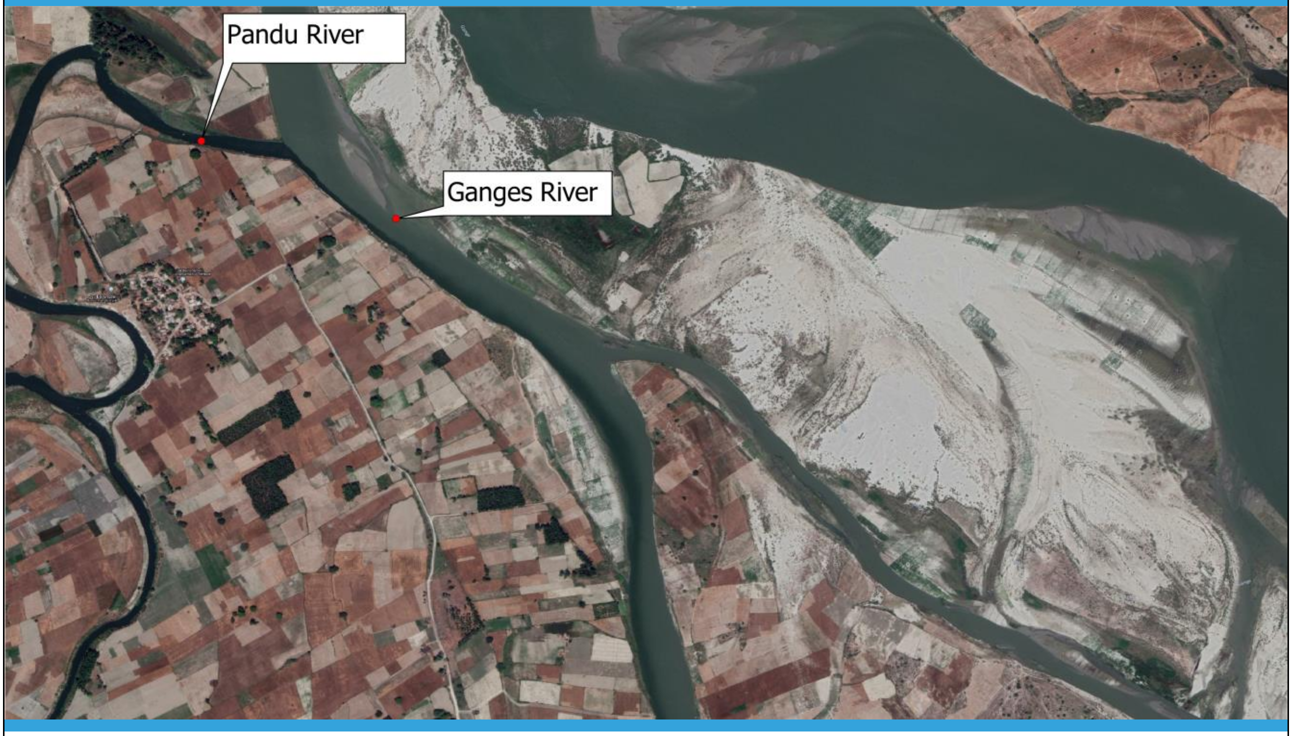

Figure 74: Pandu River confluence with Ganges; note the black water plume; 21 km SE of Kanpur

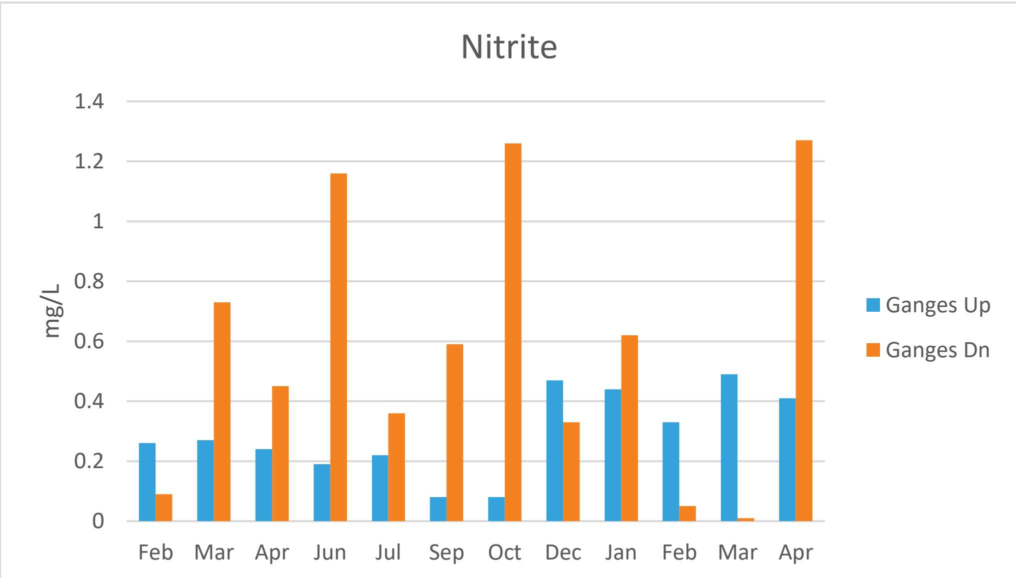

Figure 75: Comparison of nitrite concentration in the Ganges upstream ("Up") and downstream ("Dn") of the confluence of the Pandu River

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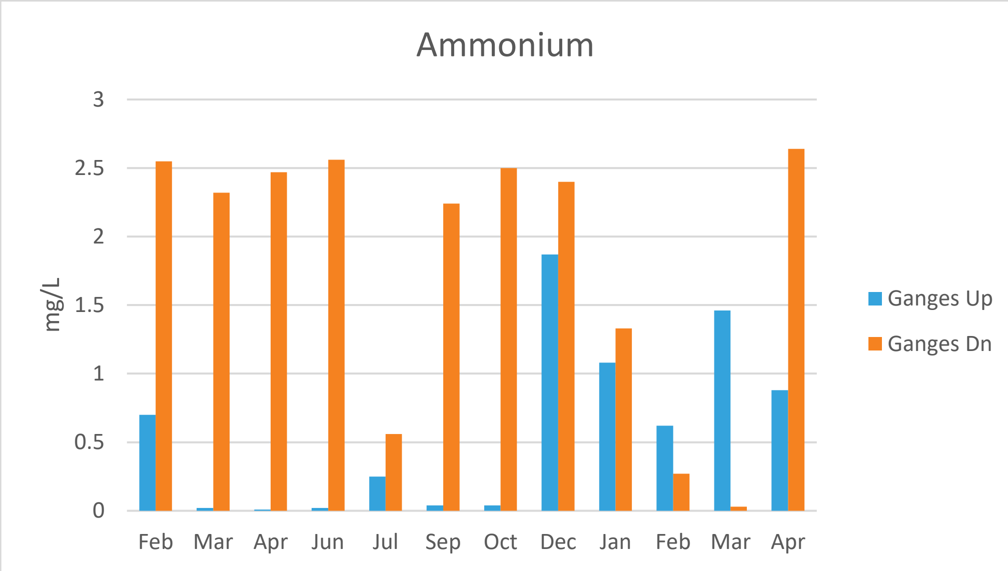

Figure 76: Comparison of ammonium concentration in the Ganges upstrem ("Up") and downstream ("Dn") of the confluence of the Pandu River

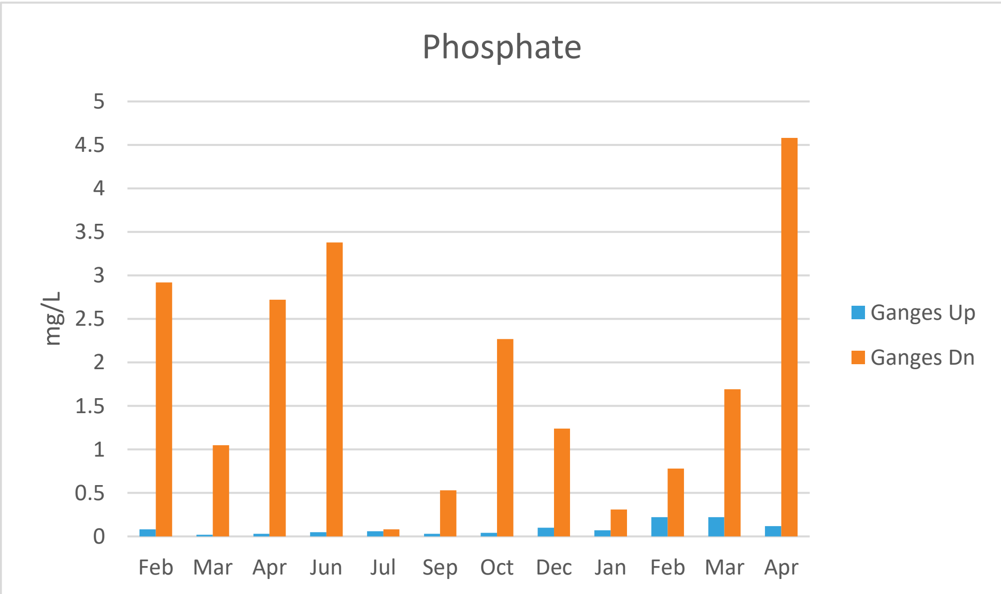

Figure 77: Comparison of phosphate concentration in the Ganges upstrem ("Up") and downstream ("Dn") of the confluence of the Pandu River

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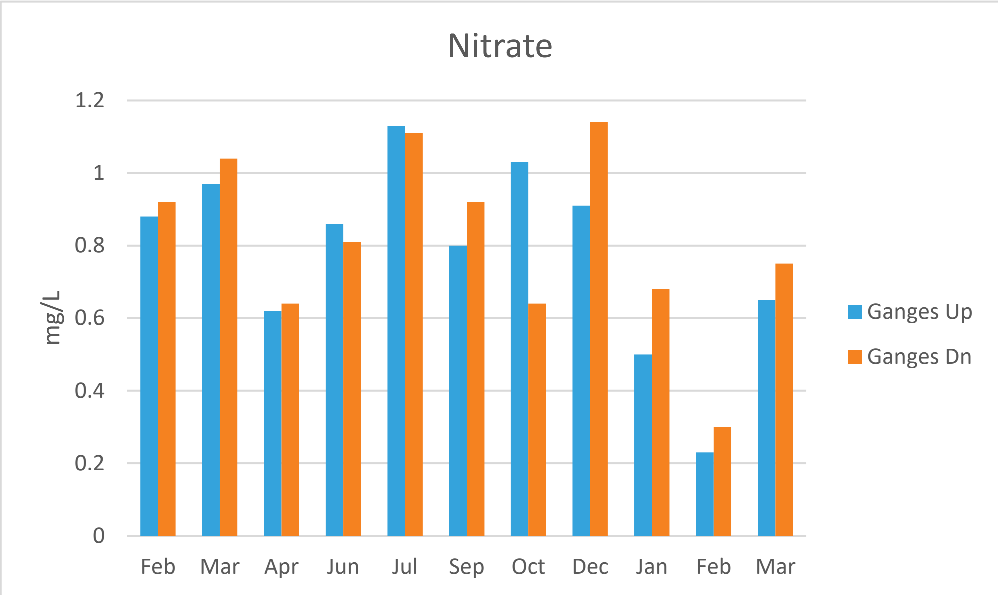

Figure 78: Comparison of nitrate concentration in the Ganges upstream ("Up") and downstream ("Dn") of the confluence of the Pandu River

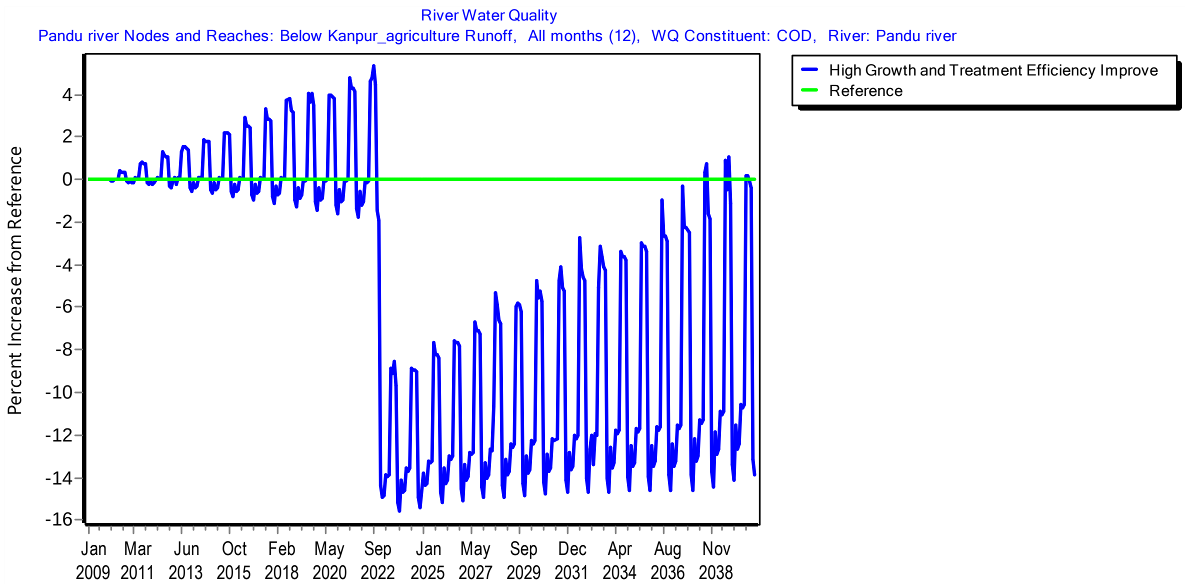

Figure 79: Percent change of COD load in the Pandu River (Reference vs High Growth and Treatment Efficiency Improvement)

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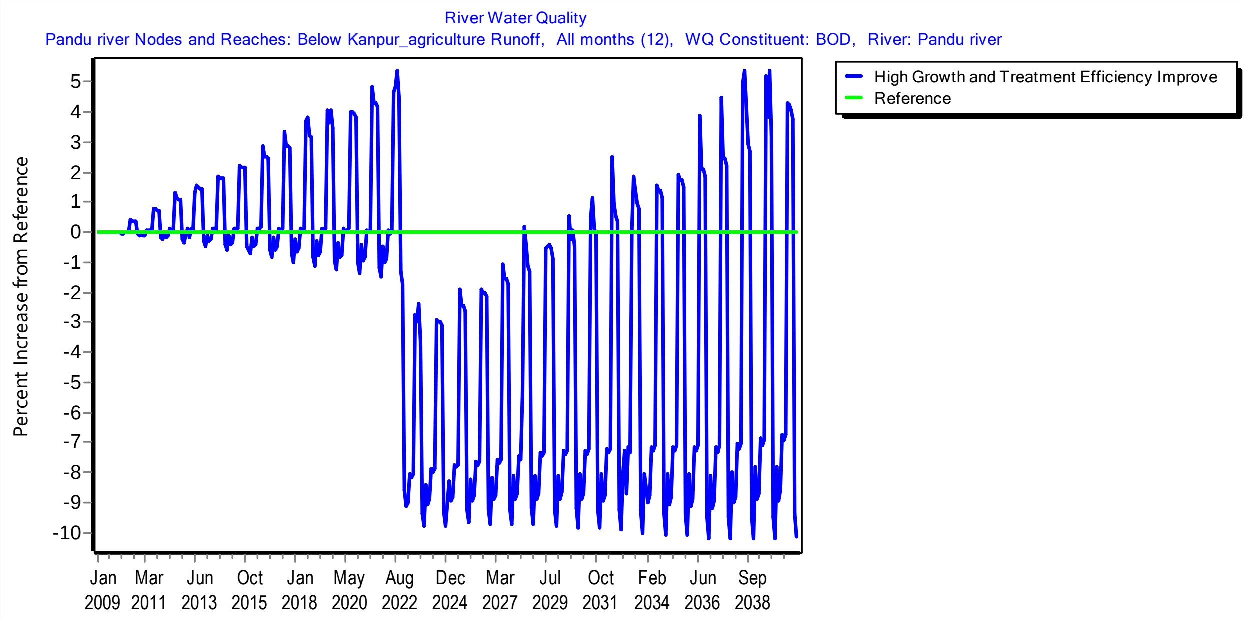

Figure 80: Percent change of BOD load in the Pandu River (Reference vs High Growth and Treatment Efficiency Improvement)

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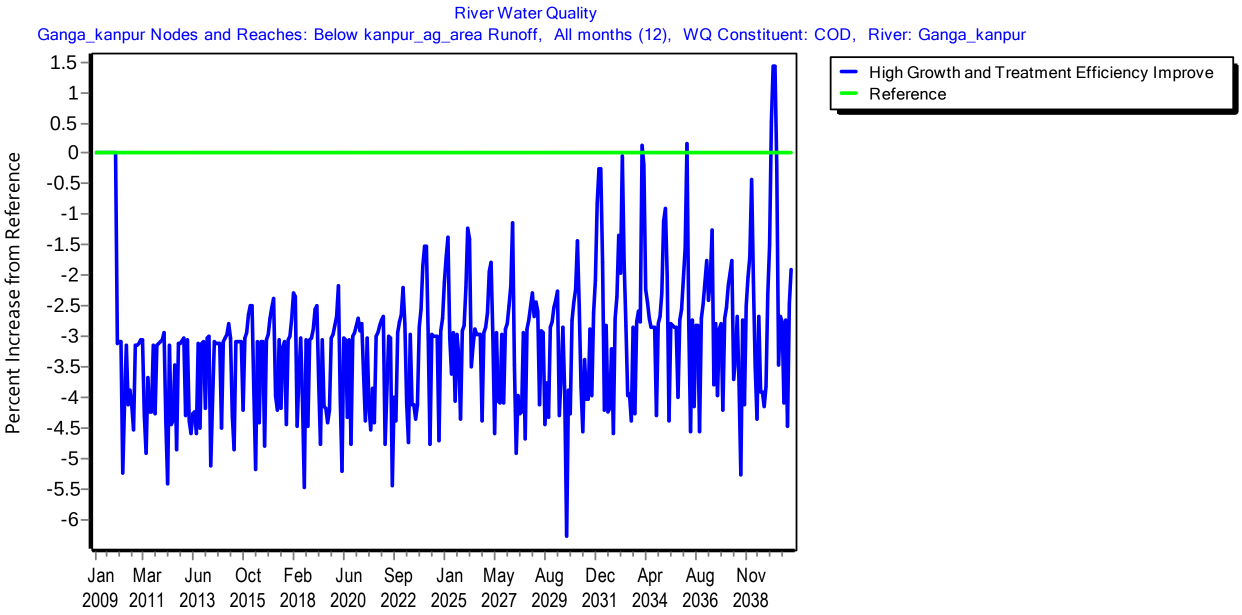

Figure 81: Percent change of COD load in the Ganges River (Reference vs High Growth and Treatment Efficiency Improvement)

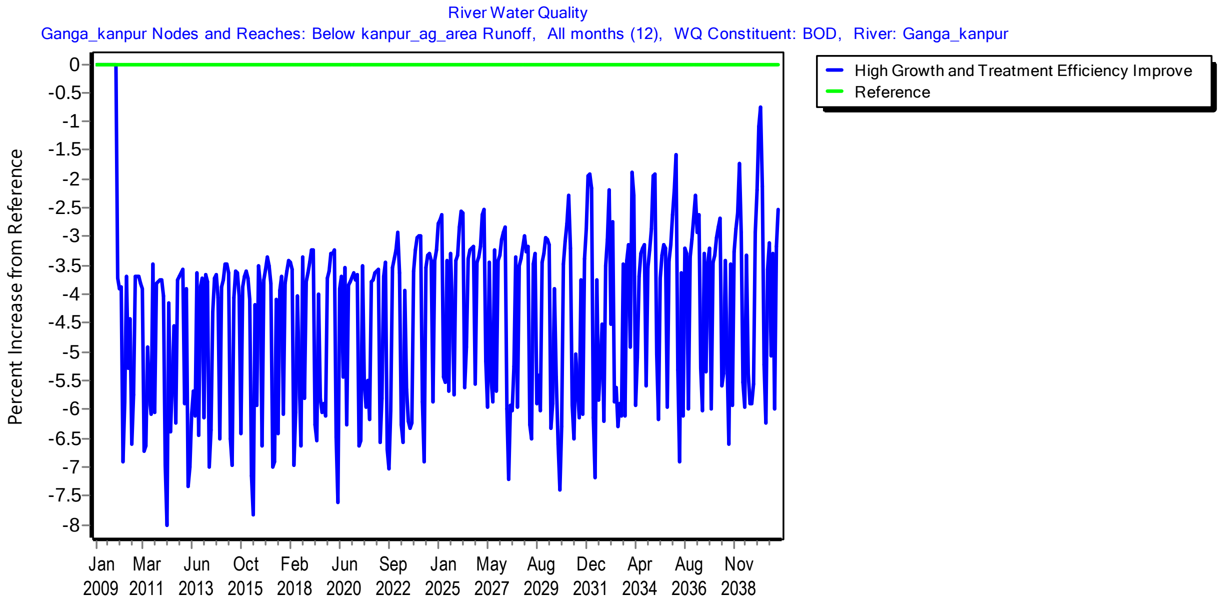

Figure 82: Percent change of BOD load in the Ganges River (Reference vs High Growth and Treatment Efficiency Improvement)

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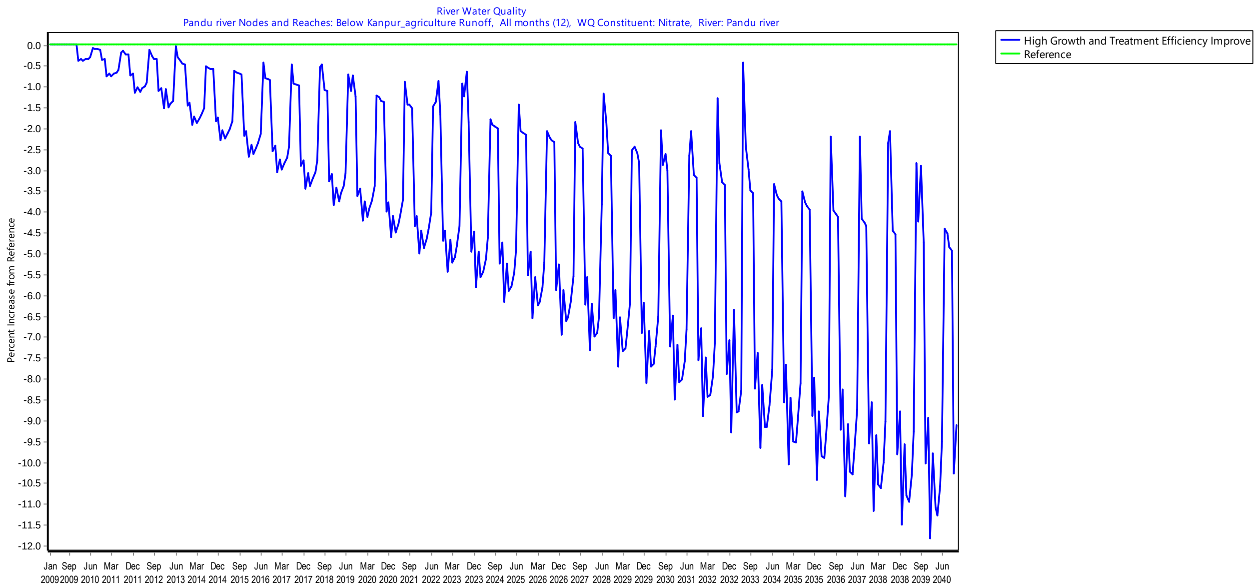

Figure 83: Percent change of nitrate load in the Pandu River (Reference vs High Growth and Treatment Efficiency Improvement)

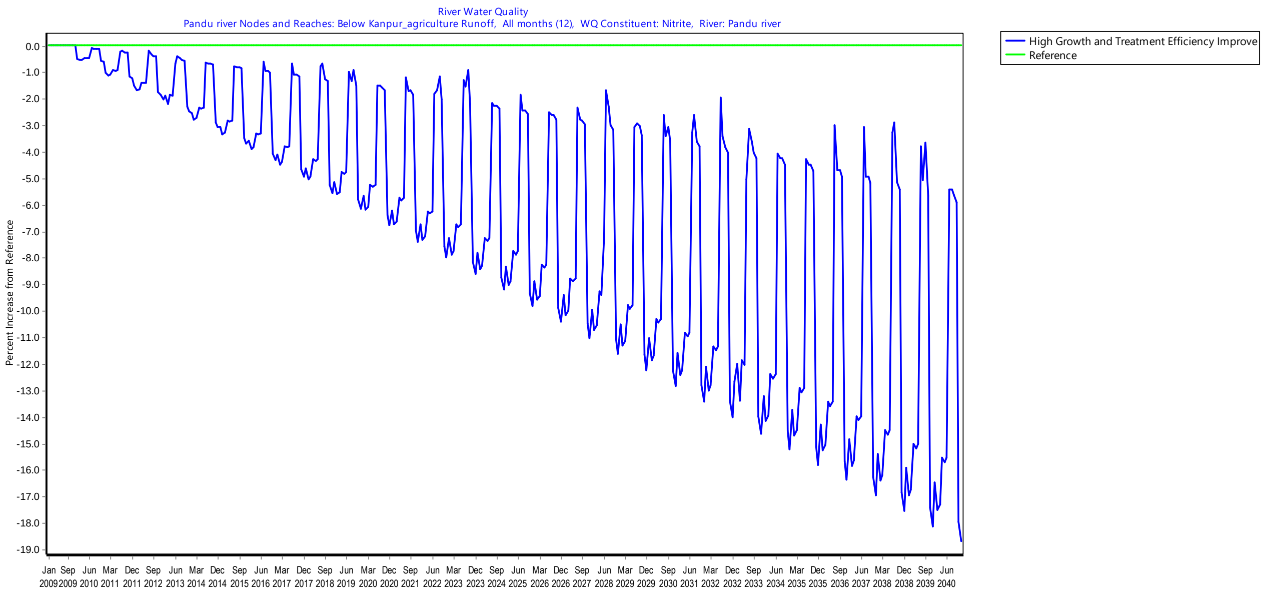

Figure 84: Percent change of nitrite load in the Pandu River (Reference vs High Growth and Treatment Efficiency Improvement)

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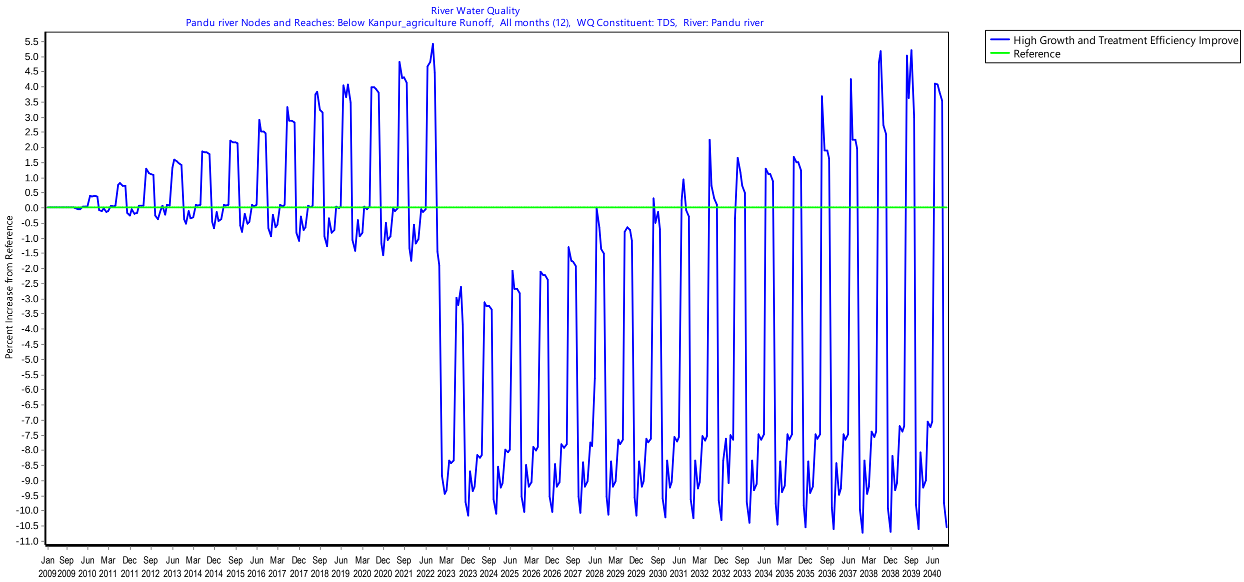

Figure 85: Percent change of TDS load in the Pandu River (Reference vs High Growth and Treatment Efficiency Improvement)

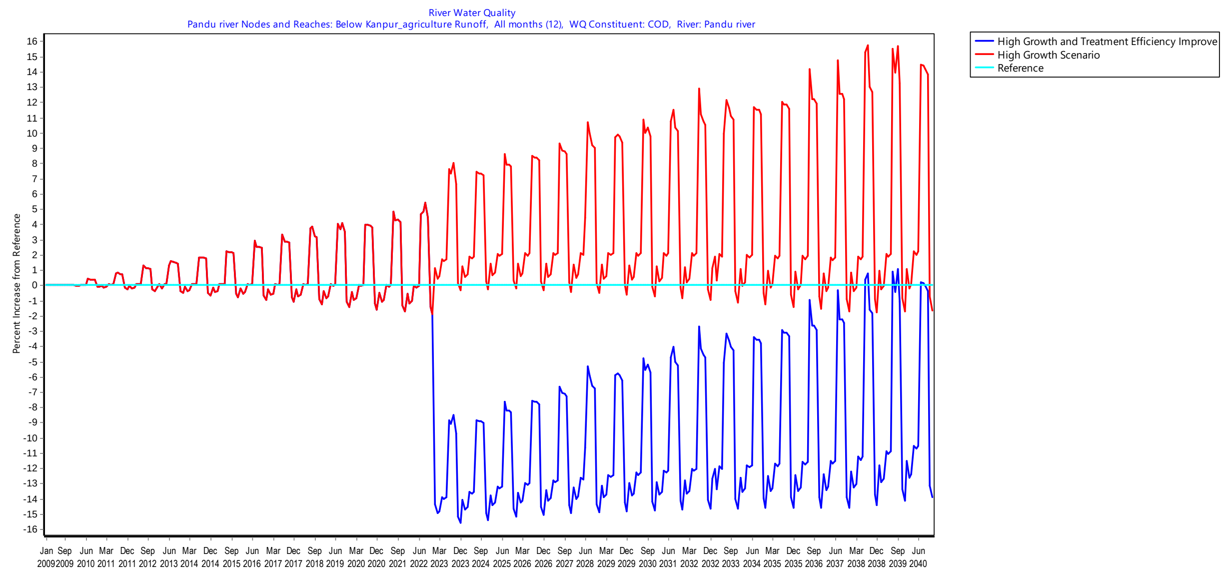

Figure 86: Percent change of COD load in the Ganges River (Reference vs High Growth vs High Growth and Treatment Efficiency Improvement)

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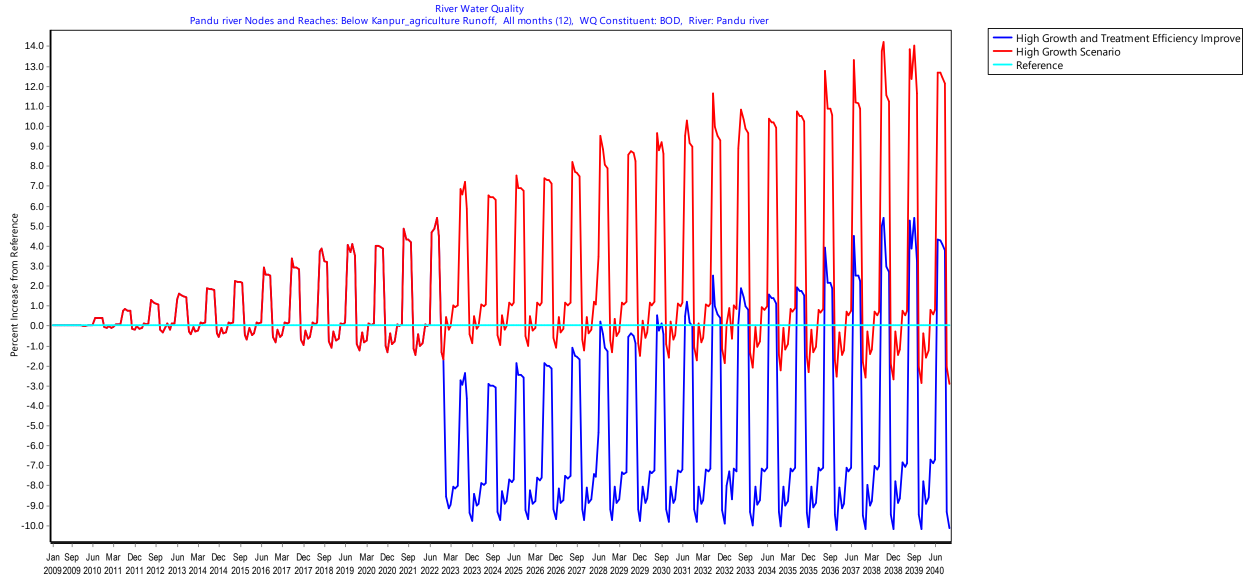

Figure 87: Percent change of BOD load in the Ganges River (Reference vs High Growth vs High Growth and Treatment Efficiency Improvement)

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5.4. Setting up the Water Balance Model for Barahpulla Catchment

The WEAP model will be used to analyze the water availability, water demand and supply, river water quality, and wastewater quality in the Barapullah catchment, for the present and also for the future years under different scenarios. The scenarios are predicted on the basis of the likely changes in the demand for water due to assumed socio-economic and environmental drivers and likely changes in water supplies from year to year as a result of climate variability. The configuration of the WEAP model is set up for the period beginning 2009 and ending 2040 on a monthly time step. The year 2009 is taken as the base year (also referred to as 'current account') and the period 2010-2040 is considered for generating scenarios. Four scenarios, namely 'reference', 'high population growth', 'CETP improvement', and 'high economic growth' are developed. The various components of the system are explained below:

5.4.1. Supply Nodes

The supply nodes include aquifers, reservoirs, withdrawal points, tributary confluence points, and special locations (such as streamflow gauges, diversions, etc.). Nodes are linked by lines that represent the natural or man-made water conduits which include rivers, diversions, and transmission and return flow links. A river reach is defined as the section of a river or diversion between two river nodes or following the last river node.

In the configured WEAP system for the Barapullah Area (See Figure 88), there is one river (the stretch of river Yamuna passing through Delhi), one natural drain (Barapullah), and four water supply sources. The four water supply sources include: 1] a groundwater source and an imported surface water source for the parts of Central, East, North, North-west and New Delhi in the Barapullah catchment; and 2] a groundwater source and an imported surface water source for the parts of South and South-west Delhi in the Barapullah catchment.

The groundwater supply nodes are represented by 'GW1' and 'GW2', and the imported surface water sources are represented by 'Imported SW1' and 'Imported SW2' in the WEAP model. For groundwater supply source, aquifer underlying Barapullah catchment was considered. Data on the aquifer's initial storage capacity, annual natural recharge, and maximum withdrawal was provided for 2009 to 2020. These were estimated for the Barapullah catchment using data from the Central Ground Water Board. The imported surface water allocation for the Barapullah catchment was estimated using 2009-2020 data from the Delhi Jal Board.

Further, four streamflow gauges (Delhi Railway Bridge, ITO Barrage, Okhla Upstream, and Okhla Barrage) on river Yamuna and two (Head flow and Barapullah Outfall) on Barapullah drain were identified. For estimating the river Yamuna flows reaching ITO Barrage (Barapullah drain outfall is between ITO and Okhla Barrage), the observed monthly discharge for 2009-2020 from the Wazirabad barrage (first barrage on river Yamuna in Delhi) was added to the outflows of the 12 drains that meet river Yamuna up to ITO Barrage. These data sets were obtained from the Delhi Jal board. The river flows reaching ITO Barrage (minus the contribution of Delhi Gate drain which is modeled separately in the WEAP) are represented at the Delhi Railway Bridge streamflow gauge node in the WEAP model. The monthly runoff for the Barapullah catchment is estimated for 2009-2019 using the SCS curve number method. They are represented by the 'Head flow' streamflow gauge node. Both the river Yamuna flows and the Barapullah catchment runoff are extrapolated up to 2040 in the WEAP model.

Further, for modeling the water quality of river Yamuna, the observed water quality data for Delhi Railway Bridge (by Central Water Commission) and Okhla upstream (by Central Pollution Control Board) for 2009-2019 are considered and extrapolated up to 2040 in the WEAP. The modeled water quality parameters include Ammoniacal Nitrogen (NH_3-N), Biological Oxygen Demand (BOD), Electrical Conductivity (EC), Total Coliforms (TC), and Total Dissolved Solids (TDS).

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For modeling the Barapullah drain water quality, observed water quality data (by Delhi Pollution Control Committee) for Barapullah Outfall for 2019-21 is considered and extrapolated up to 2040. It is assumed that the water quality trend for 2009-18 was the same as was observed for 2019-21. The modeled water quality parameters include pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS).

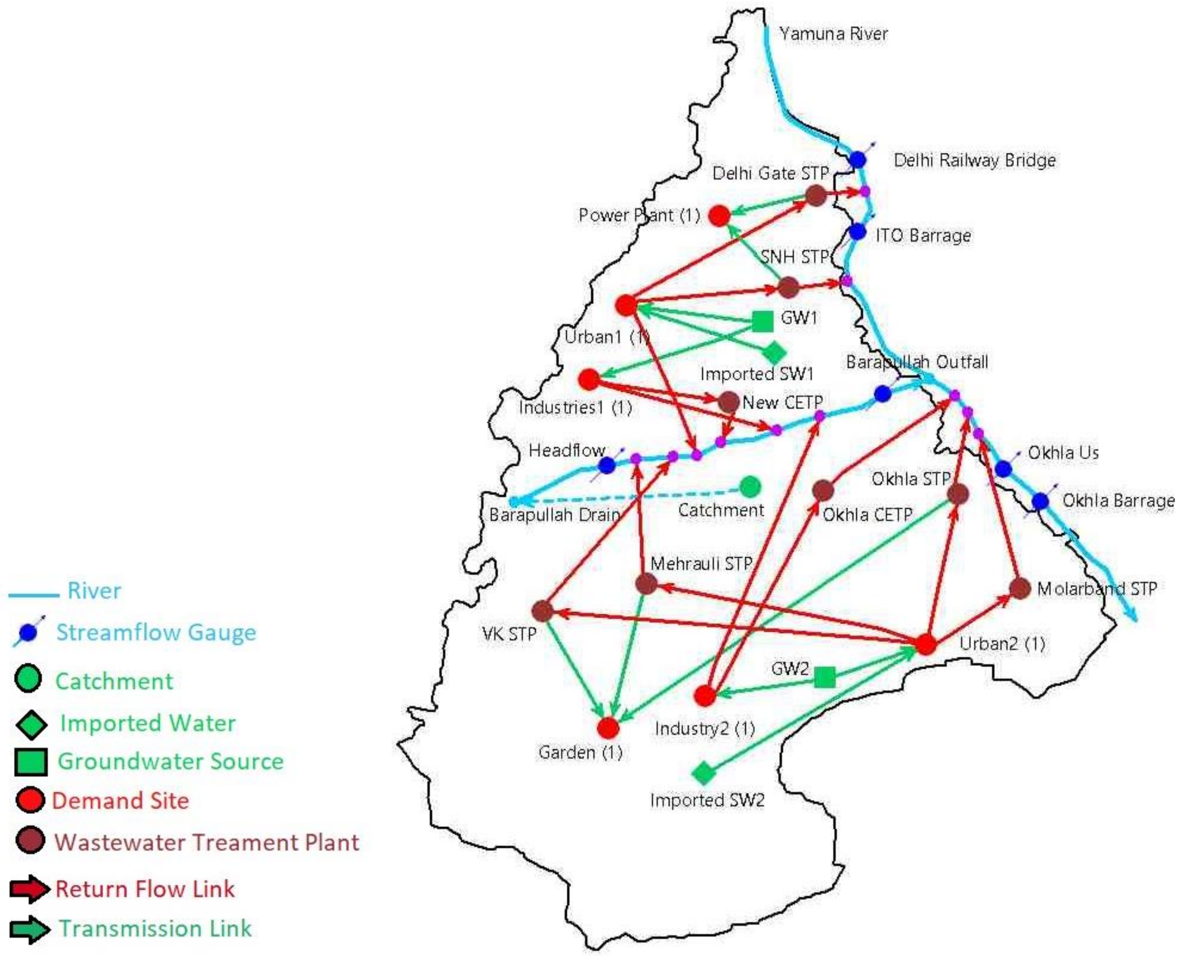

Figure 88: The WEAP Configuration for Barapullah Catchment

5.4.2. DEMAND SITES

A total of six demand sites are defined in the model. While four use groundwater and imported surface water sources (freshwater), two reuse treated wastewater. The former includes two urban and two industrial demand sites and the latter includes gardens and parks. Each of the demand sites comprises a demand tree which consists of annual activity level, annual water demand rate, actual consumption, and loss rate at the branch and sub-branch. Table 22 presents the data that is entered (base year) for the demand sites making use of fresh surface water or groundwater.

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Table 22 Data used for the demand sites (that use fresh water) in the WEAP for the base year (2009)

Demand Site	**Particulars**		
	Annual Activity Level (units)	**Annual Water Demand (thousand litre/unit)**	**Actual Consumption (at the demand site)**
Urban 1 (persons)	759,441	54.75	20%
Urban 2 (persons)	2,187,374	54.75	20%
Industries 1 (production units)	32	20,494	25%
Industries 2 (production units)	93	28,132	25%

5.4.3. CATCHMENT

The Barapullah catchment is defined in the WEAP model and its runoff was estimated. It has a catchment area of 376.27 sq. km. It is assumed that the entire runoff from the catchment contributes flows to the Barapullah drain which has an outfall between the ITO and Okhla Barrage on river Yamuna. The drain also gets return flows from the urban areas, industrial units, and wastewater treatment plants.

As stated previously, the monthly runoff for the Barapullah catchment was estimated for 2009-2019 using the SCS curve number method. For this, the catchment land use, soil type, and monthly rainfall data were utilized.

First, a Digital Elevation Model (DEM) of the Barapullah catchment was prepared using 'Cartosat-1 DEM' data of 2015 from the NRSC, Hyderabad to delineate the drainage boundaries (refer to Figure 89). Then, the land use land cover (LULC) map for Delhi (including Barapullah catchment) was prepared using MODIS land cover data for the year 2016 and re-gridded to 250m. Also, soil data was downloaded from 'Open Land Map' and re-gridded to 250m (refer to Figure 90). For preparing the CN grid, the LULC cover was reclassified to form four major categories: forest, agriculture, built-up, and water bodies (refer to Figure 91). Further, for each soil type, the hydrologic soil group (HSG) was assigned using QGIS version 3.16. The HSGs are a fundamental component of the SCS curve number method for estimation the runoff. Thereafter, the antecedent soil moisture condition (AMC), i.e., the water content present in the soil at a given time, is used to determine the final CN value (refer to Figure 92). For the Barapullah catchment, the average condition (AMC-II) was used.

Finally, the CN grid along with the daily rainfall data (2000-2019) for the Barapullah catchment was used to estimate the daily runoff from the catchment using the general equation of the SCS curve number method. For the runoff estimation, a weighted average curve number based on the area assigned to different curve numbers is used for the entire catchment.

Further, a rainfall-runoff model is developed for the catchment using the univariate regression analysis wherein the estimated runoff is considered as the dependent variable and the rainfall as an independent variable. The analysis estimates an R-square value of 0.87 which is a good fit for the developed rainfall-runoff model for the Barapullah catchment (refer to Figure 93).

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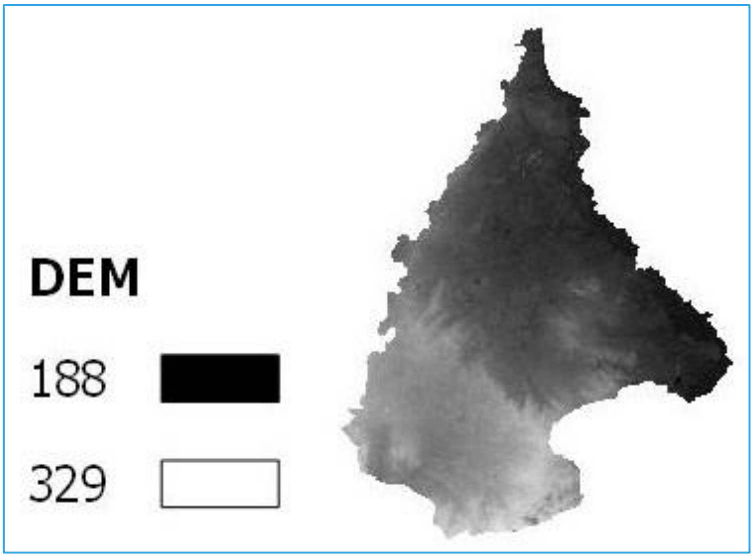

Figure 89: Digital Elevation Model of the Barapullah Catchment

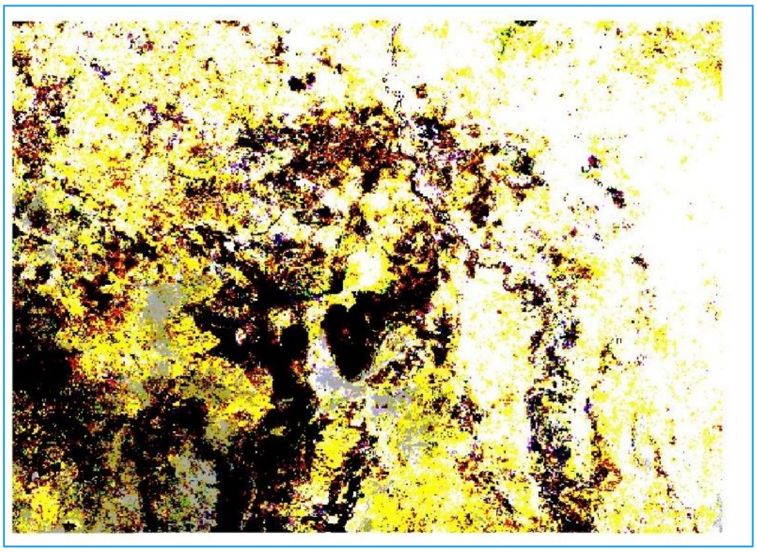

Figure 90: Soil texture of Delhi

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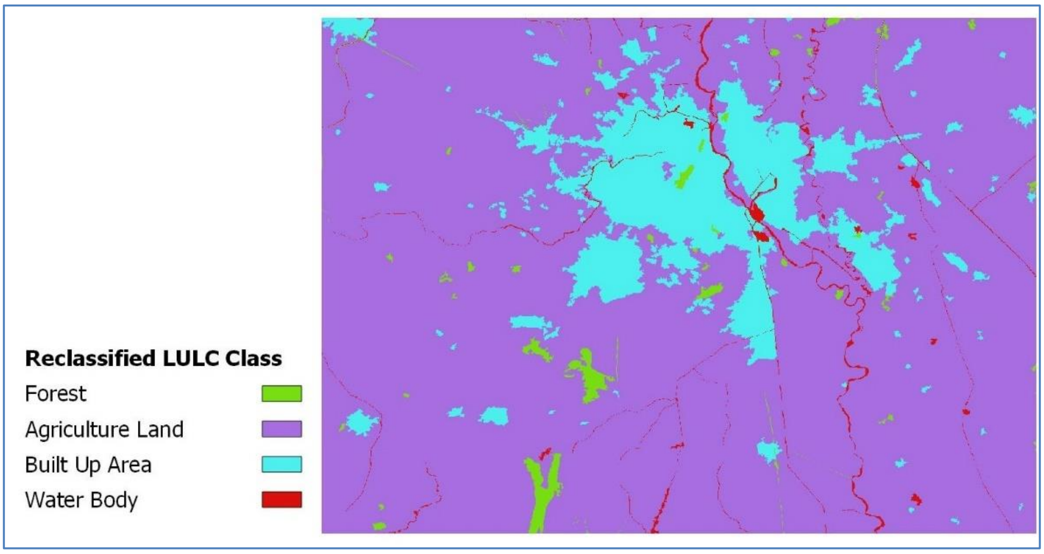

Figure 91: Reclassified LULC of Delhi

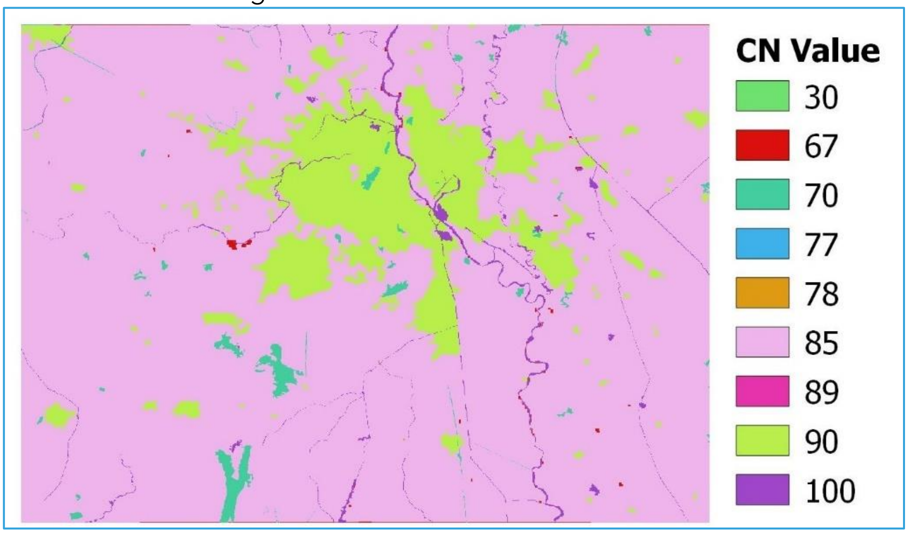

Figure 92: CN Grid of Delhi

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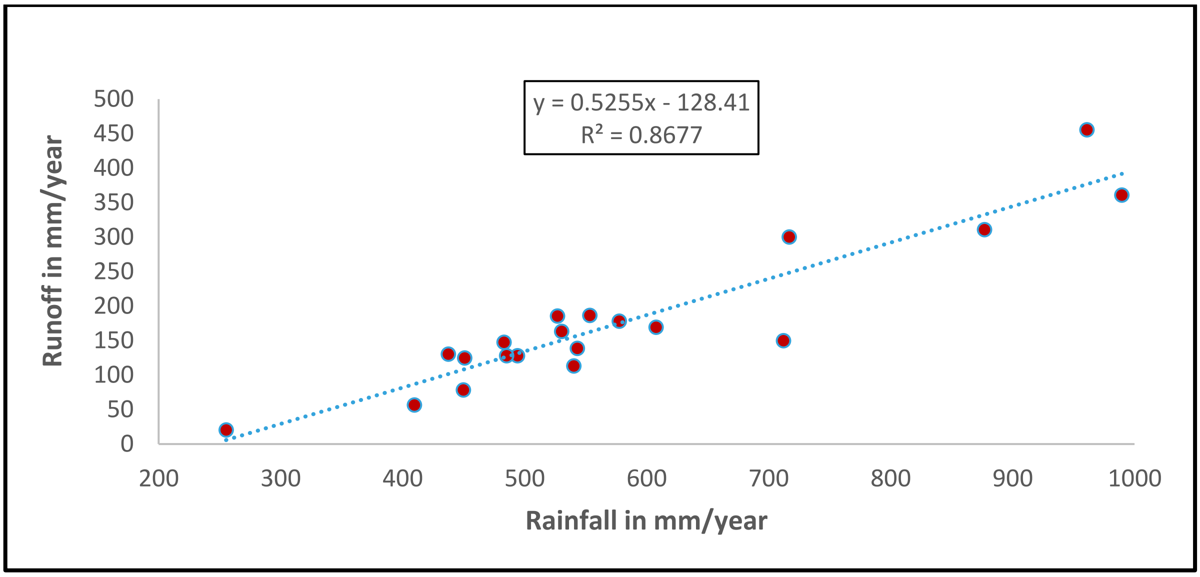

Figure 93: Rainfall-runoff model based on regression analysis for the Barapullah catchment

5.4.4. Wastewater Treatment Plants

Overall, seven wastewater treatment plants (WWTPs) are considered for the modeling. Out of these, six are sewage treatment plants (STPs) serving the urban areas and one is the common effluent treatment plant for the industries in the Barapullah catchment. Additionally, one CETP of 100 million litre per day (MLD) capacity is introduced for future scenarios. Also, the capacity of the existing CETP is increased by 100 MLD to model the impact of the treatment capacity enhancement on river Yamuna water quality in the future.

For all the WWTPs, observed influent and effluent quality data (by Delhi Pollution Control Committee) for 2019-21 is considered and extrapolated up to 2040. It is assumed that the water quality trend for 2009-18 is the same as is observed for 2019-21. For the STPs, Ammoniacal Nitrogen (NH_3-N), Biological Oxygen Demand (BOD), and Total Suspended Solids (TSS) are modeled. For the CETPs, Ammoniacal Nitrogen (NH_3-N), Biological Oxygen Demand (BOD), Total Dissolved Solids (TDS), and Total Suspended Solids (TSS) are modeled. The technical details of the WTPs considered for the base year (2009) are presented in Table 23. Overall, the contaminant removal efficiency of all the STPs is high (80% or above for most of the parameters), whereas it is low (for NH3-N and TDS) in the case of the CETP.

Table 23 Contaminant removal efficiency of the wastewater treatments plants for the base year (2009)

WWTPs	Capacity (MLD)	Technology	Year of Commissioning	Nutrient removal efficiency (%)			
				NH_3-N	*BOD*	*TSS*	*TDS*
Sen Nursing Home STP	10.0	Activated Sludge Process (ASP)	1998	89.4	95.1	95.5	-
Delhi Gate 1 STP	10.0	Activated Sludge Process (ASP)	1998	90.1	93.9	94.3	-
Mehrauli STP	67.5	Extended Aeration (EA)	2003	77.9	84.0	84.5	-
Vasant Kunj 1 STP	10.0	Extended Aeration (EA)	1998	78.6	87.7	89.3	-

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Vasant Kunj 2 STP	13.5	Extended Aeration (EA)	1998	81.7	85.7	87.8	-
Molar band STP	9	Fluidised Aerobic Bio-Reactor (FAB)	2003	79.0	86.6	87.6	-
Okhla II STP	54	Activated Sludge Process (ASP)	1983	81.9	80.1	79.9	-
Okhla III STP	166.5	Activated Sludge Process (ASP)	1993	81.5	78.3	80.1	-
Okhla IV STP	202.5	Activated Sludge Process (ASP)	1993	80.6	79.0	82.7	-
Okhla V STP	72	Activated Sludge Process (ASP)	2001	85.0	81.4	81.8	-
Okhla CETP	24	Dual Media Filter (DMF) & Activated Carbon Filter (ACF)	2003	49.0	80.0	85.0	12.0

5.4.5. Network Links

The WEAP model for the Barapullah catchment has the following network links: one showing river Yamuna; one Barapullah drain; one runoff link for the Barapullah catchment; 11 transmission links from the groundwater supply sources, imported surface water supply sources, and the treated wastewater from the WWTPs to the demand sites; and 19 return flow links from the demand sites and wastewater treatment plants either to river Yamuna or to the Barapullah drain.

The transmission link represents the conveyance of water from the supply source to the demand site. Of the total 11 transmission links, four are from the aquifer to the urban and industrial demand sites, two are from the imported surface water sources to the urban demand sites, and five are from the WWTPs to the treated water reuse demand sites (gardens and the power plant).

The return flow link simulates the return flows from the urban and industrial demand sites and from the WWTPs to the river or the drain. The latter simulates the treated wastewater that returns to the river or the drain. Of the total 19 return links, five are from the WWTPs to river Yamuna, three are from WWTPs to Barapullah drain, two are from industries to Barapullah drain, one is from urban area to the Barapullah drain, and eight from the urban and industrial demand site to the WWTPs. The return flow from the WWTP defines the fraction of the raw water which goes back to the supply sources as treated water.

Further, the conveyance losses for the transmission links are also defined. In the case of the transmission link from the imported surface water to the urban demand site, a conveyance loss of 20 percent is considered. And for the transmission link from the groundwater source to the urban and industrial demand sites, a conveyance loss of 5 percent is considered. No conveyance losses were considered for the return flow links.

5.4.6. Input Data for the WEAP Programme

Table 24 provides details of the data sets that are used for setting up the WEAP model.

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Table 24 Data sets used in the WEAP configuration for the Barapullah catchment

Particulars	Description	Time Period (Source)
DEM	Cartosat-1 DEM data	2015 (NRSC Hyderabad)
Land Use Land Cover	Reclassified to four classes- Water bodies, Urban, Forest and Agriculture	2016 (MODIS Land Cover Data)
Soil data	Three textural classes	2017 (Open Land Map)
Climate data	Rainfall	2000-2019 (India WRIS)
Streamflow	Based on monthly releases from Wazirabad barrage to river Yamuna	2000-2019 (Delhi Jal Board)
Runoff from the Barapullah catchment	Estimated by using the SCS curve number method	2000-2019
Groundwater quantity	Initial storage, groundwater recharge, withdrawal	2009-2020 (Central Ground Water Board)
Imported surface water	Inflow quantity	2009-2020 (Delhi Jal Board)
Urban water demand	Population, water use rate, and consumption are projected using 2011 data	2011 (Census of India)
Industrial water demand	Production units, water use rates, consumption	2010-2016 (Delhi Pollution Control Committee)
Yamuna river water quality	Parameters considered are Ammoniacal Nitrogen (NH_3-N), Biological Oxygen Demand (BOD), Electrical Conductivity (EC), Total Coliforms (TC), and Total Dissolved Solids (TDS)	2009-2020 (Central Water Commission and Central Pollution Control Board)
Barapullah drain water quality	Parameters considered are pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS)	2019-21 (Delhi Pollution Control Committee)
Quality of influent and effluent from the STPs	Parameters considered are Ammoniacal Nitrogen (NH_3-N), Biological Oxygen Demand (BOD), and Total Suspended Solids (TSS)	2019-21 (Delhi Pollution Control Committee)
Quality of influent and effluent from the CETP	Parameters considered are Ammoniacal Nitrogen (NH_3-N), Biological Oxygen Demand (BOD), Total Dissolved Solids (TDS), and Total Suspended Solids (TSS)	2019-21 (Delhi Pollution Control Committee)

5.4.7. POLLUTANT REMOVAL EFFICIENCY OF STPS IN BARAPULLAH CATCHMENT

The quality of treated wastewater that would finally enter Yamuna river would depend heavily on the pollutant removal efficiency of the STPs in the Barahpulla catchment. There are six sewage treatment plants (STPs) in the Barapullah catchment. The details of their existing treatment capacity, and the volume of sewage treated and reused are provided in one of the previous sections of this report.

Out of the six STPs, Molarband, Mehrauli, and Sen Nursing Home have one treatment unit each. The STPs at Vasant Kunj and Delhi Gate have two treatment units each. The biggest STP in the catchment, i.e. Okhla, has five treatment units.

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The average values (for the period from July 2019 to August 2020) of total suspended solids (TSS), biological oxygen demand (BOD), and the ammoniacal nitrogen in the influents and effluents for the six STPs are presented in Figure 94, Figure 95 and Figure 96 respectively. The average value of TSS in the influent ranges from 128 mg/l (for Delhi gate) to 261 mg/l (for Molar band) and in the effluent it ranges from a lowest of 6mg/l (Sen Nursing Home) to a highest of 35 mg/l (Mehrauli). The average BOD in influent is in the range of 86-202 mg/l and in the effluent it is in the range of 3-24 mg/l. The average ammoniacal nitrogen is in the range of 23.4-32.8 mg/l for influent, and 2.8-8.5 mg/l for effluent.

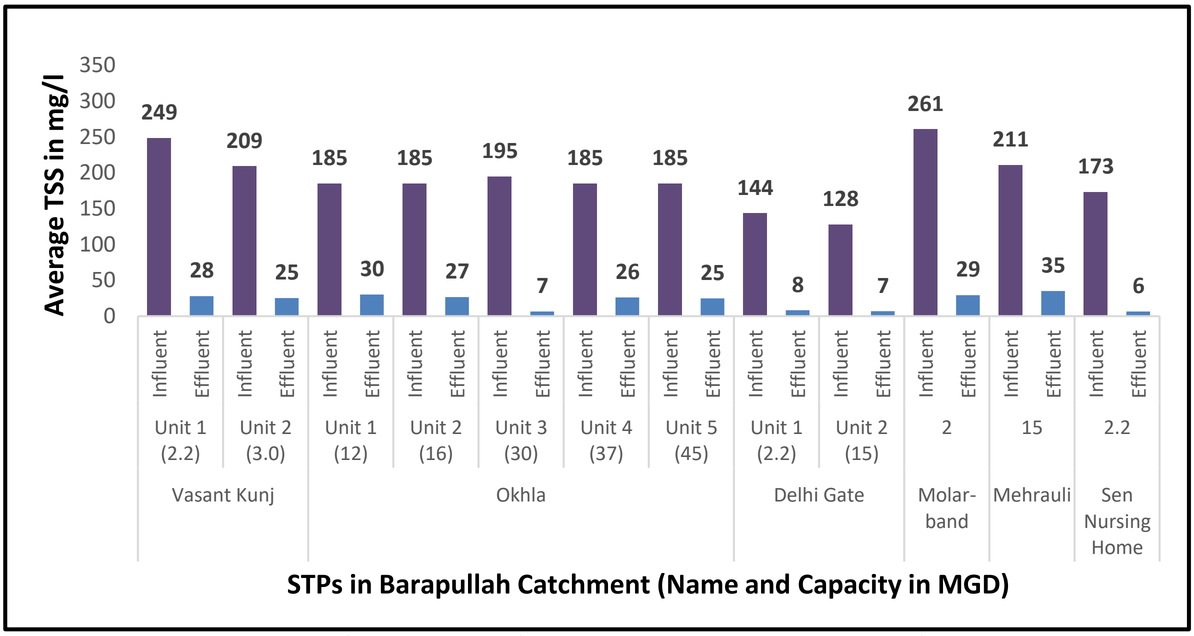

Figure 94: Average value (for the period from July 2019 to August 2020) of total suspended solids in the influents and effluents for the STPs in the Barapullah catchment

(Source: Analysis based on data accessed from Delhi Pollution Control Committee, Government of NCT of Delhi)

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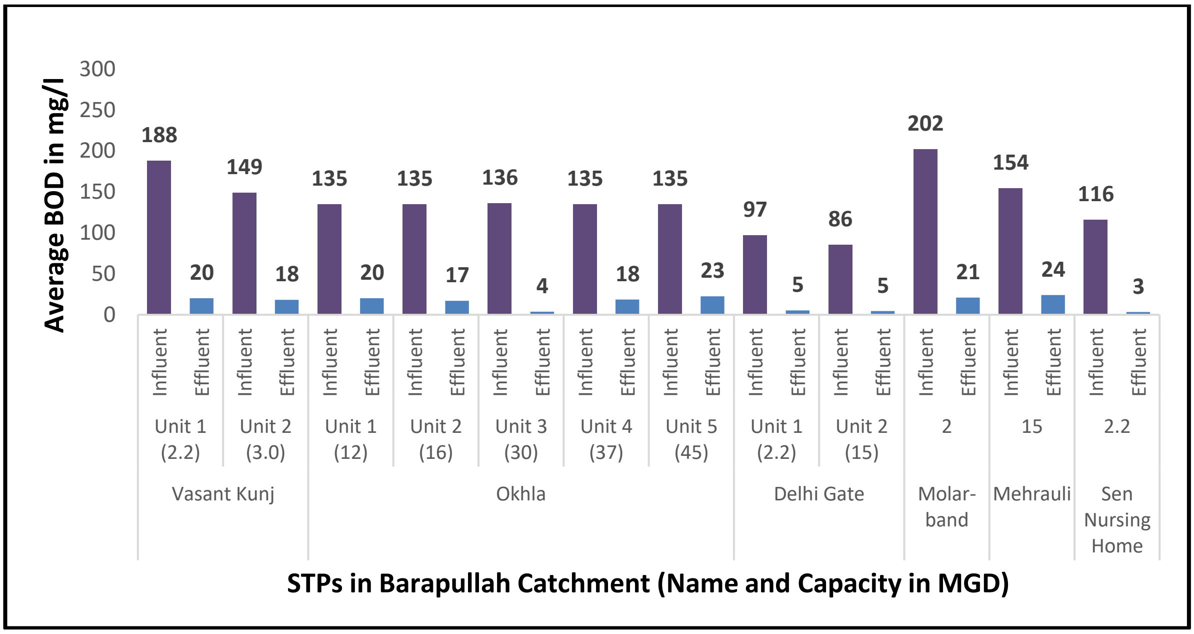

Figure 95: Average value (for the period from July 2019 to August 2020) of biological oxygen demand in the influents and effluents for the STPs in the Barapullah catchment

(Source: Analysis based on data accessed from Delhi Pollution Control Committee, Government of NCT of Delhi)

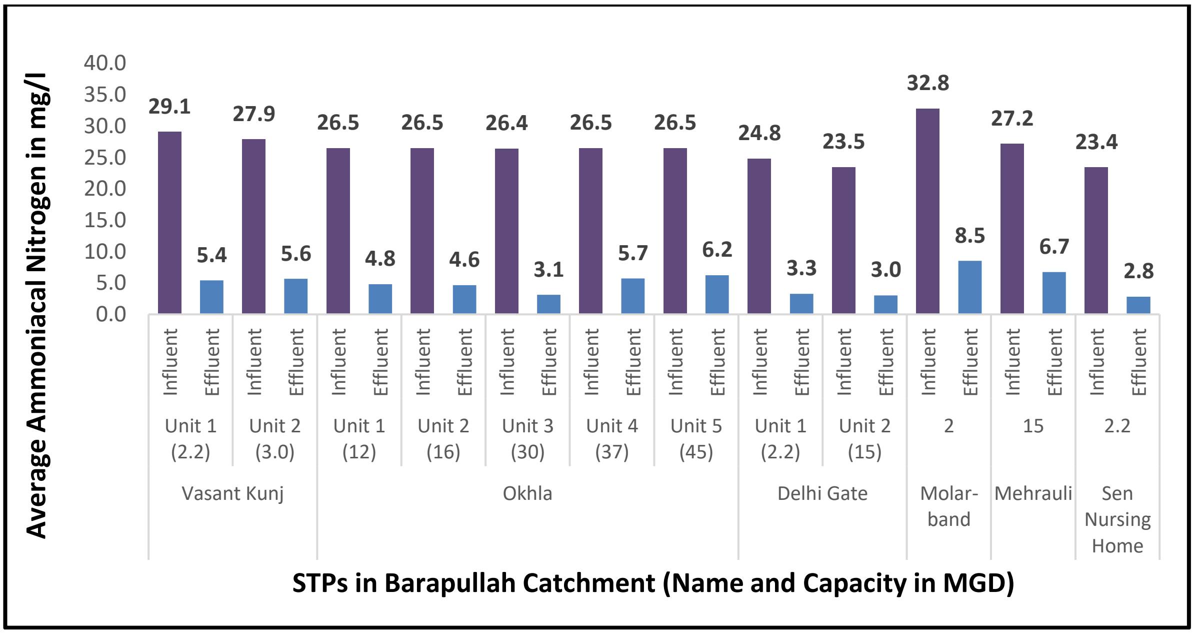

Figure 96: Average value (for the period from July 2019 to August 2020) of ammoniacal nitrogen in the influents and effluents for the STPs in the Barapullah catchment

(Source: Analysis based on data accessed from Delhi Pollution Control Committee, Government of NCT of Delhi)

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The unit-wise removal efficiency of the STPs for the three parameters, viz., TSS, BOD and Ammoniacal Nitrogen is presented in **Error! Reference source not found.**. At the aggregate level, the TSS and BOD removal efficiency of all the STPs is above 80%. For both these parameters, STP at Sen Nursing Home has the highest (96.4% for TSS and 97.1% for BOD) and that at the Mehrauli has the lowest removal efficiency (83.4% for TSS and 84.3% for BOD).

The ammoniacal nitrogen removal efficiency is also highest for the STP at Sen Nursing Home (88%), but it was lowest for the one at Molarband (74%). The STP at Okhla (average for all the five units together), having the largest treatment capacity in the Barapullah catchment, has the removal efficiency of 87.7% for TSS, 87.9% for BOD, 81.5% for ammoniacal nitrogen.

Table 25: Pollutant removal efficiency of STPs in Barapullah catchment

STP	Unit (Capacity in MGD)	Removal Efficiency (%)		
		TSS	*BOD*	*Ammoniacal Nitrogen*
Vasant Kunj	Unit 1 (2.2)	88.7	89.2	81.4
	Unit 2 (3.0)	87.8	87.7	79.8
Okhla	Unit 1 (12)	83.7	85.1	81.8
	Unit 2 (16)	85.5	87.5	82.5
	Unit 3 (30)	96.6	97.2	88.2
	Unit 4 (37)	85.9	86.3	78.5
	Unit 5 (45)	86.6	83.2	76.4
Delhi Gate Nalla	Unit 1 (2.2)	94.2	94.6	86.8
	Unit 2 (15)	94.6	94.7	87.0
Molarband	2	88.7	89.5	74.0
Mehrauli	15	83.4	84.3	75.2
Sen Nursing Home	2.2	96.4	97.1	88.0

(Source: Analysis based on data accessed from Delhi Pollution Control Committee, Government of NCT of Delhi)

5.4.8. Running the WEAP Model for Future Water Balance of Barahpulla Catchment

Presently, WEAP is used to model three future water balance scenarios. One is the 'reference scenario' which is also referred to as 'business-as-usual scenario', the second one is the 'high population growth scenario', and the third is the 'CETP improvement scenario'. The 'STP improvement scenario' is not considered as the installed capacity of STPs is sufficient for the population under the 'reference scenario' and the fact that the existing plants are operating at a high treatment efficiency. A detailed description of each scenario is provided in Table 4.

Table 4: Scenarios developed for WEAP model of KMA

Scenario	Description
Reference	▪ It is the 'business-as-usual scenario' where the human population and industrial outputs continue to grow as per the past trend, i.e., 1.3% and 4.1% per annum respectively. ▪ The STPs are operating at a NH_3-N removal efficiency of 77.9-89.5%, BOD removal efficiency of 82.9-95.1%, and TSS removal efficiency of 84.2-95.5%.

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	▪ The CETP is operating at a NH_3-N removal efficiency of 49%, BOD removal efficiency of 80%, TDS removal efficiency of 12%, and TSS removal efficiency of 85%. ▪ The rainfall-runoff relationship established based on data of rainfall and runoff during 2000-2019, is assumed to remain the same for the Barapullah catchment.
High Population Growth	▪ This scenario uses drivers that affect higher growth in water demand for consumptive use (domestic sector) in the KMA. ▪ It is assumed that the human population will grow at a higher rate than under the 'reference scenario'. ▪ The urban population is estimated to grow at 1.8% per annum. ▪ The industries continue to grow at the same rate as in the case of the 'reference scenario'. ▪ All the STPs are assumed to operate at the same removal efficiency for NH_3-N, BOD, and TSS as under the 'reference scenario'. ▪ The CETP is assumed to operate at the same removal efficiency for NH_3-N, BOD, TDS, and TSS as under the 'reference scenario'. ▪ The rainfall-runoff relationship for the catchment remains the same as considered for the 'reference scenario'.
CETP Improvement	▪ This scenario uses certain drivers/technologies which can improve the treatment capacity and efficiency of the CETPs. ▪ An additional CETP of 100 MLD capacity is introduced to serve the 'Industries 1' demand site. ▪ The capacity of the existing Okhla CETP is increased by 100 MLD and it is assumed that its treatment efficiency will be improved through the adoption of efficient technologies. ▪ For both the CETP (proposed and the existing one), it is assumed that the NH_3-N removal efficiency will be 80%, BOD and TSS removal efficiency will be 90%, and TDS removal efficiency will be 50%. ▪ The urban human population and the industries continue to grow at the same rate as in the case of the 'reference scenario'. ▪ The rainfall-runoff relationship for the catchment remains the same as considered for the 'reference scenario'.
High Economic Growth	▪ This scenario uses drivers that affect higher growth in water demand for consumptive use in the Barapullah catchment and can improve the treatment capacity and efficiency of the CETPs. ▪ It is assumed that the human population will grow at the same as rate as under the 'high population growth scenario'. ▪ It is assumed that the industries will grow at a higher rate than under the 'reference scenario'. They are assumed to grow at 4.5% per annum. ▪ The capacity and pollutant removal efficiency of CETPs is considered same as in the case of 'CETP improvement scenario'. ▪ All the STPs are assumed to operate with the same capacity and at the same removal efficiency for NH_3-N, BOD, and TSS as under the 'reference scenario'. ▪ The rainfall-runoff relationship for the catchment remains the same as considered for the 'reference scenario'.

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5.4.9. Results of WEAP Modelling for Barahpulla Catchment

This section provides the results obtained from the Water Evaluation and Planning (WEAP) model on the water availability, water demand and supply, river water quality, and wastewater quality in the Barapullah catchment for the present and the future years under different scenarios and compares them. The configuration of the WEAP model was set up for the period beginning 2009 and ending 2040. The year 2009 was taken as the base year (also referred to as 'current account') and the period 2010-2040 was considered for generating scenarios. Four scenarios, namely 'reference', 'high population growth', 'CETP improvement', and 'high economic growth' were developed and the results obtained under them were compared. A description of each scenario is provided in Section A.

→ **Yamuna River Water Availability at the ITO Barrage**

It is presented in the WEAP configuration for the Barapullah catchment in Section A that Barapullah drain outfall is between ITO and Okhla barrage. Figure 97 presents the annual surface water reaching the ITO barrage for the past, present, and future years during all the four scenarios[9]. It consists of water releases from the Wazirabad barrage (first one on the River Yamuna in Delhi) and the outfall of 12 drains up to the ITO barrage. The drains include Najafgarh, Sonia Vihar, Magazine Road, Sweeper Colony, Khyber Pass, Metcalf House, ISBT+ Mori Gate, Tanga Stand, Civil Mill, Shastri Park, Kailash Nagar, and the Delhi Gate. The estimated mean annual water availability at the ITO barrage for 32 years (2009-2040) is 3,632 million cubic metres (MCM). The water availability will be the highest (i.e., about 5,789 BCM) every fifth year. The lowest water availability for any year is about 2,357 MCM.

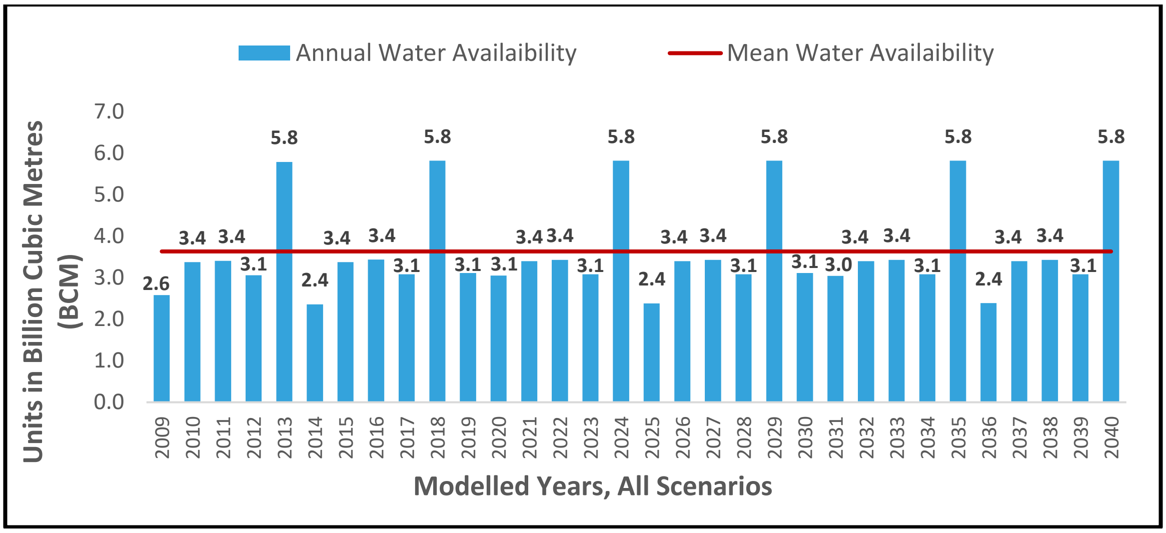

Figure 97: Water availability at the ITO barrage under the four scenarios

Further, during 2009-2030, the mean water availability will be highest during the three monsoon months, i.e., July-Sep (Figure 98). During the monsoon, water releases from the Wazirabad barrage are significant, however they reduce substantially during the non-monsoon months. Thus, during the non-monsoon months, the water availability at the ITO barrage represents mainly the discharge of the 12 drains.

[9] River Yamuna flow reaching the ITO barrage is considered to be the same under all the four scenarios.

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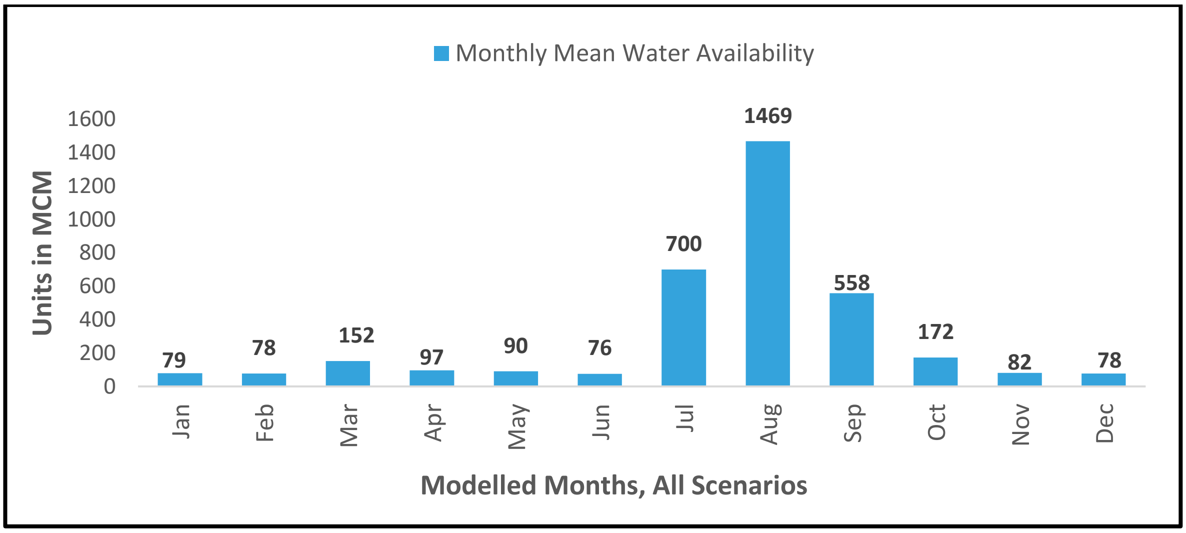
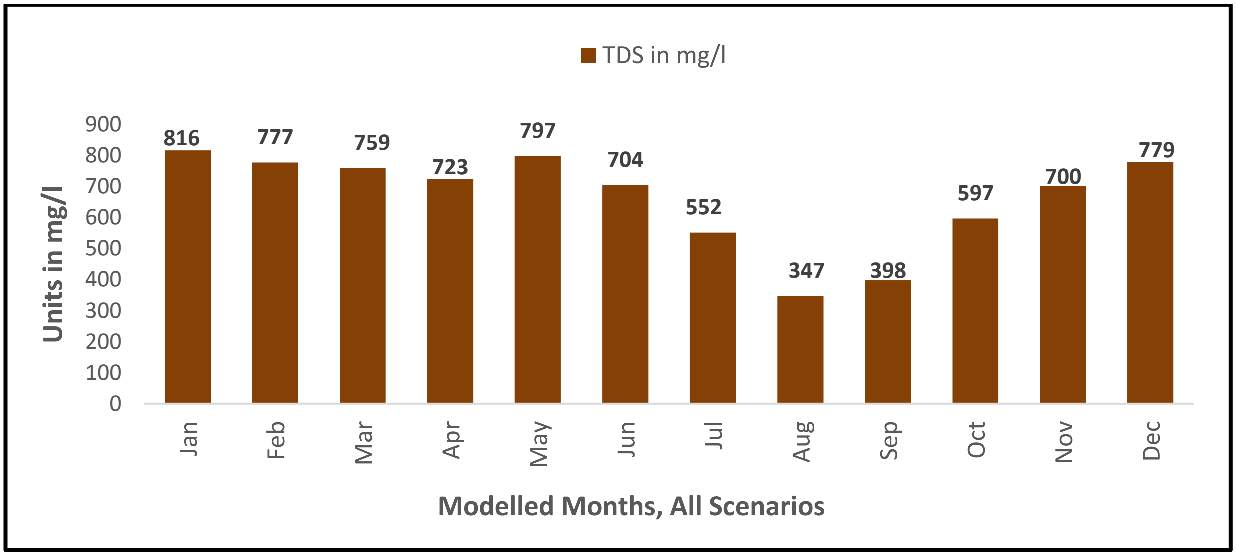


Figure 98: Monthly mean (2009-2040) water availability at the ITO barrage under the four scenarios

→ **Yamuna River Water Quality at the ITO Barrage**

The river water quality at the ITO Barrage for 2009-2030 under all the scenarios is presented in Figure 99, Figure 100, Figure 101, Figure 102 [10]. Overall, it shows that the monthly mean value of the four water quality parameters, i.e., total dissolved solids (TDS), bio-chemical oxygen demand (BOD), ammoniacal nitrogen (NH_3-N), and total coliforms (TC) start reducing from June up to August/September and increases thereafter. The observed water quality trend coincides with the substantially higher release of River Yamuna water from the Wazirabad barrage during the monsoon months (refer to Figure 98). This indicates that the concentration/value of the pollutants gets diluted between June and September.



[10] Yamuna water quality at ITO barrage is same under all the scenarios.

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Figure 99: Monthly mean (2009-2040) Total Dissolved Solids (TDS) value at the ITO barrage under the four scenarios

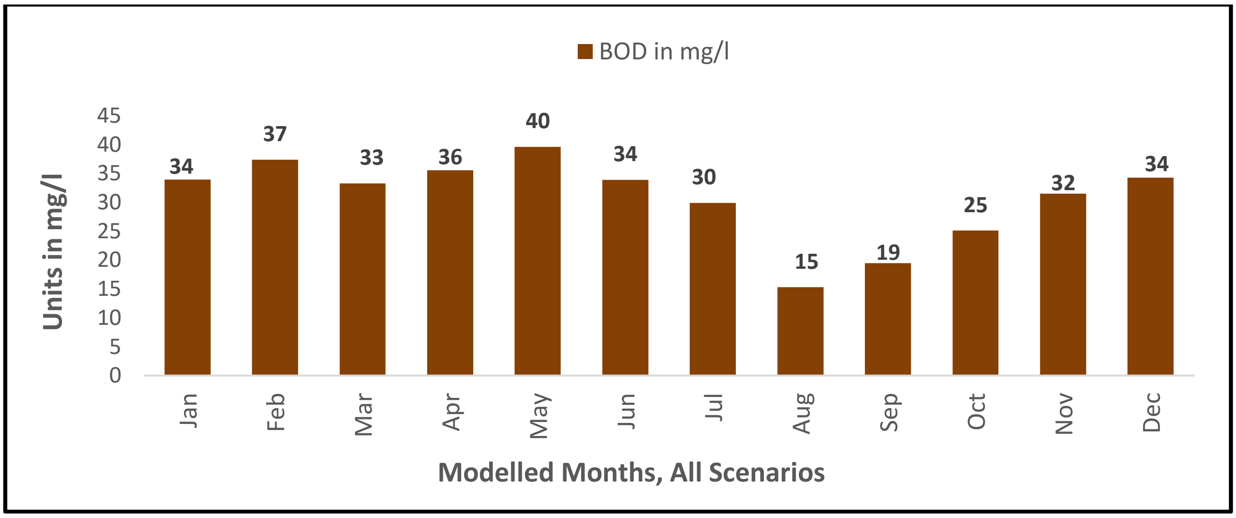

Figure 100: Monthly mean (2009-2040) Bio-chemical Oxygen Demand (BOD) value at the ITO barrage under the four scenarios

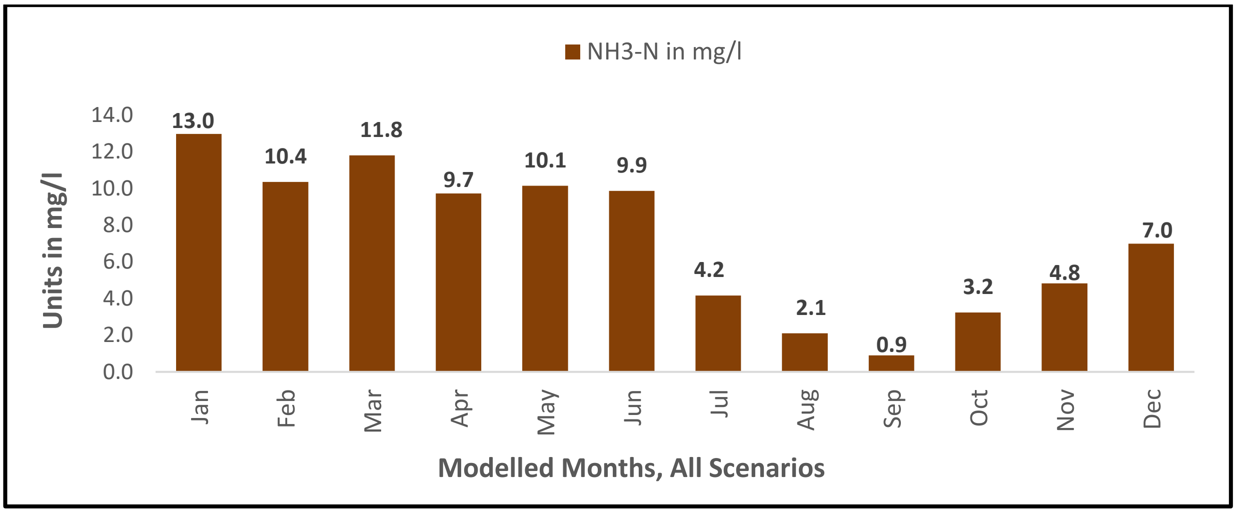

Figure 101: Monthly mean (2009-2040) Ammoniacal Nitrogen (NH3-N) value at the ITO barrage under the four scenarios

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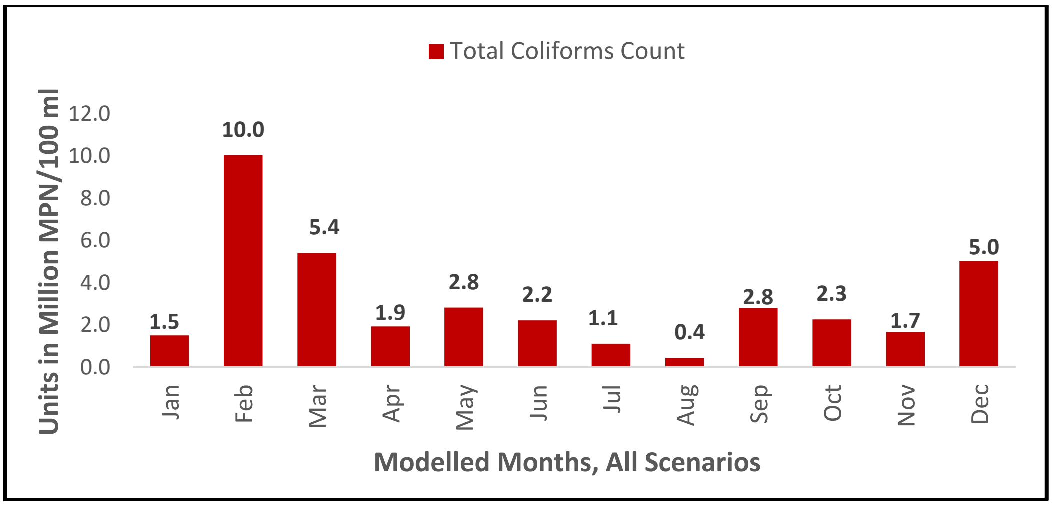

Figure 102: Monthly mean (2009-2040) Total Coliform (TC) Count at the ITO barrage under the four scenarios

→ **Unmet Water Demand**

The unmet water demand is the difference between the water supply requirement and the actual supply delivered (including conveyance losses) at the demand site. For this, urban and industrial sectors were considered. While, the urban domestic sector taps both imported surface water and groundwater, the industrial sector fully depend on groundwater supplies.

Till 2027, there would be no unmet water demand in the Barapullah catchment under the four scenarios. The groundwater reserves in the catchment would ensure the required water supplies. However, by 2028, there would be unmet water demand under the high population growth and high economic growth scenarios. For the other two scenarios (reference and the CETP improvement), water supply shortage will appear in 2037. By 2040, the annual unmet water demand at the aggregate level will be 54 MCM each under the reference and the CETP improvement scenarios[11], 92 MCM under the high population growth scenario, and 94 MCM under the high economic growth scenario. The results are presented in Figure 103.

[11] The unmet water demand under the reference scenario and the CETP improvement scenario is same as none of the drivers that can influence the water demand in the latter in comparison to the reference scenario were considered.

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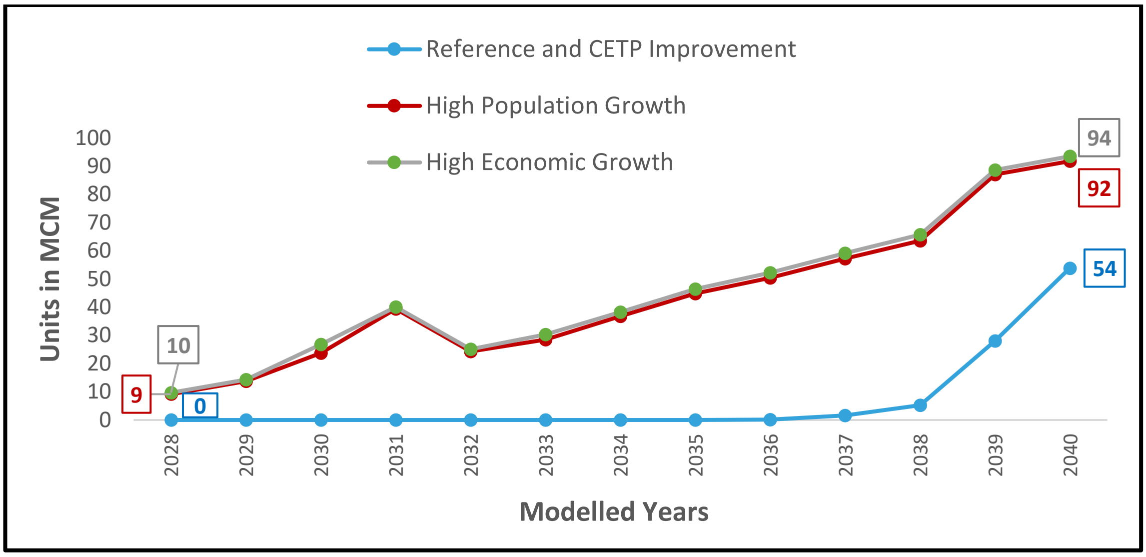

Figure 103: Unmet water demand at the aggregate level under the four scenarios in the Barapullah catchment

Sector-wise annual unmet water demand is presented in Figure 104, Figure 105. Under the four scenarios, urban domestic sector has the highest annual unmet water demand. By 2040, it will vary from 47 MCM under the reference scenario to 83 MCM under the high economic growth scenario, a difference of 36 MCM between the scenarios. For industries, the difference between the unmet water demand under the reference and high economic growth scenarios would be about 3 MCM by 2040.

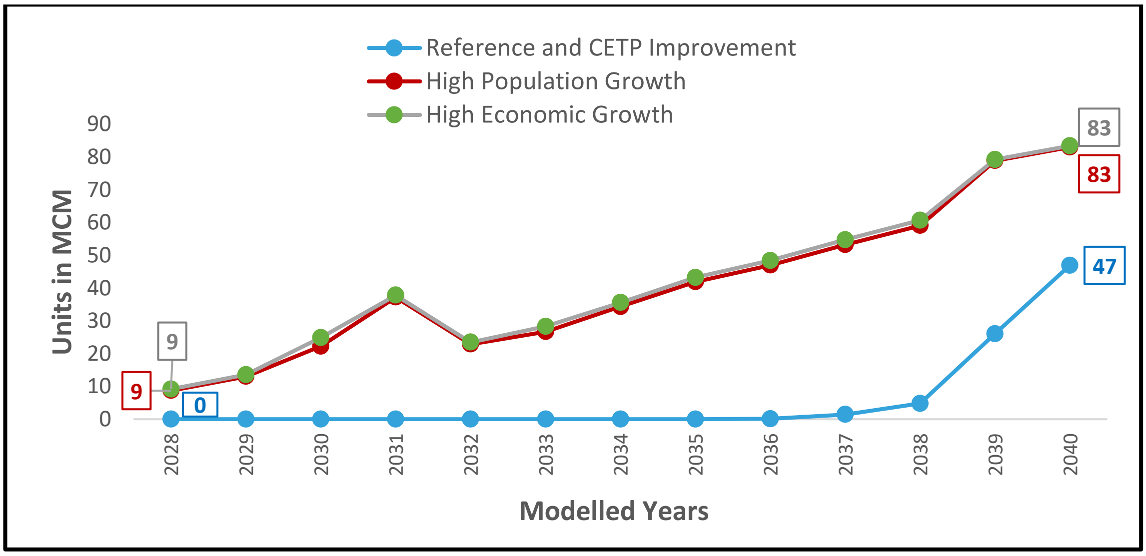

Figure 104: Unmet water demand in the urban sector under the four scenarios in the Barapullah catchment

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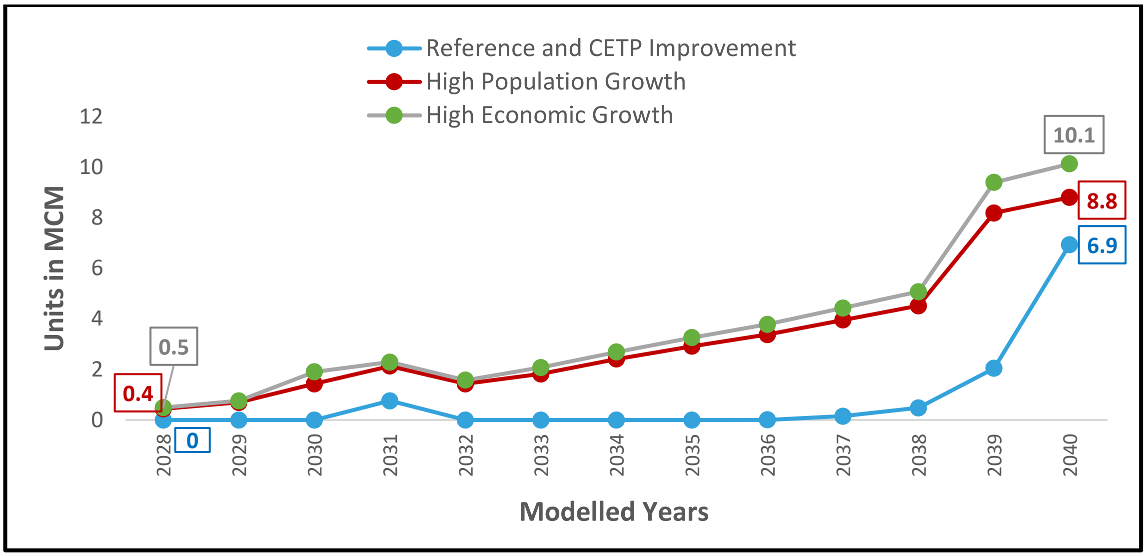

Figure 105: Unmet water demand in the industrial sector under the four scenarios in the Barapullah catchment

→ **Outflow from the Barapullah Catchment to River Yamuna**

It has been discussed in Section A that the entire estimated runoff from the Barapullah catchment is assumed to flow to the Barapullah drain. Further, the latter receives return flows from the urban areas, and the industrial units, and the treated effluents from the wastewater treatment (WWT) plants in its catchment. Five WWT plants in Barapullah catchment discharge effluents directly to river Yamuna[12]. Thus, the contribution of the Barapullah catchment to river Yamuna includes its runoff, the return flow from the domestic and economic sectors to Barapullah drain, and effluents from the WWT plants that are discharged directly to river Yamuna.

Figure 106 presents the quantity of the water (including treated and untreated wastewater) that flows from the Barapullah catchment to river Yamuna under the four scenarios[13]. It shows that the estimated mean annual outflow for 32 years (2009-2040) is 249 million cubic metres (MCM) each under the reference and CETP improvement scenarios, and 251 MCM each under the high population growth and high economic growth scenarios. Even under the high economic growth scenario, the annual outflow will increase by only 4 MCM by the end of 2040 in comparison to the reference scenario. Overall, the annual outflow from the Barapullah catchment to River Yamuna will be about 301 MCM and 305 MCM by 2040 under the reference and high economic growth scenarios respectively.

[12] It should be noted that though the Delhi Gate STP is within the Barapullah catchment, its outfall is before the ITO barrage. Therefore, it was considered as part of the river flow reaching the ITO barrage and excluded from the contribution of the Barapullah catchment.

[13] The outflow from the Barapullah catchment to river Yamuna under the reference and the CETP improvement scenarios are the same as the latter does not include any drivers that affect the water demand in the catchment in comparison to the reference scenario. Further, the outflow under the high population growth and the high economic growth scenarios are almost the same, as the water supplies does not change much between the two scenarios leading to no difference in the wastewater generation.

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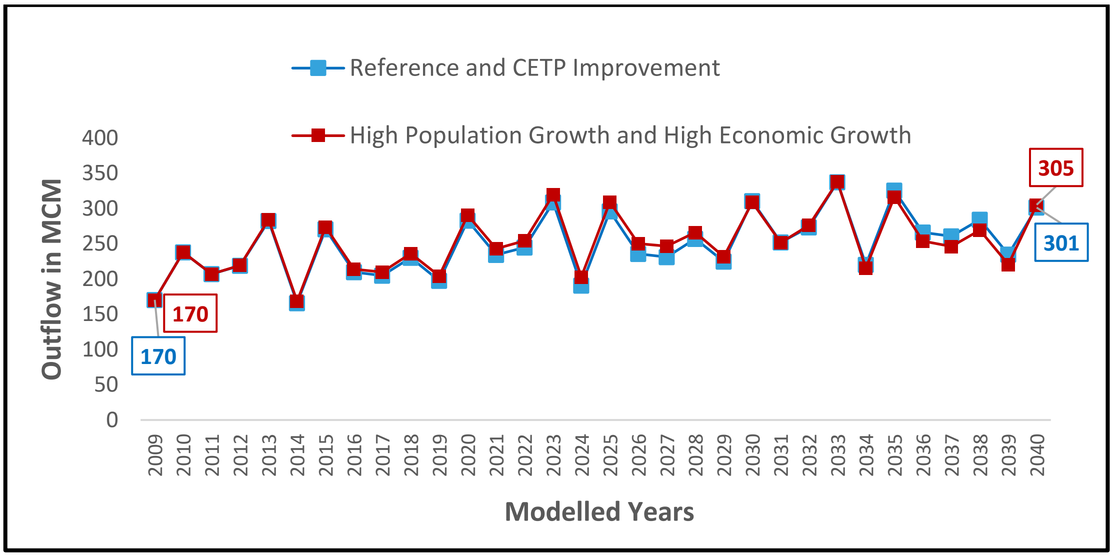

Figure 106: Contribution of Barapullah catchment to River Yamuna under the four scenarios

→ **Quality of Water in the Barapullah Drain**

The quality of water at the outfall of the Barapullah drain to river Yamuna for 2009-2030 under the reference scenario is presented in Figure 107. Overall, it shows that the monthly mean value of the three water quality parameters, i.e., TDS, BOD, and NH_3-N are the lowest during the monsoon months of July, August, and September. During the monsoon, Barapullah drain receives fresh rain water which leads to dilution of the pollutants received in the drain and thus improves in the drain water quality. The monthly mean concentration in the reference scenario was highest in October (553 mg/l) for the TDS, in December (97.4 mg/l) for the BOD, and February (49.0 mg/l) for the NH_3-N.

The changes in the concentration of the three water quality parameters (i.e., TDS, BOD, and NH_3-N) under the high population growth, CETP improvement, and high economic growth scenarios with reference to the reference scenario are presented in Figure 108, Figure 109, Figure 110. Under the high population growth and high economic growth scenarios, the mean monthly values (2009-2040) for BOD and NH_3-N increase (deterioration of the water quality) in comparison to the reference scenario (refer Figure 108 and Figure 110). The increase in the case of high economic growth scenario is the highest. However, the TDS decreases under both the scenarios in comparison to the reference scenario. But this is due to lack of data on the TDS of the effluents from the WWT plants. Nevertheless, as per the expected lines, the values of all the three parameters decrease (improvement in the water quality) under the CETP improvement scenario in comparison to the reference scenario (refer to Figure 109*Figure 110*).

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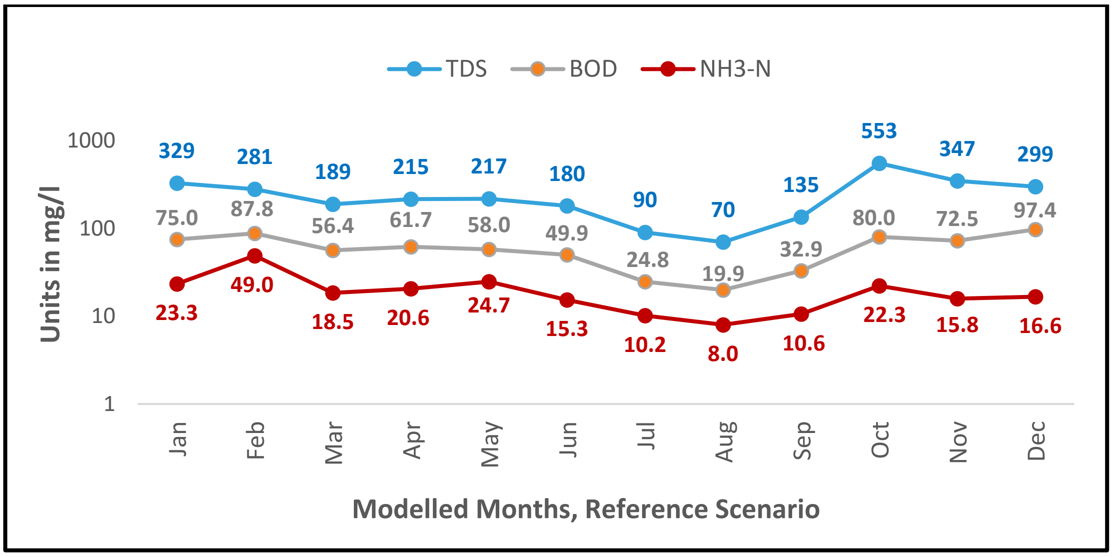

Figure 107: Monthly mean (2009-2040) values of the three water quality parameters at the Barapullah outfall to river Yamuna under the reference scenario

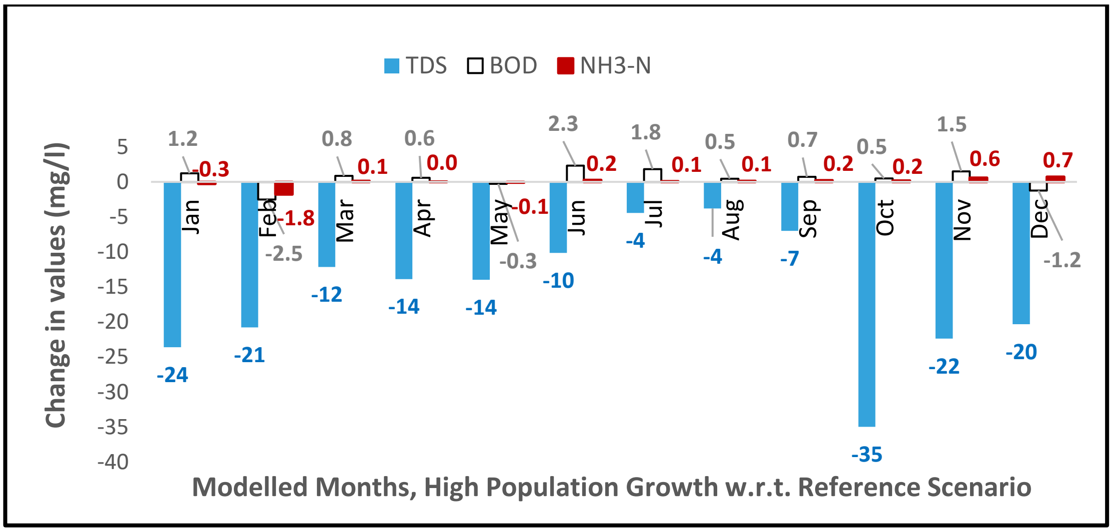

Figure 108: Changes in monthly mean (2009-2040) values of the water quality parameters under the high population growth scenario in comparison to the reference scenario

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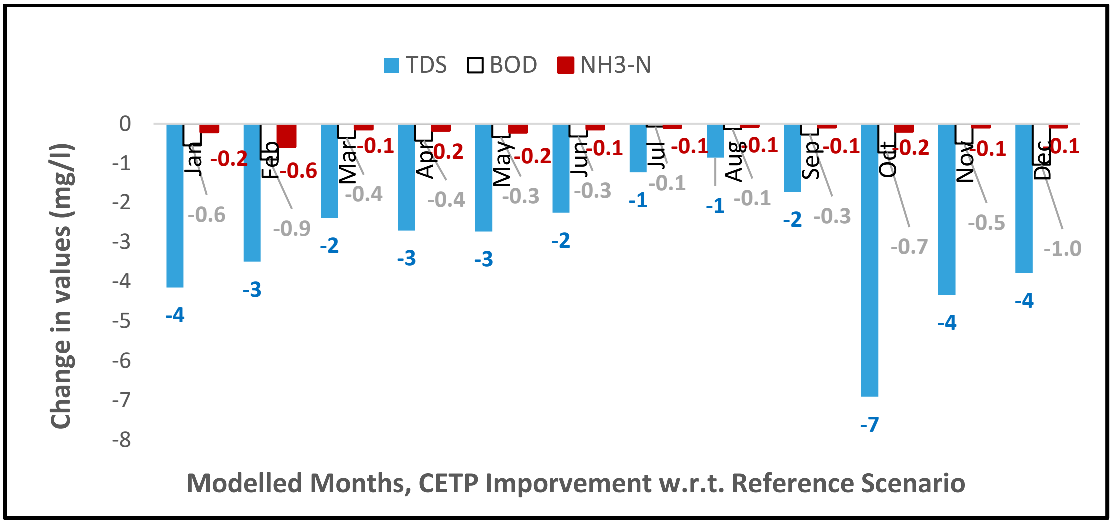

Figure 109: Changes in monthly mean (2009-2040) values of the water quality parameters under the CETP improvement scenario in comparison to the reference scenario

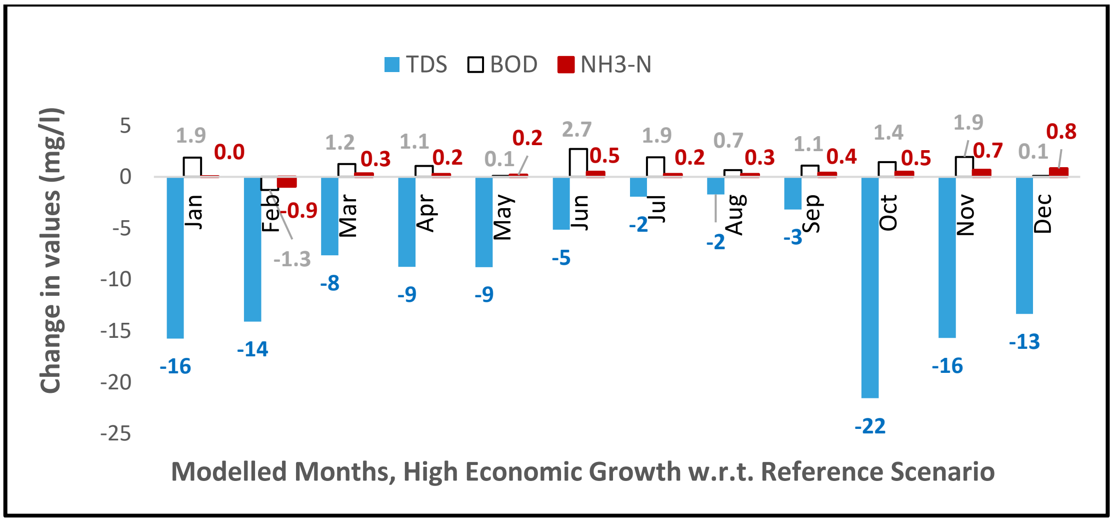

Figure 110: Changes in monthly mean (2009-2040) values of the water quality parameters under the high economic growth scenario in comparison to the reference scenario

→ **Climate Change Scenario for Barahpulla Drain**

Climate trends were incorporated into the Barahpullah WEAP model by estimating the annual rainfall for 2021 -2040 based on the rainfall trend of 1970-2020. The analysis historical rainfall for the period 2001-2020 showed a declining trend, with an average decline of 5.7 mm per year. Then annual runoff for the respective years was estimated based on the rainfall-runoff relationship developed for Barahpullah. The annual runoff values estimated from the rainfall- runoff relationship was distributed among the 12 months of the year based on the proportion of rainfall received during the corresponding months. Then the flow contributed by Barahpullah catchment to Yamuna River was estimated. The declining rainfall trends resulted in reduction of stream flow contribution from Barahpullah to Yamuna up to 42% by 2040. Figure 111 shows the changing

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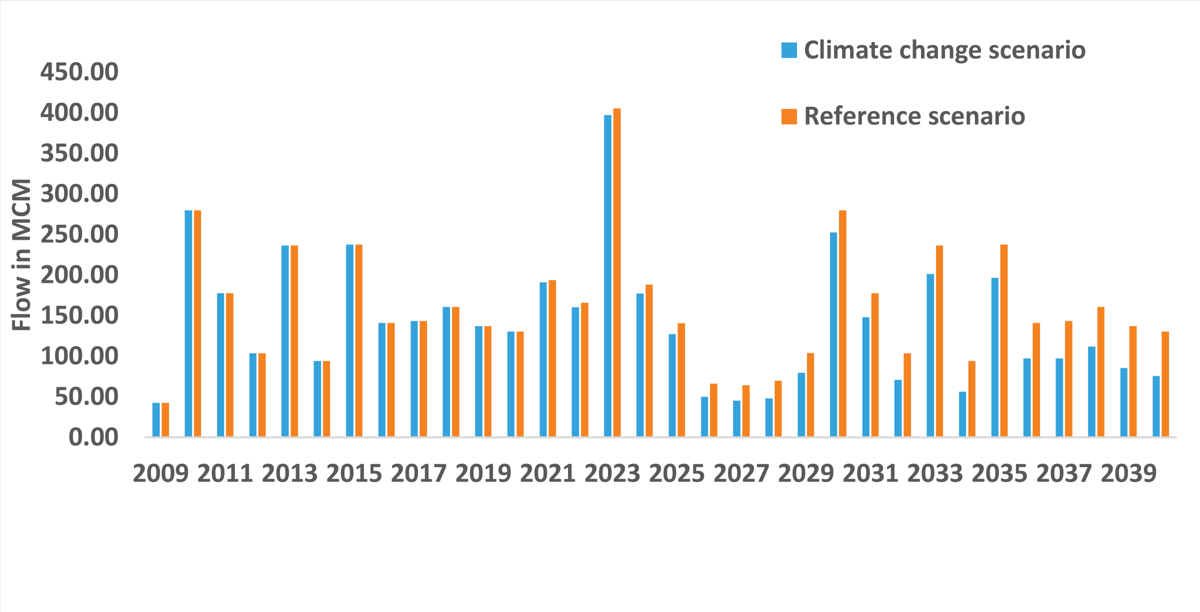
contribution of Barahpulla catchment to inflows in Yamuna River as per the model estimates for the time period from 2009 to 2040.

Figure 111: Changing Contribution of Barahpullah catchment to Yamuna River under Changing Precipitation



5.5. Conclusions from WEAP Modelling of the Two Pilot Areas

Overall, the modelling results show that the impact of **climate variability on the water supply-demand** situation and **water quality** is likely to be quite large, and larger than the impact of many of the socioeconomic changes (increased water demand, increased waste generation, etc.) in both the regions. The potential impact of the probable future change in rainfall on runoff from Barahpullah catchment to Yamuna river is much less than the impact of rainfall variability. Non-point pollution of groundwater from agriculture in Kanpur appears to be significant and needs to receive more attention in future. The analysis is quite indicative of the role of water quantity management and water allocation in managing river water quality--on an annual basis. In Kanpu**r**, availability of sufficient quantity of water to meet the demand is not a concern. What is required is building of adequate infrastructure for augmenting the supply in response to the growing demand. However, in Delhi, water demand reduction in the municipal & industrial sectors has to receive great attention as availabilityof the resource to augment the supplies is a constraint.

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CHAPTER 6 WATER QUALITY MONITORING USING MOBILE SENSORS

5.6. Original Water Quality Monitoring Plan

The plan during the first 12 months of the Pavitra Ganga project was to conduct water quality using hand held mobile devices. Due to COVID 19 restrictions this was unable to take place. In Kanpur the water quality monitoring plans have been established to take measurements at nine sites (Figure 112) using the Lovibond Photometer and the EC / pH hand held meter. The following parameters were to be monitored by IIT Kanpur staff on a monthly basis (Table 26).

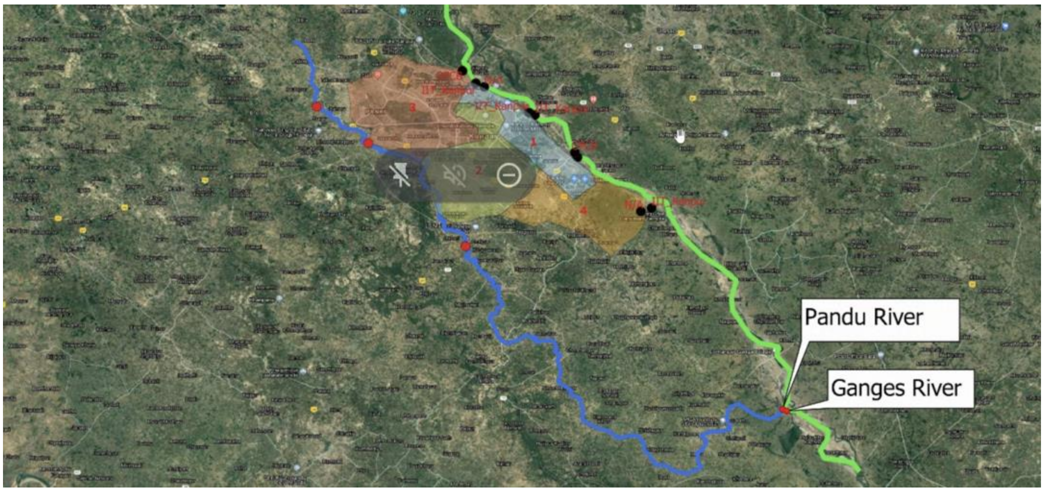

Figure 112: Location of the water quality monitoring sites in the Kanpur Metropolitan Area

Table 26: Water quality parameters to be monitored on a monthly basis

Parameter	Range	Testing method
Ammonia	0.02 - 2.5 mg/l N	Photometer
Phosphate	0 - 4 mg/l PO4	Photometer
Nitrate	1 - 30 mg/l NO3	Photometer
Nitrite	0.01 - 0.5 mg/l N	Photometer
Chromium-6	0.02 - 2 mg/l Cr	Photometer
Turbidity	10 - 1000 FAU	Photometer
Electrical Conductivity	0 - 20000 us/cm	Sensor
Temperature	0 - 60 °C	Sensor
pH	0 – 14	Sensor

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DO	0 - 20 mg/l O2	Sensor
COD	-	Lab

IIT Kanpur carried out an assessment of the handheld photometer provided by AKVO for the project – comparing measurements taken by the hand held devices and measurements in the laboratory. pH, EC and DO measurements performed well, phosphates and ammonia measurement gave indications but were not accurate, and CrVI measurements showed a very large difference between the in-situ measurements and the lab protocols. On the basis of the assessment a campaign of monthly measurements at 9 sites for 12 months was dropped. It was proposed therefore that the handheld photometer is only used for restricted number of parameters and monitoring drinking water from handpumps.

5.7. Revised Water Quality Monitoring plan

A citizen based water quality monitoring plan was devised for the two project case areas with the following broad objectives:

- Demonstrate the efficacy of using mobile water quality tools (Akvo Caddisfly) to explore existing water quality issues at these sites
- Generate data using mobile water quality monitoring tools to assess ambient water quality along with contextual information on water resource use and flag up potential water quality issues
- Monitor the potential impact of wastewater on groundwater in project locations especially in Kanpur.

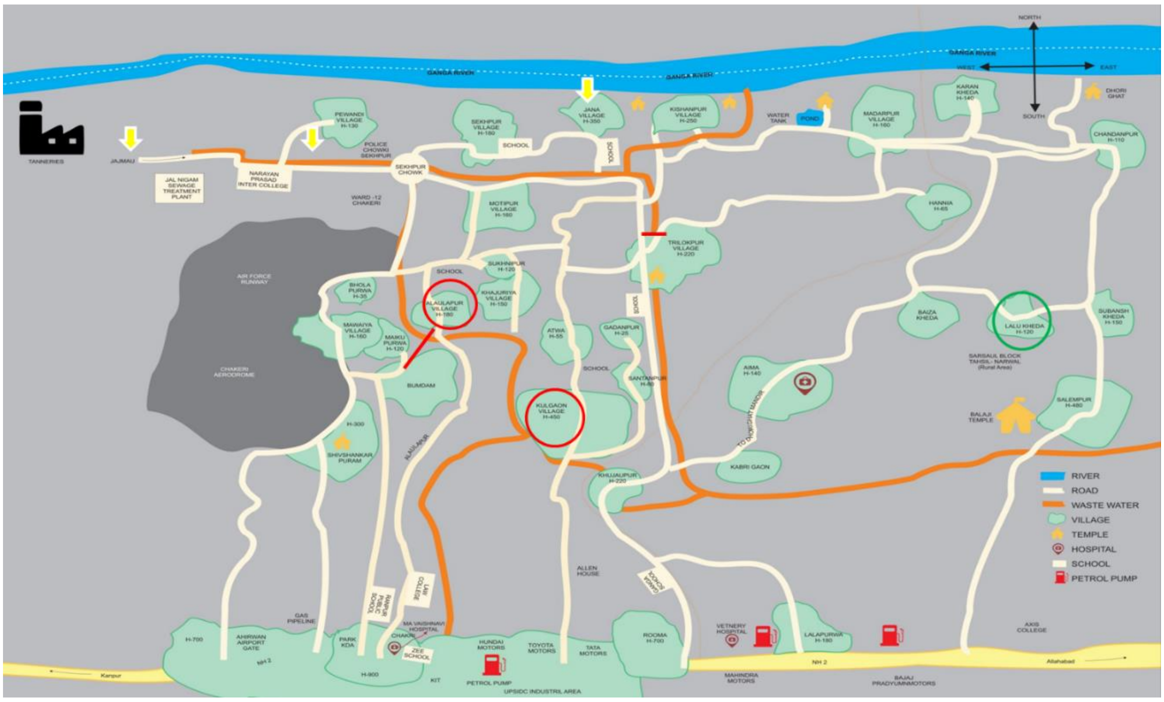

Figure 113: Map of the villages in the Jajmau Wastewater Re-use Irrigation Scheme

The information from the monitoring and the village surveys would be integrated into the overall assessment of the water management challenges in the two case areas.

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Approach

Akvo implemented the baseline survey employing the following approach:

- Defined the scope of monitoring campaign to focus on screening water quality for groundwater sources such as handpumps, submersible pumps, wells as found in the project sites;
- Focus on facilitating capacity building of regional organisation (Solidaridad) on testing and understanding local water quality challenges;
- Introduce easy to use, portable Akvo Caddisfly with simplified design, and user support to enable individuals (from Solidaridad) without extensive scientific backgrounds and technical knowledge to monitor and assess the quality of their local water resources effectively; and,
- Data collection offered an opportunity to engage with community to contribute of selection of sampling points, and share observations about quality, quantity and usage of their water sources.

5.8. Scope and methodology

- Monitoring in both locations was conducted in two periods: February/March and June/July, 2023. Selected groundwater sources in each village / unauthorised colonies were mapped
- Samples were tested for Electrical Conductivity, pH and Nitrate. The parameters are proposed by GEMS/UNEP to monitor ambient water quality (UNEP, 2018) to assess the "Proportion of bodies of water with good ambient water quality" (SDG 6.3.2). Within this approach, it is recommended to engage with citizens in their water quality monitoring using handheld devices to complement laboratory methods.
- Along with water quality tests, data was collected on general Information about the village, usage and functionality of the sampled sources and perception and exposure of health risks

Figure 114: Mobile Water quality monitoring tool, Akvo Caddisfly

a. Data Collection: Delhi

- 13 water samples (2 HP and 11 Borewell) were tested during the first round of monitoring. These samples were taken around the Barapullah drain catchment area ("upstream" / "mid-stream" / "downstream" areas) with support of TERI. Data collection was conducted by Solidaridad.
- In the second round of monitoring, we could only sample 9 sources due to unavailability of persons from whose houses the data was collected earlier.

b. Data Collection: Kanpur

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- Monitoring was conducted in six villages in Kanpur; Motipur, Trilokpur, Pewandi, Alalualpur, Kulgaon and Kishanpur. The criteria for selecting these villages is their location along the irrigation channel (connected to the Jajmau STP) and a combination of concrete lined irrigation and earthen irrigation canal. In total 30 samples were collected from the six villages.
- In each village, five groundwater sources are monitored (total 30 water sources) mainly included submersible pumps and handpumps
- Along with water quality tests, data was collected on general Information about the village, usage and functionality of the sampled sources and perception and exposure of health risks

Figure 115: Water quality monitoring in Kanpur and Delhi

5.9. Key Summary of Monitoring Results

5.9.1. Results: Delhi

	pH May	pH October
Barah pullah surya ghadi 6 - Handpump	7.46	7.98
Chilla 7 - Handpump	7.28	7.44
IHC - Borewell	7.51	6.93
Jaganath Mandir - Borewell	7.51	5.29
Lodhi Garden Glasshouse - Borewell	7.31	7.93
Mehar Chand Harijan Camp - Borewell	7.41	7.04
Sanatan Mandir Jangpura - Borewell	7.32	7.79
Sanathan mandir panthnagar - Borewell	7.34	7.93
Sarai kalekhan, ganga vihar - Handpump	7.81	7.22

	EC (May)	EC(October)
Barah pullah surya ghadi 6 - Handpump	1013	563
Chilla 7 - Handpump	1626	2220
IHC - Borewell	2080	2500
Jaganath Mandir - Borewell	1603	1466
Lodhi Garden Glasshouse - Borewell	1427	2250
Mehar Chand Harijan Camp - Borewell	1359	1360
Sanatan Mandir Jangpura - Borewell	1223	1161
Sanathan mandir panthnagar - Borewell	1917	1400
Sarai kalekhan, ganga vihar - Handpump	591	562

	Nitrate (May)	Nitrate (October)
Barah pullah surya ghadi 6 - Handpump	7.8	16.5
Chilla 7 - Handpump	8	8.8
IHC - Borewell	12	14.3
Jaganath Mandir - Borewell	>30	25.9
Lodhi Garden Glasshouse - Borewell	17.8	1.4
Mehar Chand Harijan Camp - Borewell	17.5	14.3
Sanatan Mandir Jangpura - Borewell	23	11.4
Sanathan mandir panthnagar - Borewell	>30	14.7
Sarai kalekhan, ganga vihar - Handpump	18.2	8.3

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Figure 116: Comparison of water quality parameters (pH, EC and Nitrate) in Delhi

- pH concentrations measured in the sampled sources remained consistently within the permissible limits for drinking (6.5-8.5) throughout the two monitoring cycles. However, at one of the sampling locations, a recorded pH concentration below 6.5 indicated an acidic condition.
- Electrical Conductivity in both monitoring rounds was recorded within the acceptable limit (> 2500 µS/cm)
- During the initial monitoring round in May 2023, two water sources, Jaganath Mandir and Sanathan Dharam Mandir, recorded nitrate concentrations exceeding 30 mg/l. However, these concentrations were reduced in the subsequent monitoring in October 2023. These sources are primarily utilized for bathing and cleaning purposes rather than drinking and cooking. It's also important to mention that the permissible limit of nitrate in drinking water in the Indian context is 40 mg/l.
- Additionally, the Nitrate results varied in a few sampling points between the two monitoring rounds.

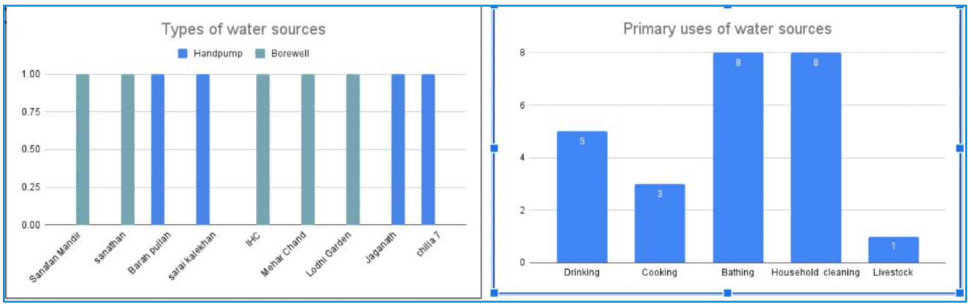

Figure 117: Type and primary usage of selected sampling points

- All sampling points monitored are mainly used by institutions such as temples, office complex or are public than private. The largest number of users are observed for two sampling points (7000-8000 users).

5.9.2. RESULTS: KANPUR

- In Alaulapur, pH concentration observed in sampled sources remained constant and within the permissible limits for drinking (6.5 -8.5) through the two monitoring cycles. However, one of the sampling locations recorded a concentration lower than 6.5 on the pH scale indicating its acidic.
- EC readings were within acceptable limits in the October esp. one of the sampling point which recorded 4940 µS/cm in May and significantly reduced during October
- Type of water sources selected in this village are Handpump and the type of irrigation channel is concrete lined

Alaulapur					
pH (May)	pH (October)	EC (May)	EC (October)	Nitrate (May)	Nitrate (October)
7.51	7.28	4940	1930	12.2	10.9
7.63	6.44	1910	1817	12.1	24.0
7.66	5.81	2250	1167	14.1	13.6
7.73	7.18	828	1249	14.5	14.7
7.86	6.53	1050	1254	18.5	14.3

Figure 118: Comparison of water quality results from Alaulapur

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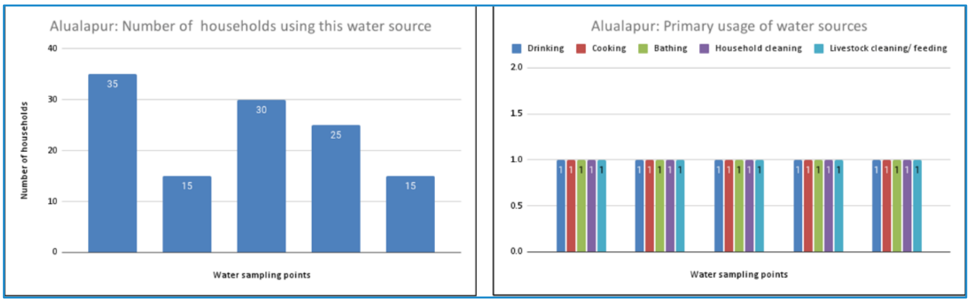

Figure 119: Number of households using the selected water sources and its primary usage (Alaulapur)

- In Kishanpur, EC readings of the two sampling points normalized during the second monitoring round as compared to reading above 2500µS/cm in May
- Nitrate concentration in three water sources reduced significantly during the second monitoring round except for one sampling point that was still observed >30 mg/l
- Kishanpur has earthen lining to the irrigation channel, possibly pervades into groundwater

Kishanpur					
pH (May)	pH (October)	EC (May)	EC (October)	Nitrate (May)	Nitrate (October)
6.89	7.86	1388	1435	>30	18.3
7.04	6.78	1301	1131	>30	15.2
7.45	5.34	4230	1394	>30	11.6
7.5	5.65	4710	1150	>30	>30
8.11	7.48	1397	1510	12.7	11.1

Figure 120: Comparison of water quality results from Kishanpur

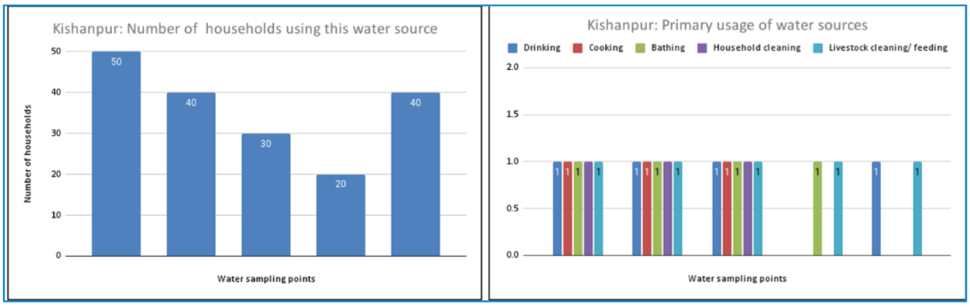

Figure 121: Number of households using the selected water sources and its primary usage (Kishanpur)

- In Kishanpur, 4 handpumps and 1 well was selected as sampling points
- Type of irrigation channel in this village: Earthen

Shiekpur					
pH (May)	pH (October)	EC (May)	EC (October)	Nitrate (May)	Nitrate (October)
7.11	7.76	3140	1978	25.5	11.9
7.33	8.39	3550	1976	17.5	19.5
7.4	6.14	4400	1497	23.5	20.1
7.44	7.91	4910	1422	22.8	15.9
7.66	7.85	5690	1426	12.8	12.6

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Figure 122: Comparison of water quality results from Shiekhpur

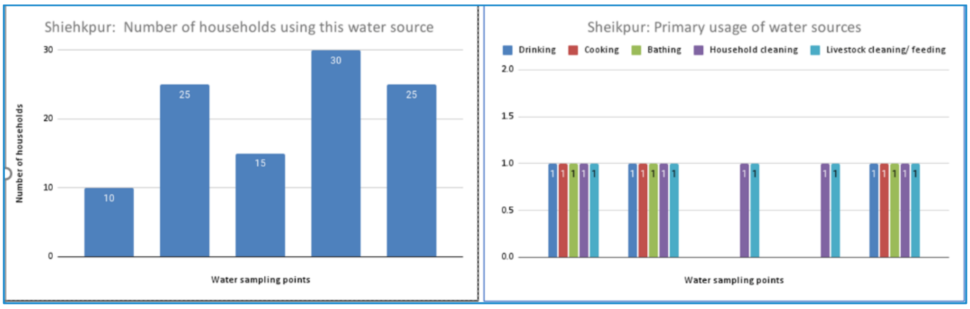

Figure 123: Number of households using the selected water sources and its primary usage (Shiekhpur)

- pH concentrations at sampling points in Shiekpur remained within permissible limits (6.5 -8.5) during both monitoring cycles
- In contrast to the elevated EC reading (>2500µS/cm) observed in the initial monitoring round, the values were observed within the acceptable limits during the October monitoring round.
- As observed in the first monitoring round, two of the selected water sources not used for drinking or cooking by households
- Type of water sources selected in this village are mostly Handpumps
- Type of irrigation channel in this village is Earthen
- Two water sources that were sampled were neither used for drinking or cooking. One of these water sources happens to be used by maximum number of households in the village but mostly for household cleaning or livestock cleaning

Trilokpur					
pH (May)	*pH (October)*	*EC (May)*	*EC (October)*	*Nitrate (May)*	*Nitrate (October)*
7.68	6.95	1611	5090	17	>30
7.81	5.9	1297	1482	27.8	17.3
7.83	7.59	1628	2220	19.5	20.6
7.93	7.69	1400	1302	29	<1
8.34	7.25	624	5430	20.1	26.4

Figure 124: Comparison of water quality results from Trilokhpur

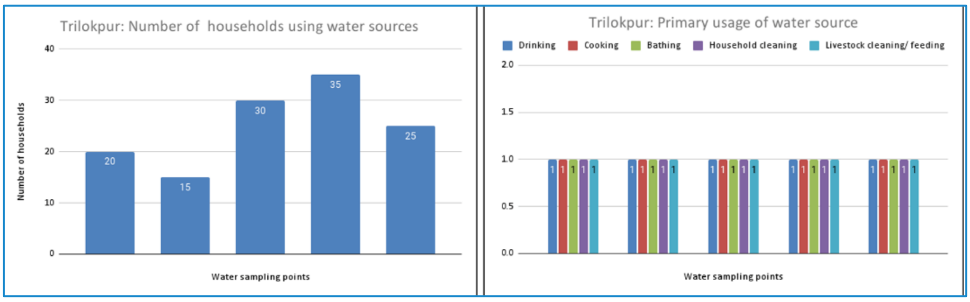

Figure 125: Number of households using the selected water sources and its primary usage (Trilokpur)

- In Trilokpur, the pH concentration at one of the sampling points fell below the permissible limit, suggesting an acidic condition.
- During the October monitoring, elevated EC readings were noted at two sampling points, in contrast to the previous monitoring round.

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- Furthermore, at one of the sampling points where elevated EC readings were recorded in October, there was also an observation of nitrate levels exceeding >30 mg/l
- Handpump was selected as main source of sampling points
- Type of irrigation channel in this village is Concrete

Kulgoan					
pH (May)	pH (October)	EC (May)	EC (October)	Nitrate (May)	Nitrate (October)
7.44	7.28	2950	2090	11.7	15.8
7.5	7.03	2100	2930	18.8	13.8
7.54	7.13	2160	3400	23.1	21.5
7.55	7.52	1492	2950	10	19.5
7.59	7.42	118	1681	15	16.2

Figure 126: Comparison of water quality results from Kulgaon

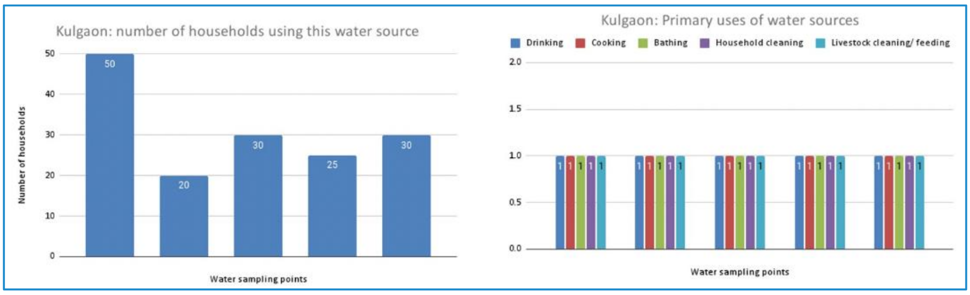

Figure 127: Number of households using the selected water sources and its primary usage (Kulgoan)

- In Kulgoan, EC was observed higher than the acceptable limit in three sampling points
- pH concentration was recorded lower than the permissible limit (6.5 - 8.5) in two sampling points in the second monitoring cycle in Motipur

Motipur					
pH (May)	pH (October)	EC (May)	EC (October)	Nitrate (May)	Nitrate (October
7.61	7.37	1870	2290	12.1	9.6
7.69	5.59	1797	2330	12.5	16.0
7.72	5.81	1327	2230	11.2	18.1
7.83	6.0	925	2290	17.6	20.9
8.3	7.43	2610	1880	13.7	12.2

Figure 128: Comparison of water quality results from Motipur

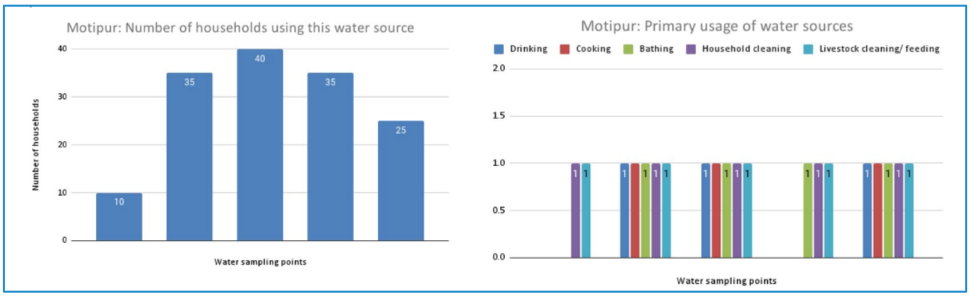

Figure 129: Number of households using the selected water sources and its primary usage (Motipur)

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- In Motipur, pH concentration was recorded lower than the permissible limit (6.5 - 8.5) in two sampling points in the second monitoring cycle
- Two water sources are not used for drinking or cooking by the households. Out of which, one is used by minimum number of households that were sampled in Motipur
- Type of water sources selected in this village are handpumps
- Type of irrigation channel in this village is Concrete
- Only 3 out of 5 water sources were used for cooking / drinking

5.10. CONCLUSIONS

The monitoring data collected through Akvo's baseline survey in Delhi and Kanpur provides insights into the water quality and management challenges in the selected villages and case areas. The parameters ph, EC and Nitrates are proposed by GEMS/UNEP to monitor ambient water quality (UNEP, 2018) to assess the "Proportion of bodies of water with good ambient water quality" (SDG 6.3.2). The use of Akvo Caddisfly, with its simplified design and user support, facilitated the participation of individuals from Solidaridad in water quality testing. Individuals from Solidaridad had a strong background in community facilitation and outreach but limited expertise in monitoring and assessing local water resources effectively. The collaborative approach, engaging the community in selecting sampling points and sharing observations, enhanced the overall data gathering process.

In both Delhi and Kanpur, the pH concentrations of the sampled water sources generally remained within the permissible limits for drinking. However, occasional deviations, particularly towards acidity, emphasize the need for continued monitoring and potential remediation measures. Electrical Conductivity (EC) readings across the monitored sources were consistently within acceptable limits, indicating overall compliance with acceptable standards.

Notably, instances of elevated nitrate concentrations in specific water sources were observed during the initial monitoring round in May 2023, particularly in Delhi. However, subsequent rounds showed a reduction in nitrate levels. Understanding the varied usage of water sources, such as for bathing and cleaning purposes rather than drinking, is crucial for appropriate interpretation and future deliberation.

The variation in nitrate levels between monitoring rounds highlights the dynamic nature of water quality and underscores the importance of continuous monitoring to capture temporal fluctuations. The results also point out the significance of considering the specific functions of water sources, as certain locations may be more prone to contamination due to their usage patterns or other reasons that could not be captured in detail during the baseline data collection.

In Kanpur, the differentiation between villages with concrete and earthen irrigation channels was observed. The collaboration with Solidaridad demonstrates the success of capacity-building efforts in enabling NGOs to contribute meaningfully to water quality assessments.

In conclusion, the monitoring results emphasize the need for sustained efforts in water quality management, community engagement, and continuous capacity building. It demonstrates a promising model for empowering non-experts to contribute to water management initiatives and understand water challenges in diverse communities, laying the foundation for informed decision-making and targeted interventions.

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ANNEX A

Additional figures of Kanpur region water treatment plants.

Figure 130: Layout of STP1.

Figure 131: CETP layout.

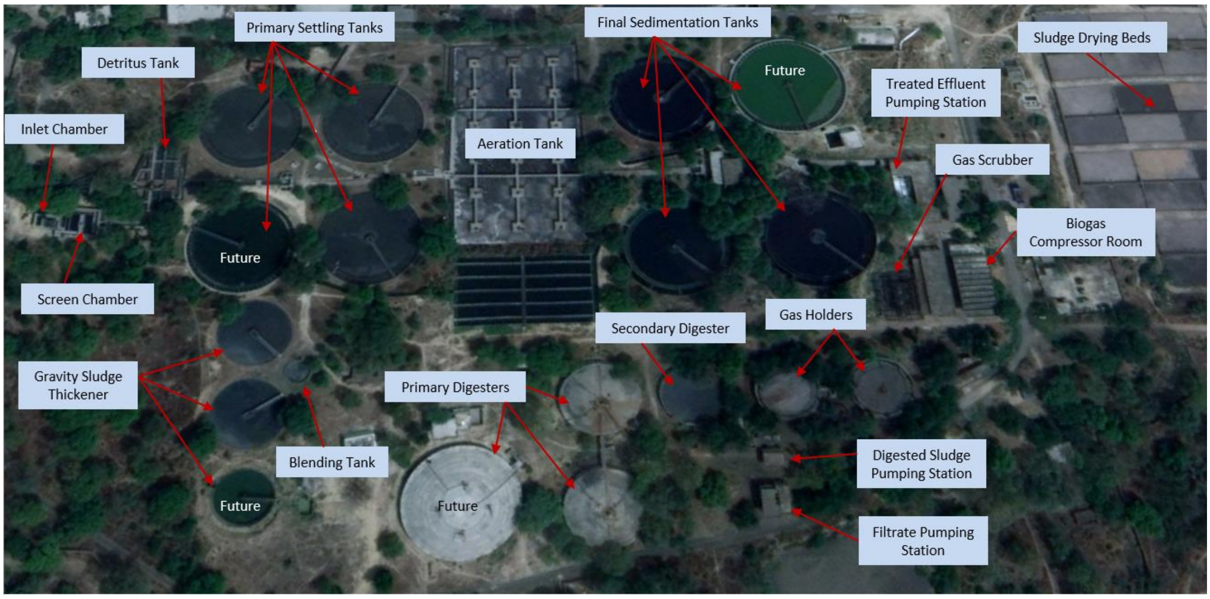

Figure 132: STP2 layout.

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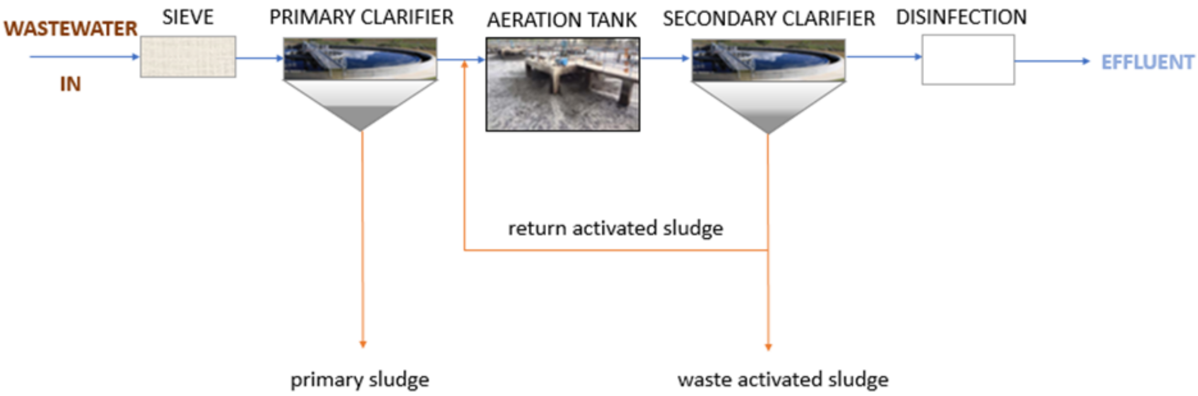

Figure 133: Activated sludge process scheme of 130 MLD plant.

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ANNEX B

Table 27: Example extract of data from the WRIS website for monthly water quality data.

Name	**Delhi Railway Bridge**
Basin	GANGA
State	DELHI
Lat, Long	28.65916667, 77.245
Class	E
PH	7.577
EC (µmhos/cm)	1363.907
SAR	3.939
RSC	0.100
CHLORIDE	189.947
CA	63.315
MG	31.350
BICARBONATE	276.476
SULPHATE	112.528
FLUORIDE	0.544
TOT_ALKALINITY	235.303
NITRATE	0.014
K	15.454
NA	159.772
CARBONATE	0.267
FE	0.233
DO (mg/l)	1.371
BOD (mg/l)	35.692
TC (MPN/100ml)	176471.063
N (mg/l)	12.457
B (mg/l)	0.365
Alk-Phen	0.220
TDS	826.855
COD	61.156
SS	1.929
HAR_Ca	846.885
pH_FLD	7.455
HAR_Total	302.671
DO_SAT%	18.140
FCol-MPN	158489.007
P-Tot	3.462
SiO2	14.133
Temp	48.995
Na%	50.254
Secchi	160.636
NO3-N	5.712
o-PO4-P	0.843
Al	0
NO2+NO3	5.726

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ANNEX C

Table 28: Status of data availability for the WEAP modelling.

Data Requirement for WEAP Modelling	Catchment	Time Scale	Agency Responsible	Remarks
Rainfall	Barapullah	Daily data for 30 years	India Meteorological Department (IMD)	Rainfall gridded daily data (0.25° x 0.25°) for 113 years (1901-2013) is available from India-WRIS
	Kanpur City	Daily data for 30 years		
Stream Flows	Barapullah	Daily	Central Water Commission (CWC)	Will not be available as Ganga is a classified river basin. Hence it will have to be estimated using US Curve Number Method from data on daily rainfall, soil, land cover for the respective catchments
	Kanpur City			
Groundwater resources (the stock and the renewable part)	Barapullah	Annual	Central Ground Water Board (CGWB)	Needs to be estimated from the CGWB 2017 estimates on groundwater development
	Kanpur City	Annual		Estimated by IRAP using CGWB 2013. Can be adjusted for CGWB 2017 estimates on groundwater development
Depth to groundwater levels	Barapullah	Season wise (pre-monsoon, post monsoon, monsoon)	Central Ground Water Board (CGWB)	IRAP has the data sets for the last 22 years (1996-2018) for the North, Central, New Delhi, South and South-west Delhi
	Kanpur City			IRAP has the data sets for the last 22 years (1996-2018) for Kanpur city.
Population	Barapullah	Annual	Census of India, 2011	This data is available
	Kanpur City			IRAP has accessed this data set (1901-2011)
Domestic water demand	Barapullah	Daily	Has to be estimated by considering a per capita supply norm	--
	Kanpur City			IRAP has estimated this considering the Census 2011 figures

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			of 150 lpcd (as per CPHHEO)	
Cropped and Irrigated Area	Barapullah	Season wise (Kharif, Rabi, Summer)	Department of Irrigation & Flood Control (DIFC), Government of Delhi	On about 10% of the area is under crop land (Source: DMP, 2018)
	Kanpur City		Department of Agriculture Statistics	Presently website is inaccessible
Irrigation water demand for different crops	Barapullah	Fortnightly	Can be estimated using FAO CROPWAT model	--
	Kanpur City			--
No., type and water demand of various Industries	Barapullah	Annual	Ministry of MSME, Government of India	IRAP has one report which provides an overview
	Kanpur City			IRAP is in possession of the data sets (2011) on the number and type of different types of industries.
Industrial water demand	Barapullah	Daily	Has to be estimated using the standard water use intensity norm for different types of industries	Available
	Kanpur City			Aggregate demand was estimated by IRAP using this 2011 data.
No of Sewage Treatment Plants	Barapullah	--	IIT Delhi/TERI/Delhi Jal Board (DJB)	--
	Kanpur City	--	Central Pollution Control Board	IRAP has this information
Capacity of the Sewage Treatment Plants	Barapullah	--	IIT Delhi/TERI/Delhi Jal Board	--
	Kanpur City	--	Central Pollution Control Board	IRAP has this information
Pollution (BOD/COD, microbial concentration, etc.) Reduction Capacity of the Plants	Barapullah Drain	One-time data	DJB	
	Kanpur City	One-time data	Kanpur Municipality	
Surface water quality	Barapullah	Monthly	IIT Delhi	IIT Delhi is monitoring the water quality of the Barapullah drain under LOTUS project
	Kanpur City		CWC and Central Pollution Control Board (CPCB)	CPCB water quality data (2000-2016) for the river Ganga (upstream and

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				downstream of Kanpur) is with IRAP
Water Quality standards for river water			Central and State Pollution Control Boards	Available
Groundwater quality	Barapullah	Season wise	CGWB and Central Pollution Control Board (CPCB)	Season wise Data needs to be obtained. **IRAP has the annual level figures (2002-2016).**
	Kanpur City			
Land use shape files for the Catchments	Barapullah	Annual (2005-06) showing areas under kharif, rabi and zaid crops, wastelands, seasonality of surface water bodies, forest vegetation and other land use classes.	National Remote Sensing Centre (through Bhuvan platform) or any other open source	Might also be requested from DIFC/IIT Delhi
	Kanpur City			--
Soil Types of the Catchments	Barapullah	One-time data in spatial format		
	Kanpur City	One-time data in spatial format		
Vol. Water Release from reservoirs/ diversion systems U/S of the two locations	Yamuna river and Ganga river	Daily or Monthly data	State Water Resources Dept. of Uttar Pradesh	
Imported Water Sources	Barapullah	Annual	Delhi Jal Board	Details provided
	Kanpur	-	-	No water import in Kanpur

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