Prioritizing 'Urban Drivers' Responsible for Pollution in Ganga River Basin and its Revival through Policy Framework and Effective Community Engagement

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Abstract

Rivers have always been the cradle of civilization as earlier settlements flourished along its flood plains that supported agriculture and farming activities. River Ganga has high socio-cultural value and is regarded as goddess by the people of India. Inspite of its sacredness, people have never hesitated to pollute it with anthropogenic activities. Even after undertaking many programs and missions to clean the river, it is still in a derelict state in many parts of the country. Various factors ('Drivers') lead to river pollution like effluent discharged from industries, urbanization, human anthropogenic activities, infrastructure development, inorganic farming, poor working of sewage treatment plants (STPs) etc.

In this research work these factors are termed 'Urban Drivers'. The research study has been divided into qualitative and quantitative analysis. Data from reports on river pollution by the Central Pollution Control Board (CPCB) has been analysed. In the absence of stakeholders' involvement to identify the critical drivers, the authorities face dilemma in budget allocations as to which must be addressed first. So, here an endeavour has been made to prioritize and rank these drivers by applying the Fuzzy Analytical Hierarchical Process technique by computing weights of the various drivers depending upon their criticalness. The results are compared with the Urban River Management Plan (URMP) of Kanpur and the underachieved objectives have been addressed.

For revival and achieving back the self-cleansing property of rivers, a dedicated policy framework for protecting the 'Riparian Zone' has been proposed. If the prototype of the proposed model is implemented on a larger scale the tangible and intangible issues would be resolved to a great extent as the proposals are within the domain of environment, social, and economic cohesion which are the three pillars of URMP.

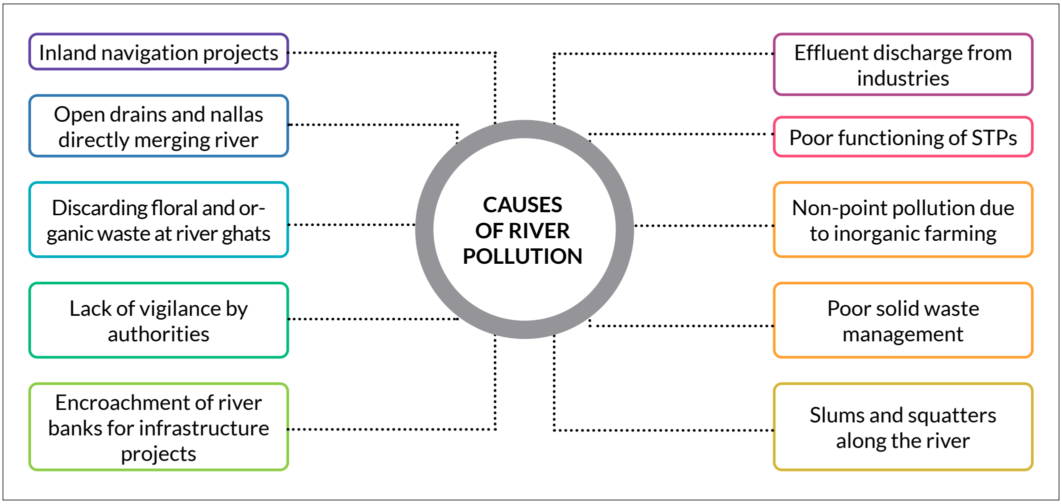
Keywords: Anthropogenic Activities, Riparian Zone, Urban Drivers, Urban River Management Plan

Introduction

India is drained by around 12 major river basins with a catchment area of about 2.5 million square kilometres. River ecosystems include flowing streams that drain the landscape, and feature biotic (living) interactions between plants, animals, and microorganisms, as well as abiotic (non-living) physical and chemical interactions between its many sections. River Ganga is in danger due to the increase of human intrusions. Ganga's quality is deteriorating at an alarming rate, despite various efforts to clean and revitalise the river. Due to an increase in anthropogenic activities the riverine ecosystem is at stake. This has led to the river turning into drains and its derelict state also needs to be tackled immediately (Khatri & Tyagi, 2015).

Causes responsible for its pollution include rapid urbanization, industrialization, infrastructure development, anthropogenic activities, lack of coordination among government entities to incorporate the launched policies, absence of stakeholders' involvement, inadequate policy vigilance, and aversion to the Public Private Partnership (PPP) model etc as depicted in Figure 1. As River Ganga passes through five states, the issues and levels of pollution vary from place to place. The Kanpur belt is one of the major industrial hubs in Uttar Pradesh. The leather tanning factories in Kanpur are the foremost sources of pollution of the river, and the Ministry of Environment, Forest and Climate Change has designated them as "Red Industries in India".

Figure 1: Causes of Pollution



By 2025, India's population is expected to exceed 1.4 billion, with 42.5 percent living in cities. The Ganga basin is the world's most densely populated river basin. The housing demand due to urbanization has resulted in the river fringe being encroached to accomplish it. Urbanization leads to deforestation and the soil becomes loose that ultimately leads to floods. As the states and cities compete for development, building barrages and dams results in the obstruction of continuous flow, which creates risk of the river being converted into a series of enormous ponds that destroys its natural and biological balance. The non-point sources of pollution i.e., fertilizers and pesticides run-off from the agriculture fields containing chemical residuals adds to the river pollution. The superstitious beliefs of people leads to disposal of floral offerings at the river ghats. Landfill sites gradually release their toxic components into the ground, thereby contaminating both the ground and the groundwater.

In recent years, many programmes and drives have been launched by the government to revitalise the Ganga basin, but not all have been completely successful. Each had some limitations and could not be accomplished entirely despite budget allocations. The need of the hour is to examine the existing policies, identify gaps, and bridge the gaps through effective stakeholder and community participation. This would aid in the development of new policies, revitalization of the Ganga River basin, and in the long run, the beneficial environmental impact will aid in the restoration of the degraded ecosystems that are caused by anthropogenic activities.

Due to an increase in anthropogenic activities the riverine ecosystem is at stake. This has led to the river turning into drains and the derelict state also needs to be tackled immediately. Due to pollution, the river has lost its self-cleansing capacity to assimilate and blend the biological waste (Dutta et al., 2020a). The environmental implications of this can result in the extinction of biodiversity and at a later stage impact human life in deleterious ways.

It is clear from the introduction that assessing the success and limitations of the earlier programmes initiated by the government for rejuvenating the river basin is vital as it will help in identifying the bottlenecks. Thus, developing strength–weakness–opportunities–threats (SWOT) matrix to derive policies and procuring the opinions of multiple stakeholders at all levels to suggest the best strategies for reaching the goals of reducing pollution, would be beneficial (Srinivas, Singh and Shankar, 2020).

Since the River Ganga Basin is divided into three segments, the issues and types of pollution threats differ from region to region as per the geographical terrains. Thus, identifying the factors which are responsible for the river degradation and applying techniques that give hierarchy to all the factors as per their criticalness would be advantageous in reaching the best possible solutions. The cities that have prepared their own Urban River Management Plan (URMP) will be assessed to check whether they adhere to the principles or not and will also give an insight to improve the underachieved objectives.

Research Methodology

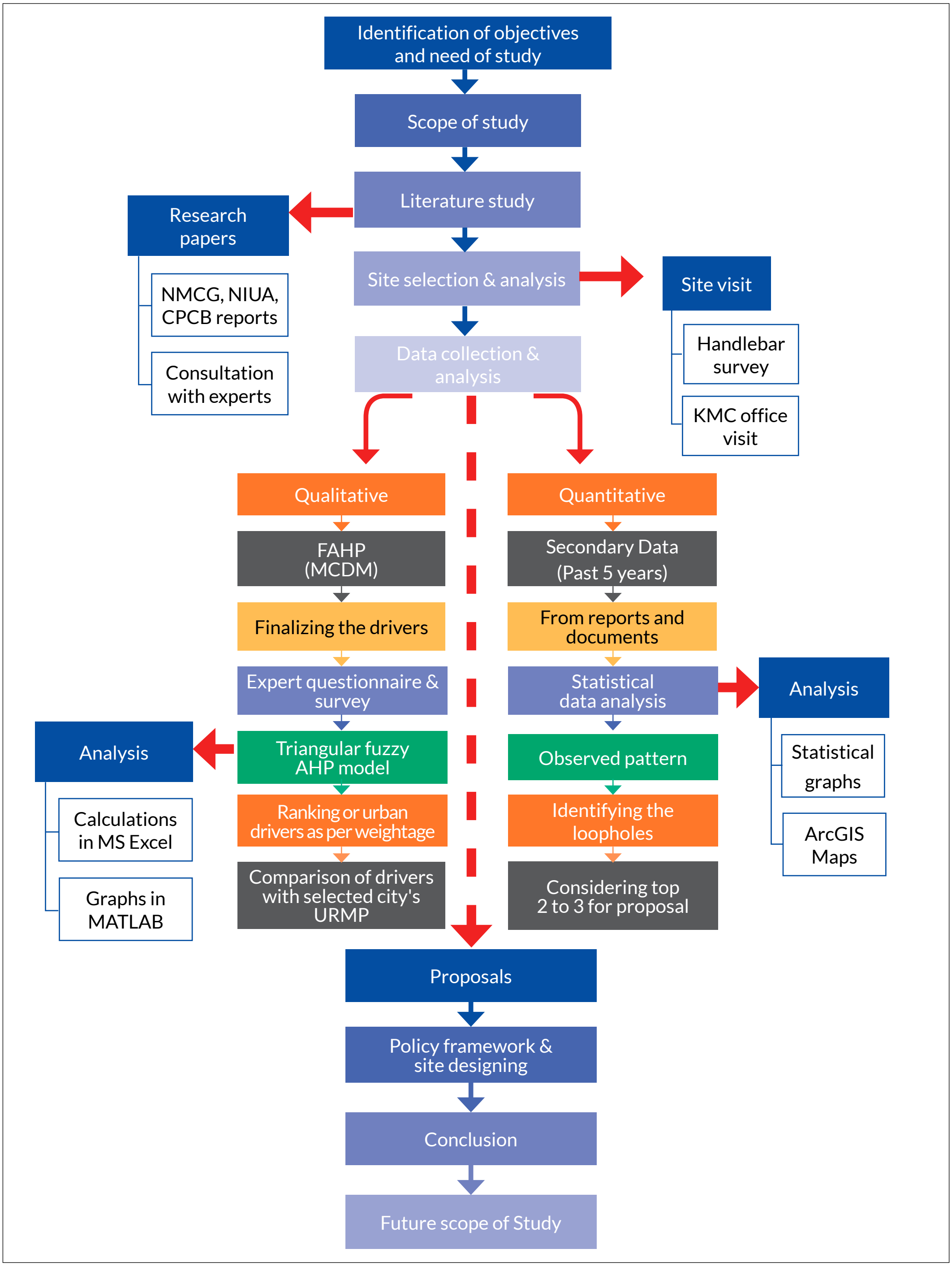
The entire research has been framed in two broad categories: Qualitative analysis and Quantitative analysis. The qualitative analysis comprises Fuzzy Analytic Hierarchy Process (FAHP) which is a multi-criteria decision-making technique (Srinivas et al., 2017). This can assist a decision-maker in making more efficient, adaptable, and realistic decisions that are based on the available criteria and alternatives by employing the FAHP approach. It provides a coherent framework for a needed decision by quantifying its criteria and alternative options and tying those parts to the broader purpose. For this, the polluting drivers were finalized from the literature study and then a comparative matrix questionnaire was prepared that was filled by experts from five different domains.

The domains pertained to experts who were closely associated with the agenda of river water pollution. An ensemble of academicians, environmentalists, research scholars, consultants, and policy makers were identified and were asked to fill the prepared questionnaire. Five experts from each domain with an experience of more than eight to ten years were chosen. Finally, FAHP was applied and the global weight of factors was calculated. The drivers were ranked as per their weightage. These were compared with the URMP of the selected site i.e., Kanpur that helped in the proposal formation of the underachieved objectives.

The quantitative part comprises data collection and analysis from primary and secondary sources. To study the existing condition of the ghats of River Ganga, a site visit to the Kanpur Municipal Corporation office and a handlebar survey was undertaken. The secondary data consists of the statistical data analysis of the annual reports (from 2017 to 2021) that were related to river pollution for the past five years which were taken from the National Mission for Clean Ganga (NMCG) and Central Pollution Control Board (CPCB). For better understanding of the ground scenario, Normalised Difference Vegetation Index (NDVI), and Normalised Difference Water Index (NDWI) maps were prepared and studied in ArcGIS. The NDVI and NDWI analysis was done using Landsat 7 imagery that was taken from USGS (United States Geological Survey) Earth Explorer. The bottleneck was identified and proposals were given for the same.

The crux of the methodology adopted is explained in Figure 2 and proposals were framed accordingly.

Figure 2: Methodology

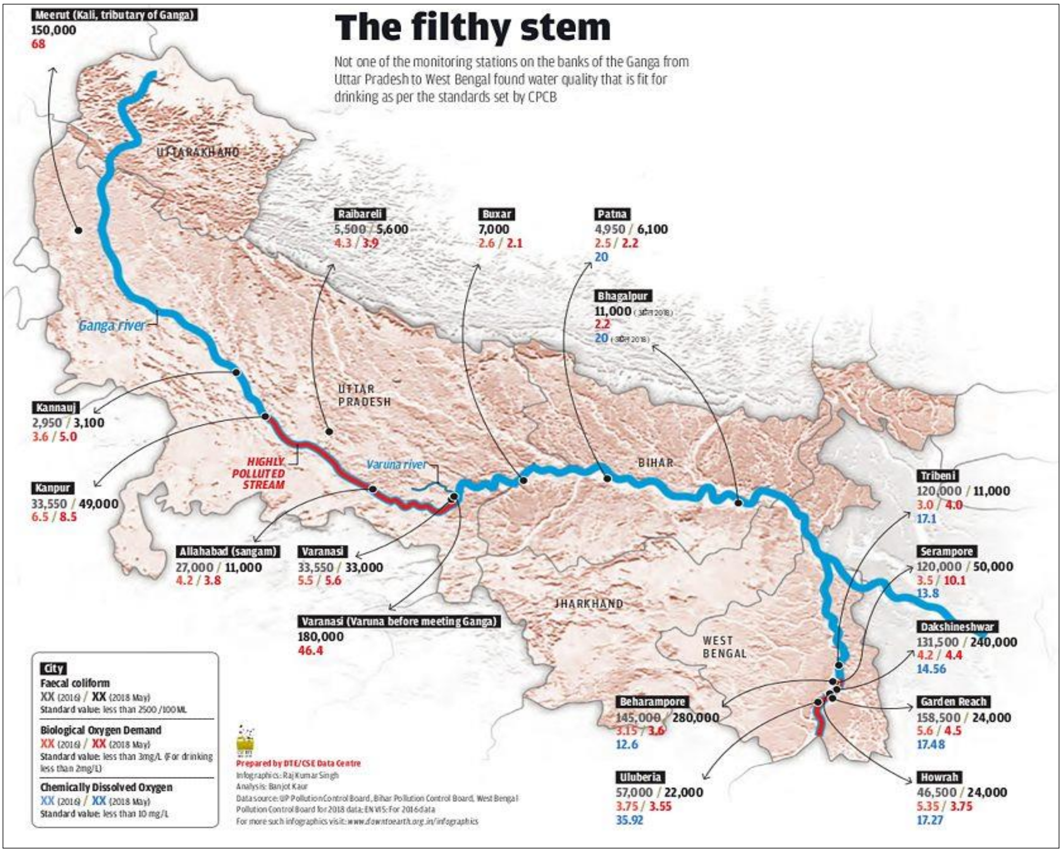


Context of the Site

Kanpur is the twelfth most populous city in India and second most in the state of Uttar Pradesh after Lucknow. It is bounded by the River Ganga on the northern side and River Pandu on the southern side. The city is considered the commercial capital of UP. It is an educational and economic hub which is famous for its leather and textile industries. Although these industries boost the economy of the city, they are also the main culprits behind the pollution of the river.

The water quality of any river is measured by six major factors that are its pH level, the Dissolved Oxygen level {D.O.(mg/l)}, the Biological Oxygen Demand {B.O.D.(mg/l)}, the Chemical Oxygen Demand {C.O.D.(mg/l)}, the total Coliform (M.P.N./100ml), and the Faecal Coliform (M.P.N./100ml). According to a report published by the Central Pollution Control Board in 2013 titled 'Pollution Assessment: River Ganga', the stretch from Kanpur to Varanasi has been declared as the most polluted due to the presence of leather industries and tanneries. (Pollution Assessment: River Ganga, 2013). As seen in Figure 3, the Faecal Coliform, and the Biological Oxygen Demand is the highest in Kanpur city and hence it has been chosen as the study area.

Figure 3: Pollution Content of Different Cities



Source: WordPress, Retrieved from https://flushitblog.wordpress.com.

Kanpur is situated on the banks of the Ganges, and as a result, it is home to various ghats, each with its own unique characteristics. In fact, the Bithoor region of Kanpur was originally known as “Bavan Ghaton ki Nagari” (City of 52 ghats). Many of these are religious ghats where people visit to take holy dip in the river on special occasions as well as to perform rituals. Some are crematoria ghats where both traditional (wooden logs) and electric cremation are adopted. Boating also exists at some of the ghats. But in spite of so many efforts the ghats are still not clean. Although many trash bins have been installed to discard the floral and organic waste but due to the unfathomable attitude and deep-rooted religious beliefs of the people, they continue to discard and immerse floral waste into the river.

Figure 4: Sarsaiya Ghat, Kanpur

Source: Author, Date 22-05-2022, Time 1:04 pm

Sarsaiya is the most visited ghat of the city for religious purposes and during special occasions. It witnesses huge devotee footfalls for a holy dip in the river. As per the boatmen of the area, the depth of water is only around 4-5’ in summer and reaches 25-30’ in the rainy season.

Figure 5: Parmat Ghat, Kanpur

Source: Author, Date 22-05-2022, Time 1:45 pm

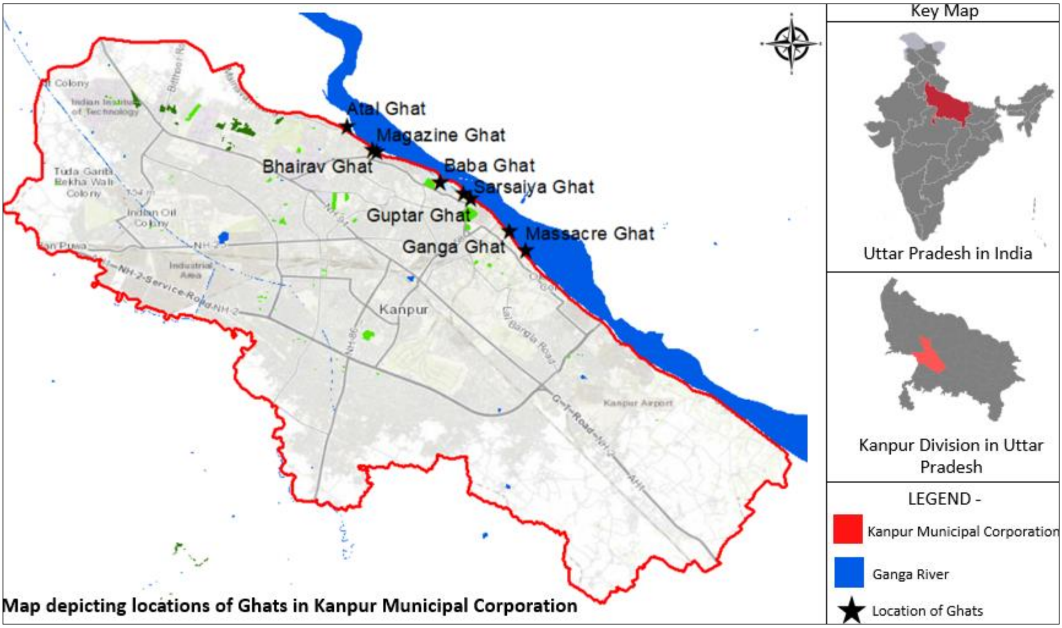
The regretful state of the ghats in the city can be seen in Figures 4 and 5. Despite installing huge trash bins and providing vigilance by the ‘Ganga Praharis’ people still discard floral and other organic waste in the river. Not only organic but plastic waste is also found near the river beds and as you all are aware, plastic litter is a serious menace to the water bodies. The most visible impact of plastic debris is the ingestion, suffocation, and entanglement of hundreds of marine species.

Figure 6: Tapping Station at Guptar Ghat, Kanpur

Source: Author, Date 22-05-2022, Time 2:12 pm

To tap and divert the river's flow to the nearest STPs, 'Nallah' tapping stations have been constructed near the river ghats. Guptar Ghat Nallah Tapping Station can be seen in Figure 6. The right-side image shows the dry drain after this station. It flows only during the rainy season, thus carrying storm water with it.

Figure 7: Ghats of Kanpur

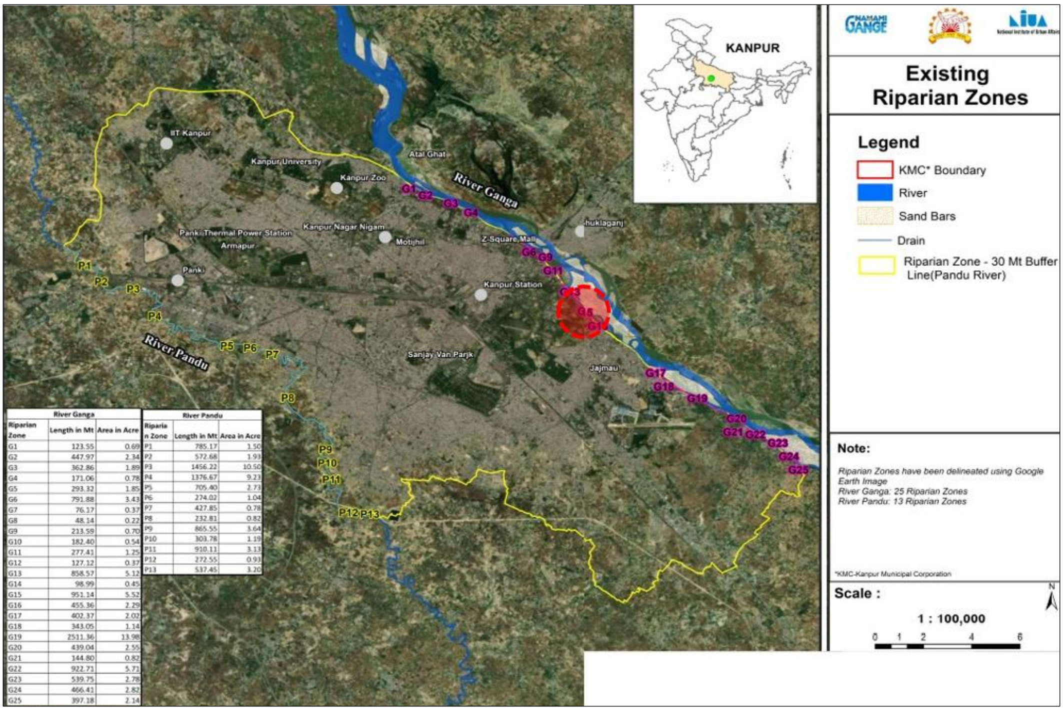


Source: Primary Survey, 2022, Kanpur Boundary: https://extract.bbbike.org/

Figure 8: Selected Site

Source: Google Earth (https://earth.google.com)

Figure 9: Riparian Zones Declared by Kanpur Municipal Corporation



River Ganga		
Riparian Zone	Length in Mt	Area in Acre
G1	123.55	0.69
G2	447.97	2.34
G3	362.86	1.89
G4	171.06	0.78
G5	293.32	1.85
G6	791.88	3.43
G7	76.17	0.37
G8	48.14	0.22
G9	213.59	0.70
G10	182.40	0.54
G11	277.41	1.25
G12	127.12	0.37
G13	858.57	5.12
G14	98.99	0.45
G15	951.14	5.52
G16	455.36	2.29
G17	402.37	2.02
G18	343.05	1.14
G19	2511.36	13.98
G20	439.04	2.55
G21	144.80	0.82
G22	922.71	5.71
G23	539.75	2.78
G24	466.41	2.82
G25	397.18	2.14

River Pandu		
Riparian Zone	Length in Mt	Area in Acre
P1	785.17	1.50
P2	572.68	1.93
P3	1456.22	10.50
P4	1376.67	9.23
P5	705.40	2.73
P6	274.02	1.04
P7	427.85	0.78
P8	232.81	0.82
P9	865.55	3.64
P10	303.78	1.19
P11	910.11	3.13
P12	272.55	0.93
P13	537.45	3.20

Source: Kanpur Urban River Management Plan (Uttar Pradesh, n.d.)

The Kanpur Municipal Corporation has earmarked 25 Riparian zones along the River Ganga and 13 Riparian zones along the River Pandu. Their length in meters and their area in sq km has been defined and development of the Riparian zones has been proposed for these places. The selected site is 625m in length and 325m in width. Out of the 25 identified sites, this is site number G15. Figure 9 highlights the selected sites:

Data Analysis

Data analysis has been divided into two parts - quantitative and qualitative. Qualitative data analysis is based on the results obtained through the expert questionnaire. Fuzzy Analytic Hierarchy Process (FAHP), a Multi Criteria Decision Making (MCDM) technique has been applied. The quantitative analysis consists of data that is collected from primary and secondary sources; this includes quantifiable data that can be statistically analysed. The quantitative part comprises of data that is collected from the annual reports of Central Pollution Control Board, National Mission for Clean Ganga, Ministry of Jal Shakti etc. This includes point and non-point source pollution data of all the five states (Uttarakhand, Uttar Pradesh, Jharkhand, Bihar, West Bengal). This data has been analysed for the past five years and a pattern has been observed for the various factors that lead to river pollution.

Qualitative Data Analysis

The qualitative data comprises factors that lead to pollution and calculating their weights as per the expert questionnaire. Around thirty research papers were referred to finalize the polluting factors. Based on the literature review, total twenty-six factors were identified that lead to pollution and these were clubbed under seven major heads:

Table 1: Finalized Main Drivers and Sub Drivers

Sr. No.	Main Driver	Main Driver Code	Sub-Driver	Sub-Driver Code
1	Urbanization	M1	Exponential population growth leads to over withdrawal of surface & ground water	U1
2			Lack of awareness among people regarding waste disposal	U2
3			Human greed to over exploit water resources on upstream river	U3
4			Competitive development amongst states along or on the river catchment	U4
5	Industrial Inventorization	M2	Direct or partially treated effluent discharge from industries	I1
6			Rapid increase in the number of GPIs	I2
7			Dumping of hazardous industrial waste near water bodies	I3

Sr. No.	Main Driver	Main Driver Code	Sub-Driver	Sub-Driver Code
8	Anthropogenic Activities	M3	Slums & squatters	A1
9			Superstitious nature of people	A2
10			Partially or untreated municipal sewage discharge in rivers	A3
11			Landfill sites located near the water bodies	A4
12	Governance and Finance	M4	Lack of priority, vision, and mission	G1
13			Dearth of dispute resolving mechanisms	G2
14			Lack of know-how and poor tech-savvy level of the Government	G3
15			Insufficient funds	G4
16	Enforcement	M5	Meagre state of regulations & policies to safeguard rivers	E1
17			Poor surveillance by authorities	E2
18			Leniency in taking actions against GPIs	E3
19			Interoperability of laws amongst various states	E4
20	Artificial Jeopardies	M6	Intensive use of fertilizers & pesticides	AJ1
21			Deforestation leading to soil erosion	AJ2
22			Poor working of STPs	AJ3
23			Polluted stormwater drainage, nallas & tributaries getting merged with the river	AJ4
24	Infrastructure Development	M7	Hydropower & barrage projects	ID1
25			Construction projects leading to either flooding or drying of local water bodies	ID2
26			Riverfront projects degrade riverine ecosystem & changes in LULC (Land Use Land Cover)	ID3

The ensemble of experts was from different domains like environmentalists, researchers, academicians, policy makers, and consultants. Depending upon their professions and the types of work they handled, their views differed on which factors are more responsible for river pollution. Fetching all under one umbrella would be beneficial as issues would then be addressed from a holistic perception. Here the sample size is 11, experts from each domain filled the questionnaire.

The average of all the final weights was taken and the top ten have been listed in Table 2.

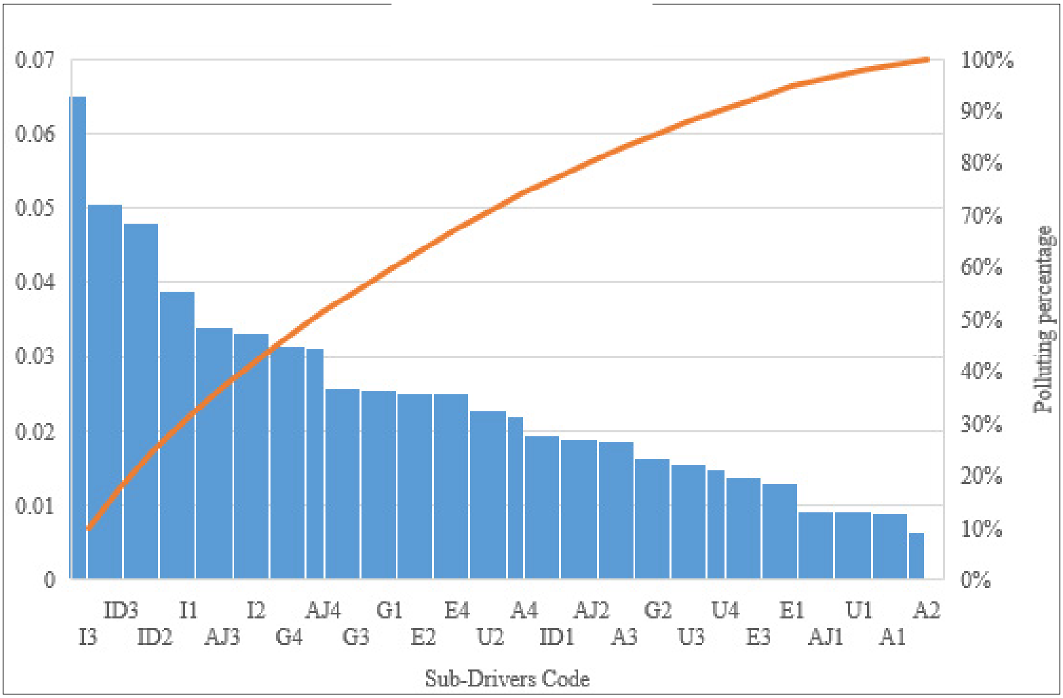
Table 2: Final Ranking of Drivers

Sr. No.	Main Driver	Main Driver Code	Sub Driver	Sub-Driver Code	Final Weight (Geometric Mean)	Ranking
1	Infrastructure Development	M7	Riverfront projects degrade riverine ecosystem & changes in LULC	ID3	0.0880	1
2	Infrastructure Development	M7	Construction projects lead to either flooding or drying of local water bodies	ID4	0.0771	2
3	Industrial Inventorization	M2	Dumping of hazardous industrial waste near water bodies	I3	0.0688	3
4	Enforcement	M5	Interoperability of laws amongst various states	E4	0.0563	4
5	Governance and Finance	M4	Insufficient funds	G4	0.0543	5
6	Industrial Inventorization	M2	Direct or partially treated effluent discharge from industries	I1	0.0537	6
7	Industrial Inventorization	M2	Rapid increase in the number of GPIs	I2	0.0525	7
8	Enforcement	M5	Poor surveillance by authorities	E2	0.0523	8
9	Governance and Finance	M4	Lack of know-how and poor tech-savvy level of the Government	G3	0.0496	9
10	Artificial Jeopardies	M6	Polluted stormwater drainage, nallas & tributaries getting merged with the river	AJ4	0.0458	10

Source: Primary Survey, 2022 (Based on FAHP)

As per the results of the calculated global weights of all the drivers, Urbanization (M) is the only Main Driver that was the least responsible for river pollution. Hence, it is not included in the top ten most polluting drivers.

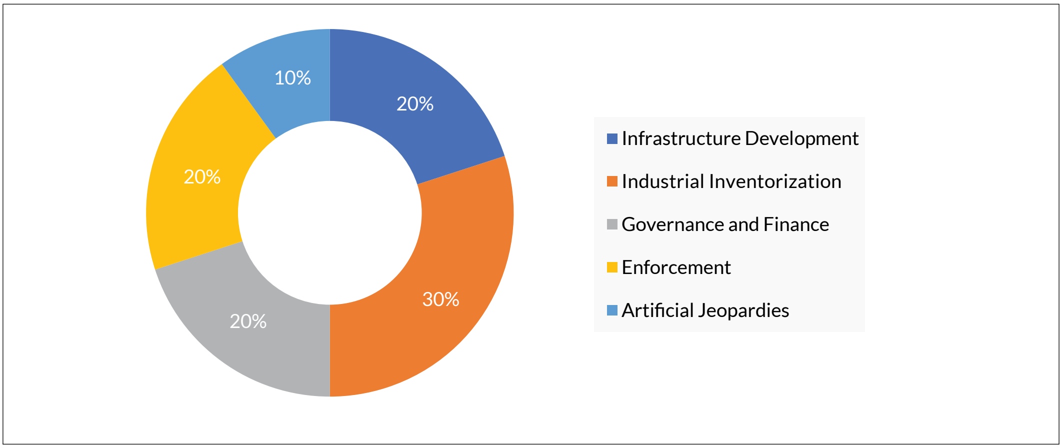
Figure 10: Ranking of Drivers



Source: Primary Survey, 2022

As concluded from the table and graph in Figure 10, the highest weightage is 0.088 for Riverfront projects that degrade the riparian buffer and riverine ecosystem. According to the results, Construction projects that lead to either flooding or drying of local water bodies are the second most polluting factor with 0.0771 weightage. Dumping of hazardous industrial waste near water bodies has 0.0688 weightage with third rank. Interoperability of laws amongst various states has fourth rank with 0.0563 weightage. The drivers with more weightage and towards the left side of 50% of the pareto line are more critical and need to be addressed. The top eight drivers from where the pareto line crosses the histogram are termed as critical and must be tackled. Thus, the top ten polluting drivers are from Infrastructure Development, Industrial Inventorization, and Enforcement and Government-the Finance aspect.

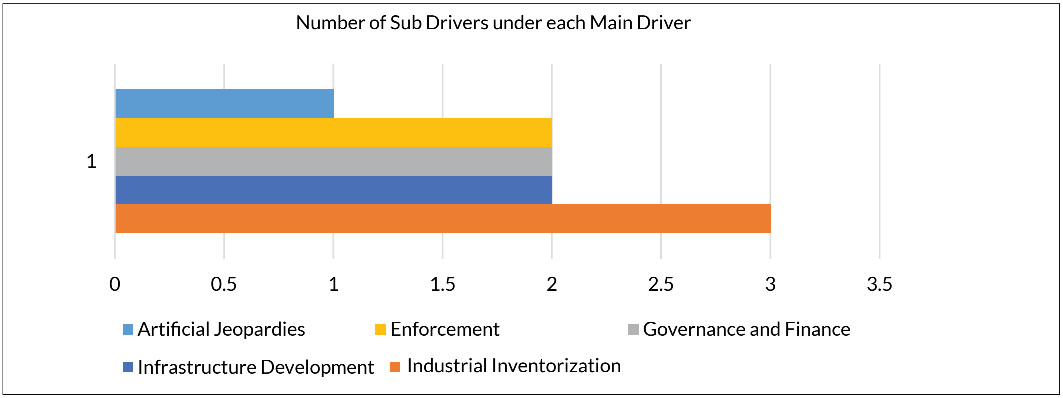
Figure 11: Main Drivers



Source: Primary Survey, 2022

According to the expert's opinions and after removing the fuzziness from their responses, the above-mentioned Main Drivers as shown in Figure 11 were the major contributors that were responsible for river pollution.

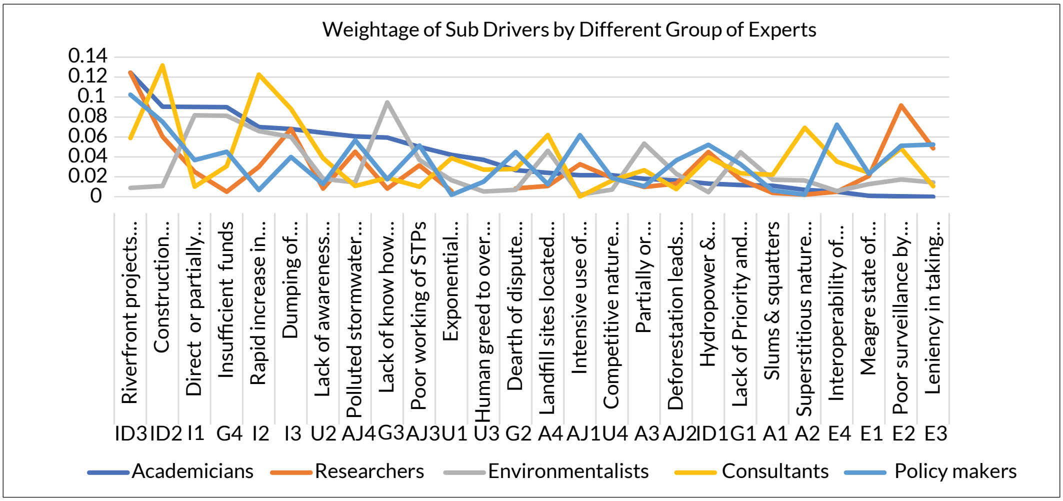
Figure 12: Sub Drivers



Source: Author Primary Survey, 2022

Three drivers are under Industrial Inventorization, followed by Infrastructure Development, and Enforcement and Government-Finance which has two drivers from each head, respectively. Artificial Jeopardies has one driver as depicted in Figure 12.

Figure 13: Opinion of All Stakeholders



Source: Primary Survey, 2022

Figure 13 shows the global weightage of all the drivers as concluded by the responses of all the experts. It is observed that most of the experts gave critical polluting status to following drivers; (Refer Table 1 and 2 for the list or Sub-drivers and the most polluting drivers, respectively).

- Riverfront infrastructure projects degrade riverine ecosystem & changes in LULC
- Construction projects lead to either flooding or drying of local water bodies
- Direct or partially treated effluent discharge from industries
- Rapid increase in the number of GPIs
- Superstitious nature of people

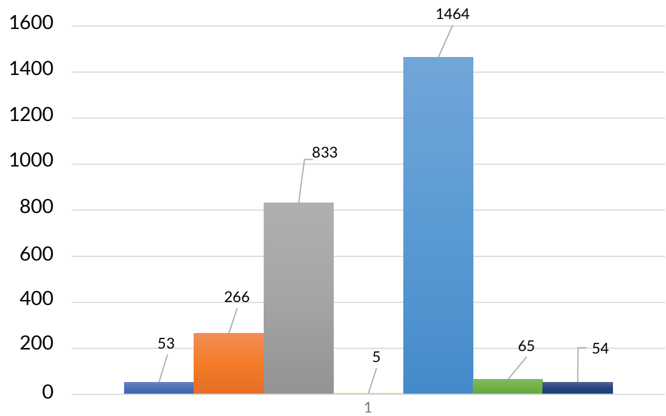
Quantitative Analysis

Industrialization

Industries discharge their chemical wastes in rivers, lakes, and streams that comprise of substances called effluents. Sometimes, factories turn waterbodies into open sewers by dumping oil, toxic chemicals, and other harmful liquids called effluents into them. The industries that discharge more than 100 KLD of wastewater or hazardous chemicals into the water bodies are termed as Grossly Polluting Industries (GPIs). Pulp and paper mills, distilleries, sugar mills, textile units, tanneries, thermal power plants, the food, dairy and beverage industries, chemical units, slaughterhouses, etc. come under the category of GPIs (Srinivas & Singh, 2018).

The GPI data shown in Figure 14 for the year 2020-2021 has been acquired from the CPCB website. In this, along with the mainstream river, industries that lie along the tributaries of the River Ganga have also been considered. In other words, all industries along the GRB (Ganga River Basin) have been considered.

Figure 14: State-wise Number of Grossly Polluting Industries



Bihar	53
Delhi	266
Haryana	833
Jharkhand	5
Uttar Pradesh	1464
Uttarakhand	65
West Bengal	54

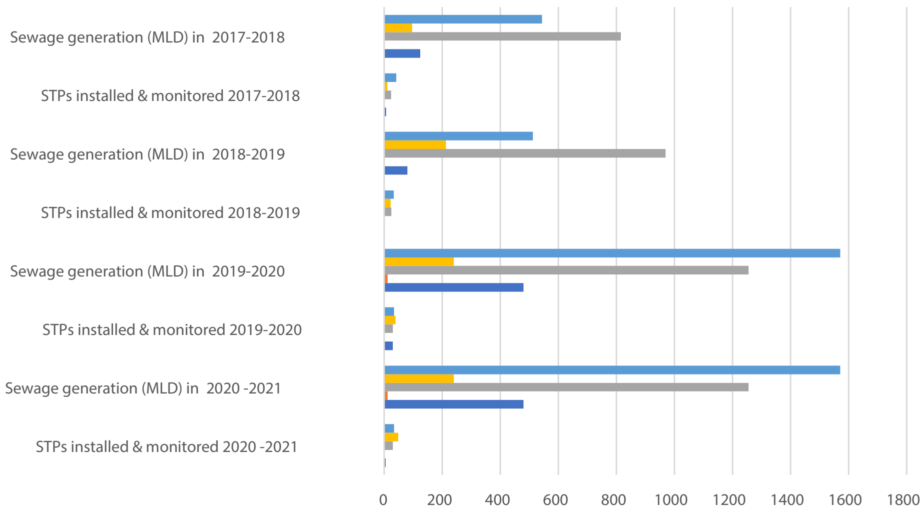
Source: Data compiled by author from NMCG Annual Report, 2016-17

Uttar Pradesh has the highest number of Grossly Polluting Industries (GPIs) which is 53.43% of the total number of industries. Jharkhand contributes the least i.e., 0.18% of the total industries. Kanpur has the highest number of textile industries and tanneries and both these are major contributors to river pollution. According to studies, the stretch from Kannauj to Kanpur has been declared the most polluted stretch and hence this site was chosen. Kanpur – Unnao region is amongst the largest industrial hubs of GRB where various industries exist (Chaudhary & Walker, 2019).

Anthropogenic Activities

These include impact due to agriculture activities, and inorganic farming practices. In urban and rural areas, the water quality gets affected by both point and non-point sources of pollution. Many Sewage Treatment Plants (STPs) are in poor working conditions and in some cases their potential is not fully utilized. Slums & squatters located near water bodies directly discharge their domestic waste into the river but this does not affect much as compared to other factors because by the time such waste enters the river, their level of toxicity decreases. Superstitious nature of people leads to direct discharge of floral, organic waste, mass bathing, and crematorium activities at river ghats.

Figure 15: STPs and Sewage Generation



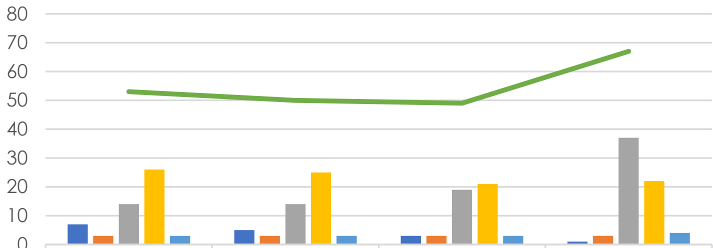
	STPs installed & monitored 2020 -2021	Sewagegen-eration (MLD) in 2020 -2021	STPs installed & monitored 2019-2020	Sewagegen-eration (MLD) in2019-2020	STPs installed & monitored 2018-2019	Sewagegen-eration (MLD) in 2018-2019	STPs installed &monitored 2017-2018	Sewagen (MLD) in2017-2018 STPsinstalled &monitored 2017- 2018
West Bengal	34	1571.5	34	1571.5	33	512.15	42	544
Uttarakhand	49	239.8	39	239.8	22	213.07	11	96
Uttar Pradesh	30	1255.2	30	1255.2	25	969.26	24	815
Jharkhand	2	12	0	12	0	0	0	0
Bihar	5	480	30	480	2	80	7	124

Source: Data compiled by author from NMCG Annual Report, 2016-17; Annual Report, 2020-21; Department of Water Resources, River Development and Ganga Rejuvenation, Ministry of Jal Shakti, Government of India

As per the 2021 report, Uttarakhand has the highest number of installed and monitored STPs but the flow in MLD is less as compared to other states. West Bengal has the highest sewage generation, 44.16% of the total discharge from the year 2018 to 2021. Although the number of STPs have decreased in this state but sewage generation has increased. The State-wise data is depicted in Figure 15.

Figure 16 depicts the State-wise number of crematoria ghats and Figure 17 depicts the number of religious ghats along the River Ganga as per the Annual Report, 2020-21, National Mission for Clean Ganga.

Figure 16: Crematoria Ghats



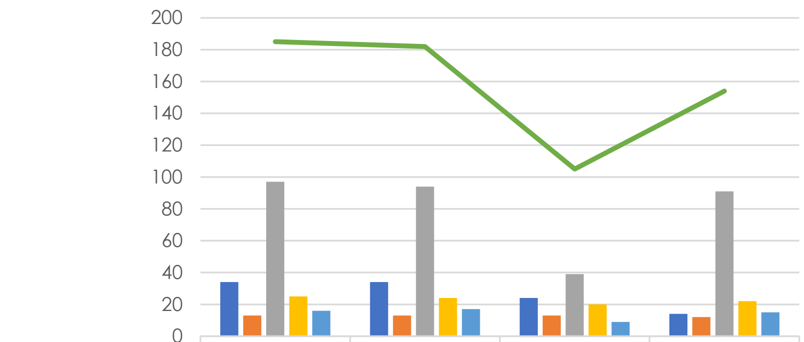
	No. of crematoria ghats 2020-2021	No. of crematoria ghats 2019-2020	No. of crematoria ghats 2018-2019	No. of crematoria ghats 2016-2017
Bihar	7	5	3	1
Jharkhand	3	3	3	3
Uttar Pradesh	14	14	19	37
Uttarakhand	26	25	21	22
West Bengal	3	3	3	4
Total	53	50	49	67

Source: Data compiled by author from the Annual Report 2020-21, National Mission for Clean Ganga, Department of Water Resources, River Development and Ganga Rejuvenation, Ministry of Jal Shakti, Government of India

According to the reports, Uttar Pradesh had the highest number of crematoria ghats in the year 2016-2017. In the Year 2020-2021, Uttarakhand had the highest number of crematoria ghats. Year 2018-2019 saw a downfall in the number of crematoria ghats for all states. Many states developed and shifted to electric crematoriums so the number of crematoria ghats decreased from 2016 to 2021. State-wise the number of religious ghats along the River Ganga also decreased as per the CPCB report.

According to a paper, Uttar Pradesh has the highest number of religious ghats which is 53.42% of the total (Journal et al., 2018). The year 2018-2019 saw a downfall in the number of religious ghats for all states. Many new ghats across various states have been developed and some old dilapidated ones have been restored so the year 2021 witnessed the highest number of religious ghats.

Figure 17: Religious Ghats



	No. of religious ghats 2020-2021	No. of religious ghats 2019-2020	No. of religious ghats 2018-2019	No. of religious ghats 2016-2017
Bihar	34	34	24	14
Jharkhand	13	13	13	12
Uttar Pradesh	97	94	39	91
Uttarakhand	25	24	20	22
West Bengal	16	17	9	15
Total	185	182	105	154

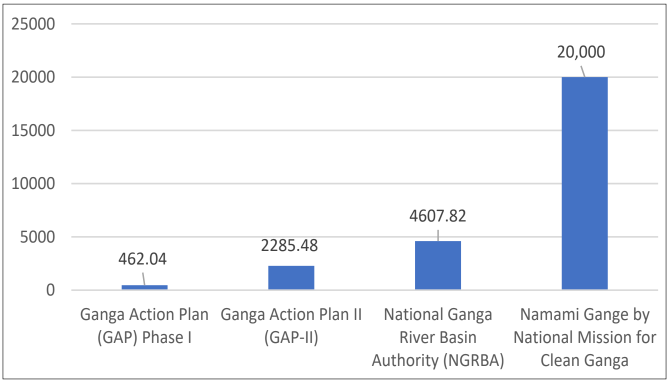
Source: Data compiled by author from the Annual Report 2020-21, National Mission for Clean Ganga, Department of Water Resources, River Development and Ganga Rejuvenation, Ministry of Jal Shakti, Government of India

Governance and Finance

Over the past 40 years many projects and programs have been launched by the Government of India, to clean the River Ganga. The first pollution abatement plan, Ganga Action Plan (GAP) was launched in 1985 after a comprehensive survey was conducted by the Central Pollution Control Board (CPCB) (Deekshit, n.d.). The studies conducted by the CPCB indicated that most of the pollution is derived from municipal waste and industrial effluent.

Figure 18 shows the budget/funds allotted for various Ganga cleaning missions under different programs. The budget has increased exponentially over a period of time. The cost shown in the graph is in crores.

Figure 18: Budget Allotted (In Crores INR)



Source: Data compiled by author (Deekshit, n.d.)

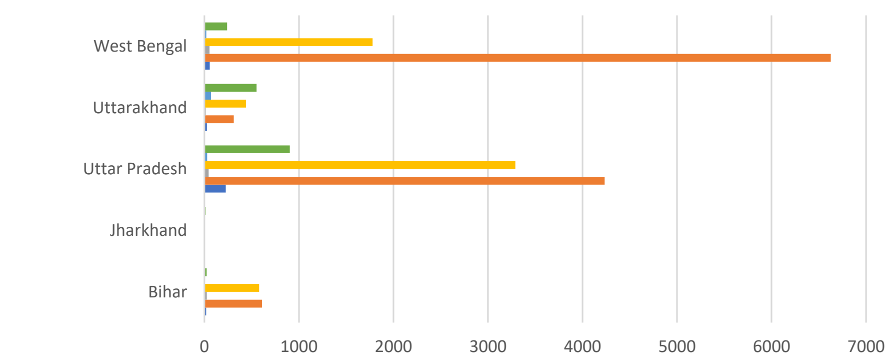
Table 3: Various Schemes to clean River Ganga

Sr. No.	Name of Scheme	Period	Budget Allotted (Rs crores)	Unbridged Gaps
1.	Ganga Action Plan (GAP) Phase I	1985 – 2000	462.04	• The emphasis was limited to the expansion of wastewater treatment facilities. • Technologies used for sewage treatment did not meet the standards for suitability and efficiency. • Absence of water resource management, conservation, and prudent use measures. • Lack of broad knowledge, public participation, and participation by numerous stakeholders (Dutta et al., 2020)
2.	Ganga Action Plan II (GAP-II)	1993 - 1999	2285.48	• Lack of adequate budgetary allocations and resources for operations and maintenance of wastewater treatment facilities resulted in the primary focus on engineering-centric approach, no focus on ecological entities of the river, and a lack of cooperation between federal, state, and local governments.
3.	National Ganga River Basin Authority (NGRBA)	February 2009 – September 2016	4607.82	• It was not possible to integrate the ecological fluxes in Ganga and its tributaries into the basin. • The environment management strategy for the entire Basin neglected to take into account the large and small tributaries. • Lack of long-term involvement of municipal and planning authorities.
4.	Namami Gange by National Mission for Clean Ganga	12 August 2011 – 7 October 2016 (continuing since 2014)	20,000	• Insufficient policy and legal framework • Lack of coordination across diverse riparian states • Decreased emphasis on the river's ecological and geological integrity • Smaller Ganga tributaries have not been added. • Environmental flow allocations are suboptimal industrial pollution control. (Dutta et al., 2020)

Artificial Jeopardies

The ongoing agricultural practices in the Northwest Indo-Ganga Plain (NWIGP) which includes Punjab, Haryana, and western Uttar Pradesh are not sustainable under the current scenario of environmental and agricultural change. Compaction prevents the soil from being able to hold more water and concentrate water flow therefore, it speeds up the flow of water on the soil's surface. This in turn increases the volume and speed of water that is flowing into the waterways and heightens the risk of flooding.

Figure 19: Drains Discharging into River Ganga

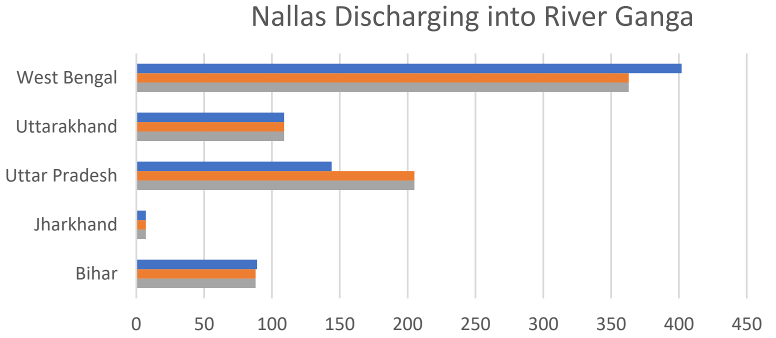


	Bihar	Jharkhand	Uttar Pradesh	Uttarakhand	West Bengal
Total Flow (MLD) 2019	24	12	903	552	240
No. of Drains in 2019	3	1	29	69	20
Total Flow (MLD) 2020	579	0	3289	440	1779
No. of Drains in 2020	25	0	45	14	54
Total Flow (MLD) 2021	609.48	2.89	4234.63	310.3	6627.45
No. of Drains in 2021	19	6	226	27	56

Source: Data compiled by author from Status of Post-Monsoon 2021 Monitored Drains Discharging into River Ganga and its Tributaries (Banganga Ramganga, Kali-East, Pandu, Etc.), Retrieved from https://cpcb.nic.in/ngrba/Drains-Post-Monsoon-2021.pdf

The number of drains discharging into the River Ganga have increased from 2019 to 2021 followed by an increase in flow (in MLD). For the year 2021, Uttar Pradesh had the highest number of drains, 226 which is 67.66% of the total. It is alarming to note that the number of drains in this state have increased five times as compared to the year 2020 that had just 45 drains. West Bengal is discharging 6627.45 MLD of sewage in spite of having 56 drains. This is 56.23% of the total discharge. From the year 2019 to 2021 the sewage discharge has increased 6.80 times which is quite disturbing. In spite of launching so many programs and budget allocations the situation is not in control and open drains continue to pollute the river. The state-wise number of drains with flow in MLD is depicted in Figure 19. The number of nallas directly getting discharged into the river is shown in Figure 20.

Figure 20: Nallas Discharging into River Ganga



	Bihar	Jharkhand	Uttar Pradesh	Uttarakhand	West Bengal
2020-2021	89	7	144	109	402
2019-2020	88	7	205	109	363
2018-2019	88	7	205	109	363

Source: Data compiled by author Annual Report 2020-21, National Mission for Clean Ganga, Department of Water Resources, River Development and Ganga Rejuvenation, Ministry of Jal Shakti, Government of India

West Bengal is the major contributor of river pollution as it has the highest number of nallas i.e., 53.52% of the total for the year 2021. From the year 2018 to 2021, the number of nallas has decreased in Uttar Pradesh whereas it remained constant or had increased in other states. The overall number of nallas has decreased from 772 to 751 for the year 2018 to 2021. So, 21 nallas were either shut down or trapped which is a significant change.

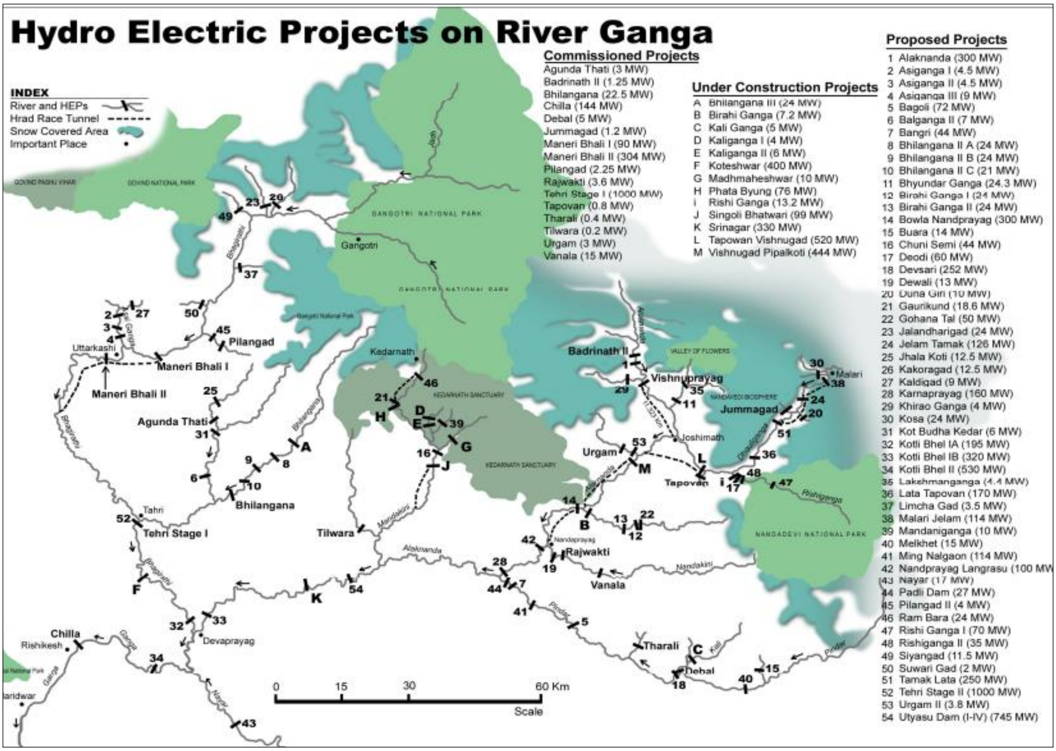
Infrastructure Development

Modifications in the river system of the Upper Ganga segment have occurred due to the construction of Run of the River and Run of the River with Ponding (ROR + RORP) Hydro-Electric Projects. Implementation of these projects have resulted in significant alterations in hourly, daily, and seasonal flows over a substantial river length. Figure 21 depicts the number of Hydro Electric Projects on River Ganga.

Consequences of these projects include:

- Area near such plants suspected to undergo decline of forest cover.
- Frequent landslides.
- Release of greenhouse gases.
- Drying up of natural water resources.
- Moderation in local climate.
- River ecosystem under stress.

Figure 21: Distribution of Hydro Electric Projects on River Ganga



Source: National Ganga River Basin Project (Prasad et al., 2021)

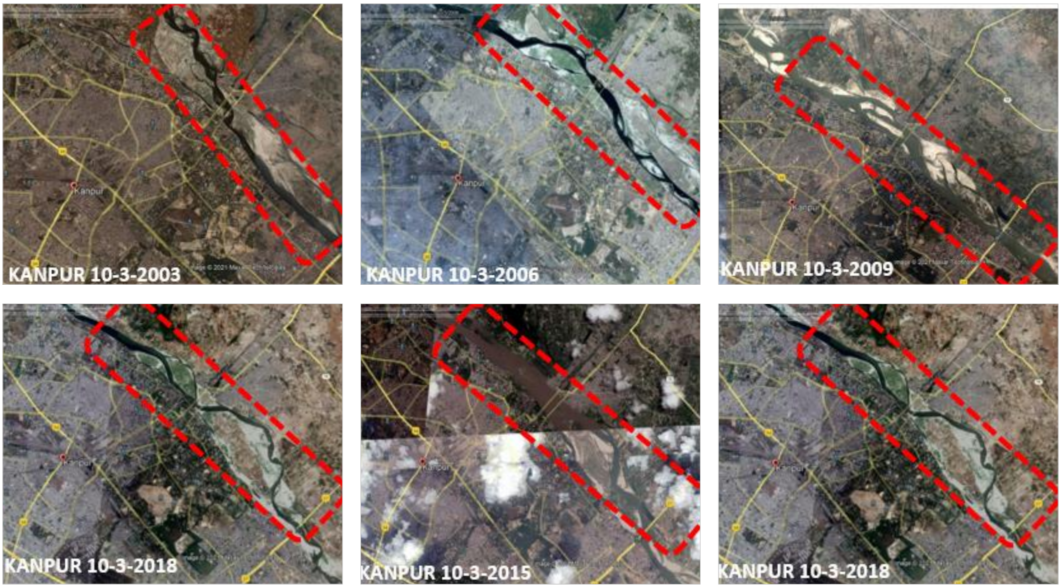
Flow Alteration

A change in flow regime is a major threat to the sustainability of a river's health and its ecosystem services. Increasing water extraction for agriculture, urban, and industrial use severely alters the hydrology in major river basins of the world. The GRB is one of the most vulnerable river basins in the world due to the combined effects of climate changes and development pressures in terms of construction of dams. Alteration of flow regimes in the Ganga basin due to large dams negatively affects the endangered species such as the Ganga River dolphin. Diversion of water for irrigation through canals also reduces the flow of the Ganga. Flow decline in River Ganga during non-monsoon period is a main problem. More than 80% of the annual flow in this river occurs during monsoon which causes widespread flooding.

The satellite imagery of the Ganga River flowing along Kanpur has been studied. The width of the river basin has shrunk and will continue to shrink due to flow alteration. Its direction of flow and colour has changed due to heavy metal discharge from effluent of industries that surround Kanpur city.

There is a change in the ecological flow of the river as visible in the satellite images in Figure 22. The satellite imagery with a three years gap shows the drift in the flow of water. There is a shift in the direction of the river and many sand bars are also visible, which shows that the basin is shrinking and the water is depleting. Due to this, a problem in the ecological flow of the river is observed.

Figure 22: E-flow Alteration in Kanpur

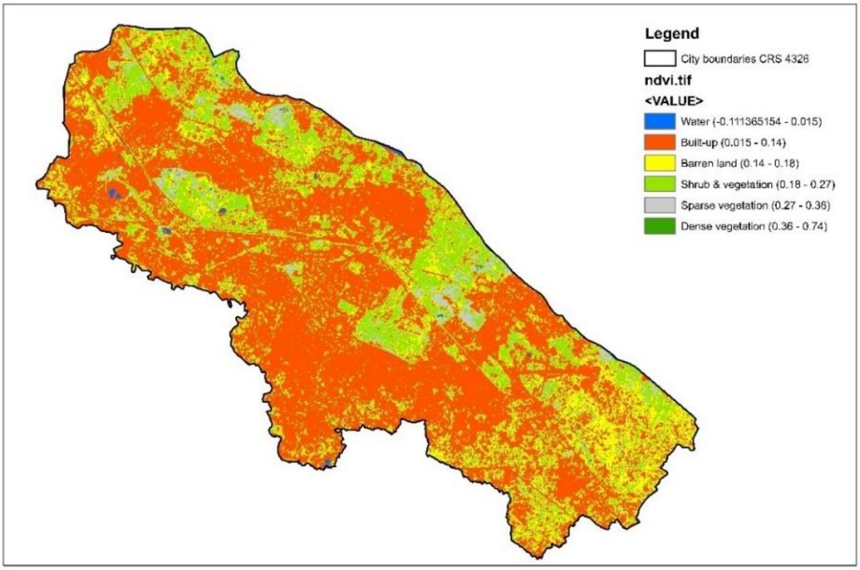


Source: Google Earth (https://earth.google.com/)

Normalized Difference Vegetation Index (NDVI)

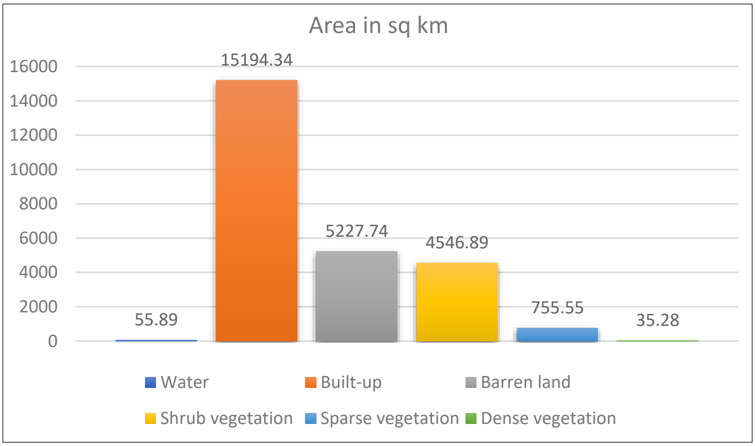
NDVI stands for Normalized Difference Vegetation Index. The near-infrared and visible light reflected from vegetation is used by the NDVI to remotely detect and quantify the presence of live green vegetation health and land use. For the most part, the NDVI measures how healthy and dense the vegetation is in a given pixel of a satellite image. When analysing remote sensing data, NDVI is used to determine whether the target under observation has live, green vegetation that is capable of photosynthesis.

Figure 23: NDVI of Kanpur



Source: Author

Figure 24: NDVI Area of Kanpur Municipal Corporation



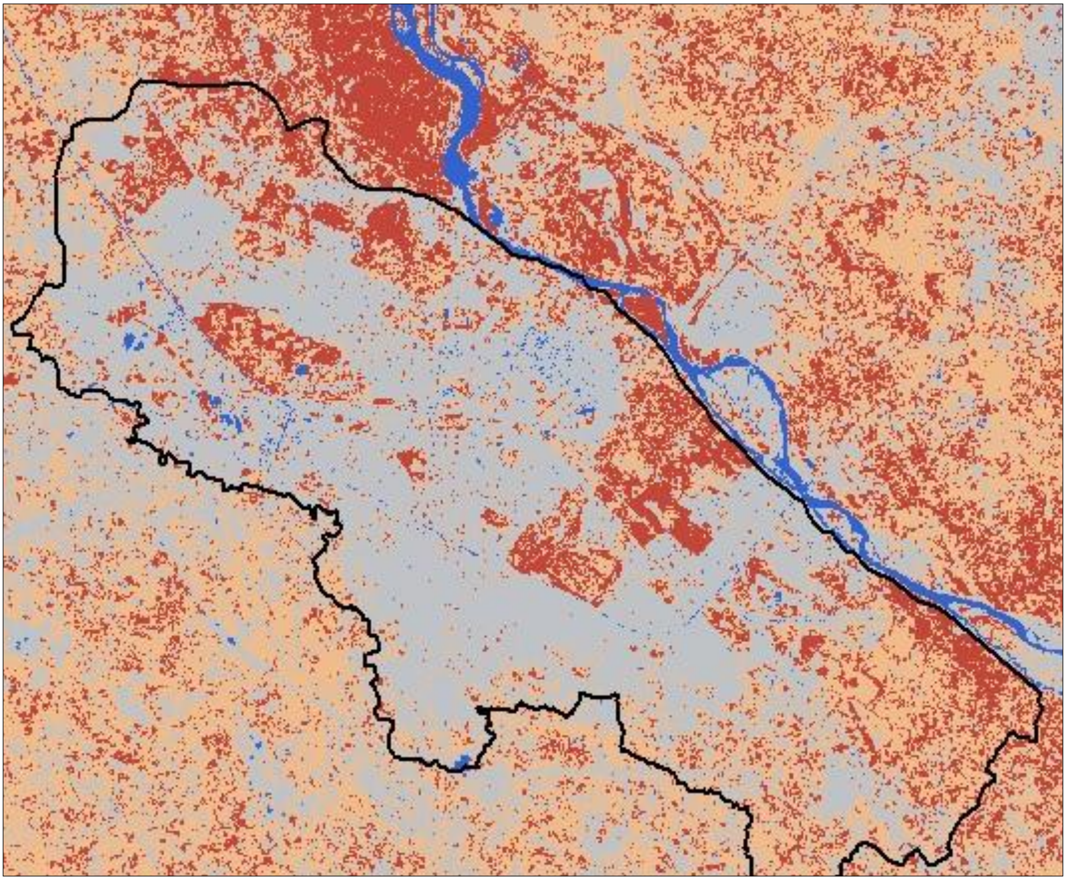
Source: Author

For Landsat-8 the formula for NDVI is B5 – B4 / B5 + B4. Its value is always from -1 to +1. Figure 24 shows that a lot of built-up is present on the northern side from where the river flows. So, the river fringe needs to be protected. Dense vegetation is scanty near the river edge and in the entire city. Shrub vegetation is present in the outer part of the boundary and in the middle of the cantonment area.

Normalized Difference Water Index (NDWI)

The Normalized Difference Water Index (NDWI) is used in satellite imagery to emphasise the open water features, thus allowing a body of water to "stand out" against the land and vegetation. The NDWI determines the moisture content accurately. Figure 25 is the NDWI analysis of Kanpur city:

Figure 25: NDWI of Kanpur



Source: Analysis based on Landsat 7 imagery from USGS Earth Explorer

For Landsat-8 the formula for NDWI is B3 – B5 / B3 + B5. Its value is always from -1 to +1. The values up to 0.2 show extremely dry area, up to 0.4 it shows wet, and > 0.6 shows extremely wet, aqueous surface.

Proposals

Non-point source (NPS) pollution is a major danger to the water ecosystem. NPS pollution control can benefit from riparian zones because of their low energy consumption and minimal operational requirements (He et al., 2020). Numerous studies have documented the removal of nitrate

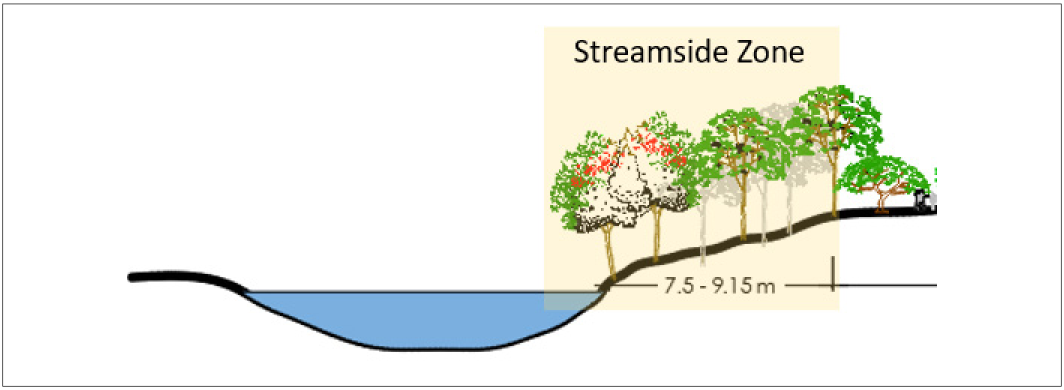
(NO_3-N) from the surface and sub-surface agricultural runoff within the moist riparian habitats. Nitrate is a worldwide water pollutant that causes health problems in new-borns and animals and leads to cultural eutrophication of natural water bodies (Fennessy & Cronk, 1997). Non-saturated and saturated soils in riparian buffer strips are favourable to nitrogen transformations, such as denitrification. When denitrification is complete, nitrogen gas is released, which removes nitrogen permanently from the system.

Hence, an appropriate policy framework needs to be prepared to protect the ecotone of the riparian zones. Tables 4, 5, and 6 elaborate the proposed Riparian Zone Policy for the streamside, middle, and outer zones. The succeeding figures show the sections and native species that must be planted in that particular zone. The native species change from region to region, here it is discussed for Kanpur.

Table 4: Riparian Zone Policy (Zone-I) for Ganga Basin in Kanpur

Name of the Zone	Streamside Zone
Zone Width	Minimum 25 - 30 feet or 7.6 – 9.15 m
Type of Vegetation	Native riparian trees with dense canopy, and grasses adapted to a moist environment and beneficial to animals present in this zone. Fast-growing tree species to maintain banks are preferred.
Main Objective of Zone	To protect the physical integrity of the stream's ecosystem.
Zone Functions	• Remove pollutants that are delivered from the stormwater and filter non-point source pollutants. • Reduce the sediments entering the stream and soil erosion. • Maintain base flow of the stream.
Activities Permitted	• Activities that do not hinder and disturb the natural riparian vegetation. • Bioswales can be constructed to filter the stormwater entering the river. • Walkways are permitted.
Activities Restricted	• Discourage grazing by animals and livestock. • Restrict vehicular movement • Discourage cutting of trees
Envisaged Outcomes	• Reduction in erosion of bank soil. • Flood control. • Improved habitat for aquatic life.

Figure 26: Streamside Zone



Source: Author

Figure 27: Native Species of Zone-I

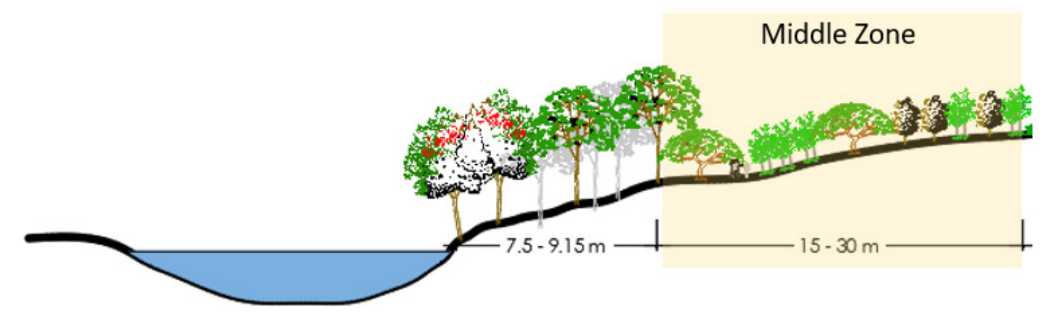
Source: Kanpur URMP

Table 5: Riparian Zone Policy (Zone-II) for Ganga Basin in Kanpur

Name of the Zone	Middle Zone
Zone Width	Minimum 50 - 100 feet or 15.25 – 30.50 m
Type of Vegetation	Predominantly native riparian trees, shrubs, forbs, and grasses must be grown here.
Main Objective of Zone	Provide sufficient distance between streamside and upland development.
Zone Functions	• Stabilize the river bank by beholding the soil. • Denitrification of pollutants by vegetative species. • Protect riparian wildlife habitat.
Activities Permitted	• Walkways, cycle tracks, and temporary wooden structures like decks can be constructed. • Stormwater best management practices (BMPs)
Activities Restricted	By managing vegetation and grading, prevent gullies from forming. Although management for timber or wildlife is encouraged, leaf litter and shade levels should be maintained.

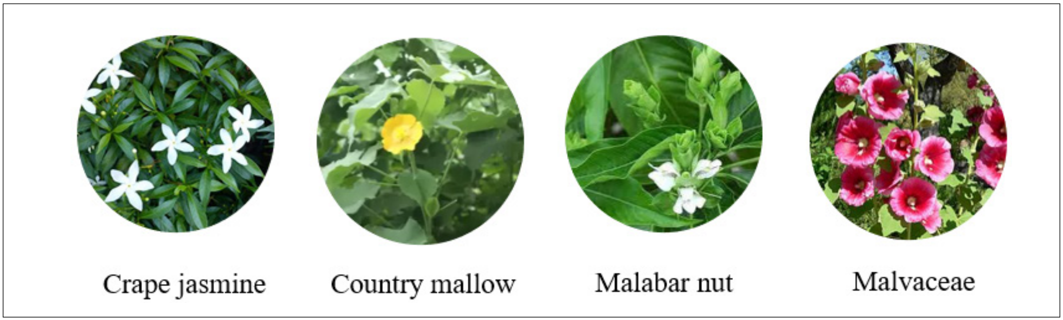
Envisaged Outcomes	• Removal of water pollutants by denitrification • Reduce watershed imperviousness

Figure 28: Middle Zone



Source: Author

Figure 29: Native Species of Zone-II



Source: Kanpur URMP

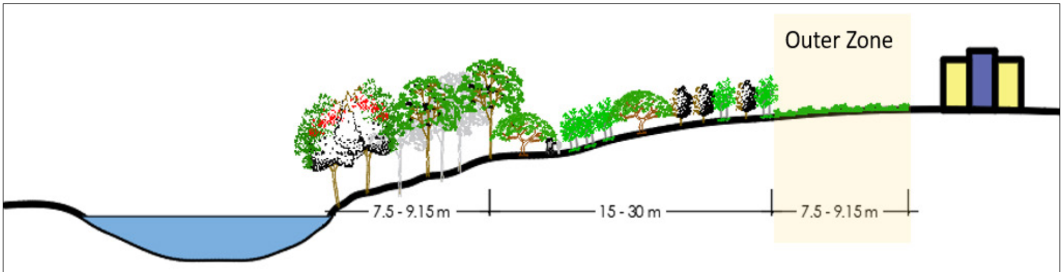
Table 6: Riparian Zone Policy (Zone-III) for Ganga Basin in Kanpur

Name of the Zone	Outer Zone
Zone Width	Minimum 25 - 30 feet or 7.6 – 9.15 m
Type of Vegetation	Dense perennial grasses and some forbs, herbaceous ungrazed grassland must be present.
Main Objective of Zone	Prevent encroachment near river/waterbodies and filter the backyard runoff.
Zone Functions	• Create recreational opportunities • Refurbish the scenic value of the riverfront.
Activities Permitted	• Recreational spaces such as parks, gardens. • Small scale biodegradable compost yards • Low rise diffused settlements for rural areas.
Activities Restricted	Commercial activities, high-rise structures, housing societies

Envisaged Outcomes	• Wetland protection • Dense flora improves microclimate

Source: Author

Figure 30: Outer Zone



Source: Author

Figure 31: Native Species of Zone-III

Source: Kanpur URMP

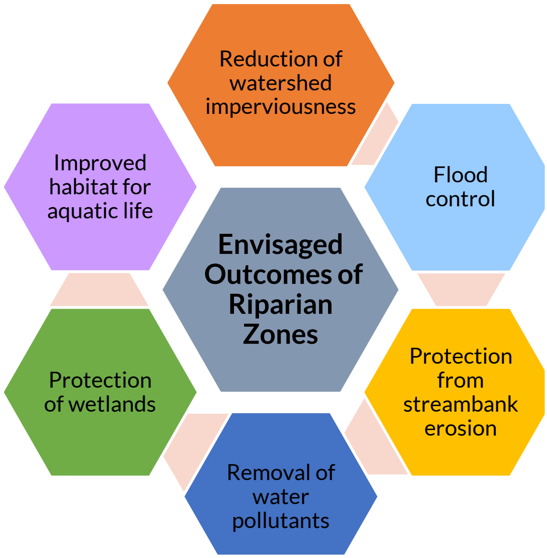
Envisaged Outcomes of Riparian Zones

Reduction of watershed imperviousness – Buffers discourage excessive enclosing of storm drains and hardening of channels. They limit the increase in runoff from impermeable surfaces, as well as erosion and overflow of headwater streams.

Flood control – Properties adjacent to streams often get flooded during monsoon as the stream widens and water overflows. This buffer acts as a shock absorber and barrier thereby protecting the adjoining properties (He et al., 2020b).

Protection from streambank erosion – The consolidation of floodplains and streambank soils by tree roots reduces the likelihood of severe soil erosion. Avoiding development on steep slopes along a stream is the most effective method of preventing erosion (Diversity and Distributions - 2007 - Richardson - Riparian Vegetation Degradation Alien Plant Invasions and Restoration, n.d.).

Figure 32: Outcomes of Riparian Zone



Removal of water pollutants – When placed properly, buffers remove pollutants and regulate flow of water through the developed regions. When planned properly, they provide effective pollutant removal for development within 150 feet of the buffer's perimeter. A forest canopy inhibits the additional warming of streams in developed watersheds.

Protection of wetlands – Stream buffers protect wetlands that are found near streams.

Improved habitat for aquatic wildlife – Many stream ecosystems rely on leaf litter as their primary food supply, and forests offer woody debris that provides cover and habitat structure for water invertebrates and fish. Significant terrestrial habitat, such as forest cover, is preserved via riparian corridors. They are important, species-rich transition zones. Uninterrupted stream buffers serve as "highways" for the passage of plant and animal populations. Amphibians, which require both aquatic and terrestrial habitats to complete their life cycle, require buffers as well. Buffers preserve the stream's base flow.

A ghat cum recreational space for the identified riparian zone has been proposed. Its salient features are given in the next section.

Ghat Proposal

The existing vegetation of the site has been retained as it is, thereby discouraging deforestation. As one enters the space, towards the right is the 'Garden of Fragrance' and towards the left is community based 'Organic Farming'. There is a circular central plaza that acts as a focal point with water features and informal tiered seating space. Some way ahead is the 'Agroforestry zone' where plants and trees will be planted by the citizens of Kanpur of different age groups. A dedicated space for developing the 'Bio-diversity Park' in the future has been assigned opposite the kids play area. Near the entrance, eateries are also provided in this zone.

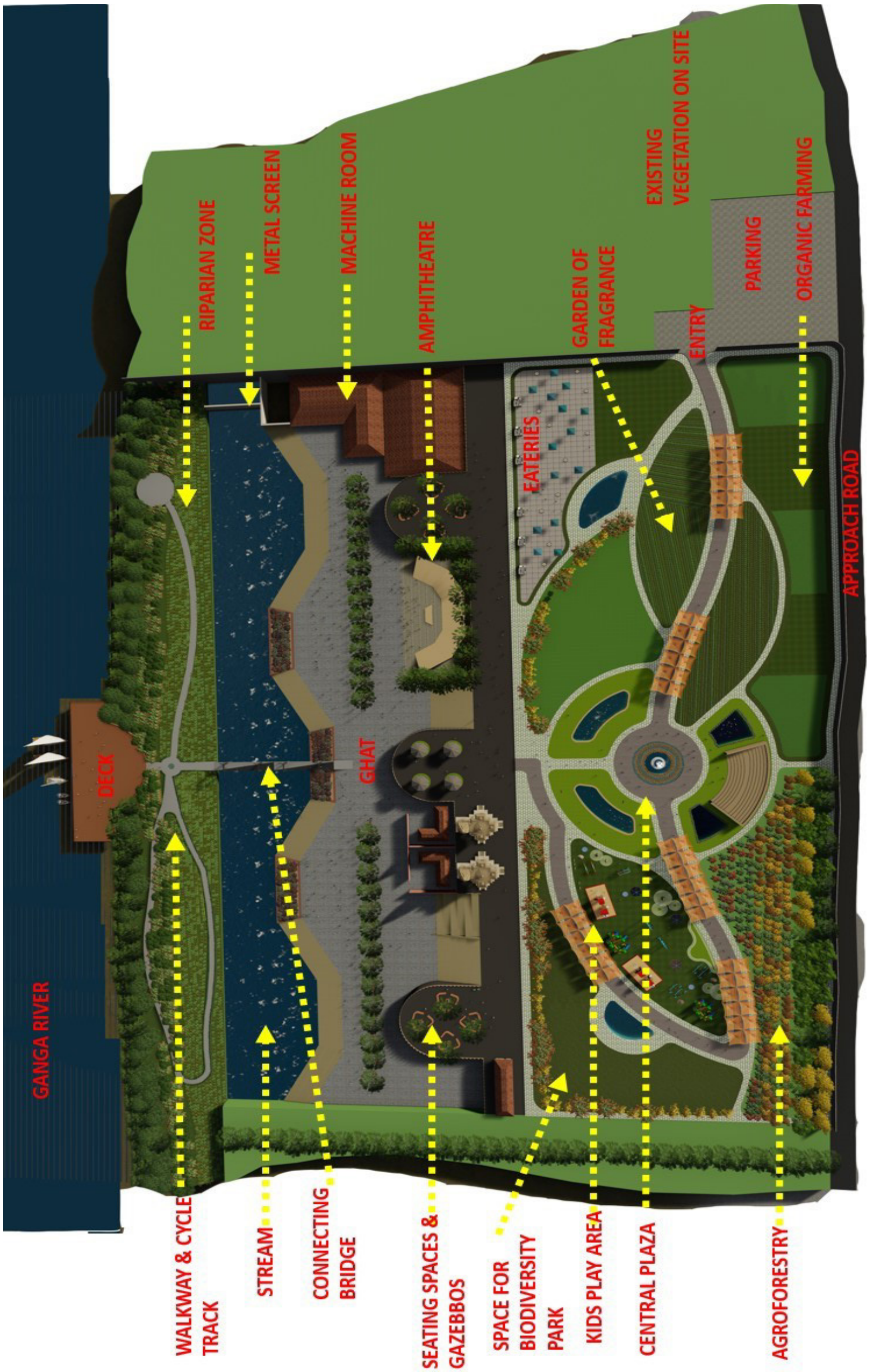
After this is the Ghat area with male and female changing rooms, bio-digester toilets, and gazebos for seating. Keeping in mind the religious sentiments of the people, temples have also been proposed. An artificial stream has been created by diverting the actual river, so the people can take holy baths. Trash bins have been provided to discard the floral and organic waste. Assuming that even after providing trash bins people will still discard the waste in the stream so a metal screen has been provided at the other end to trap all the waste. This will be sent to the machine room where it will be converted to organic manure that can be utilized in the farmland thereby promoting organic farming.

An amphitheatre has been constructed to accommodate around 400 people to witness the evening 'Ganga Arti'. This space can also be utilized by the 'Ganga Praharis' to demonstrate skits to raise awareness. A foot over connecting bridge leads to the 'Riparian Zone'. This has dense plantation, walkways, and cycle track for people to spend their leisure time.

Since the river potential of the city is not up to the mark, a wooden deck for boating is provided at the end which will attract a lot of tourists. An underground 'Bioswale' channel is provided in the riparian zone so that filtered good quality return flow can be achieved for the city, which is one of the priority targets of KURMP (Kanpur Urban River Management Plan). The water from the stream can be treated and utilized for irrigation of the farmland and for some other tertiary purposes.

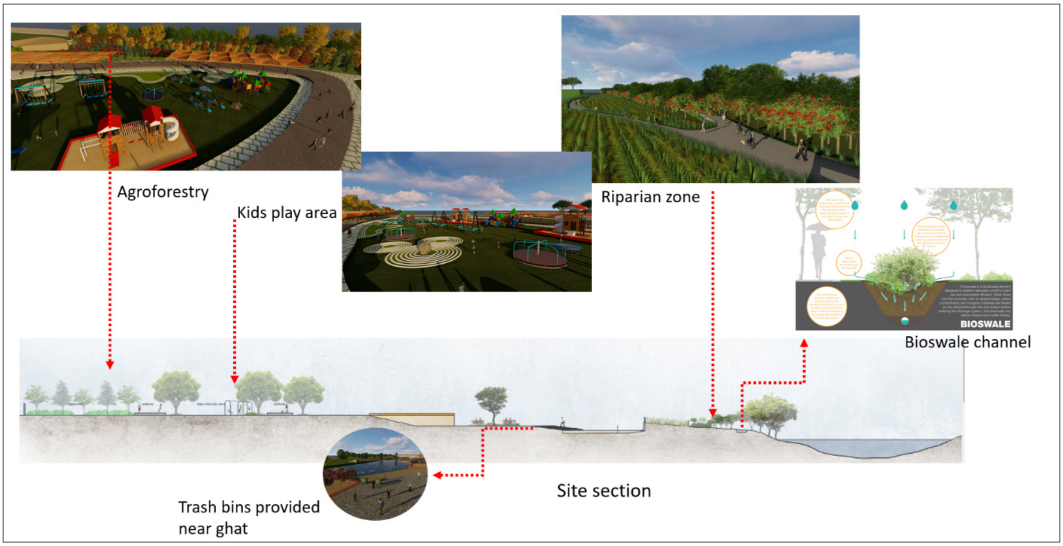
Engaging citizens in the development of this space will create a sense of belonging and sensitize them to river-centric behaviour. Hence, Nature-based Solutions are proposed to mitigate river pollution and an attempt has been made to achieve the components of KURMP that need improvement. Figure 33 depicts the detailed site plan of this space and Figure 34 shows the site section with views of each part.

Figure 33: Proposed Site of Eco-Friendly Ghat on Ganga River, Kanpur



Source: Author

Figure 34: Site Section



Source: Author

Effective Community Engagement/Public Participation

The proposals are within the domain of three broad principles of the Urban River Management Plan that talks about solutions. The proposals are environment friendly, economic, and encourage social cohesion. Figure 35 depicts the three pillars of community engagement.

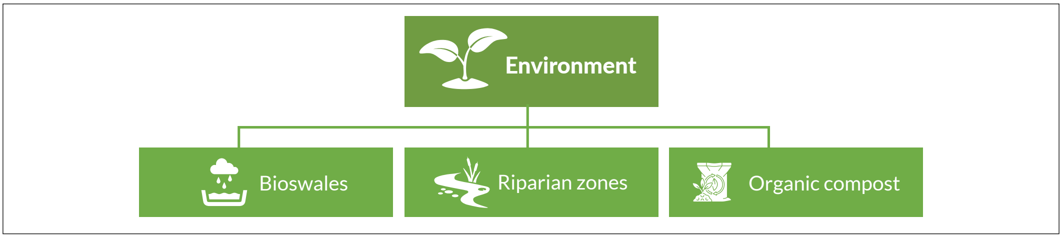
Figure 35: Community Engagement

Source: Author

Environmental

Bioswale will help in filtering the non-point source pollutants and sediments that enter the storm water. In this way good quality filtered return flow to the river will be encouraged. As some catchments are blocked in the city , constructing new catchment areas would invigorate in achieving the target of good quality return flow to the river. The enhanced riparian buffer will help in reducing pollution by denitrification of pollutants and would also act as a shock absorber to mitigate floods. The compost from biodegradable waste will be used as manure for agriculture purposes thereby promoting organic farming. Figure 36 depicts the domains of the Environmental proposals.

Figure 36: Environmental Proposal

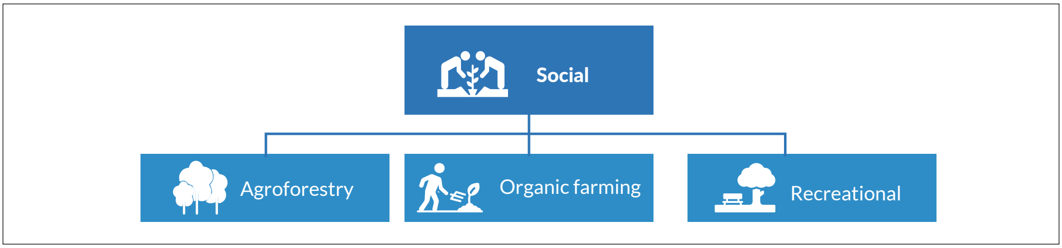


Source: Author

Social

The amalgamation of recreational spaces along with river ghats will boost social gatherings and promote interactions amongst citizens. Agroforestry also has the potential to improve the ecosystem services by sequestering carbon, preventing deforestation, conserving biodiversity, and conserving soil and water. Citizens will be engaged in agroforestry. The flood preventing gabion wall constructed by the citizens will inculcate a sense of belonging to that place. This comes under engaging community in river management activities. The biodiversity/botanical park will induce river and environment sensitive behaviour amongst citizens by educating them about the rich native flora and fauna of their region that needs to be preserved. Figure 37 depicts the domains of Social proposals.

Figure 37: Social Proposal

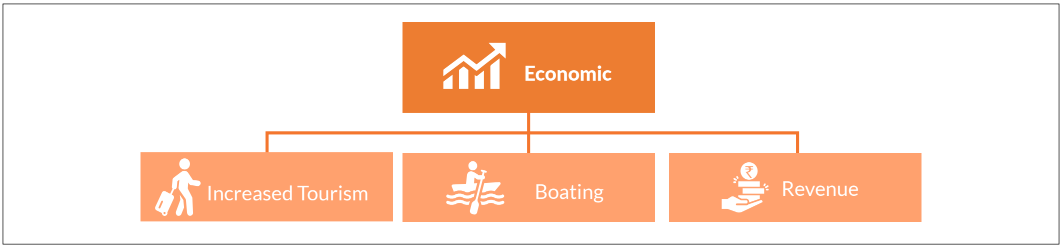


Source: Author

Economic

Most of the riverfront projects in the city are in the form of Ghats (24 in all). So, by clubbing riverfront projects with ghats, and including biodiversity and riverfront parks with them can boost the economy. The only current economic activities that are associated with the river in Kanpur is boating so by introducing a formal boating island with a wooden deck the local commerce (boatmen) near the ghats can be benefitted. The untapped economic potential of the river can be explored further. Visit to the riparian zone would be paid. It has walkways and cycle tracks apart from vegetation. Thus, revenue can be generated from this which can be utilized for the operation and maintenance of such places. Figure 38 depicts the domains of Economic proposals.

Figure 38: Economic Proposal



Source: Author

Outcomes of the Study

The outcomes of an urban river management plan includes various benefits such as improved environmental quality, increased recreational and aesthetic opportunities, capacity building, integration of the river as a vital entity in the development plan, and enhanced economic development.

Conclusion and Way Forward

The results from FAHP prioritized and ranked the pollution drivers, which helped to bring out the pain points in the different segments of the Ganga River Basin. As the stakeholders were from five different domains, so bringing all of them under one umbrella addressed the issues from a holistic approach. These rankings of drivers helped to throw spotlight on some intangible aspects that were included in the sub-drivers but remained neglected.

The 'Handle Bar Survey' conducted in Kanpur along the ghats of the Ganga River gave the on-ground reality check of the current status of the river and the ghats. Interacting with the officials of the Municipal Corporation gave insights on the overall scenario of the city and helped in knowing about the under-achieved targets of Kanpur's URMP.

The proposed policy framework for the riparian zone can be incorporated for other river centric cities as it helps in protecting the river fringe and reducing pollution to a large extent. The Master Plan includes a detailed strategy for improving the riparian buffer along both sides of rivers or the river-centric cities. The following should be included in the strategy:

- Wherever possible, set aside a 30-meter buffer zone.
- Designate a suitable land use for the riparian buffer.
- Clarify land ownership in the buffer zones.
- The concerned authorities and agencies must create a riparian planting action plan that incorporates the native species.

The learning recreational spaces like botanical gardens and biodiversity parks and paid visit to the riparian zone that has walkways and cycle tracks would generate and boost the economy of the entire city. The development of such projects will help to create awareness amongst citizens, sensitize them to river-centric behaviour, and aid in adapting them to such positive changes. The implementation of this prototype model would change the microclimate of that area and if incorporated for more stretches the entire city would benefit especially during the scorching summers as dense vegetation along the river bank would cool down the climate.

Due to the riparian zone policy some people might have to give up their land to the government and ULBs as no construction will be allowed in this zone, so a precise policy framework is required to give compensation to such land owners. This may vary in class 1 and class 2 cities as well as in urban and rural areas. The compensation to such people can be provided in the form of money, FSI, or Transferable Development Rights (TDR) depending upon the feasibility.

If such a prototype is implemented on a larger scale there would be a surge in the economic benefit of the city as revenue would be generated. More employment opportunities would be created for the people. If required the estimated project cost can be reduced by selling chunks of land to farmers for agricultural purposes only. As technology changes swiftly, after a few years some new technique might be invented to filter stormwater and decompose organic waste, so there should be provision for its inculcation.

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Conflict of Interest

Authors have no conflict of interest to declare.

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