URBAN WETLAND/WATER BODIES MANAGEMENT GUIDELINES

APPLICATION OF TOOLKIT IN BHAGALPUR CITY

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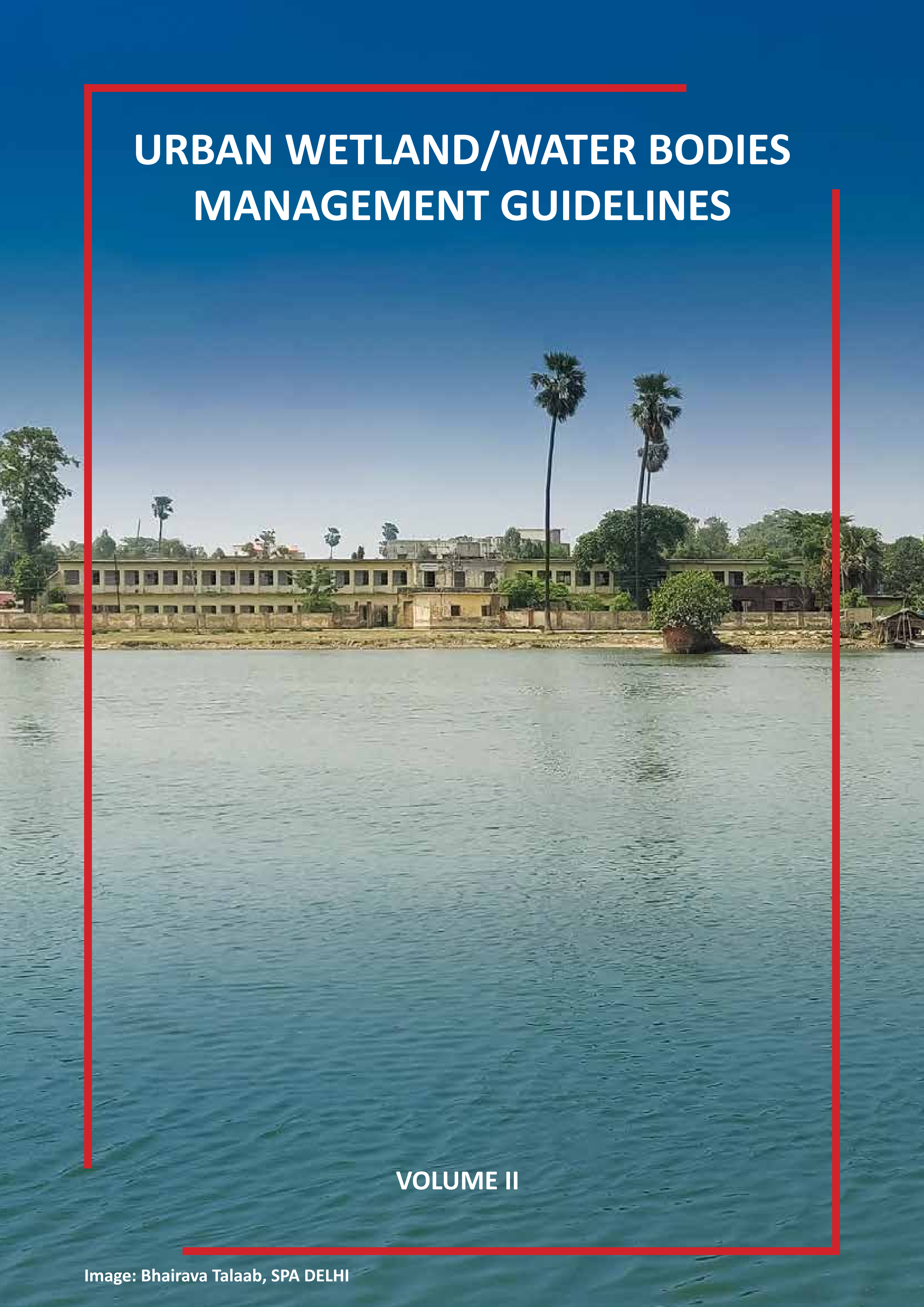
Volume II

NAMAMI GANGE
NATIONAL MISSION FOR CLEAN GANGA

SCHOOL OF PLANNING & ARCHITECTURE, NEW DELHI

URBAN WETLAND/WATER BODIES MANAGEMENT GUIDELINES



VOLUME II

Image: Bhairava Talaab, SPA DELHI

जल शक्ति मंत्री
भारत सरकार
Minister for Jal Shakti
Government of India

सत्यमेव जयते

स्वच्छ भारत
एक कदम स्वच्छता की ओर

Message

The value of wetlands especially in urban settings, is evidenced through our history where water bodies were respected and valued by all communities creating a sense of belonging and ownership towards them. Water bodies within an urban precinct, including smaller ones, form vital ecosystems supporting local livelihoods, with social, economic, ecological and aesthetic benefits. Their value as part of an extensive food chain and biological diversity is immense. For a city, they can provide a wide range of important resources and ecosystem services such as food, water, groundwater recharge, water purification, flood moderation, erosion control, climate regulation and rainfall sinks. They are an important part of our natural wealth and liquid assets.

Sustainable urban water body management encapsulates the linkages between functioning of water cycle and river rejuvenation guided by ecosystem approaches. Government of India's Jal Shakti Abhiyan also recognizes this need and accords high priority to conservation and wise use of wetlands in our country. National Mission for Clean Ganga has made significant inroads by initiating multiple projects and regulatory frameworks to support State Governments for integrated management. Conservation of wetlands would also go a long way in achieving Hon'ble Prime Minister's dream of 'Nal Se Jal' in each household.

This toolkit has been envisioned in a strategic step towards increasing the capacity of city urban wetland managers. I am happy to note that the progress made in this direction has been documented through these volumes, as a step by step guidance framework. I am sure the toolkit will inspire cities to re-imagine their urban wetlands as part of the integrated vision for the city and process of urban planning. The Ministry looks forward to working with the State Governments and concerned citizens to secure these natural assets.

(Gajendra Singh Shekhawat)

सत्यमेव जयते

जल शक्ति
और सामाजिक न्याय एवं अधिकारिता राज्य मंत्री
भारत सरकार

**MINISTER OF STATE FOR
JAL SHAKTI AND SOCIAL JUSTICE & EMPOWERMENT
GOVERNMENT OF INDIA**

Message

Wetlands are life support systems for urban cities, ensuring effective functioning of the water cycle. They help recharge groundwater aquifers, cleanse polluted waters and act as sponges to mitigate floods. Especially for river basins, urban wetlands play a multi-layered role of not only supporting the rivers but also provide ecosystem services to a city. Urban wetlands serve as special attributes contributing to the cultural heritage, and have deep connections with a city's ethos. The value of wetlands in securing local livelihoods through activities such as fishing, farming and tourism, is incomparable. They are indeed an important part of a city's natural wealth and "liquid assets".

The Ministry of Jal Shakti holds the conservation and rejuvenation of urban wetlands in high priority. We are initiating long-term actions for conserving wetlands in the Ganga basin, build the momentum for their revival and to make it a people's movement.

In a strategic step towards increasing the capacity of urban wetland managers in integrated and holistic management of wetlands, a toolkit has been developed for local stakeholders, as Urban Wetland Management Guidelines. This toolkit will be beneficial for all to systematically approach, prioritize and plan for urban wetland management.

The Ministry looks forward to working with State Governments, experts, NGOs, private sector and concerned citizens from all walks of life to restore and revive urban wetlands.

(Rattan Lal Kataria)

Foreward

The National Mission for Clean Ganga (NMCG) under its 'Namami Gange' program has taken up an initiative to conserve the wetlands in Ganga River Basin. The wetlands are highly productive ecosystems supporting rich biodiversity that protect the environment in various ways including supply of water, aiding in its purification and waste assimilation. The wetlands play a crucial role in recharging groundwater, increasing the base flow of rivers and helping in erosion control. Several wetlands on the Ganga basins are home to key flora and fauna, including migratory species. The National Environment Policy 2006, recognised the ecosystem services provided by wetlands and emphasized the need to set up a regulatory mechanism for all wetlands so as to maintain their ecological character and ultimately support their integrated management.

India is a signatory to the Ramsar Convention on Wetlands and is committed to conservation and wise use of all wetlands within its territory. The Ramsar Convention in its 10th meeting of the Conference of the Contracting Parties (COP 10) in 2008 adopted Resolution X.27 on 'Wetlands and Urbanization' and expressed concern that many wetlands in urban and peri-urban environments are or are becoming degraded through encroachment of surrounding populations, pollution, poorly managed waste and infilling or other developments, and that these activities have diminished both the ecosystem services that urban wetlands can provide. It recognized the crucial role of capacity building in enabling local governments, including municipalities, to ensure the conservation and wise use of wetlands, in urban and peri-urban areas, under their jurisdiction.

The foundation of NMCG as an authority is structured on an underlying principle of managing an integrated ecosystem of river Ganga, its tributaries, associated wetlands and ground water. It is imperative to look at the bigger picture of River-sensitive sustainable urbanization. Properly managed wetlands, especially lakes, in urban areas have an important role as a source of water supply, controlling runoff and groundwater recharge. River and river flood plains are water rich areas but the cities on these floodplains are still facing water scarcity. Instead of the wetlands giving water to the base-flow of the river, they are now actually pulling the water. This is the issue that needs to be tackled.

The water bodies are to be maintained to give life to the river. The 'Jal Shakti Abhiyan' of Government of India brought wetlands into the focus of various government bodies when it recognized this need for rejuvenation of wetlands and brought out a list of water bodies for priority work. NMCG has been closely working with the experts, stakeholders and with line departments such as, State Wetland Conservation Authorities, Wetland Division of MoEF&CC and Wetland International India to take forward the cause of wetland conservation in Ganga Basin. Land and water, two major ecological constituents of wetland ecosystems, are enlisted as State subjects as per the Constitution. As such the State Governments and Union Territory Administrations need to take into account the wetland ecosystem services and biodiversity values likewise within their developmental programming and economic well-being. The functions of wetlands are widely known. However, when it comes to managing these functions, the municipal bodies are lagging behind. The "Urban

Wetland Management Guidelines – A Toolkit for Local Stakeholders" prepared in collaboration with the School of Planning and Architecture, Delhi aims to educate the local stakeholders on the management plan to maintain the urban floodplain wetlands, including mapping the city information, mapping wetlands/ water bodies & their attributes to cover the information gap, identifying their link with the groundwater dynamics (ground water status and the level at which it is maintained), urban development alongside the wetlands and land suitability analysis (demarcating the zone of influence), looking at the impact of development and trends in the city Master Plans and identification of critical wetlands, and accordingly finalization of the action plan.

This Toolkit has been tested for the city of Bhagalpur, which is downstream to river Ganges and is a water rich area. It was found that these urban wetlands are interwoven with settlement pattern and economic activities including agriculture, rearing of fish, among others. Apart from scientific and community engagement, the Toolkit also strives to acknowledge traditional knowledge which should also be made a part of water management within the cities.

This Toolkit represents NMCG's efforts towards establishing urban wetlands as part of the city's water fabric, conserving and nourishing them to become public spaces as well as a valuable contribution to local environment. It is our fervent hope that urban municipal bodies and local stakeholders find the Toolkit useful and it will motivate them towards the common goal of River Rejuvenation.

Rajiv Ranjan Mishra

Director General

National Mission for Clean Ganga

Preface

India's wetlands/water bodies are extraordinarily diverse-ranging from lakes and ponds to marshes, mangroves, backwaters and lagoons -and play a vital role in maintaining water balance, flood prevention, support biodiversity and food security and livelihoods. Wetlands/Water bodies are systematically converted into "real estate' by vested interests or simply used as a dumping ground for sewage and garbage and are receptacles for toxic waste. While community and court actions are in process across the country, the lack of enforcement of legal instruments has hampered any real progress in many of these cases.

Urban areas have flourished around water, be it river, lake, springs or a steady availability of ground water. What was earlier identified as source to sustain urban development is increasingly being transformed as a sink for waste- both solid and liquid. In the rapid pace of urbanization we have overlooked the role of water bodies, with the plans of many cities not even indicating their existence on the map. This has led to their rapid encroachment and degradation. Today we do not have an inventory of water bodies of all urban settlements whereas it is available at state for wetlands of greater areas. For the capital city of Delhi data has been provided by the Delhi Parks and Gardens Society (DPGS), which state that there are over 1000 water bodies in the city. However, almost 30% of these are untraceable and area under water bodies has reduced by 7% from 1999 to 2002, The ownership and maintenance of water lie with multiple agencies, however in recent years, there has been increased awareness about the importance of rejuvenating water bodies to enhance water security and an initiative of reviving 201 bodies is underway in the capital.

Wetlands/ Water bodies are a essential for human well-being, economic security and climate change mitigation and adaptation. The multiple benefits provided by wetlands are essential in achieving Sustainable Development Goals. Forming an integral part of the hydrological cycle, properly managed wetlands/water bodies in urban areas have an important role as a source of water supply, controlling run-off and recharging groundwater. For prevention of pollution, conservation and restoration of wetlands, the government has come up with different policies and acts which needs to be taken forward for implementation at local levels. The present toolkit puts forth a methodology to assess the role of water bodies, prioritize them for conservation/rejuvenation and mainstreaming conservation of wetlands/water bodies in the development/planning process.

Prof. Dr. PSN Rao

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The study would not have been completed without the support from the officers from Bhagalpur District and City,Bihar; which was taken up to develop and test the toolkit - Ms.Vandana Kini, IAS, Commissioner, Bhagalpur division, Shri Pranav Kumar IAS, Collector Bhagalpur District, Smt Seema Saha, Mayor, Municipal Commissioners - Shri Meena (upto 10th July 2019) and Smt J. Priyadarshini (from 11th July 2019 onwards) and officers of Bhagalpur Municipal Corporation, Ward Councilors , NGOs and local people of the city of Bhagalpur.

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ABBREVIATIONS/ ACRONYMS

AAI: Airport Authority of India
CCA: Culturable Command Area
CETP: Common Effluent Treatment Plant
CGWA: Central Ground Water Authority
CGWB: Central Ground Water Board
CPCB: Central Pollution Control Board
CZMA: Coastal Zone Management Authority
DPAP: Drought Prone Area Programme
DEM: Digital Elevation Model
DPR: Detailed Project Report
EC: Environmental Clearances
FTL: Full Tank Level
GIS: Geographical Information System
HFL: High Flood Level
IWDP: Integrated Wasteland Development Programme
IWMP: Integrated Watershed Management Programme
JSA: Jal Shakti Abhiyan
MLD: Million Litres Per Day
MOEFCC: Ministry of Environment, Forest and Climate Change
MOWR, RD & GR: Ministry of Water Resources, River Development and Ganga Rejuvenation
NBC: National Building Code
NDMA: National Disaster Management Authority
NDZ: No Development Zone
NEERI: National Environmental Engineering Research Institute
NGO: Non Governmental Organization
NHAI: National Highways Authority of India
NMCG: National Mission for Clean Ganga
NOC: No Objection Certificate
NPCA: National Plan for Conservation of Aquatic Ecosystems
PERT: Program Evaluation Review Technique
PMKSY: Pradhan Mantri Krishi Sinchai Yojana
PWD: Public Works Department
RCZ: River Conservation Zone
RRR: Repair, Renovation and Restoration
RWH: Rain Water Harvesting
SLUSI: Soil and Land Use Survey of India
STP: Sewage Treatment Plant
SWM: Solid Waste Management
TCPO: Town and Country Planning Organization
ULB: Urban Local Bodies
UT: Union Territory
USGS: United States Geological Survey
WUA: Water Users Association
ZOI: Zone of Influence

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ABOUT THE TOOLKIT

The toolkit is targeted at providing a set of practical and policy-relevant methods for information collection which can be used by those involved in wetland conservation and development planning. The Scope of the study shall be limited to one city within the Ganga Basin. The main objectives of the toolkit are:

A. Mapping of city baseline information
B. Mapping of urban wetlands/water bodies
C. Valuation of ecosystem services of water bodies
D. Ground water assessment
E. Land suitability for ground water recharge
F. Evaluation of impact of urban development on water bodies
G. Preparation of action plans for conservation of water bodies
H. Preparation of management plan for conservation of water bodies

STAGE I

IDENTIFICATION OF URBAN WETLANDS/WATER BODIES FOR CONSERVATION

01 MAPPING CITY LEVEL INFORMATION

02 MAPPING OF URBAN WETLANDS /WATER BODIES & ITS ATTRIBUTES

03 IDENTIFICATION OF ECOSYSTEM SERVICE OF URBAN WETLANDS/WATER BODIES

04 GROUND WATER ASSESSMENT

STAGE II
ACTION PLAN FOR IDENTIFIED URBAN WETLANDS/ WATER BODIES

05
LAND SUITABILITY FOR GROUND WATER RECHARGE

06
IMPACT OF URBAN DEVELOPMENT TRENDS/ MASTER PLAN PROVISIONS ON WETLANDS/WATER BODIES

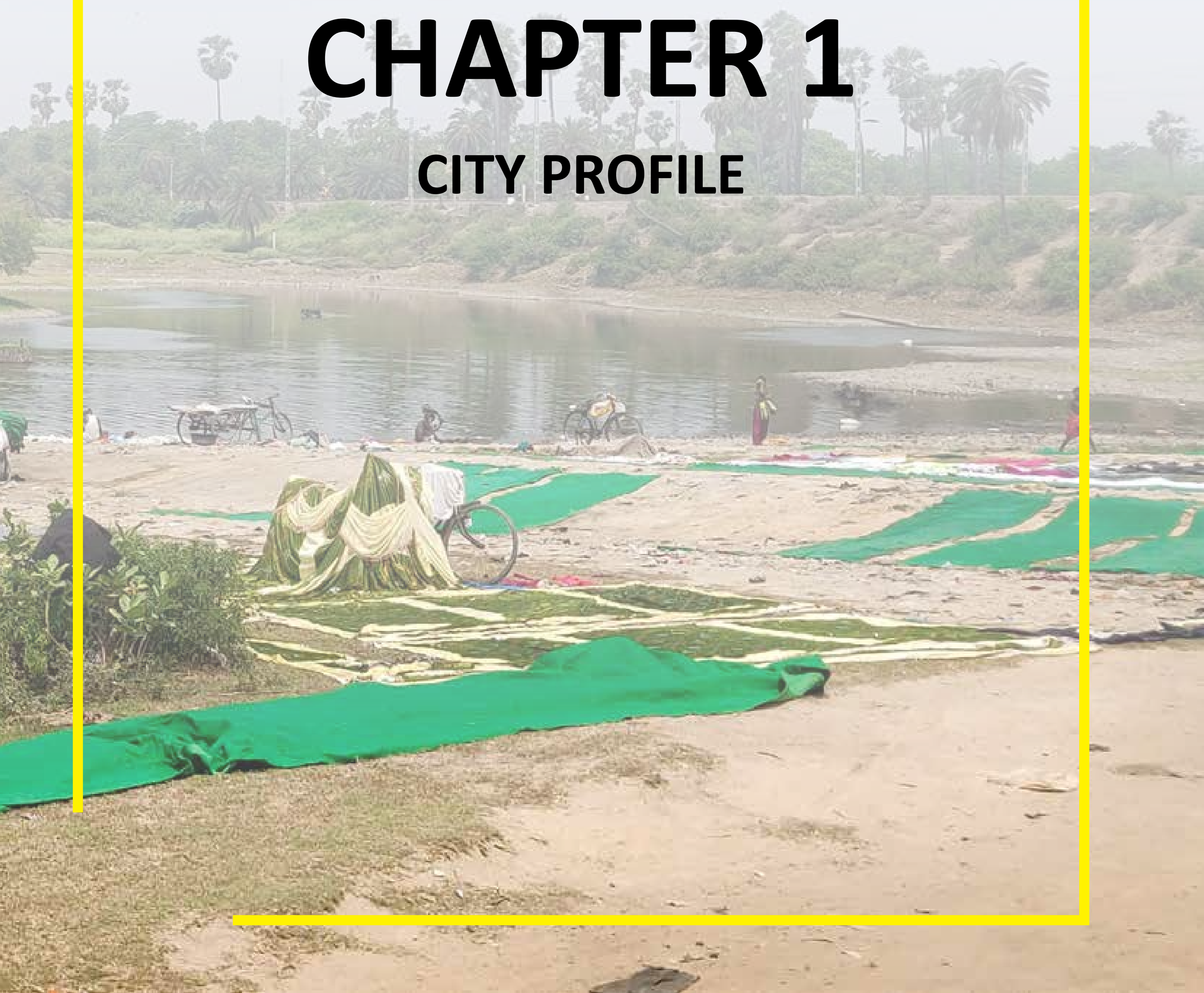
07
PREPARATION OF ACTION PLAN FOR CONSERVATION OF URBAN WETLANDS/WATER BODIES

08
PREPARATION OF MANAGEMENT PLAN FOR CONSERVATION OF URBAN WETLANDS/ WATER BODIES

METHODOLOGY

CHAPTER 1

CITY PROFILE



1. CITY PROFILE

1.1 INTRODUCTION

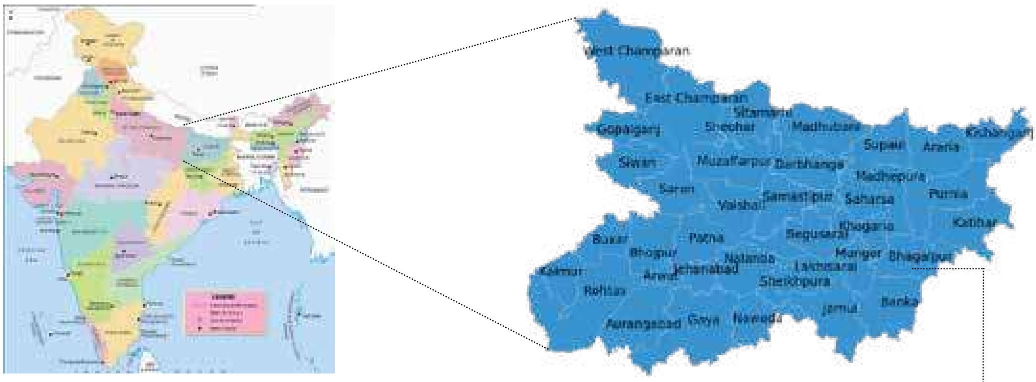
Bhagalpur is located 220 km east of Patna and 410 km North West of Kolkata. Geographically, it is located at 25° 15' 0" North latitude and 87° 0' 0" East longitude on the southern alluvial plains of River Ganga. Bhagalpur is well connected with the rest of the country through rail and road networks. NH 80 runs through the city and connects it to Patna. In addition, SH 19 and 25 are the main arterial roads. Nearest railway station is Bhagalpur which is within the city. Bhagalpur is the sub district head quarter of the city. District head quarter of the city is Bhagalpur. Patna is the state head quarter of the city and is 225 km far from here.

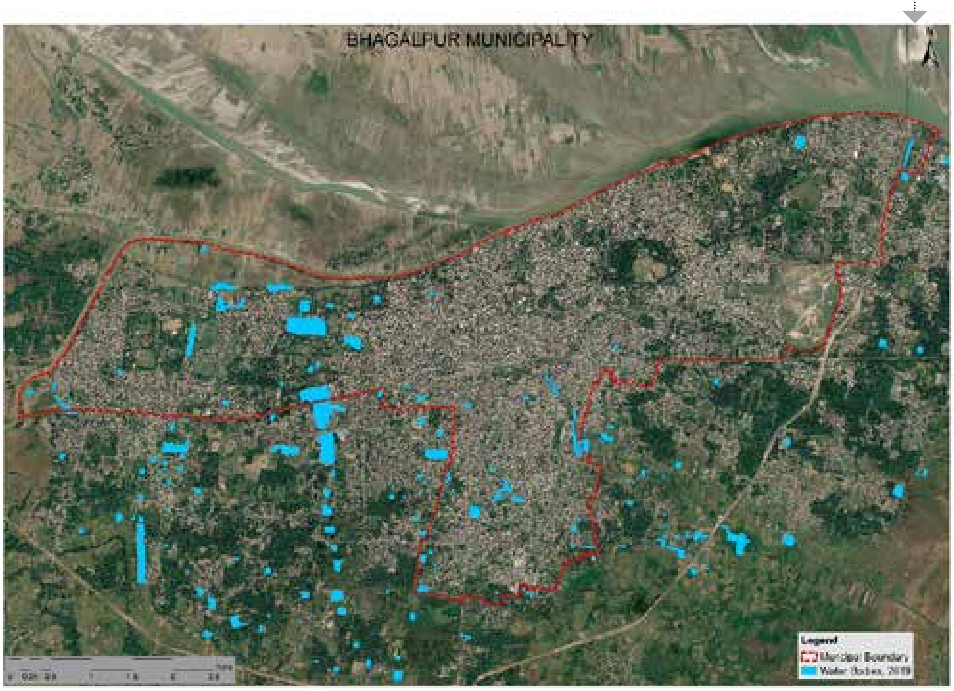
Bhagalpur Municipal Corporation, with population of 400146 persons (Census 2011) is Jagdishpur sub district's only municipal corporation located in Jagdishpur sub district of Bhagalpur district in Bihar State of India. Total geographical area of Bhagalpur municipal corporation is 26 km2. Population density of the city is 15367 persons per km2. There are 51 wards in the city.

Bhagalpur, the Silk City of Bihar, is famous for its sericulture, manufacture of silk yarn, and weaving of Tussar silk. The Bhagalpur cluster ranks second highest in silk fabric production and exports after the silk cluster in Karnataka. The third largest urban center of the state, Bhagalpur is a district headquarter serving multiple functions of an administrative, trade and commerce, service and distribution center, especially for crops, cottage industry of silk products and tourism.

The location of Bhagalpur municipality has been shown in map in figure 1.

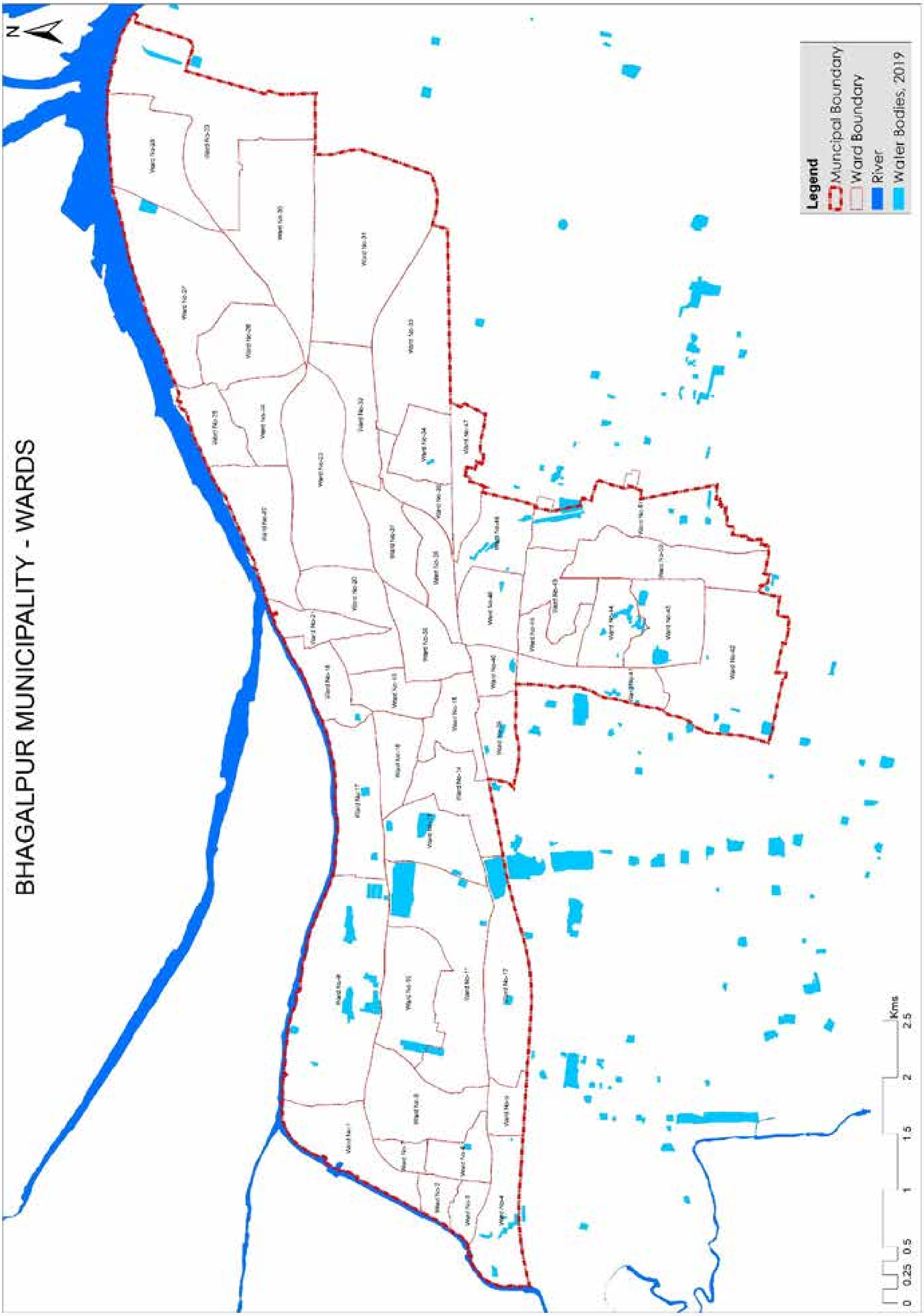
Figure 1: Location of Bhagalpur Municipality





Source: Google Earth, 2019

Figure 2: Bhagalpur Municipality with Wards



Source: Bhagalpur Municipality

1.2 NATURAL SETTING

1.2.1 Climate and Rainfall

Bhagalpur city experiences a warm and a humid climate. Winter starts from November and extends upto February. The summer period begins from March with the peak temperature of 400 C in May-August. The month of March and April are the driest months of the year with the relative humidity of 50-55% in the morning and 35-40% in the afternoon.

The humidity increases in May and June to 80% or more. About 80% of the rainfall is under the influence of southwest monsoon, which normally breaks in the second fortnight of June. The monsoon last till the later part of the September. The annual rainfall for the last 5 years has been shown below in table 1.

Table 1: Annual Rainfall in Bhagalpur District

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
2014	5.6	38.1	3.8	0	197.6	95.3	476.3	203.3	149.6	9	0	0.2	1178.8
2015	28.4	3.7	31.9	71.4	53.7	204.2	360.1	300.7	188	11.4	0	0	1253.5
2016	23.6	0.9	1.6	7.2	92	104.9	315.3	117.1	320.1	27.1	0	0	1009.8
2017	4	0	18.4	22.6	111.3	66.8	377.5	319.3	216	272.3	0.1	0	1408.3
2018	0	0	13.5	35.5	49.3	156	338.3	345.9	83.3	61.6	0	`3	1083.4
Avg.	12.32	8.54	13.84	27.34	100.78	125.44	373.50	257.26	191.40	76.28	0.02	0.04	1186.76

Source: IMD

1.2.2 Geomorphology and Soil

Geo-morphologically, the Bhagalpur city forms a part of the Mid-Ganga Foreland Basin. The north and central Bhagalpur towards the north and south of Ganga respectively forms a flat Indo-Gangetic alluvium tract. The slope is towards the river Ganga.

The soils are mainly derived from the older and newer alluvium. These alluvial plain soils are light grey to dark grey in colour, rather heavy and texturally fine in nature. The pH values range from neutral to acidic and the acidity of the soil gradually increases from north to south.

1.2.3 Ground Water Scenario

The sand layers in the Quaternary Alluvium (both newer and older) form the main source of ground water. Based on the strata logs and hydrogeological properties, the aquifer system can be divided into two categories;

- The shallow aquifers within 50 m depth.
- The deep aquifers within 50 – 200 m depth.

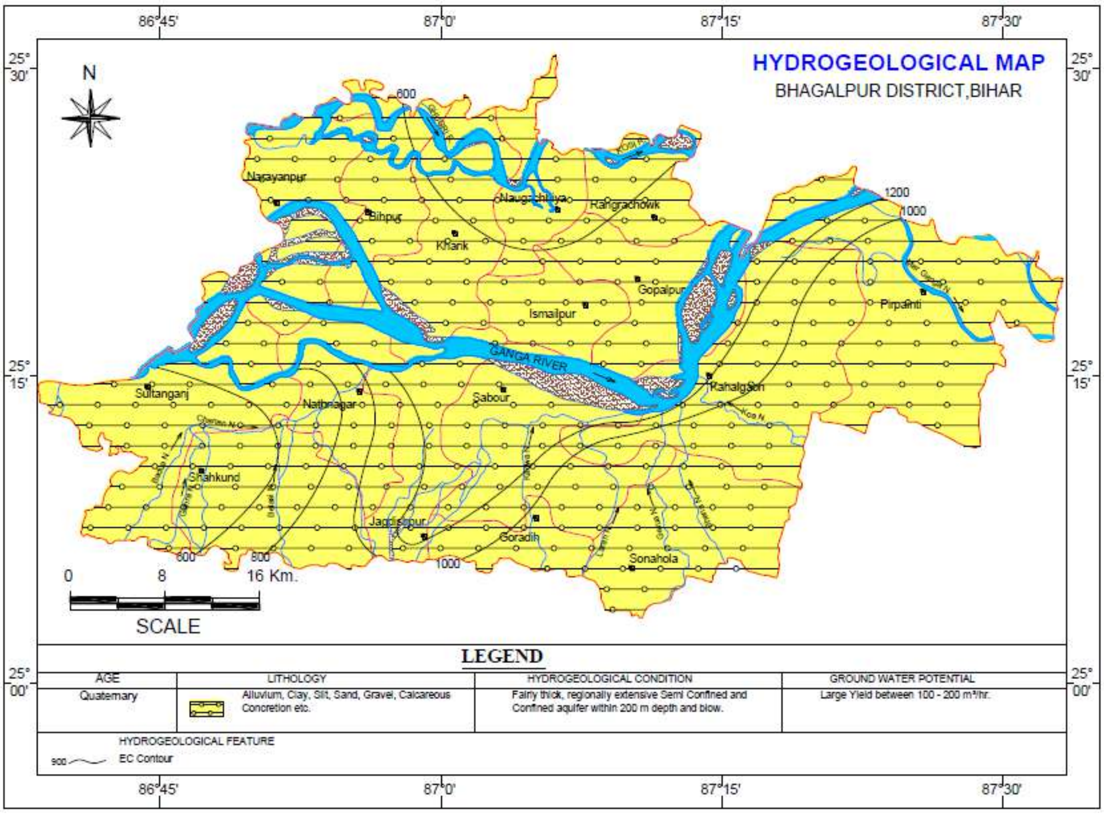
In shallow aquifers, the ground water occurs under unconfined condition and in deeper aquifers under semi-confined to confined conditions. The shallow aquifers consisting of fine to medium sand with clay, silt and kankars are the main sources of ground water in the marginal alluvial tract in the south Bhagalpur. In general, the thickness of these aquifers varies from 13 to 18 m. The thickness of the aquifer is controlled by the geometry of the underlying basement rock. The deeper aquifers mainly consist of sand, gravel and calcareous nodules with alternating layers of clay. The exploration data reveals the presence of four to five major aquifers with cumulative thickness 20 to 85 m. These aquifers thin out towards the western part since clay dominance increase.

The composition of the aquifer is not homogeneous at many places. These are very often mixed with silt and little clay, which impedes their water yielding capacity.

The composition of the aquifer is not homogeneous at many places. These are very often mixed with silt and little clay, which impedes their water yielding capacity

The pre-monsoon water level data of the year 2011 (Fig. 4) reveals that the depth to water level remain within 5 – 10.69 mbgl, with the deepest of 10.69 mbgl and the shallowest of 5 mbgl. In post-monsoon, the depth to water level (Fig. 4) in the city comes to be within 1.53 – 8.04 mbgl. The pre and post-monsoon water level data indicates that the water level has registered a rise of 0.77 to 5.14 m within the season.

Figure 3: Hydrogeological map of Bhagalpur district, Bihar



Source: Ground Water information Booklet, Bhagalpur, CGWB

1.2.4 Ground Water Quality

Bhagalpur city is affected by arsenic contamination in ground water. The ground water in the has been reported to be containing arsenic more than the permissible limit of 50 mg/L (as per WHO norm). PHED, Govt of Bihar has conducted a blanket testing for arsenic in the state. Arsenic occurs sporadically in hand pumps and it largely depends on the depth of the hand pump and from which formation it taps water. A sudden surge in arsenic concentration in the tube wells is found between the depth range of 12 and 40 m. After 40 m there is a drastic decline in arsenic concentration. In dug wells arsenic concentration is reported as below detection limit (BDL).

Figure 4: Ground water depth to water level, May 2011

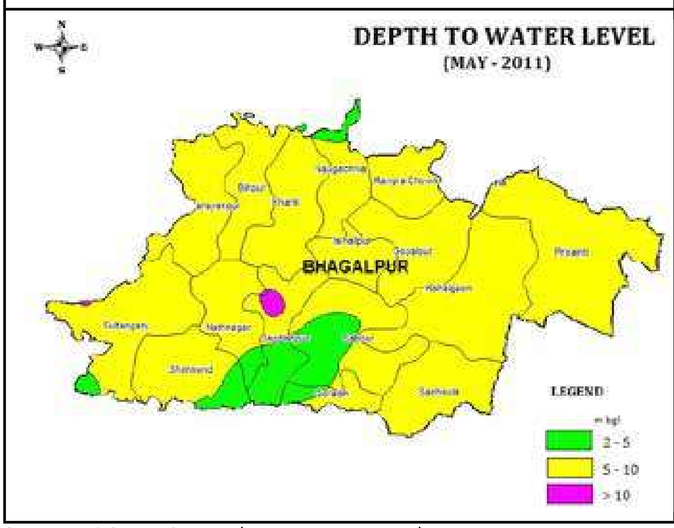
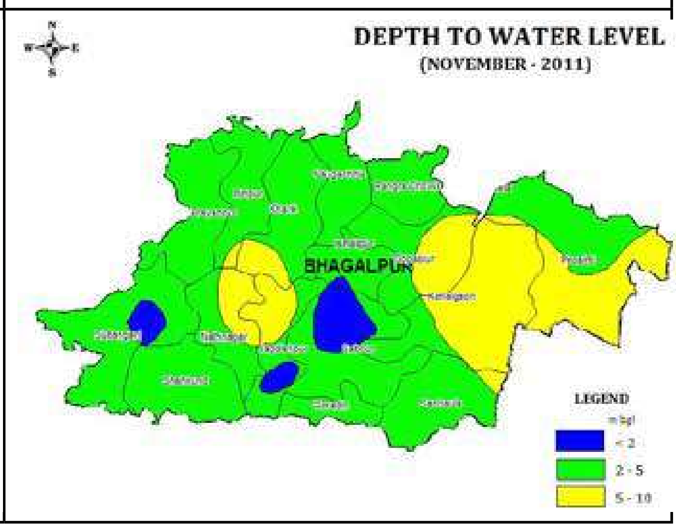
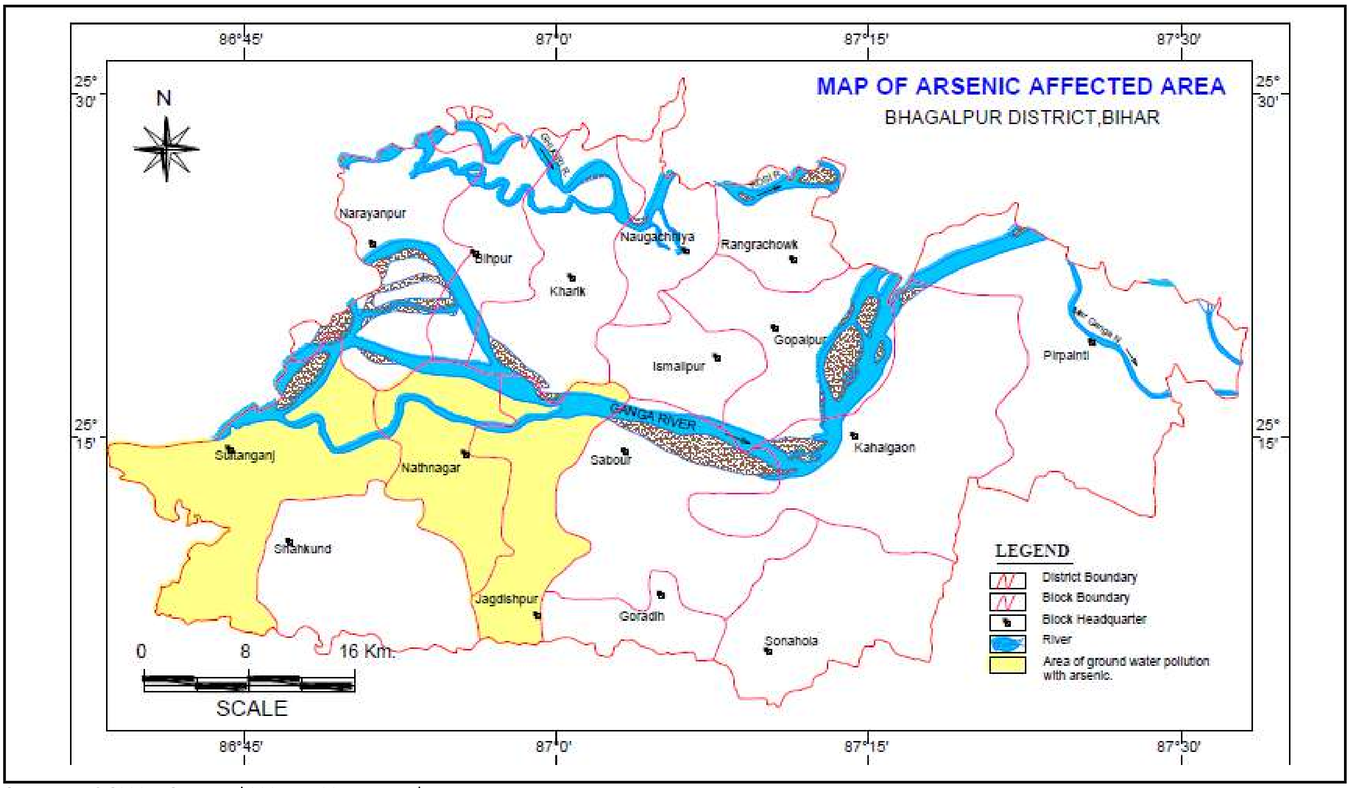


Figure 5: Ground water depth to water level, Nov 2011



Source: CGWB Ground Water Year Book

Figure 6: Map showing areas affected by arsenic contamination of ground water



Source: CGWB Ground Water Year Book

1.3 URBAN SETTING

Bhagalpur is a city of historical importance on the southern banks of the river Ganges in the Indian state of Bihar. It is the 3rd largest city of Bihar and also the headquarters of Bhagalpur district and Bhagalpur division. Known as Silk City, it is a second largest and major educational, commercial, and political centre after Patna city, and is listed for development under the Smart City program, a joint venture between Government and industry. The city is also well-known industrial place for silk and cottage industry.

The name Bhagalpur is etymologically derived from Bhagdatpuram (meaning city of good luck). Bhagalpur formed a part of the ancient Sanskrit kingdom of Anga, said to be ruled by the King Karna of Mahabharata. The city is bounded by river Ganga on the north, Champa River on the west and railway line on the southwest.

1.3.1 Demography

As of the 2011 India census, Bhagalpur town has a population of 4001463, while the district as a whole has a population of 3 million. It is the 3rd largest city in Bihar in terms of urban population. Males constitute 54% of the population and females 46%. Bhagalpur has an average literacy rate of 81.16%, while the male literacy rate is 85.38% with women at 76.31%.

Table 2: Ward Population and Density

Ward No.	Population (2011)	Area (Ha)	Population Density (pph)	Slum Area	Area (Sq.m)	Area (Sq. Kms)
1	9411	51.7	182	10.92	516956.852	0.517
2	6535	11.89	549.6	1.11	118855.191	0.119
3	7772	13.05	595.6	1.9	130523.057	0.131
4	6926	46.21	149.9	6.54	462110.898	0.462
5	9655	15.76	612.6	0	157583.911	0.158
6	8085	22.92	352.7	1.05	229212.946	0.229
7	7902	10.56	748.3	0	105578.405	0.106

Ward No.	Population (2011)	Area (Ha)	Population Density (pph)	Slum Area	Area (Sq.m)	Area (Sq. Kms)
8	8538	59.91	142.5	3.57	599124.149	0.599
9	7562	142.1	53.22	6.43	1421391.11	1.421
10	8355	56.32	148.3	0	563213.876	0.563
11	6991	110.6	63.21	4	1106388.95	1.106
12	8358	64.73	129.1	3.03	647300.426	0.647
13	7637	44.65	171	5.54	446459.366	0.446
14	8207	40.04	205	1.35	400389.263	0.400
15	7305	31.11	234.8	0	311130.411	0.311
16	8869	28.25	313.9	1.34	282486.272	0.282
17	5674	57.14	99.3	2.72	571378.036	0.571
18	7454	29.16	255.6	2.06	291557.513	0.292
19	6647	26.3	252.7	0.19	262970.441	0.263
20	7104	52.18	136.1	0.37	521813.231	0.522
21	6205	21.52	288.3	1.25	215192.592	0.215
22	7065	58.25	121.3	1.2	582546.177	0.583
23	6635	95.77	69.28	0	957729.342	0.958
24	8818	35.18	250.7	1.5	351778.967	0.352
25	5765	29.63	194.6	3.79	296281.293	0.296
26	10024	52.33	191.6	8.33	523311.164	0.523
27	7681	114.3	67.2	3.83	1143476.49	1.143
28	9781	65.18	150.1	10.82	651758.971	0.652
29	9284	127.7	72.7	1.7	1277312.19	1.277
30	5100	98.19	51.94	0.94	981919.331	0.982
31	10557	142.8	73.93	11.7	1427558.36	1.428
32	4645	45.43	102.2	0.5	454286.511	0.454
33	11335	90.35	125.5	2.65	903525.935	0.904
34	8114	30.48	266.2	2.54	304804.929	0.305
35	5881	21.66	271.5	2.14	216596.439	0.217
36	6839	28.66	238.6	0.92	286604.131	0.287
37	7717	35.99	214.4	0.72	359929.394	0.360
38	5955	35.53	167.6	0	355290.420	0.355
39	6622	24.42	271.2	3.78	244240.928	0.244
40	7221	16.51	437.4	2.01	165057.196	0.165
41	7853	33.9	231.7	4.15	338961.581	0.339
42	8416	104.5	80.54	4.04	1045460.46	1.045
43	10415	47.33	220.1	3.24	473306.464	0.473
44	8733	32.1	272.1	1.67	321044.974	0.321
45	7255	21.12	343.5	0.49	211172.373	0.211
46	6944	36.08	192.5	0.25	360800.162	0.361
47	10040	29.01	346.1	2.38	290085.978	0.290
48	8962	37.03	242	3.77	370282.350	0.370

Ward No.	Population (2011)	Area (Ha)	Population Density (pph)	Slum Area	Area (Sq.m)	Area (Sq. Kms)
49	7443	33.92	219.4	2.05	339242.250	0.339
50	8697	59.96	145	59.9642	599641.972	0.600
51	9157	79.88	114.6	10.16	798785.029	0.799
Total	400146	2599.29		204.6042	25994408.7	25.994

Source: Bhagalpur Municipality

The population of Bhagalpur city projected for the horizon period-2030, as mentioned in the CDP of Bhagalpur city, had been done by studying the following aspects: (a) State trends in urban growth; (b) Migration characteristics of population into urban areas; (c) District level and city migrant population characteristics; (d) Economic opportunities in the city; and (e) Regional potential of the city. The projection of population has been done by various methods. The ratio method has been adopted due to its growth rate being similar to the projected urban population growth rate of the state by the Census of India. The population of Bhagalpur is projected to be 5.36 lakhs in 2030.

Table 3: Population of Bhagalpur city

Census Data	Population	Growth Rate
Census 1901	75760	
Census 1911	74349	-1.9
Census 1921	68878	-7.4
Census 1931	83847	21.7
Census 1941	93254	11.2
Census 1951	114530	22.8
Census 1961	143850	25.6
Census 1971	172202	19.7
Census 1981	225062	30.7
Census 1991	253225	12.51
Census 2001	340767	34.57
Census 2011	400146	17.4

Source: Census Abstract

Bhagalpur attracts large population of the region for various purposes like sale of agriculture products, business, shopping, official work, banking, treatment etc. The floating population of the city has been considered as 5% of the total population.[1]

1.3.2 Projected and Floating Population of Bhagalpur Town

The projected and floating population as provided in Bhagalpur Sewerage DPR has been taken for our assessment to maintain synergy with infrastructure development and needs of city.

Table 4: Population Projection of Bhagalpur city

Year	Graphical Method	Floating Population
Census Year (2011)	400146	20007
2018	454028	22701
2023	501553	25078
2028	554052	27703
2033	612047	30602
2038	676112	22806
2043	746884	37344
2048	825063	41253

1 Bhagalpur Sewerage DPR

Source: Bhagalpur Sewerage DPR

The land use distribution of Bhagalpur city has been given below. Bhagalpur falls under medium town as per the URDPFI norms. The suggested developed area density for medium town (plain area) is given as 100-150 persons per hectare[2] and the Bhagalpur city has a developed area density of 154 which exceeds the prescribed norm.

Table 5: Land Use of Bhagalpur city

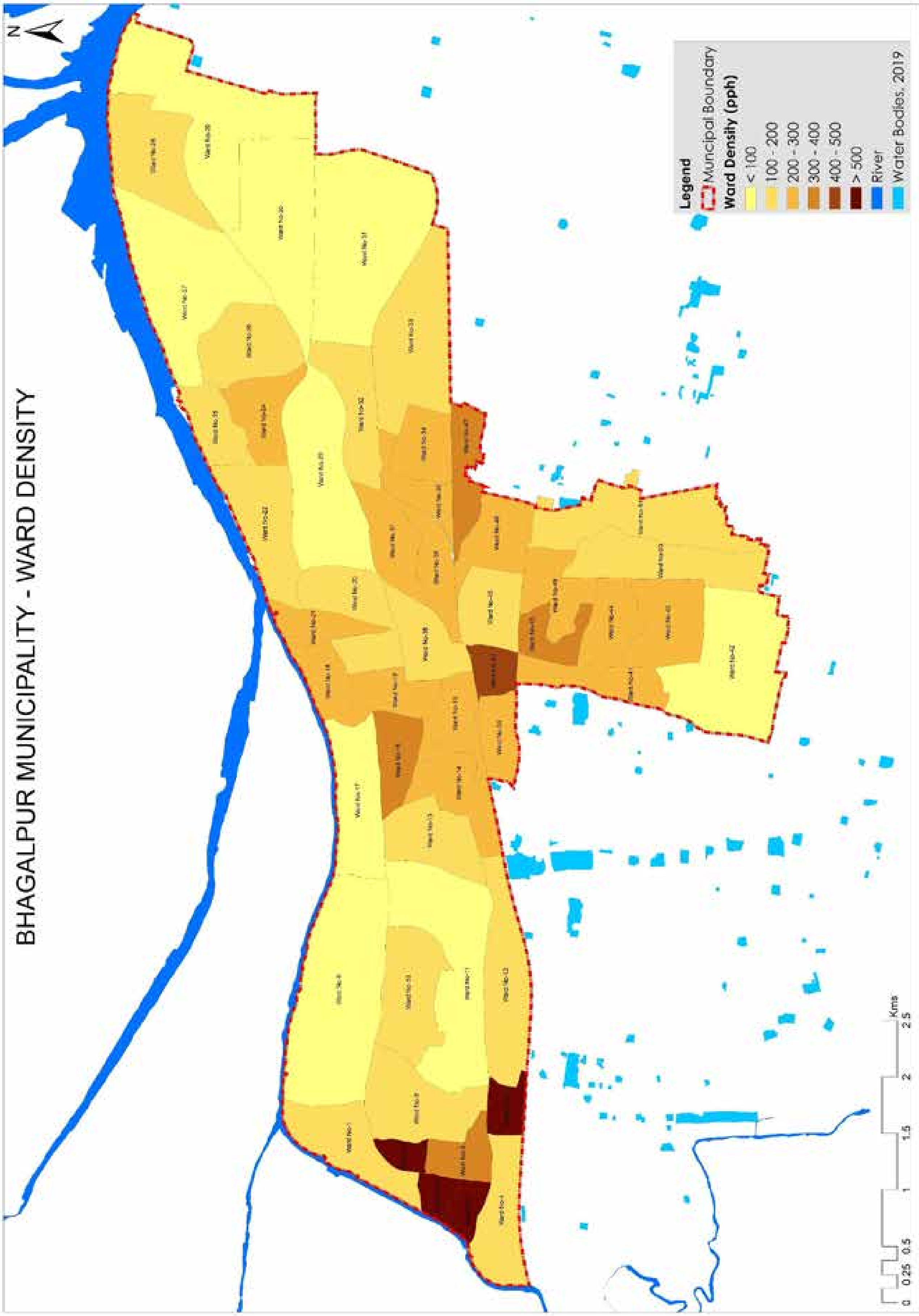
Land Use	Area (Sq.m)	Area (Sq. Km)	Percentage	URDPFI Norms<?> (%)
Residential	7781315.396	7.78	29.93	43 -48
Commercial	829792.143	0.83	3.19	4 – 6
Mixed Use	1623529.759	1.62	6.25	
Industrial	91552.318	0.091	0.35	7 - 9
PSP	2856061.771	2.86	10.99	6 - 8
Transportation	2671188	2.671	10.28	10 - 12
Utility	27967.933	0.028	0.11	
Government	3734443.618	3.73	14.37	
Recreational	21343.673	0.021	0.08	12 – 14
Green Belt	887113.820	0.887	3.41	Balance
Water Bodies	462479.732	0.462	1.78	Balance
Vacant Land	5007620.225	5.01	19.26	
Total	25994408.7	26	100	

Source: Bhagalpur Municipality

We can clearly see that the city lacks recreational space with respect to URDPFI proposed land use structure.

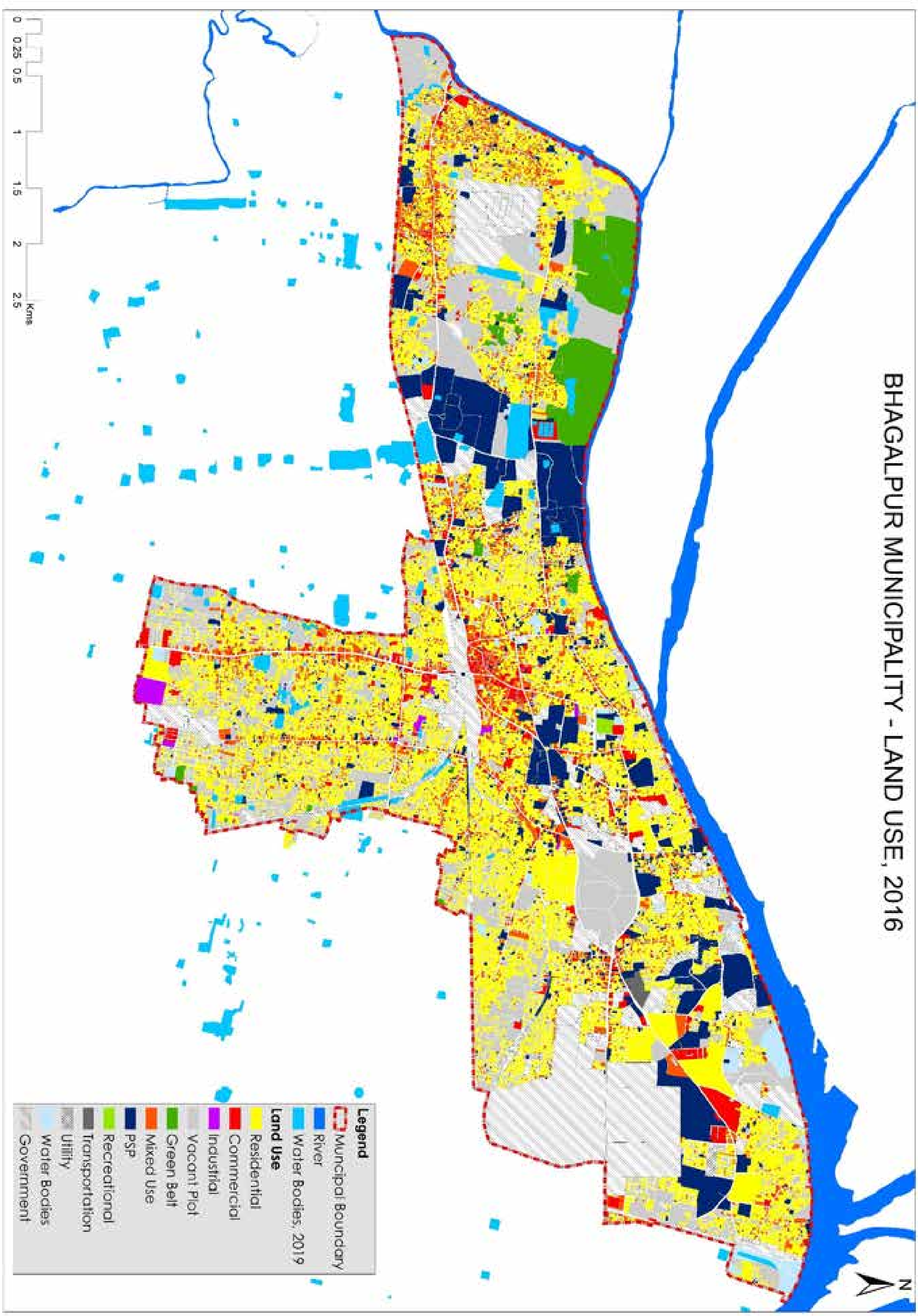
2 URPFI Guidelines Volume 1, 2015

Figure 7: Bhagalpur Ward Density Map



Source: Bhagalpur Municipality

Figure 8: Bhagalpur Land Use Map, 2016



Source: Bhagalpur Municipality

1.3.3 Economy

Bhagalpur has been associated with the silk industry for hundreds of years, and famous all over India for its Tussar Silk & Bhagalpuri Saree. Silkworms are employed to produce the renowned Tussar Silk from which Tussar Saree is manufactured. The Silk Institute and Agricultural University are located in the city. However, due to the industrial revolution, large portions of the silk business, based on the handloom were affected.

The main occupation of the people of Bhagalpur district is agriculture. The cultivators are fully conscious of the beneficial effects of rotation of crops. Rice is the most important crop of the district. It covers the largest portion of the gross area sown. Wheat is the main Rabi crop, Maize forms another important cereal and an item of food among poor masses. Sugarcane is the most important non-food crop of the district. The next important non-food crop are oil seeds. But all these things can only give us an idea of the economic structure of Bhagalpur district rather than the Bhagalpur city.

The account of the economic elements in urban area i.e., Bhagalpur municipal area is described in brief below.

1.3.3.1 Fisheries

The large number of river streams low-lying fields where water accumulates in the rainy season, ponds and marshes indicate a rich potential for pisciculture. Certain portions of the bed of Ganga near Bhagalpur are particularly noted for a large variety of spawn. A large number of tanks are kept reserve for rearing fish. There are bug traders who directly import or export fish. Quite a large quantity of fish is received in Bhagalpur market everyday from the other sided of the Ganga mostly from Katihar and Khagaria. In Bhagalpur town, the fish brought from different parts of the country are sent to the wholesale fish market at Sujaganj. From this market fish are sent to the retailers on auction basis. Particular kind of fishes such as Hilsa and Bhetki, etc. and lobsters packed in ice are imported from Kolkata. Fresh water fish such as Rohu and Katla are sent out from Bhagalpur to Kolkata.

1.3.3.2 Industries

Bhagalpur has been famous for its industrial potentiality since long. Tassar silk, Dyeing, Salt, Indigo, Glassware are some of the main industries. Cloth manufacture was one of the important industries. Besides there are number of small-scale industries and some of them still exist till date. A number of industries have come up in the post-independence period. Among the medium scale industries, Government Silk Institute in Nathnagar and Sheo Mills Co. Private Ltd., are important. Among the household industries which plays an important role in the economy of the district, handloom industry finds an important place in the city as well as in the Bhagalpur district. Dairy, Pottery making and manufacture of materials from cork bamboo, cane, leaves, etc. are quite significant.

There is hardly any large and medium scale industrial establishment in the city. The city however has numerous household industries. According to 1991 Census, there were 190 small scale industries in the district out of which 30% were concentrated in Bhagalpur city.

Apart from them there are many saw mills, shoe making, printing woolen products, drugs and pharmaceuticals, candle manufacturing and plastic goods manufacturing units.

As far as the importance of Bhagalpur is concerned, it is famous for its silk cloth production from its very beginning.

1.3.3.3 Trade and Commerce

The position of Bhagalpur on the map of Bihar has prime importance for trade and commerce. It is well connected to other towns through railway and roadways. A portion of Bhagalpur district lies on the north of the river Ganga and grows luxuriant maize and other crops. Bhagalpur has also been in close contact with Nepal through Purnia district. Trade in Bhagalpur district consists mainly of export of jute, oil seeds, food-grains, sugar, timber, tassar silk, buffaloes and cows, handloom products, blankets and carpets. There are mainly three commodities viz., clothing, grains and turmeric arranged accordingly to importance in which wholesale business is carried on in the district. Bhagalpur town has been the chief marketing centre in the district since long being the headquarters of the division and the district as well. It has the advantage of all the modes of communication. The main retail marketing centres in the district are Bhagalpur, Sabour, Nathnagar, Jagdishpur in the city and Sultanganj, Naugachia, Colgong, Banka and Bihpur outside the city in the district. At all these places retail shops of almost all the commodities locally consumed are found. Among retail trade large number of shops deal with grocery.

Table 6: Distribution of main workers in Bhagalpur city

Ward No.	Main Workers	Cultivators	Agricultural Labourers	Household Industry Workers (HHI)	Other Workers
Ward 1	2,499	85	547	496	1371
Ward 2	2,139	11	12	1166	950
Ward 3	2,112	82	29	737	1264
Ward 4	2,105	54	63	912	1076
Ward 5	2,114	25	24	591	1474
Ward 6	2,028	16	6	177	1830
Ward 7	1,876	64	49	973	790
Ward 8	2,030	2	18	352	1658
Ward 9	1,562	346	242	82	892
Ward 10	1,737	14	229	70	1424
Ward 11	1,694	186	59	318	1131
Ward 12	1,898	27	36	74	1761
Ward 13	1,746	56	301	50	1339
Ward 14	2,141	37	84	351	1669
Ward 15	1,658	7	14	79	1558
Ward 16	2,114	52	27	163	1872
Ward 17	1,473	30	30	260	1153
Ward 18	1,731	21	42	198	1470
Ward 19	1828	9	7	208	1604
Ward 20	1948	27	49	397	1475
Ward 21	1380	19	30	68	1263
Ward 22	1753	58	60	96	1539
Ward 23	1713	99	42	23	1549
Ward 24	1787	12	14	33	1728
Ward 25	1607	26	142	72	1367
Ward 26	2217	58	107	320	1732
Ward 27	1209	23	25	20	1141
Ward 28	1849	15	176	81	1577
Ward 29	1719	51	192	54	1422
Ward 30	1160	16	6	8	1130
Ward 31	2326	84	416	75	1751
Ward 32	1160	19	65	46	1030
Ward 33	2026	22	51	138	1815
Ward 34	2166	34	73	37	2022
Ward 35	1394	7	31	97	1259
Ward 36	1637	12	2	27	1596

Ward No.	Main Workers	Cultivators	Agricultural Labourers	Household Industry Workers (HHI)	Other Workers
Ward 37	2408	19	71	321	1997
Ward 38	1723	26	8	282	1407
Ward 39	1339	17	7	113	1202
Ward 40	1712	21	51	506	1134
Ward 41	2040	44	51	222	1723
Ward 42	2131	26	70	140	1895
Ward 43	2375	9	80	307	1979
Ward 44	1986	8	20	239	1719
Ward 45	1914	9	20	184	1701
Ward 46	1742	15	55	168	1504
Ward 47	2301	21	53	127	2100
Ward 48	2181	17	44	26	2094
Ward 49	1448	8	18	79	1343
Ward 50	1943	29	43	118	1753
Ward 51	2298	32	140	169	1957

Source: Bhagalpur District Census Handbook

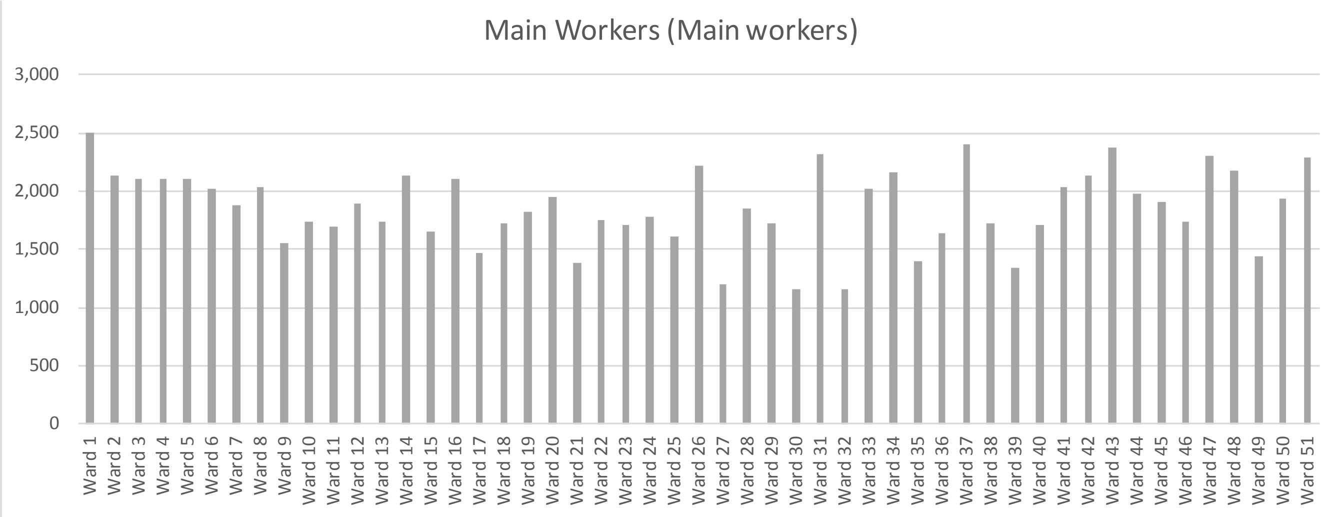
Table 7: Distribution of marginal and non workers in Bhagalpur city

Ward No.	Marginal Workers	Marg_ Cultivators	Marg_ Agricultural Labourers	Marg_HHI workers	Marg_Other Workers	Non-Worker
Ward 1	698	88	144	275	191	6214
Ward 2	842	1	115	539	187	3554
Ward 3	479	20	11	206	242	5181
Ward 4	318	21	53	129	115	4503
Ward 5	827	12	43	214	558	6714
Ward 6	123	9	9	32	73	5934
Ward 7	390	5	15	104	266	5636
Ward 8	422	1	8	75	338	6086
Ward 9	377	29	131	23	194	5623
Ward 10	636	34	250	62	290	5982
Ward 11	588	19	25	77	467	4709
Ward 12	508	12	1	38	457	5952
Ward 13	193	3	31	25	134	5698
Ward 14	516	12	8	8	488	5550
Ward 15	721	8	40	307	366	4926
Ward 16	688	80	65	51	492	6067
Ward 17	448	5	22	85	336	3753
Ward 18	1213	38	26	700	449	4510
Ward 19	177	13	6	23	135	4642
Ward 20	442	19	21	96	306	4714
Ward 21	419	1	72	23	323	4406
Ward 22	453	6	9	12	426	4859
Ward 23	226	56	9	5	156	4696

Ward No.	Marginal Workers	Marg_ Cultivators	Marg_ Agricultural Labourers	Marg_HHI workers	Marg_Other Workers	Non-Worker
Ward 24	501	25	39	71	366	6530
Ward 25	130	11	13	10	96	4028
Ward 26	341	20	18	23	280	7466
Ward 27	834	8	21	8	797	5638
Ward 28	1032	15	48	34	935	6900
Ward 29	943	24	125	41	753	6622
Ward 30	486		68		418	3454
Ward 31	562	12	199	36	315	7669
Ward 32	114	5	7	4	98	3371
Ward 33	443	1	49	33	360	8866
Ward 34	392	9	6	6	371	5556
Ward 35	433	4	3	39	387	4054
Ward 36	253	4	12	82	155	4949
Ward 37	297	5	9	8	275	5012
Ward 38	96	4	2	17	73	4136
Ward 39	313	9	2	39	263	4970
Ward 40	658	5	20	173	460	4851
Ward 41	348	98	124	45	81	5465
Ward 42	487	11	111	59	306	5798
Ward 43	532	3	79	50	400	7508
Ward 44	860	15	16	133	696	5887
Ward 45	244	9	7	20	208	5097
Ward 46	191	2	5	10	174	5011
Ward 47	744	5	39	147	553	6995
Ward 48	268	13	9	11	235	6513
Ward 49	403	5	20	17	361	5592
Ward 50	359	5	20	39	295	6395
Ward 51	301	4	41	8	248	6558

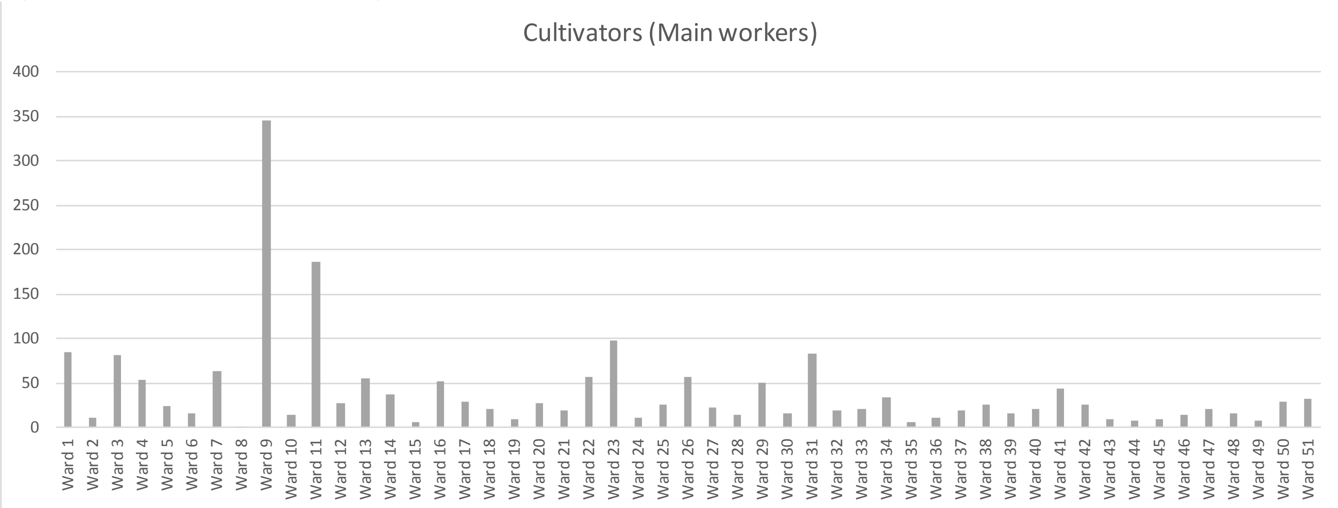
Source: Bhagalpur District Census Handbook

Figure 9 :Main Workers in Bhagalpur City



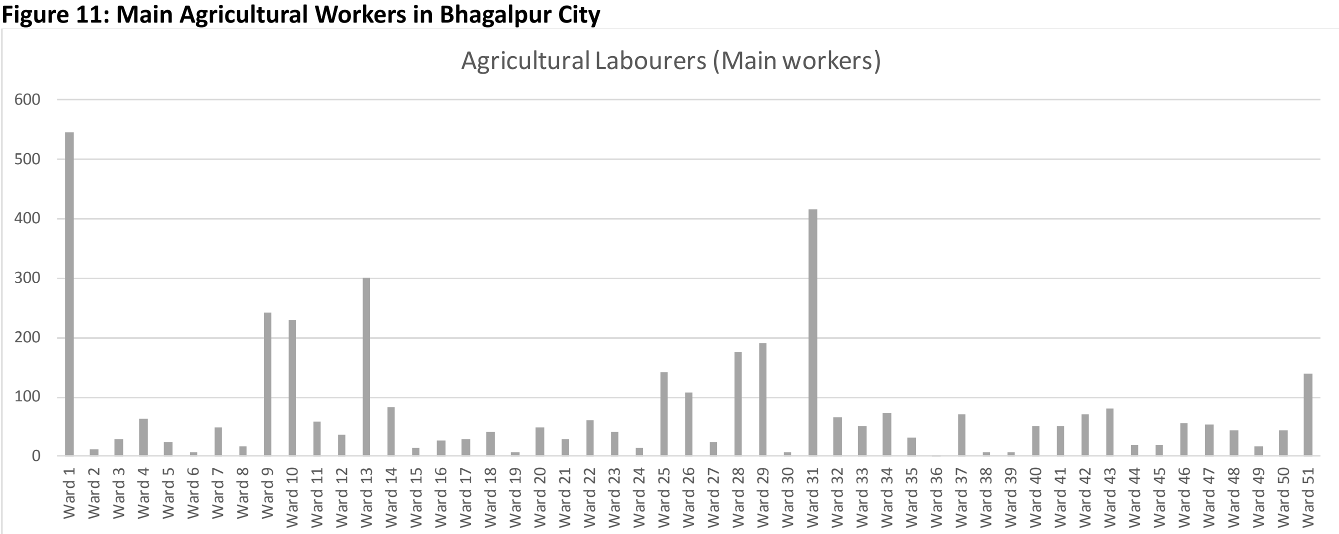
Source: Bhagalpur District Census Handbook, 2011

Figure 10: Main Cultivators in Bhagalpur City



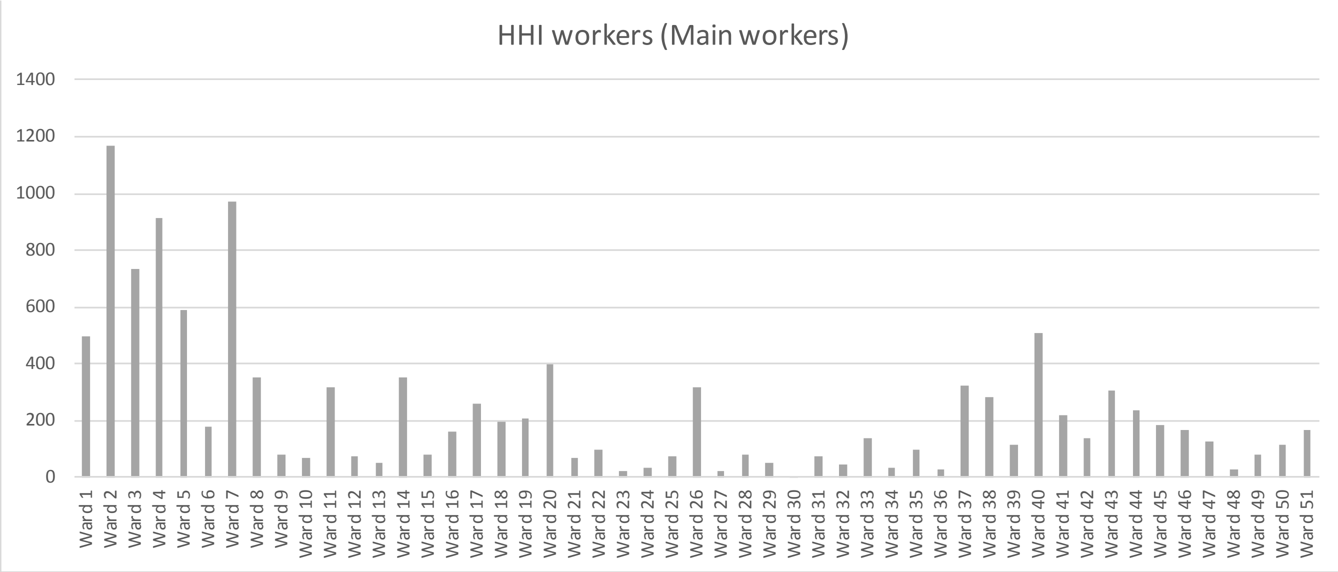
Source: Bhagalpur District Census Handbook, 2011

Figure 11: Main Agricultural Workers in Bhagalpur City



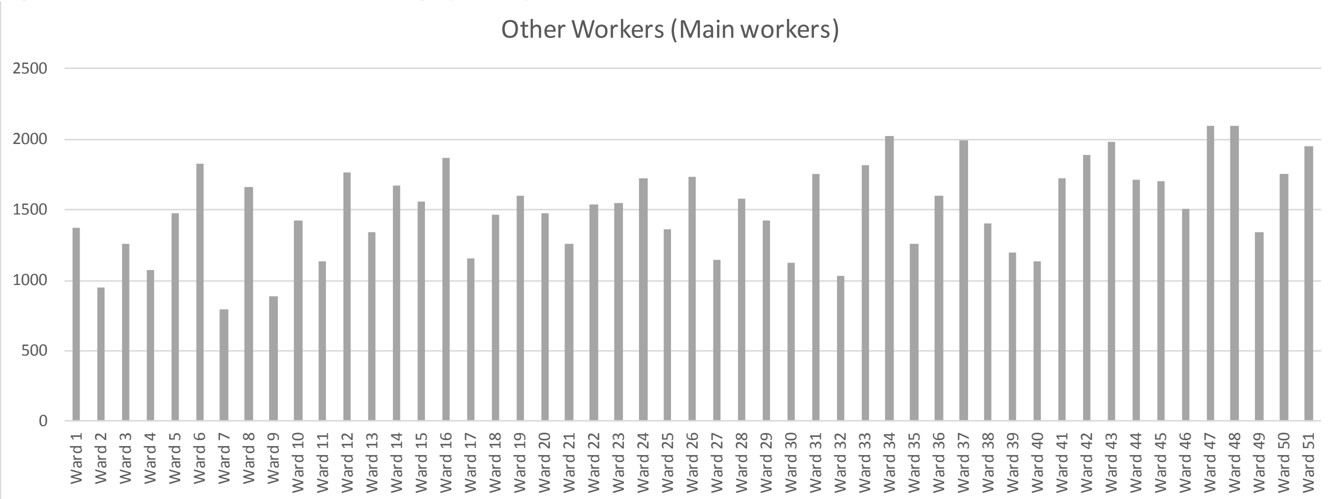
Source: Bhagalpur District Census Handbook, 2011

Figure 12: Main Household Industry Workers in Bhagalpur City



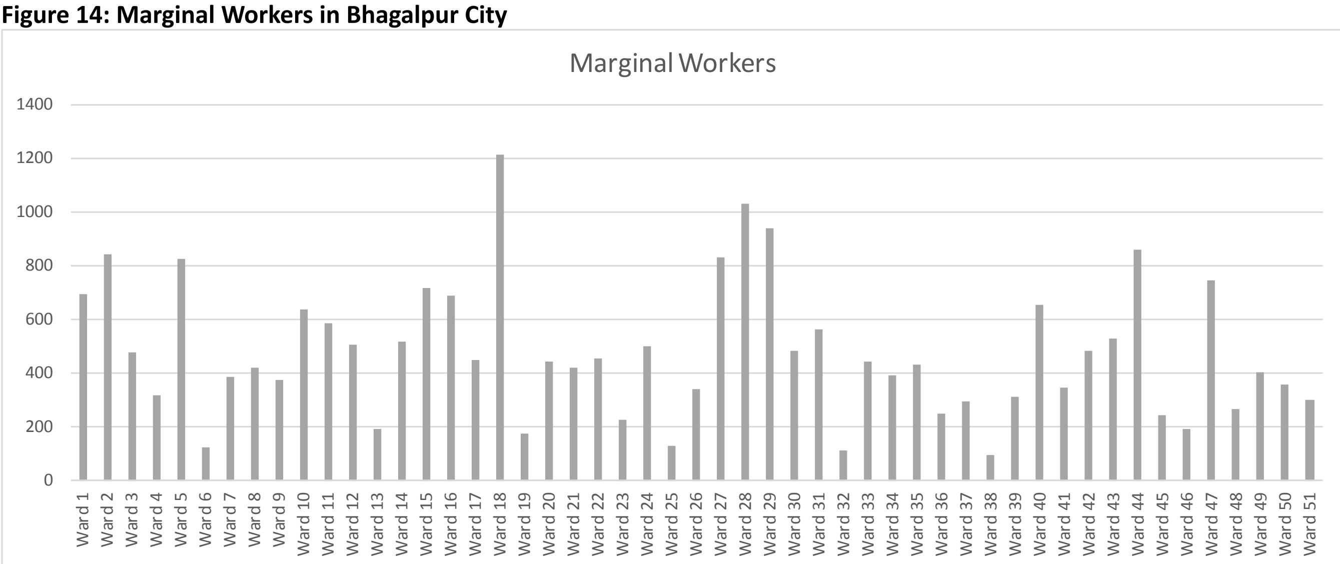
Source: Bhagalpur District Census Handbook, 2011

Figure 13: Main Other Workers in Bhagalpur City



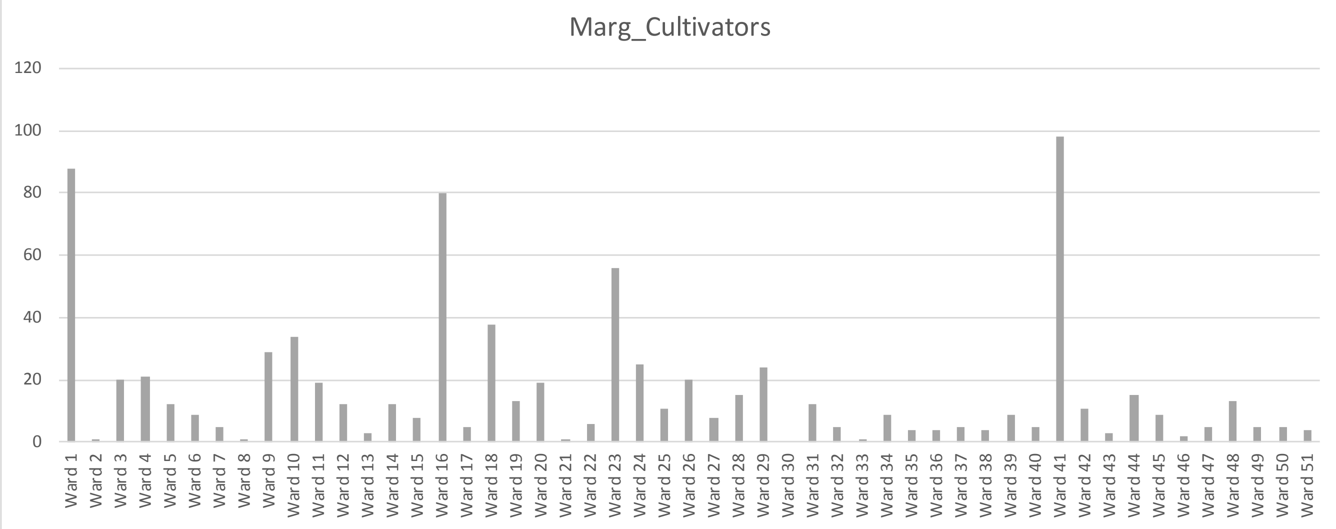
Source: Bhagalpur District Census Handbook, 2011

Figure 14: Marginal Workers in Bhagalpur City



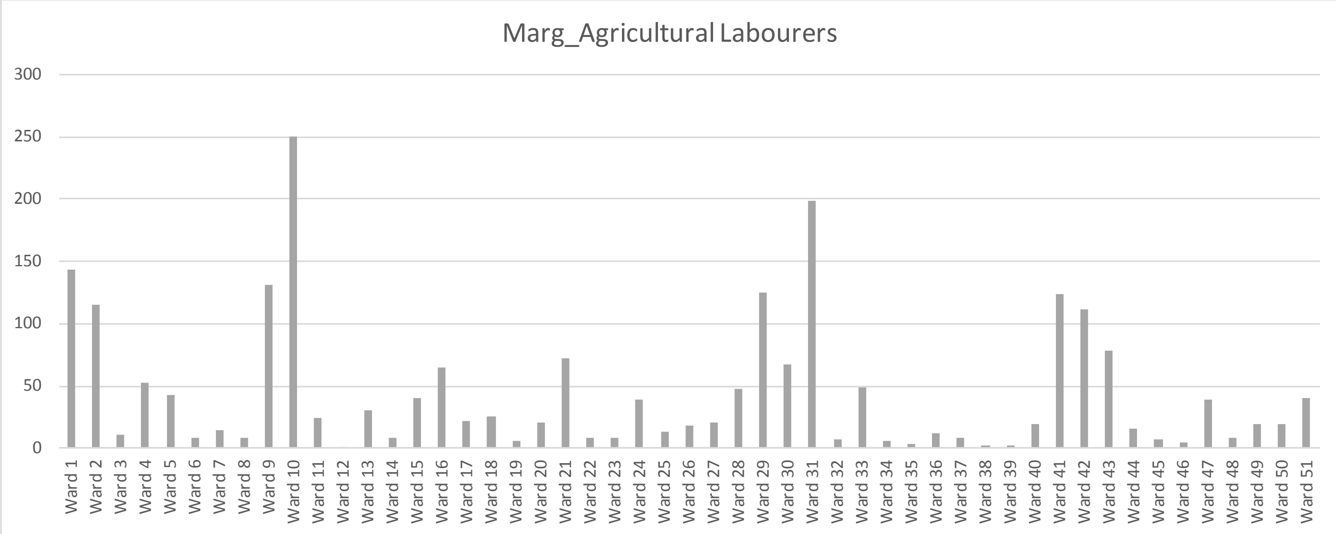
Source: Bhagalpur District Census Handbook, 2011

Figure 15 :Marginal Cultivators in Bhagalpur City



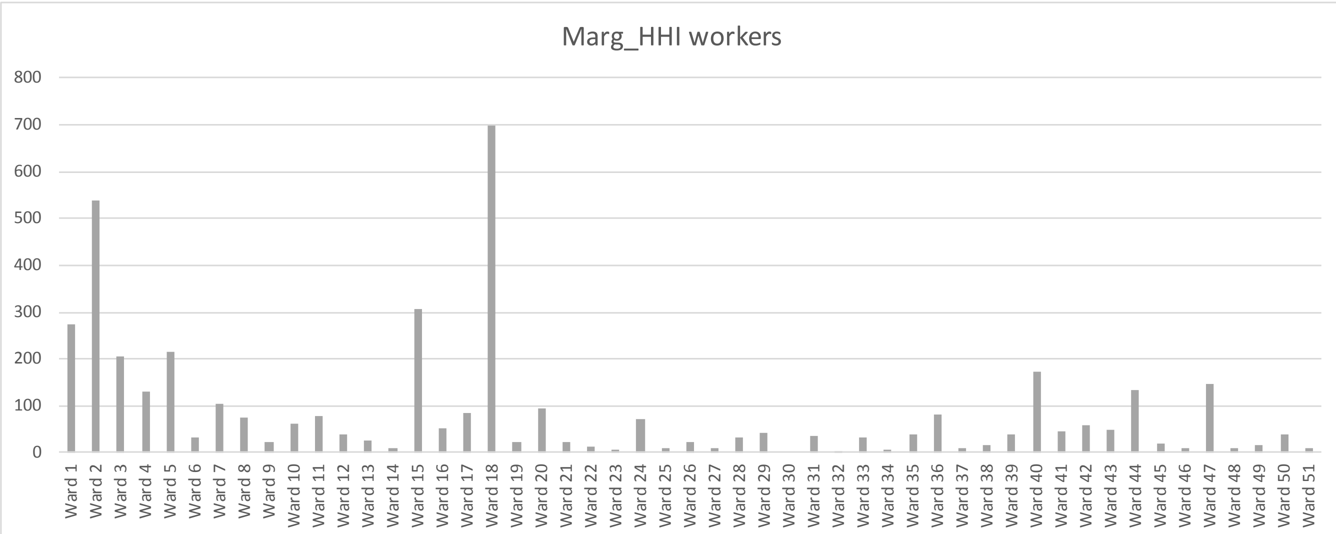
Source: Bhagalpur District Census Handbook, 2011

Figure 16 :Marginal Agricultural Labourers in Bhagalpur City



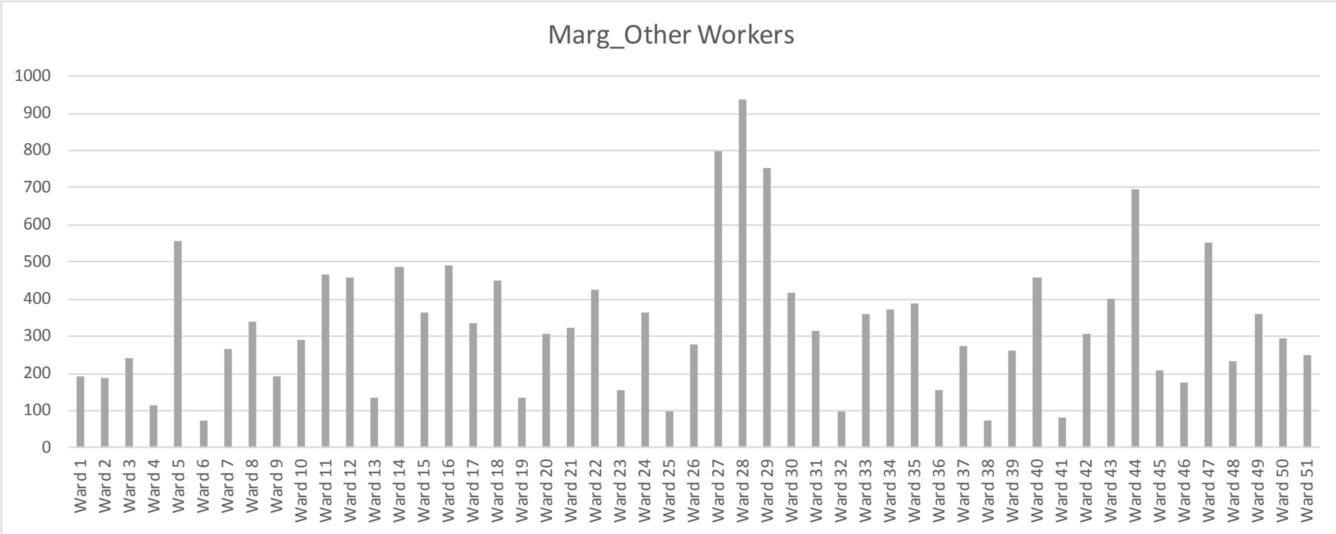
Source: Bhagalpur District Census Handbook, 2011

Figure 17 :Marginal Household Industry Workers in Bhagalpur City



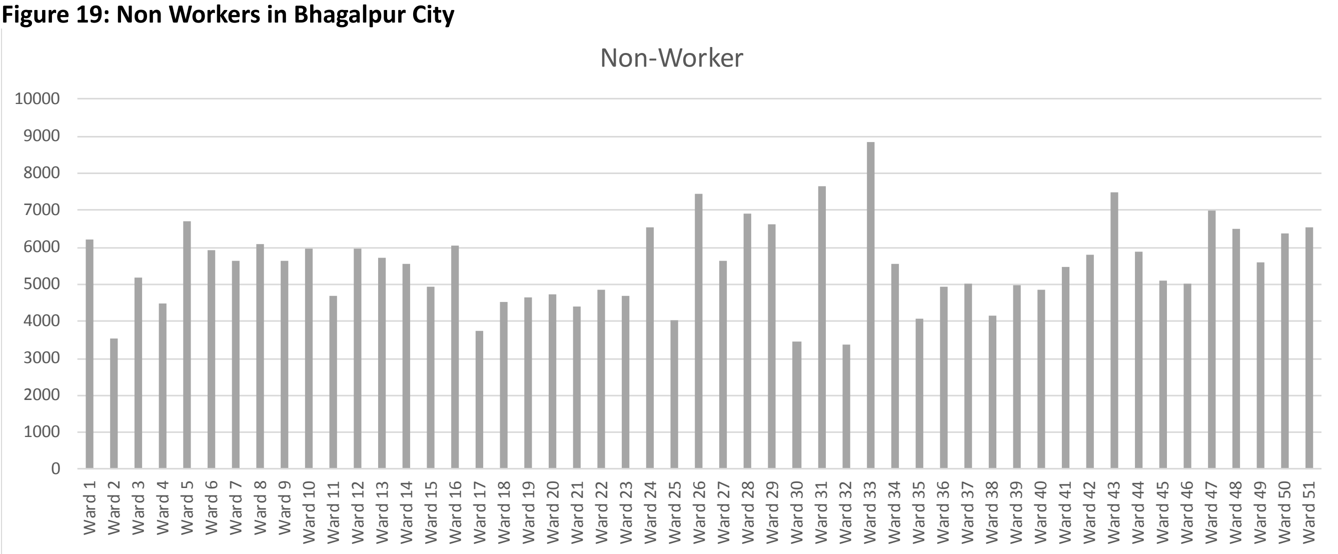
Source: Bhagalpur District Census Handbook, 2011

Figure 18: Marginal Other Workers in Bhagalpur City



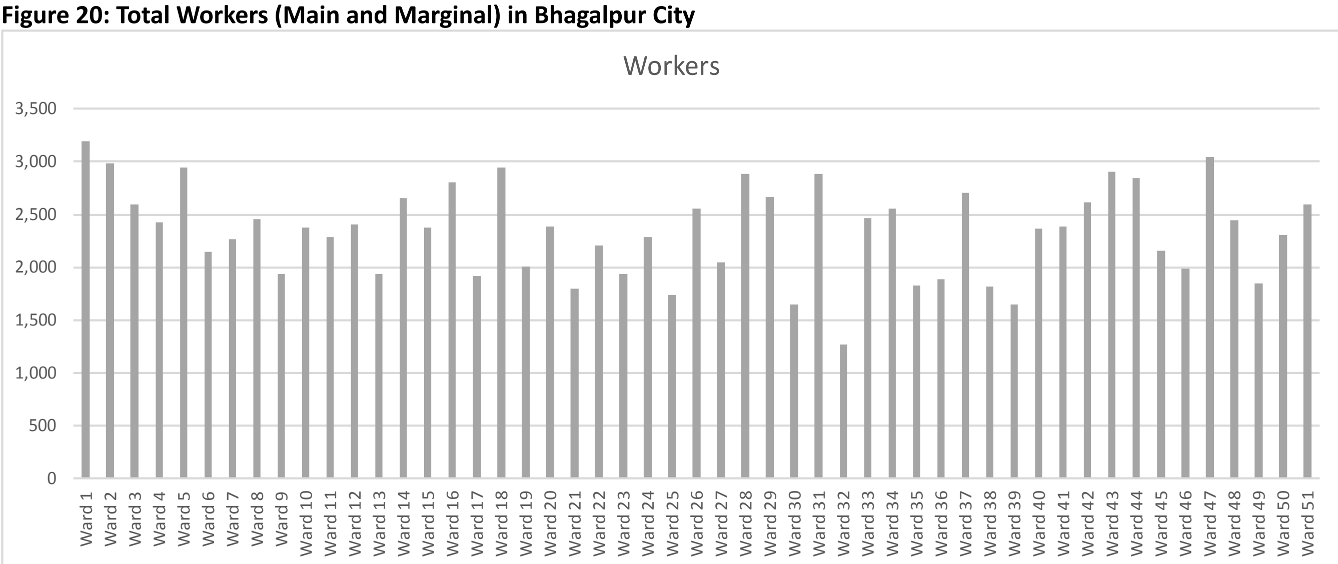
Source: Bhagalpur District Census Handbook, 2011

Figure 19: Non Workers in Bhagalpur City



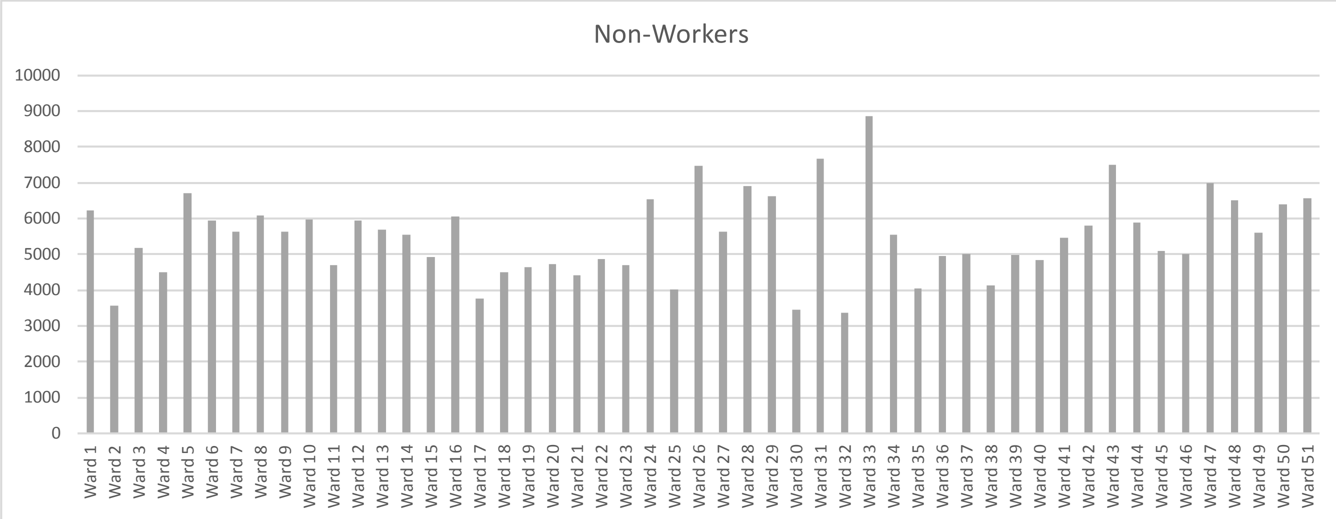
Source: Bhagalpur District Census Handbook, 2011

Figure 20: Total Workers (Main and Marginal) in Bhagalpur City



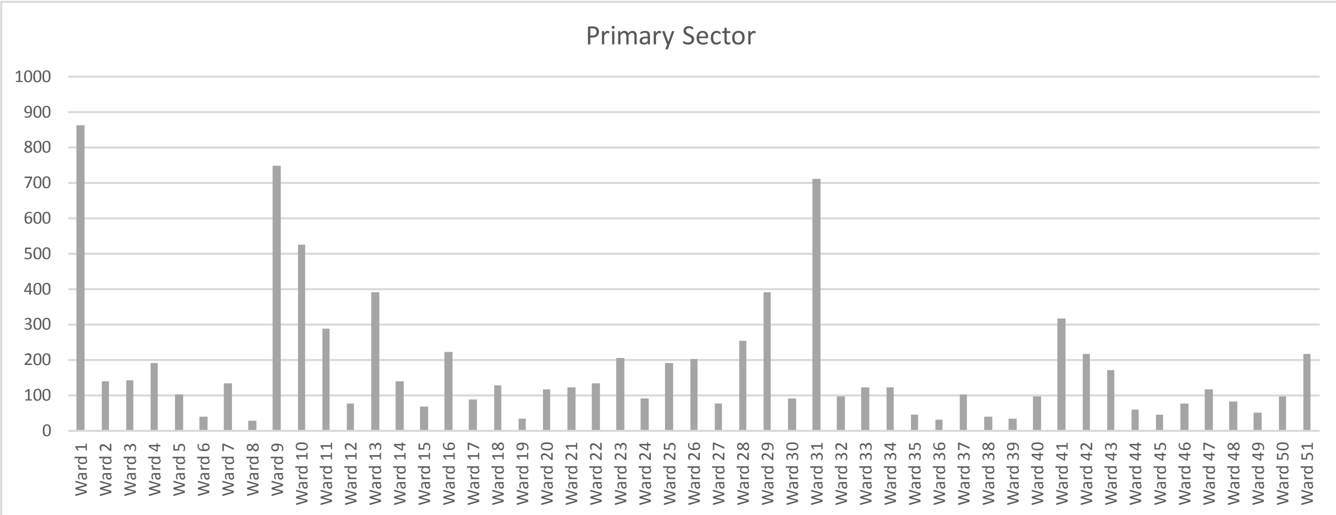
Source: Bhagalpur District Census Handbook, 2011

Figure 21: Total Non-Workers (Main and Marginal) in Bhagalpur City



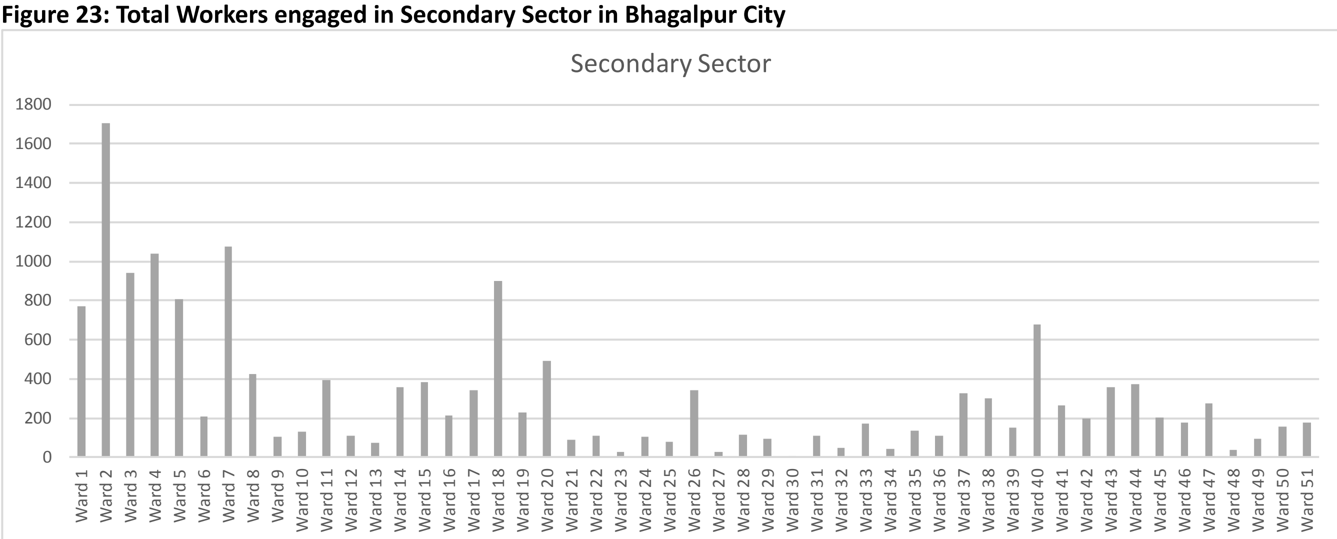
Source: Bhagalpur District Census Handbook, 2011

Figure 22: Total Workers engaged in Primary Sector in Bhagalpur City



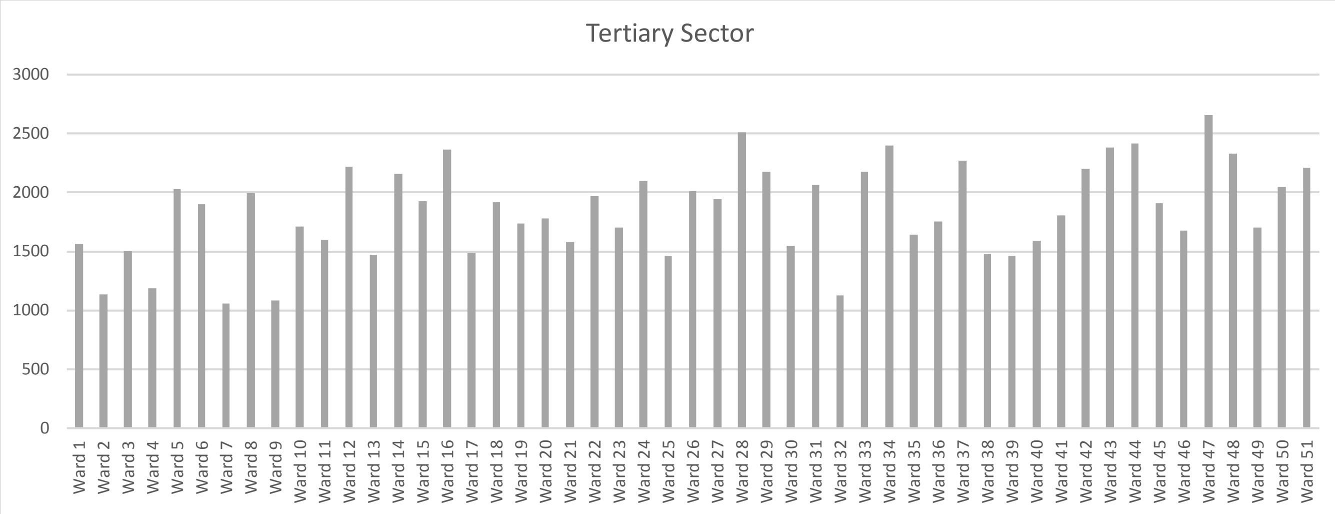
Source: Bhagalpur District Census Handbook, 2011

Figure 23: Total Workers engaged in Secondary Sector in Bhagalpur City



Source: Bhagalpur District Census Handbook, 2011

Figure 24: Total Workers engaged in Tertiary Sector in Bhagalpur City



Source: Bhagalpur District Census Handbook, 2011

1.4 PHYSICAL INFRASTRUCTURE

1.4.1 Water Supply

The sources of water supply in the city are 17.27 MLD from Ganga River and 21.09 MLD through 51 nos. of tube wells.

The pre-monsoon (May 2006) and post-monsoon (November 2006) water level in the district shows a variation between 3.5 to 9.7 mbgl and 1.35 to 3.35 mbgl respectively at Bhagalpur district. The ground water level for various years show a declining trend in some areas of Bhagalpur city which poses a major concern.

The ground water level for the year 2006, 2011 and 2015 for Bhagalpur city have been shown in table 8 below.

Table 8: Ground water level in Bhagalpur city

Year	Pre-Monsoon (mbgl)	Post-Monsoon (mbgl)
2006	3.5 – 9.7	1.35 – 3.35
2011	5 - 10	2 – 10
2015	2 - 20	2 - 20

Source: CGWB Ground Water Year Book

Ground water Contains very high percentage of iron (3.0 to 5.0 %) and issue of depleting level ground water are the major concern. Surface water source from Ganga River has to be resorted too. There are number of tube-wells through which ground water is drawn. It has been reported that over a period of time the existing water supply distribution system is deteriorated and most of the house service connections are not functional.

Presently area covered by piped water supply is 11.5%. Surface water is withdrawn with the help of intake 1 and intake 2 located at the banks of river Ganga (Barari). The design capacity of the three water treatment plants (WTPs) is 3.8 MGD (17.27 MLD).

Table 9: Water Treatment Plant Type & Capacity

Sl. No.	Type of WTP	Capacity in (MGD)
1	Mechanical WTP	0.6
2	Peterson WTP	1.2
3	Jewel WTP	2
4	Total	3.8

Source: Bhagalpur Sewerage DPR

Table 10: Existing Water Supply Situation

Sl. No.	Particulars		Values
1	Municipal Area (Sq. Km)		26
2	Area covered by piped water supply (%)		11.5
3	Total number of households with water supply connection		8350
4	Major source of water		River Ganga
	Intake Works	Intake – 1 (Barari Ghat)	
		Intake – 2 (Barari Ghat)	
	River source (3 WTP)		3.8 MGD* (14.383 MLD)
	WTP	Mechanical WTP	0.6
		Peterson WTP	1.2
		Jewel WTP	2
	Tube well (51 in number)		11.084 MLD
	Hand Pump		-
5	Per capita supply (lpcd)		27
6	Average hours of supply (hours)		6
7	Storage (OHT)		5.6 lacs gallon* (2.12 ML)
	OHT	CTS OHT	1 lakh gallon
		Ghomta Ghar	1 lakh gallon
		Isac Chowk	1 lakh gallon
		Sikanderpur	1 lakh gallon
		Masak Chowk	1 lakh gallon
		Housing Board	20000 gallons
		Jail OHT	40000 gallons
8	Transmission and Distribution losses (%) (UFW)		15
9	Pumping of clean water		2 Pump House

Source: BMC Bhagalpur & SPUR Bihar Patna; Bhagalpur Sewerage DPR

* 1 gallon = 3.785 litres

The water demand is projected to meet the requirements of the city population and the floating population for the year 2048. According to UDPFI norms, the per capita water demand for domestic and floating population has been taken as 135 lpcd and 45 lpcd respectively. The floating population has been estimated by assuming 5% of the total population. The water demand has been estimated by year 2011, 2018, 2033 & 2048.

Table 11: Water Demand Projection

Demand Sector (Municipal Area)	**2011**	**2018**	**2033**	**2048**
Population	400146	454028	612047	825063
Water Demand (MLD) @135 lpcd	54.02	61.29	82.63	111.38
Demand Sector (Floating Population – 5% of total population)	**20007**	**22701**	**30602**	**41253**
Water Demand (MLD) @45 lpcd	0.9	1.02	1.38	1.86

Total Water Demand (Domestic & Floating) (MLD)	54.92	62.32	84	113.24
Gross water demand including 15% UFW in MLD	63.16	71.66	96.6	130.23
Fire Fighting Demand* (MLD)	0.085	0.091	0.11	0.122
Total Water Demand (MLD)	63.245	71.751	96.71	130.35

Source: Adapted from Bhagalpur Sewerage DPR

*The CPHEEO Manual recommends fire-fighting water demand as a function of population, i.e. water demand for fire-fighting purpose = 100√P, where P stands for forecasted population may be adopted for communities larger than 50,000.

1.4.2 Sewerage

Bhagalpur town has no integrated wastewater management system. As a result, effluents from septic tanks and sullage are discharged into storm water drains and finally pollute the river Ganges. Only effluents of some open drain outfalls are collected through a 6 km trunk sewer and discharge in a treatment plant (capacity 11 MLD with only aeration lagoon facility).

Lifting pumps are not working and only about 4 MLD is treated (remains idle for major portion of time due to power cut it). Presently outfalls of Naya Bazaar and Hattia Nala are only taken to STP as intermediate pumping stations are not working (out of order).

The water demand is projected on the demand on the requirement for domestic usages and floating population. Based upon the projected population and the adopted water demand per capita, the wastewater generation (80% of the water demand as per CPCB) has been projected till 2048.

Table 12: Waste water generation projection

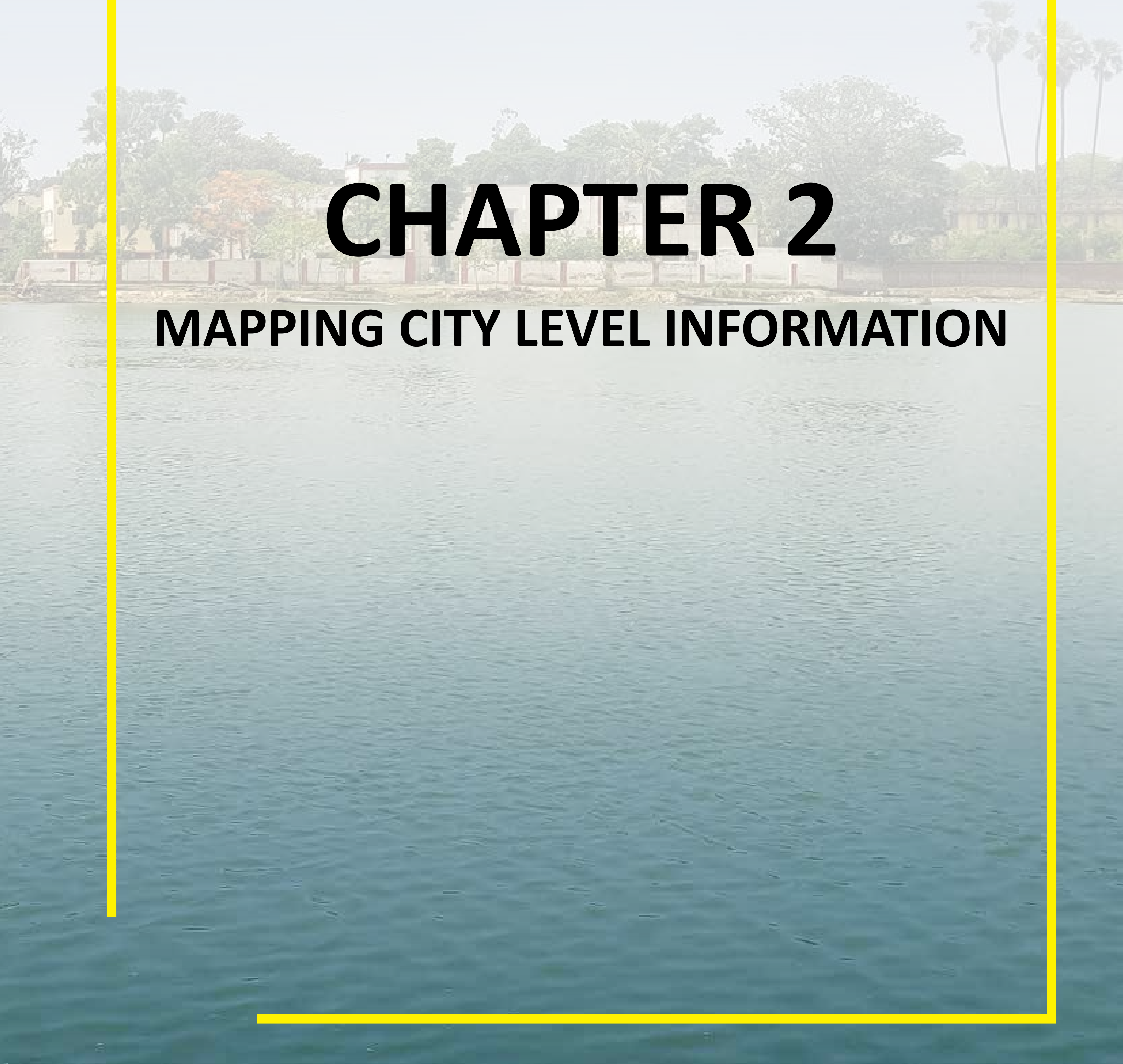
Demand Sector	2011	2018	2033	2048
Domestic Water Demand (135 lpcd)				
Population	400146	454028	612047	825063
Water Demand	54.02	61.29	82.63	111.38
Floating Population Demand (45 lpcd)				
Population	20007	22701	30602	41253
Water Demand	0.9	1.02	1.38	1.86
Total Demand	54.92	62.32	84	113.24
Waste Water Generation	43.94	49.85	67.20	90.59
Waste Water Treatment Gap (11 MLD capacity)	32.94	38.85	56.2	79.59

Source: Adapted from Bhagalpur Sewerage DPR

Based on all the above figures, we can clearly see the need of ground water recharge in Bhagalpur city. The assessment for conservation of wetlands/water bodies is necessary in order to conserve them and support the ground water recharge to meet the requirements of growing population.

CHAPTER 2

MAPPING CITY LEVEL INFORMATION



2. MAPPING CITY LEVEL INFORMATION

2.1 INTRODUCTION

The first step towards preparation of management plan for conservation of water bodies/wetlands involves mapping of city baseline information. The following data requirements essential involves:

Table 13: City Level Data Requirement

Data Requirement	Source of Data	Output
1. Municipal boundary, Planning boundary & Ward map of city 2. Land use & Land cover map of city 3. Water bodies within the city and peri-urban area 4. Drainage map of city 5. Sewerage network of city 6. Soil map of city/district 7. Rainfall data of city/district 8. Watershed map of district scaled down to urban area (macro, meso, micro and basin) 9. Ground water level (depth) - district/city scale 10. Agricultural practices in peri-urban areas	1. Municipality & Development Authority 2. Municipality & Development Authority, land cover can also be prepared via satellite imagery in Erdas/ArcGIS or freely available in Bhuvan portal. 3. Municipality & Development Authority; can be digitized from satellite imagery and validated via primary survey 4. Municipality & Development Authority (Drainage DPR) 5. Municipality & Development Authority (Sewerage DPR) 6. Available with Geological Survey of India, CGWB, Department of Agriculture, Cooperation & Farmers Welfare, SLUSI, Bhuvan Portal 7. IMD 8. SLUSI, Bhuvan Portal; can also be generated in ArcGIS from DEM 9. CGWB report for districts 10. Primary survey (note: Prioritization of watershed is based on various indicators identified by environmentalists, hydrologists, researchers and published journal and reports from Ministry for watershed management)	1. GIS Baseline map preparation 2. Prioritization of watershed (watershed containing the city) 3. Delineation of catchment areas of water bodies 4. Delineation of zone of influence of water bodies

Source: SPA Delhi

The data can be brought into ArcGIS to prepare a baseline map. The watershed delineation would require a hydrologist or the same can be done in ArcGIS via DEM. DEM can be procured online from USGS Explorer, BHUVAN Portal, Global Mapper, etc., or it can be taken from Municipality based on their availability.

Land and water both are most vital natural resources of the earth as life and various developmental activities depend on it. These resources are limited, and their uses are increasing day by day due to population rise. Therefore, a need for water resources planning, conservation and better management for its sustainable use is required for sustained growth of a country like India. Watershed management plays a significant role in conservation of water and soil resources and their sustainable development.

Adoption of better watershed management practices overcomes issues of drought, flood, excessive runoff, poor infiltration, soil erosion, human health, and low productive yield.

Horton (1932, 1945) has explained the need of quantitative geomorphological analysis in management of water resource. Afterwards many geomorphologists have further developed the methods of watershed morphometry (Gregory, 1966; Schumm, 1956; Strahler, 1957, 1964). In India, many authors (Sreedevi, Subrahmanyam, & Ahmed, 2005; Yadav, Dubey, Szilard, & Singh, 2016; Yadav, Singh, Gupta, & Srivastava, 2014) used remote sensing and GIS tools in morphometric analysis and other (Balázs, Bíró, Gareth, Singh, & Szabó, 2018; Paudel, Thakur, Singh, & Srivastava, 2014; Rawat & Singh, 2017; Singh, Basommi, Mustak, Srivastava, & Szabo, 2017; Singh, Mustak, Srivastava, Szabó, & Islam, 2015).

Morphometric analysis is a significant tool for prioritization of sub-watersheds even without considering the soil map (Biswas, Sudhakar, & Desai, 1999). Morphometry is the measurement of the configuration of earth's surface shape and dimension of its landform (Clarke, 1996). It gives a quantitative description of drainage basin which is very much useful in studies such as hydrologic modelling, watershed prioritization, natural resources conservation and management, and rehabilitation.

Literature review suggests that previously drainage morphometric parameters were either extracted from topographical maps or field surveys. With advent of high-resolution digital elevation model (DEM), the extraction of drainage parameters from DEM gets more popularity in last three decades due to rapid, precise, updated and cost-effective way of performing watershed analysis (Maathuis & Wang, 2006; Moore, Grayson, & Ladson, 1991).

Morphometric parameters of any watershed plays a crucial role in prioritization of sub-watershed, scientific literature have discussed role of morphometric parameters: watershed prioritization in the Guhiya basin, India (Khan, Gupta, & Moharana, 2001), check dam positioning by prioritization of micro-watershed using the Sediment Yield Index (SYI) model (Nookaratnam, Srivastava, Venkateswarao, Amminedu, & Murthy, 2005), computed morphometric characteristics of Lonar Nala, watershed in Akola district, Maharashtra prioritization of watershed (Moharir & Pande, 2014). Manju and George (2014) carried out critical evaluation and assessment through the calculation of morphometric parameter of Vagamon and Peermade sub-watershed of Kerala. Rais and Javed (2014) used morphometric parameters for the artificial recharge sites in Manchi Basin, Eastern Rajasthan. Yadav et al. (2016) have used the remote sensing and GIS for prioritization of the sub-watersheds of agricultural dominated northern river basin of India. Prioritization of sub-watersheds based on morphometric and land use analysis (Javed, Yousuf, & Rizwan, 2009).

In the present study, morphometric analysis and prioritization of sub-watershed are carried out for a watershed of Lower Ganga River Basin in Bhagalpur district of Bihar, India. Watershed morphometric parameters namely bifurcation ratio, drainage density, stream frequency, stream length, circulatory ratio, elongation ratio etc. were extracted. The objectives of the morphometric analysis include:

- to extract the morphometric parameters (bifurcation ratio, stream length, density of streams, number of streams, perimeter of study area, slope and elevation difference of drainage basin) from DEM using GIS technique and
- to prioritize sub-watersheds primarily for groundwater potential and conservation structures.

2.2 METHODOLOGY

The USGS DEM was used for estimation of morphometric parameter of Lower Ganga river basin such as: Bifurcation ratio (Rb), Drainage density (Dd), Stream frequency (Fs), Stream length ratio (Rl), Mean stream length (Lµ), Form factor (Ff), Elongation ratio (Re), Circulatory ratio (Rc), Length of overland flow (Lo), Basin relief (Rr), Gradient ratio (Gr) etc. The detailed adopted methodology is expressed through flowchart. Table 1 explains the formulae used for quantitative determination of morphometric parameters. All the analysis was performed in the Geographical Information System environment with the aid of ArcGIS software.

Prioritization rating of five sub-watershed of Ganga River is carried out through ranking the computed morphological parameters. The sub-watershed with lowest ranking is given the highest priority in terms of soil erosion and less conservation measure. Groundwater condition which is assessed on the basis of groundwater map acquired from CGWB, India.

For the purpose of Prioritization of Watershed, the following aspects of watershed have been studied:

1. Linear Aspects
2. Aerial Aspects and
3. Relief Aspects

Figure 25: Watershed Prioritization (Morphometric Parameter)

Source: SPA Delhi

Formulae used for calculation of morphometric parameters are as follows:

Table 14: Formulae for morphometric analysis

Sl. No.	Parameter	Formulae	References
Linear Aspects			
1	Stream Order (U)	Hierarchical rank	Strahler (1952)
2	Stream Number (Nu)	Total number of stream segments of order U	Horton (1945)
3	Stream Length (Lu)	Stream length of order u	Strahler (1964)
4	Mean Stream Length ($\overline{Lu}$)	Lu/Nu	Strahler (1964)
5	Stream Length Ratio (RLu)	Lu/Lu-1	Strahler (1964)
6	Bifurcation Ratio (Rb)	Nu/Nu+1	Strahler (1964)
7	Mean Bifurcation Ratio ($\overline{Rb}$)	Average of bifurcation ratios of all order	Strahler (1964)
8	RHO Coefficient (ρ)	$\overline{Lu}$/Rb	Horton (1945)
Aerial Aspects			
1	Watershed Area (A)	ArcGIS/Software analysis	Schumm (1956)
2	Perimeter (P)	ArcGIS/Software analysis	Schumm (1956)
3	Basin Length (L_b)	ArcGIS/Software analysis	Schumm (1956)
4	Form Factor (Rf)	$A/(L_b)^2$	Horton (1932)
5	Elongation Ratio (Re)	$\{(2/L_b) * (A/3.41)^{0.5}\}$	Schumm (1956)
6	Circulatory Ratio (Rc)	$4\pi(A/P^2)$	Miller (1953)
7	Drainage Texture (Dt)	Total Nu/P	Horton (1945)
8	Texture Ratio (Rt)	N1/P	Schumm (1956)
9	Compactness Coefficient (Cc)	$0.2841 * [P/(A^{0.5})]$	Gravelius (1914)
10	Stream Frequency (Fs)	Nu/A	Horton (1932)
11	Drainage Density (Dd)	Lu/A	Horton (1932)
12	Constant of Channel Partner (C)	1/Dd	Schumm (1956)
13	Drainage Intensity (Di)	Fs/Dd	Faniran (1968)
14	Infiltration Number (In)	Fs * Dd	Faniran (1968)
15	Drainage Pattern (Dp)		Horton (1932)
16	Length of Overland Flow (Lg)	A/ (Lu*2)	Horton (1945)
Relief Aspects			
1	Minimum Height of Basin (z)	ArcGIS/Software analysis	
2	Maximum Height of Basin (Z)	ArcGIS/Software analysis	
3	Total Basin Relief (H)	Z-z	Strahler (1952)
4	Relief Ratio (Rh)	H/L_b	Schumm (1963)
5	Ruggedness Number (Rn)	Dd * (H/1000)	Strahler (1964)
6	Melton Ruggedness Number (MRn)	$H/(A^{0.5})$	Melton (1965)

Source: Applied Water Science (2019) 9:27, https://doi.org/10.1007/s13201-019-0905-0

Linear Aspects

The linear aspects of a drainage basin include the study of stream networks. The information on numbers of stream segments in a drainage basin, their hierarchical orders, length of stream segments, mean stream segments, bifurcation ratio, etc., are determined and explained below.

Stream order (U): Stream order is an important parameter as it provides information about the size of the watershed. The stream order of the watershed was calculated using the Strahler method as shown in Fig. (Strahler 1957). It is calculated from the starting source of stream segments. The streams flow from the start point of a drainage basin, which is generally a high relief point, called streams of the first order (U), and the stream segments starting from the confluence of two streams of the first order are called streams of second order (U + 1), and so on.

Stream number (Nu): It is a total number of stream segments per stream order. Stream number depends upon the factors such as geology, soil type, slope, vegetation and rainfall in a watershed (Sujatha et al. 2015). The presence of a greater number of streams in a watershed indicates large run-off conditions. Besides, the number of first-order streams indicates the probability of flash flood after heavy rainfall in the downstream (Pande and Moharir 2017). The stream number for sub-watersheds is shown in Table 15.

Table 15: Stream Order in various sub-watersheds

Stream Order	1	2	3	4	Total
WS1	155	53	52	22	282
WS2	23	14	12	0	49
WS3	7	5	1	0	13
WS4	30	23	16	0	69
WS5	36	30	5	9	80
WS6	23	27	18	0	68
WS7	12	12	2	0	26
WS8	8	6	2	0	16

Source: SPA Delhi

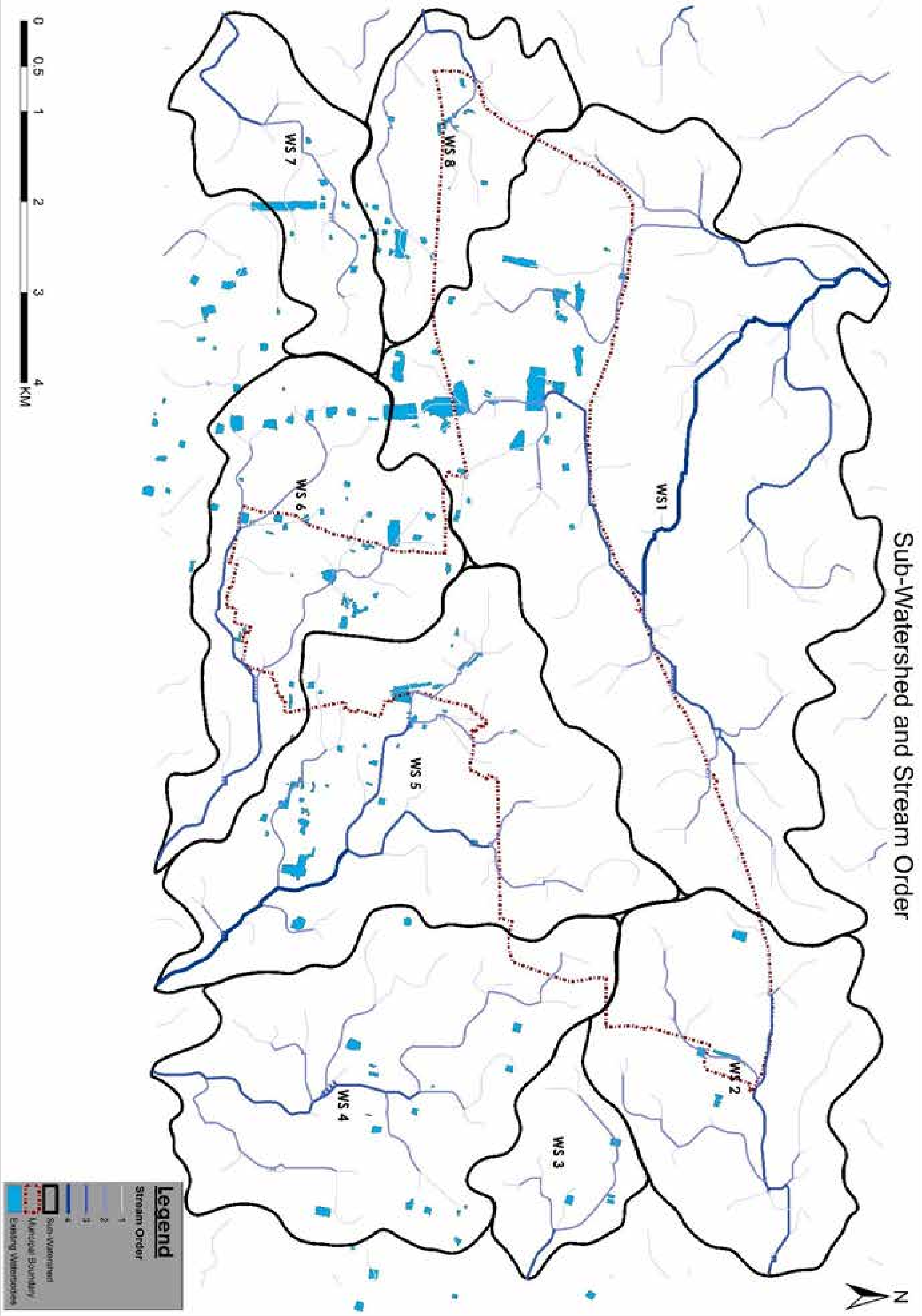
Stream length (Lu): The stream length of the segments was obtained through GIS software. It is an important factor to understand surface run-off characteristics in a watershed. The small length of the streams indicates an area with large slope and fine texture, and longer length represents flat gradient basins (Oruonye et al. 2016).

Mean stream length ($\overline{Lu}$): Mean stream length is calculated by dividing the total length of stream segments of an order by the total number of stream segments. The value of Lu differs for sub-watersheds, as it is directly proportional to the size and topography of the basin. Strahler (https ://link.springer.com/article/10.1007/s1320 1-015-0298-7—CR231964) indicated that Lu is a characteristic property related to the size of the drainage network and its associated surfaces.

Stream length ratio (R$\overline{Lu}$): Horton states the stream length ratio as the ratio of the mean of length segment of order Lu to the mean of length segment of order Lu - 1 that is likely to be constant throughout the successive orders in a drainage basin. The sub-watersheds in the studied area have varied stream length ratios for different orders. Variation in stream length ratio indicates late youth stage of geomorphic development (Reddy et al. 2017). The calculated values of stream length mean stream length, stream length ratio of sub-watersheds is given in Table 16.

Bifurcation ratio (Rb)/ Mean Bifurcation ratio ($\overline{Rb}$): The bifurcation ratio is expressed as the ratio of the number of stream segments of a given order U to the number of stream segments of the next higher order (U + 1). The ratio is useful to predict various features of a drainage basin. Horton (1945) specified that the bifurcation ratio of less than two indicates flat or rolling drainage basin, whereas three to four is highly stable and dissected drainage basins. Strahler (1969) mentioned that bifurcation ratios are constant from one order to other in a uniform stage of development, and variation in the ratio at different orders indicates geological and lithological developments in the basin (Kumar and Chandrakantha, 2016). High Rb values indicate high overland flow, while low Rb values reflect high infiltration rate and less number of stream segments in the watershed.

Figure 26: Sub-Watershed & Stream Order



Source: Generated in ArcGIS, SPA Delhi

Weighted mean bifurcation ratio ($\overline{Rb}w$): The bifurcation ratio varies from one order to other in most watershed areas. Therefore, to determine a single value, Strahler (1953) proposed the concept of weighted mean bifurcation ratio. The ratio is calculated by multiplying the bifurcation ratio for each successive pair of orders by the total number of streams involved in the ratio and taking the mean of the sum of these values.

RHO coefficient (ρ): It is defined as a ratio of stream length ratio to bifurcation ratio. It is a significant parameter to determine the relationship between the drainage density and the physiographic development of the basin used to assess the storage capacity of the drainage network (Horton 1945).

The mean RHO coefficient of the sub-watersheds varied from 0.36 to 0.76. RHO values of the basins indicate good storage capacity during flood periods.

Table 16: Linear Aspects of Sub-Watershed

U	Nu	Lu	$\overline{Lu}$	$R\overline{Lu}$	Rb	U+(U-1)	Rb*{Nu+(Nu-1)}	$\overline{Rb}w$	RHO Coeff.
WS1									
1	155	29974.494	193.384						
2	53	14854.053	280.265	1.449	2.924	208	608.301		
3	52	10745.979	206.653	0.737	1.019	105	107.019	2.3	0.543
4	22	5644.801	256.582	1.242	2.364	74	174.909		
Total		61219.328		1.143	2.102	387	890.230		
WS2									
1	23	7525.408	327.192						
2	14	5317.326	379.809	1.161	1.643	37	60.786	1.446	0.695
3	12	3611.838	300.986	0.792	1.167	26	30.333		
Total		16454.571		0.977	1.405	63	91.119		
WS3									
1	7	1783.428	254.775						
2	5	2925.349	585.070	2.296	1.4	12	16.8	2.6	0.525
3	1	624.294	624.294	1.067	5	6	30		
Total		5333.071		1.682	3.2	18	46.8		
WS4									
1	30	9371.773	312.392						
2	23	9474.541	411.937	1.319	1.304	53	69.130	1.361	0.679
3	16	3572.287	223.268	0.542	1.437	39	56.062		
Total		22418.602		0.930	1.370	92	125.193		
WS5									
1	36	11931.197	331.422						
2	30	8030.142	267.671	0.808	1.2	66	79.2		
3	5	3721.333	744.267	2.780	6	35	210	2.983	0.609
4	1	2855.866	2855.866	3.837	5	6	30		
Total		26538.538		2.475	4.067	107	319.2		
WS6									

U	Nu	Lu	$\overline{Lu}$	R$\overline{Lu}$	Rb	U+(U-1)	Rb*{Nu+(Nu-1)}	$\overline{Rb}$w	RHO Coeff.
1	23	7986.357	347.233						
2	27	5868.617	217.356	0.626	0.852	50	42.593	1.156	0.763
3	18	4570.972	253.943	1.168	1.5	45	67.5		
Total		18425.946		0.897	1.176	95	110.093		
WS7									
1	12	3806.619	317.218						
2	12	3136.401	261.367	0.824	1	24	24	2.842	0.361
3	2	889.673	444.836	1.702	6	14	84		
Total		7832.693		1.263	3.5	38	108		
WS8									
1	8	4755.608	594.451						
2	6	3300.938	550.156	0.925	1.333	14	18.667	1.939	0.443
3	2	1094.838	547.419	0.995	3	8	24		
		9151.384		0.96	2.167	22	42.667		

Source: SPA Delhi

Aerial Aspects:

The area (A), perimeter (P) and basin length (Lb) of the sub-watersheds were computed using Arc GIS software. The aerial parameters are provided in Table 17.

Form factor ratio (Rf): The form factor is the ratio of the area of a watershed to the square of its length. The value gives an idea of the shape of the watershed. Lower Rf value indicates an elongated basin. The water flows in such basins for a longer duration with a flat peak. The Rf values of sub-watersheds are given in Table. It is easy to manage the flood flows in elongated basins than to circular basins (Reddy et al. 2002).

Elongation ratio (Re): Elongation ratio is the ratio of the diameter of a circle of the same area as the basin to the maximum basin length (Schumm 1956). It is a significant parameter to analyze the shape of the watershed. The low Re value indicates a steep slope and an elongated basin. An index of elongation ratio, proposed by Schumm and further interpreted by Strahler, is used to evaluate the shape of the watersheds, i.e. circular (0.9–0.10), oval (0.8–0.9), less elongated (0.7–0.8), elongated (0.5–0.7) and more elongated (< 0.5).

Circulatory ratio (Rc): Circularity ratio is defined as the ratio of watershed area to the area of a circle having the same perimeter as the watershed (Miller 1953). The value of 1 indicates the circular shape of the watershed. The Rc values of sub-watersheds were less than 0.5 indicating the characteristics of an elongated basin with moderate relief.

Drainage texture (Dt): Drainage texture is defined as a ratio of the sum of stream segments to the perimeter of the watershed area. It depends upon the soil type, slope and water holding capacity of the basin. More number of stream segments in a basin indicates impermeable surface. The Dt values of seven basins ranged from 0.001 to 0.009 and represent fine texture conditions. The higher values of Dt relate to poor permeability in the basins.

Texture ratio (Rt): Texture ratio is the ratio between first order stream and perimeter of watershed. It depends upon the soil type, infiltration and basin relief. The high value of Rt indicates low infiltration and more run-off. It depicts the presence of large number of first-order streams in the basin that means there is a variation in topology.

Compactness coefficient (Cc): Cc of a watershed is the ratio of the perimeter of the watershed to the circumference of a circular area, which equals the area of the watershed (Pareta and Pareta 2011). Cc is inverse of circulatory ratio and expresses run-off in the drainage basin. It is dependent on the slope of the watershed. Lower the value of Cc, more the run-off and erodibility.

Stream frequency (Fs): Stream frequency of a drainage basin is the total number of stream segments per unit area. The Fs values of watersheds varied between 3 and 9. A high value of stream frequency relates to an impermeable subsurface material, low infiltration capacity and high relief conditions.

Drainage density (Dd): Drainage density is a parameter calculated as the total length of stream segments divided by an area of the basin. It is a measure of how well a basin is drained by its stream segments. It depends upon the permeability, slope, vegetation cover and surface run-off of the basin area.

High values of Dd indicate fine drainage texture, impermeable land, steep slope and limited vegetation cover that contribute to the larger run-off in a watershed. Such basins are susceptible to flood risk due to a rapid run-off in channels. The Dd values of sub-watersheds indicate that all basins have moderate permeability and low infiltration properties.

Constant of channel partner (C): Constant of channel maintenance (C) is the reciprocal of drainage density. It is a measure to know minimum area required for the development of 1-km-long drainage channel (Schumn 1956). Low value indicates structural disturbances in the basin having high run-off and low permeability.

Drainage intensity (Di): Drainage intensity is defined as the ratio of stream frequency to the drainage density (Faniran 1968). The drainage density calculated was 1700–4600 for sub-watersheds. The values obtained for drainage density, drainage intensity and stream frequency indicate that the sub-watersheds have good permeability and high infiltration characteristics.

Infiltration number (In): It is defined as a product of drainage density and stream frequency. The number provides information about the infiltration characteristics of the watershed. The infiltration number is inversely related to infiltration capacity; hence, greater the number, lower the infiltration rate.

Drainage pattern (Dp): The drainage pattern in basins is dendritic in nature. The dendritic pattern develops in a terrain, where the bedrock is uniform in nature.

Length of overland flow (Lg): Overland flow comprises the water that flows over the ground surface to stream channels. The overland flow occurs due to the inability of water to infiltrate the surface either because of high intensity of rainfall or because of poor infiltration capacity. Horton (1945) defined the length of overland flow as half of the reciprocal of drainage density. The length of overland flow ranged between 250 to 300 meters in the studied basins.

Table 17: Aerial Aspects of Sub-Watershed

Sl.	Parameters	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8
1	Area	30777129.3	9507502.1	2872121.7	12603874.64	14180516.81	9314335.75	4734019.77	5199510.18
2	Perimeter	29403.556	12798.801	7791.037	16579.398	18813.823	16631.851	11298.743	10859.475
3	Basin Length	36622.893	15174.769	9231.423	20090.714	22313.897	19926.134	13383.774	13661.99
4	Form Factor	0.023	0.041	0.034	0.031	0.028	0.023	0.026	0.028
5	Diameter of Circle	6259.927	3479.272	1912.303	4005.966	4249.142	3443.746	2455.106	2572.98
6	Radius (Basin Area)	3129.964	1739.636	956.151	2002.983	2124.571	1721.873	1227.553	1286.49
7	Elongation Ratio	0.171	0.23	0.2076	0.199	0.19	0.173	0.183	0.19
8	Radius (Basin Perimeter)	4679.725	2036.994	1239.983	2638.696	2994.316	2647.044	1798.252	1728.34
9	Area of Circle	68800281	13035542.5	4830377	21873992	28167262.3	22012617.7	10158996.3	9384435.3
10	Circulatory Ratio	0.447	0.729	0.595	0.576	0.5036	0.4236	0.466	0.554
11	Sum of Stream Segments	282	49	13	69	80	68	26	16
12	Drainage Texture	0.01	0.004	0.002	0.004	0.004	0.004	0.0027	0.001
13	Texture Ratio	0.005	0.002	0.001	0.002	0.002	0.001	0.0017	0.0007
14	Compactness Coefficient	1.495	1.171	1.297	1.317	1.41	1.537	1.465	1.343
15	Stream Frequency	9.163	5.154	4.526	5.474	5.641	7.3006	5.492	3.077

Sl.	Parameters	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8
16	Total Stream Length	61219.328	16454.571	5333.071	22418.602	26528.54	18425.95	7832.693	9151.385
17	Drainage Density	0.002	0.0017	0.002	0.0017	0.002	0.002	0.0016	0.0017
18	Constant of Channel Partner	502.735	577.803	538.549	562.206	534.337	505.501	604.392	568.166
19	Drainage Intensity	4606.39	2977.9	2437.62	3077.8	3014.484	3690.45	3319.42	1748.37
20	Infiltration Number	0.018	0.009	0.008	0.009	0.01	0.014	0.009	0.005
21	Drainage Pattern	Dendritic	Dendritic	Dendritic	Dendritic	Dendritic	Dendritic	Dendritic	Dendritic
22	Length of overland flow	251.367	288.901	269.274	281.103	267.168	252.75	302.196	284.083

Source: SPA Delhi

Relief aspects

The relief aspect in the morphometric study is important to understand the hydrological response of the watershed. The parameters evaluated include basin relief, relief ratio and ruggedness number.

Basin relief (R): Schumm (1956) defined basin relief (R) as the difference between the maximum and minimum elevations of a drainage basin. It determines the slope for stream segments and the volume of sediments transported with the stream.

Relief ratio (Rr): It is the ratio of basin relief to the basin length. The Rr value relates the steepness and erosion in the basin due to the slope of the watershed. Schumm suggested that sediment loss per unit area is closely correlated with the relief ratio in a watershed area. The relief ratio of SW4 and SW7 is higher in comparison with other sub-watersheds, indicating higher run-off in the sub-watersheds.

Ruggedness number (Rn): The ruggedness number is calculated as the product of basin relief and drainage density. A high value of Rn indicates the steep slope and high drainage density. Such basins are susceptible to flood risk.

Melton ruggedness number (MRn): Melton (1965) defined the Ruggedness number as the ratio of basin relief to the square root of the basin area. Wilford et al. (2004) defined the classification of the watershed into a debris flow, debris flood and flood hazard watersheds. As per the classification, the sub-watersheds are debris flood basins. In this type of basin, stream segments deposit a significant amount of sediments beyond the channel on the fan.

Table 18: Relief Aspects of Sub-Watershed

Sl.No	Parameters	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8
1	Minimum Height of the basin	13	14	29	24	28	28	30	25
2	Maximum Height of the basin	73	70	56	63	71	59	57	58
3	Total basin relief (H)	60	56	27	39	43	31	27	33
4	Basin Length	36622.89	15174.77	9231.424	20090.71	22313.89	19926.13	13383.77	13662
5	Relief Ratio (Rhl)	0.001638	0.00369	0.002925	0.001941	0.001927	0.001556	0.002017	0.002415
6	Basin Perimeter	29403.56	12798.8	7791.037	16579.4	18813.82	16631.85	11298.74	10859.47
7	Relative Relief Ratio	0.204057	0.437541	0.346552	0.235232	0.228555	0.186389	0.238965	0.303882
8	Drainage Density	0.001989	0.001731	0.001857	0.001779	0.001871	0.001978	0.001655	0.00176
9	Ruggedness Number (Rn)	0.119347	0.096919	0.050135	0.06937	0.080474	0.061325	0.044673	0.058082
10	Basin Area	30777129	9507502	2872122	12603876	14180517	9314336	4734020	5199510
11	Melton Ruggedness Number (MRn)	0.010815	0.018162	0.015932	0.010985	0.011419	0.010157	0.012409	0.014472

Source: SPA Delhi

Prioritization of Watershed

For prioritization of sub-watersheds, the morphometric parameters, such as elongation ratio, drainage density, stream frequency, drainage texture, texture ratio and RHO coefficient of delineated sub-watersheds, were calculated using the weighted rank method. Parameters were selected and assigned weight based on the positive correlation with improving the ground water table as shown in Table 19. Various researchers have used the parameters for the identification of groundwater recharge potential zones in a watershed (Sreedevi et al. 2005; Patil and Mali 2013; Patil and Mohite 2014 Tolessa and Rao 2013; Kandpal et al.2018; Chandniha and Kansal 2017). The elongation ratio and drainage density are assigned to 0.20 weight each. The elongation ratio is a shape parameter and its low value of elongation ratio is susceptible to high erosion and sedimentation load (Reddy et al. 2002) and drainage density is important as related to peak discharge time in a watershed area (Wilford et al. 2004). Stream frequency is the measure of peak discharge, and a high value indicates flash floods in a watershed. Drainage texture is influenced by infiltration capacity. The coarse drainage texture shows a longer duration to peak flow. Similarly, texture ratio depends on the underlying lithology, infiltration capacity and relief aspect of the terrain and one of the useful parameters in drainage basin morphometry (Altaf et al. 2013). RHO coefficient is a parameter to determine the amount of water that could be stored during the flood period. It relates the drainage density to physiographic development of a watershed (Arshad 2009; Pande and Moharir 2017).

Once the weights were assigned, ranks were provided to each sub-watershed based on the morphometric analysis. The final calculation of prioritization of sub-watersheds is done using the following equation:

Prioritized Sub-Watershed = (Drainage density × 0.2) + (Elongation ratio × 0.20) + (Stream frequency × 0.15) + (Drainage texture × 0.15) + (Texture ratio × 0.15) + (RHOCoefficient × 0.15)
The final calculation for all sub-watersheds was done by multiplying the weight for each parameter by its rank and adding the resulting values. Based on the total, the sub-watersheds were divided into three major classes (high, medium and low zones). The calculations are provided in Table 19, and the final prioritization map of the study area is shown in Figure 28.

Table 19: Prioritization of Sub-Watershed

Parameters	WS1	Score	WS2	Score	WS3	Score	WS4	Score	WS5	Score	WS6	Score	WS7	Score	WS8	Score
Elongation Ratio (0.2)	0.171	1.000	0.229	1.000	0.207	1.000	0.199	1.000	0.190	1.000	0.173	1.000	0.183	1.000	0.188	1
Drainage Density (0.2)	0.002	1.000	0.002	1.000	0.002	1.000	0.002	1.000	0.002	1.000	0.002	1.000	0.002	1.000	0.002	1
Stream Frequency (0.15)	9.163	4.000	5.154	4.000	4.526	5.000	5.475	4.000	5.642	4.000	7.301	4.000	5.492	4.000	3.077	5
Drainage Texture (0.15)	0.010	5.000	0.004	5.000	0.002	5.000	0.004	5.000	0.004	5.000	0.004	5.000	0.002	5.000	0.001	5
Texture Ratio (0.15)	0.005	5.000	0.002	5.000	0.001	5.000	0.002	5.000	0.002	5.000	0.001	5.000	0.001	5.000	0.001	5
Rho Coefficient (0.15)	0.540	5.000	0.690	5.000	0.530	5.000	0.680	5.000	0.610	5.000	0.760	5.000	0.360	3.000	0.440	4
Score	1.492		0.924		0.801		0.964		0.977		1.245		0.915		0.566	

Source: SPA Delhi

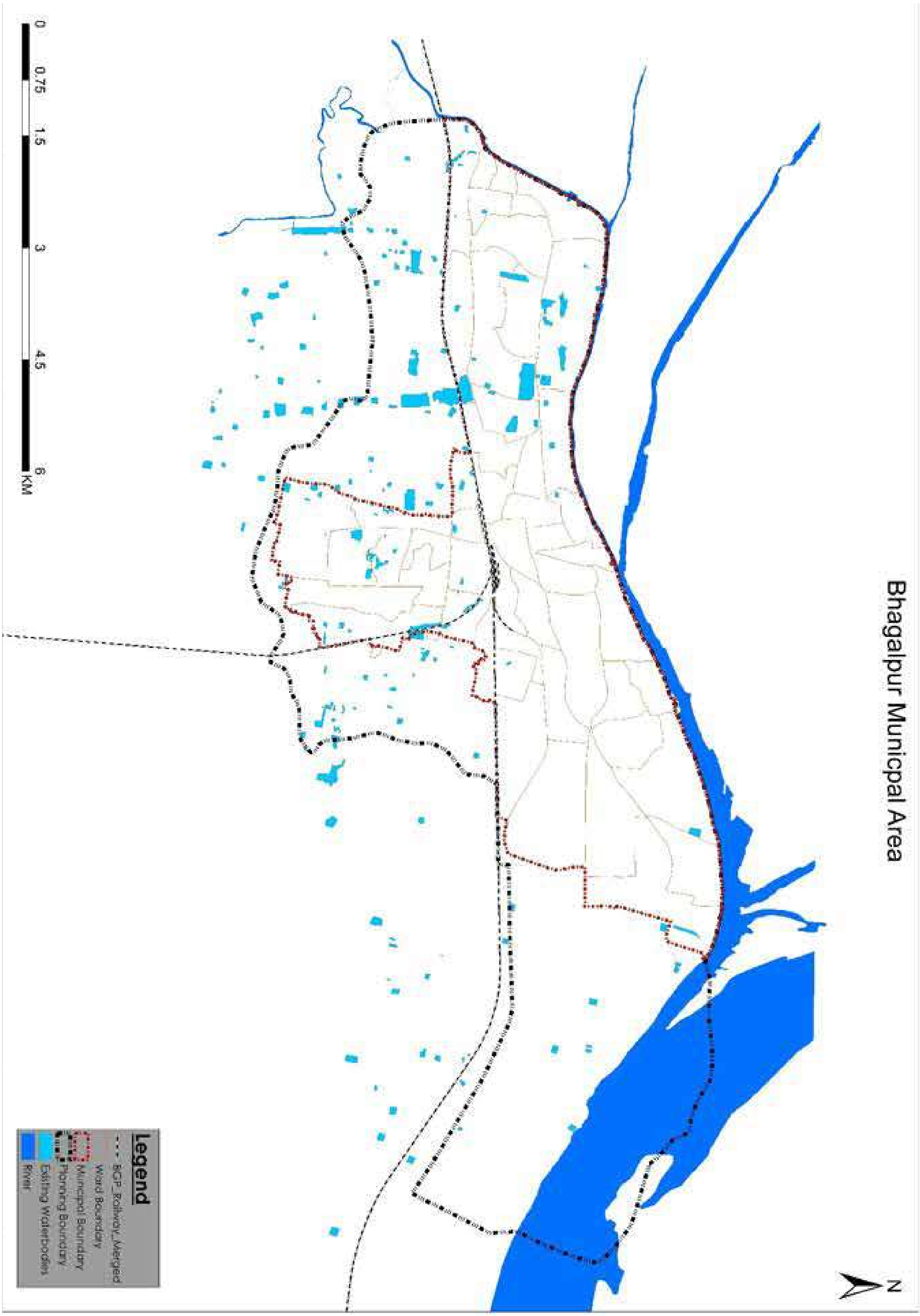
Table 20: Assigned Weights and ranks to morphological parameters

Parameter	Weightage Factor	Indicator	Score	Assigned Rank	References
Elongation Ratio	0.2	Circular	0.9 - 1.0	5	Pareta and Pareta, 2011
		Oval	0.8 - 0.9	4	
		Less Elongated	0.7 - 0.8	3	
		Elongated	0.5 - 0.7	2	
		More Elongated	< 0.5	1	

Parameter	Weightage Factor	Indicator	Score	Assigned Rank	References
Drainage Density	0.2	Very Coarse	< 2	5	Tavassol, 2016 & Smith, 1950
		Coarse	2 - 4	4	
		Moderately Coarse	4 - 6	3	
		Fine	6 - 8	2	
		Very Fine	> 8	1	
Stream Frequency	0.15	Low	0 -5	5	Venkatesan, 2014
		Moderate	5 -10	4	
		Moderately High	10 -15	3	
		High	15 - 20	2	
		Very High	20 - 25	1	
Drainage Texture	0.15	Very Coarse	< 2	5	Pareta and Pareta, 2011
		Coarse	2 - 4	4	
		Moderately Coarse	4 - 6	3	
		Fine	6 - 8	2	
		Very Fine	> 8	1	
Texture Ratio	0.15	Low	< 3	5	Gradation based on the fact that lower the value of texture ratio, more the capacity for storage of water in a watershed.
		Moderate	3 - 4	4	
		Moderately High	4 - 5	3	
		High	5 - 6	2	
		Very High	> 6	1	
RHO Coefficient	0.15	Low	< 0.2	1	Gradation based on the fact that higher the value of RHO coefficient, more the capacity for the storage of water in a watershed.
		Medium	0.2 - 0.3	2	
		Moderately High	0.3 - 0.4	3	
		High	0.4 - 0.5	4	
		Very High	> 0.5	5	

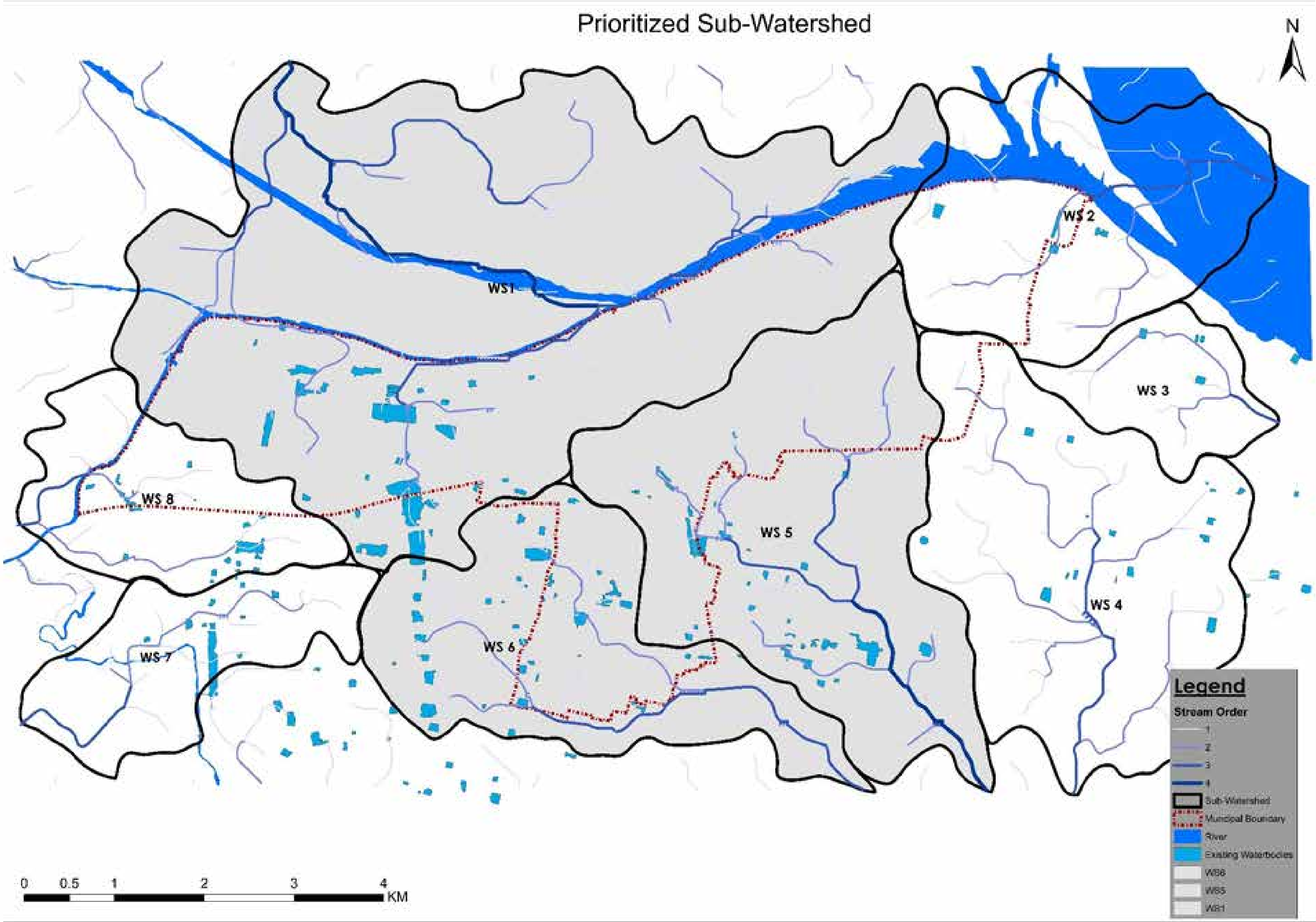
Source: Applied Water Science (2019) 9:27, https://doi.org/10.1007/s13201-019-0905-0

Figure 27: Bhagalpur Administrative Boundaries



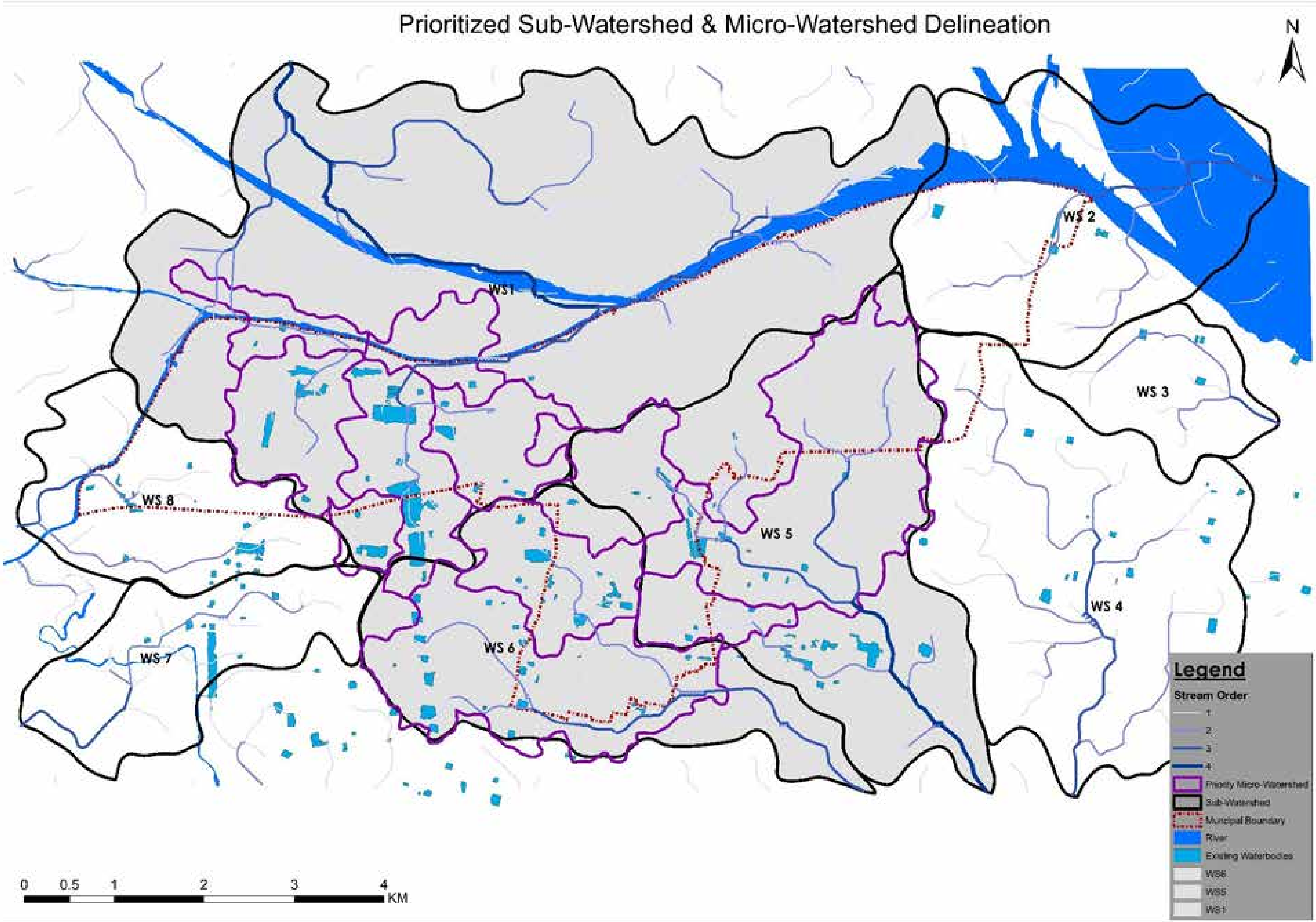
Source: SPA Delhi, Bhagalpur Municipality

Figure 28: Prioritized Sub-Watershed



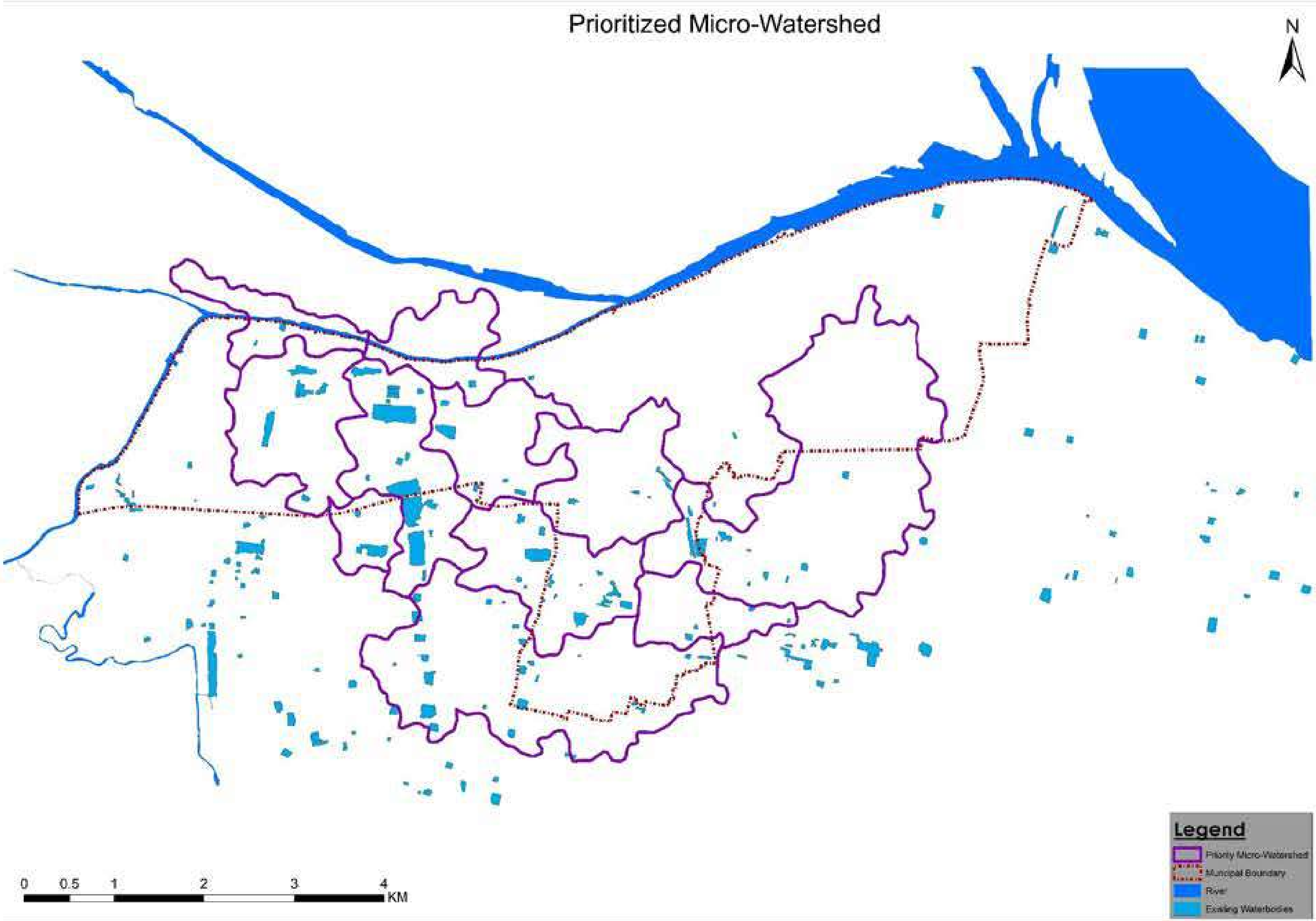
Source: SPA Delhi, Bhagalpur Municipality

Figure 29: Prioritized Sub-Watershed & Micro-Watershed Delineation



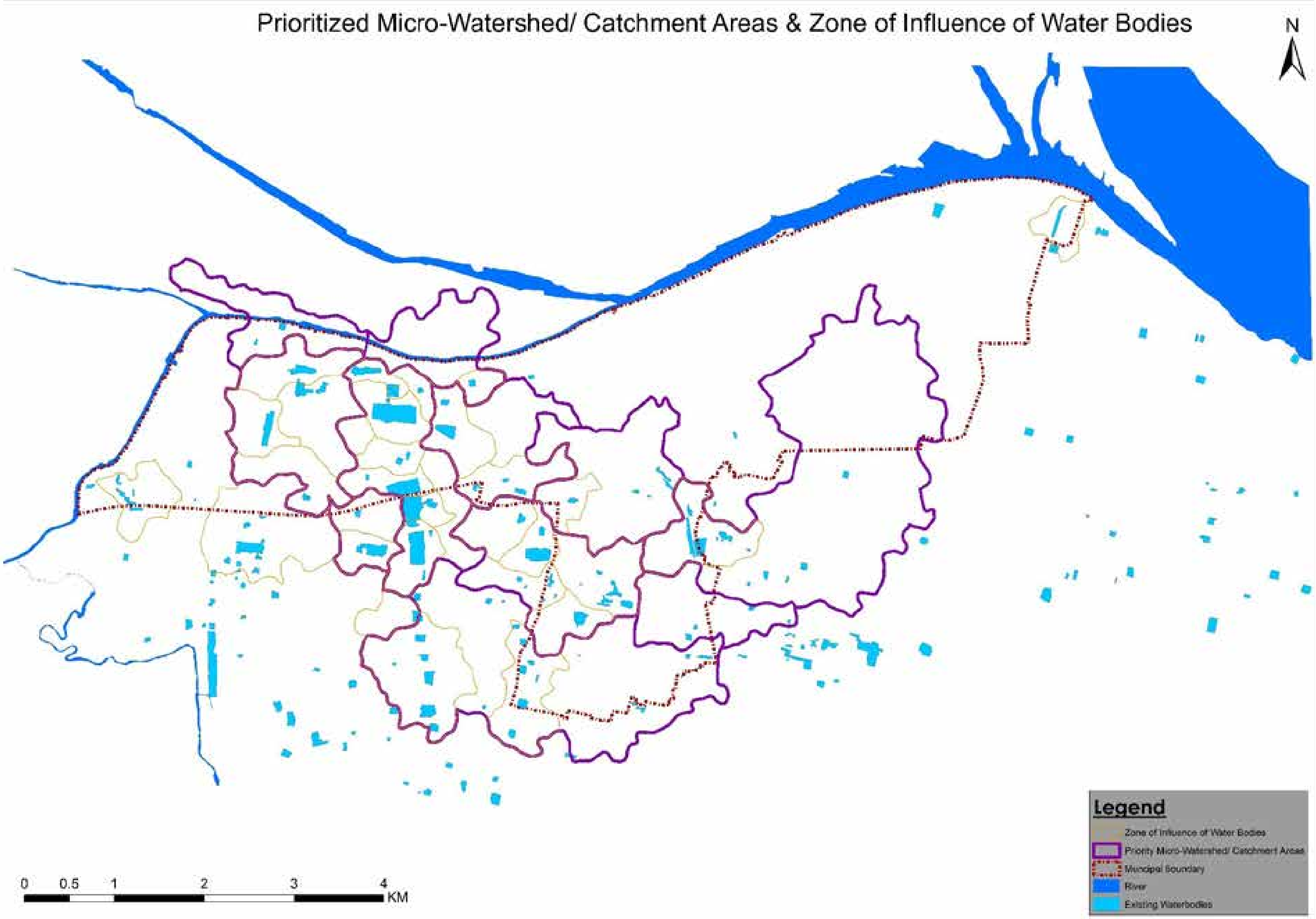
Source: SPA Delhi, Bhagalpur Municipality

Figure 30: Prioritized Micro-Watershed

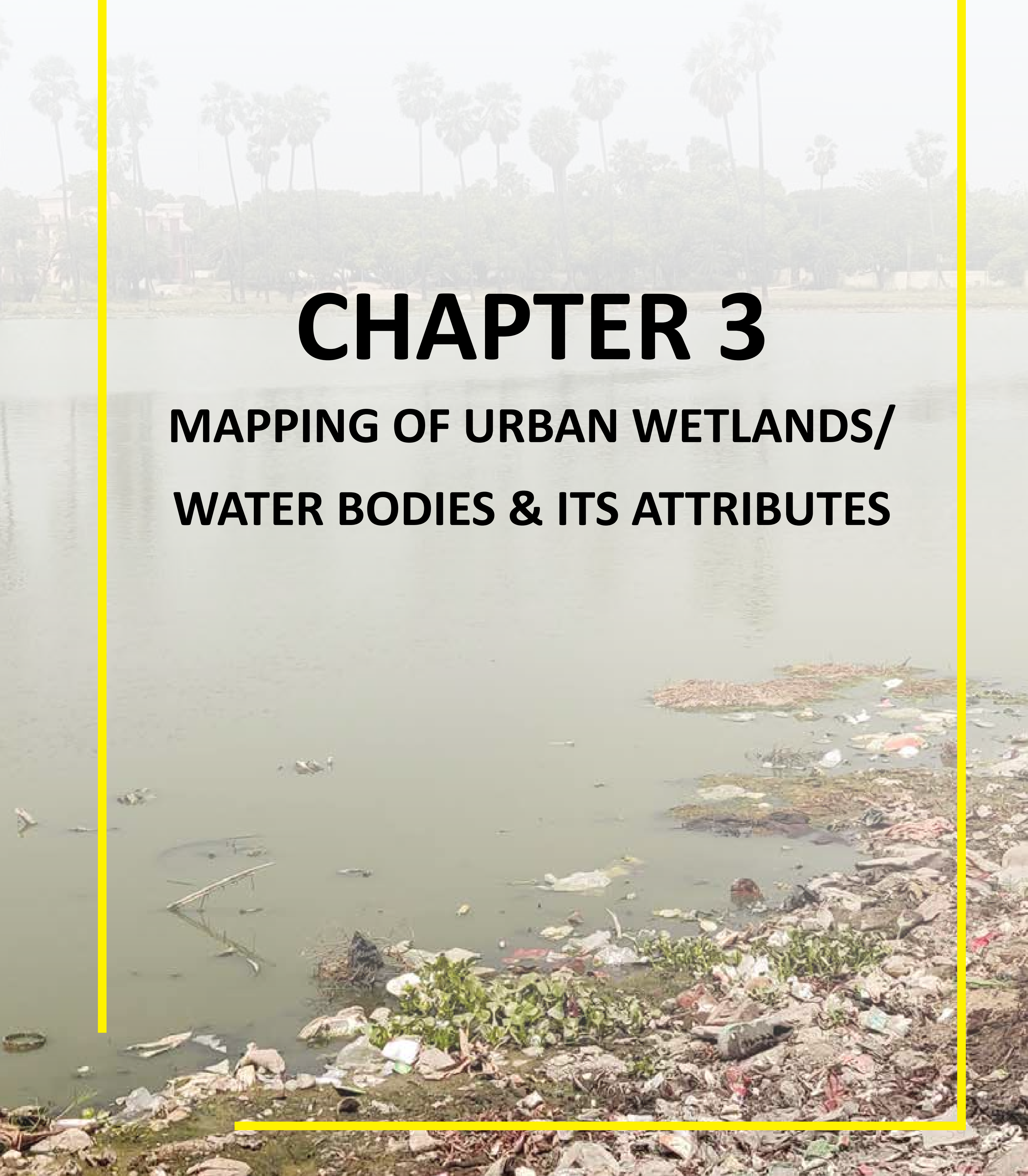


Source: SPA Delhi, Bhagalpur Municipality

Figure 31: Prioritized Micro-Watershed/Catchment Area & Zone of Influence of Urban Wetlands/Water Bodies



Source: SPA Delhi, Bhagalpur Municipality



CHAPTER 3

MAPPING OF URBAN WETLANDS/ WATER BODIES & ITS ATTRIBUTES

3. MAPPING OF URBAN WETLANDS/WATER BODIES & ITS ATTRIBUTES

3.1 INTRODUCTION

Preparation of Interactive GIS Map includes identifying and mapping of urban water bodies at city scale. This may also include the peri-urban areas. Look for the available information with local administration, with former and current landowners or land users, local groups and NGOs. Most cities have official survey records of natural resources, geological, forests, water resources, etc. Try to use this data, which are often precise and of good quality. Make a list of all available maps and data. The best way to organize data from different sources and to make those data work for you, is to develop a Geographical Information System.

Table 21: Data requirements for mapping of wetlands/water bodies

Data Requirement (Input)	Source of Data	Output
1. Primary & secondary survey 2. Historical dataset of satellite maps (10 years) 3. Location of water bodies 4. Size of water bodies 5. Characteristics of water bodies - perennial or seasonal 6. Ownership details of private water bodies 7. Physical and chemical characteristics of water bodies 8. Ecosystem Services of Water Bodies	1. Reports from published journals, articles and research papers 2. Google earth imagery, satellite imagery from USGS, NASA, SOI Maps 3. Satellite imagery and validated by ground truthing 4. Satellite imagery and validated by ground truthing 5. Satellite imagery and validated by ground truthing 6. Ward Commissioner, Municipality & Development Authorities 7. Primary survey is essential for physical characteristics of site and water quality analysis is required to capture the chemical characteristics of water bodies; standards as per CPCB and is: 10500:2012 and amendment no.1 8. Primary survey of stakeholders are essential to capture the Ecosystem Services; Ward Commissioner, Municipality & Development Authorities	1. Classification of water bodies based on size and existing condition. 2. Prioritization of water bodies for management

Source: SPA Delhi

3.2 ATTRIBUTES FOR MAPPING WATER BODIES

Table 22: Attributes for mapping water bodies

Aspect	Parameters
General Information	1. Name of water body 2. Location of water body 3. Area of water body (in Ha.) 4. Depth of water body (in meters): Pre-Monsoon & Post-Monsoon 5. Type of water body: Perennial or Seasonal 6. Ecosystem services provided by the water body: Provisioning, Supporting, Regulating and Cultural
Hydrology	1. Source of water 2. Water level fluctuation (annually in meters)
Catchment	1. Catchment area (in Sq. Kms) 2. Land Use & Land Cover of Catchment area 3. Availability of sewerage connection 4. Availability of STP Facility 5. If STP is available, Volume of sewage treated in MLD. 6. Solid waste disposal in water body or along its fringes (if any) including religious offerings/idol immersion, etc. 7. Availability of Solid waste management (SWM) 8. Quantity of solid waste generated (in tonnes or Kgs) and disposal process 9. Quantity of waste water generated (in lpcd or MLD)
Water Quality and Pollution Status	1. Sources of Pollution – Domestic sewage/ industrial effluents/ stormwater/ agricultural runoff/ human activity/ cattle wading/ others (specify) 2. Chemical composition of water bodies: Based on CPCB Norms
Biodiversity	1. Aquatic Plants – Submerged/ Emergent/ Free Floating/ Algae 2. Aquatic Animals – Zooplankton/ Benthic Invertebrates/ Mollusca/ Fish/ Amphibia/ Reptiles/ Birds/ Mammals 3. Important/ Rare/ Endemic/ Exotic species (name)
Functions and Values	1. Existing use of water body – Drinking water supply/ Irrigation/ Fisheries/ Recreational/ Religious activity/ others (specify) 2. Use of biological resources - Fish/Reeds & Grasses for thatch or fodder 3. Functions of water body – Ground water recharge / flood mitigation/ tourism/ supports biodiversity/ influence of micro-climate/ socio-cultural/ aesthetic
Threats/ Problems	1. Reduction in area (Shrinkage) 2. Reduction in depth (Siltation) 3. Encroachments 4. Algal Blooms 5. Aquatic weeds 6. Decline or loss of fisheries 7. Eutrophication 8. Organic Pollution 9. Toxic Pollution 10. Disposal of solid waste

Aspect	Parameters
Any restoration activities proposed	1. Improvement of water quality by in-situ treatment (De-weeding/ De-siltation/ Ozonation/ Bio-remediation) 2. Treatment of sewage 3. De-siltation for removal of organic/ toxic sediments 4. Weed removal 5. Catchment treatment to check erosion (afforestation) 6. Others (specify) 7. Activities already undertaken 8. Agencies involved in restoration activities
Ownership Details	1. Government/ Private 2. If private, please specify name of individual, location of residence, use of water bodies – pisciculture/ others (specify)

Source: SPA Delhi

3.3 PRIORITIZATION OF URBAN WETLANDS

Based on the background study of various policies and programmes, the following parameter were considered suitable for the prioritization of urban wetlands for the management purposes.

In view of the prevailing dynamic situation, urban local bodies may revise the priority list at an interval of 5 years covering different geographic regions of the city.

A. Hydrological Criteria

Physical parameters of the lake are:-

(i) Water bodies of size >2ha are considered suitable for the management based on size and also based on potential of convergence with other scheme and programmes.

> As per NPCA, April 2019, Wetlands/Waterbody located within urban, peri urban and semi urban areas of size ≥ 5 Ha is proposed for inclusion in its programme.
> Water bodies having minimum 5 ha in rural area & urban water bodies with water spread area between 2ha and 10 ha will be eligible for inclusion under RRR scheme.

(ii) Waterbody depth (maximum depth) > 3 m (at its peak level)

B. Scientific Criteria

1. The waterbody is justifiably prioritized by the concerned Urban Local Bodies (ULBs) or if the water body is highly degraded and cannot be put to its traditional use primarily because of either (a) or (a) & (b) as indicated under:

(a) Discharge of domestic and industrial waste water into the waterbody

(b) (i) Dumping of municipal solid waste

(ii) Other non-point sources of pollution

(iii) Flow of heavy silt loads in water-bodies from the catchment area.

2. The water body is degraded and not meeting the desired standards. In the absence of specific water quality criteria developed in respect of waterbodies, for the present Designated Best Use criteria for surface waters for bathing quality as given by Central Pollution Control Board (CPCB) shall be the target for lake water quality (Table 23).

Table 23: Designated Best Use Criteria for Surface Waters

Designated Best Use	Class of Criteria	Criteria
Drinking Water Source without conventional treatment but after disinfection	A	1. Total Coliforms Organism MPN/100 ml shall be 50 or less. 2. pH between 6.5 to 8.5 3. Dissolved Oxygen @6ml/l or more. 4.Biochemical Oxygen Demand: 5 days @20^{0}C should be 3mg/l or less.

Designated Best Use	Class of Criteria	Criteria
Outdoor Bathing (Organized)	B	1. Faecal Coliforms Organism MPN/100ml shall be 2500 (max permissible) or 1000 (desirable). 2. pH between 6.5 to 8.5 3. Dissolved Oxygen @ 5mg/l or more. 4. Biochemical Oxygen Demand: 5 days @20^0 C should be 3mg/l or less.
Drinking water source after conventional treatment and disinfection	C	1. Total Coliforms Organisms MPN/100ml shall be 5000 or less. 2. pH between 6 to 9 3. Dissolved Oxygen 4mg/l or more 4. Biochemical Oxygen Demand: 5 days @20^0 C 3mg/l or less.
Propagation of Wildlife and Fisheries	D	1. pH between 6.5 to 8.5 2. Dissolved Oxygen @4mg/l or more 3. Free Ammonia @1.2 mg/l or less.
Irrigation, Industrial Cooling, Controlled Waste Disposal	E	1. pH between 6.0 to 8.6 2. Electrical Conductivity at 25^0 C micro mhos/cm Max.2250 3. Sodium absorption Ratio Max. 26 mg/l 4. Boron Max. 2mg/l.

Source: CPCB

C. Administrative Criteria

The lake if getting degraded/under condition of eutrophication, is an important source of drinking water supply, domestic use, recreational use, provide other goods & services, may be proposed for management under this guideline, when:

(i) there is a high degree of demand from a public forum/local stakeholder for its conservation and if

(ii) the forum/stakeholders give their commitment to bear 10% out of ULBs share in the project cost.

3.4. ECOSYSTEM SERVICES OF WATER BODIES

The key to sustainable development is achieving a balance between the exploitation of natural resources for socio-economic development, and conserving ecosystem services that are critical to everyone's wellbeing and livelihoods (Falkenmark et al., 2007). There is no blueprint for obtaining this balance. However, an understanding of how ecosystem services contribute to livelihoods, and who benefits and who loses from changes arising from development interventions, is essential.

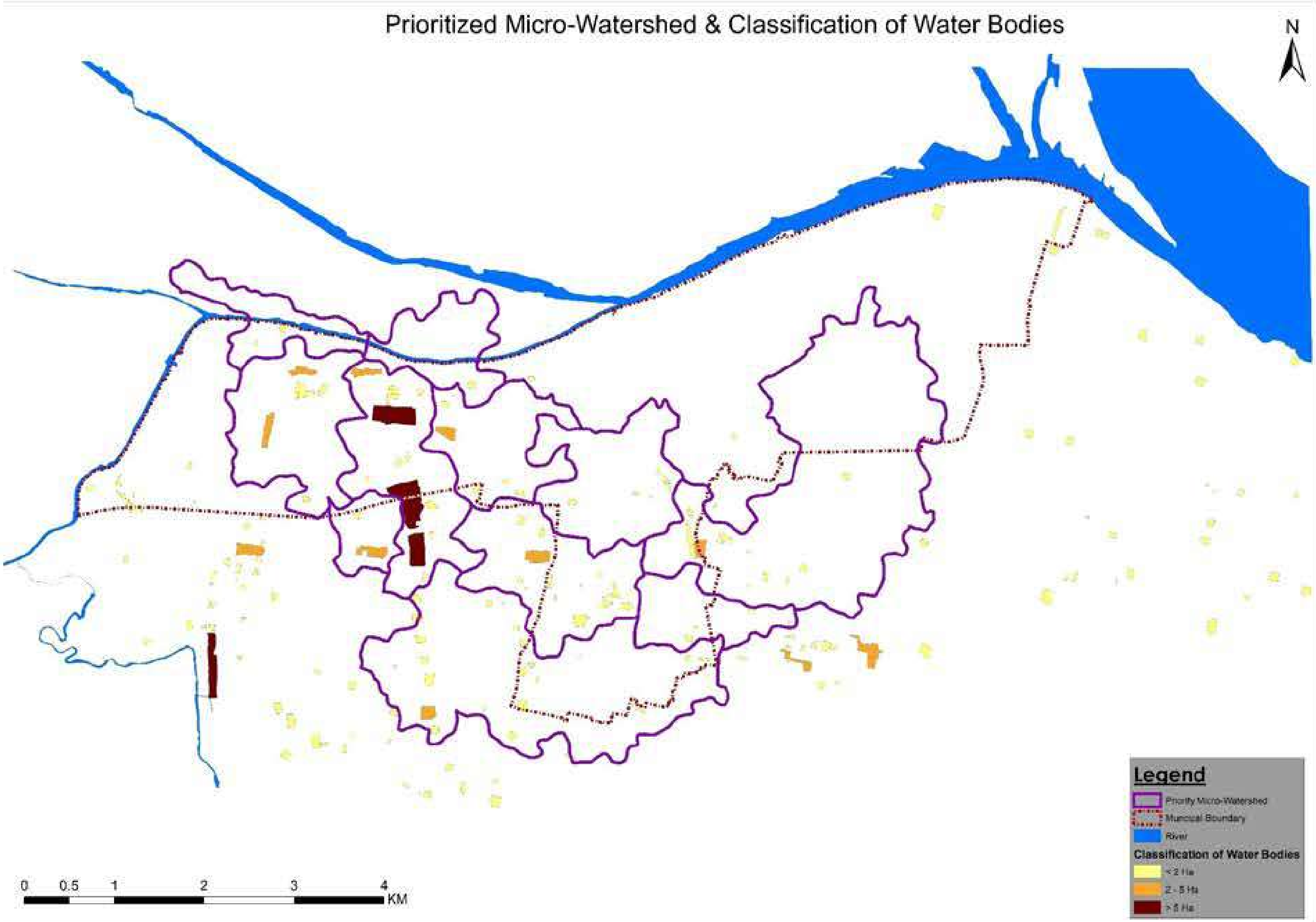
The Sustainable Development Goals (SDGs) proposed for water and sanitation (SDG 6) and ecosystems (SDG 15) have targets for restoring and maintaining ecosystems to provide water related services. The targets mention the need to integrate ecosystem values into planning, development processes, and strategies for reducing poverty.

Ecosystem services are the benefits people get from nature. Tangible benefits include supplies of food and freshwater, flood mitigation and improvements to water quality. Less tangible benefits include contributions to cultures.

Ecosystems often provide "bundles" of interlinked benefits. The way in which this occurs is complex and specific to the type of ecosystem. Many ecosystem services depend on water and are affected by changes in water flows. Although it is difficult to put a monetary value on an ecosystem service, economists are increasingly demonstrating the value of different services (Russi et al., 2013).

Nature also contributes to the resilience of communities. It can reduce the risk of natural hazards and mitigate adverse impacts by, for example, supplying food and water following a disaster.

Figure 32: Prioritized Micro-Watershed and Classification of Water Bodies



Source: SPA, Delhi

Table 24: Attributes of Water Body within Catchment Area

Water Bodies	Catchment Area	Population within Catchment Area	Population Density	Catchment Land Use - Built Up Area	Catchment Land Use - Agricultural Land	Catchment Land Use - Scrub Land/ Vegetation	Catchment Land Use - Water Bodies	Catchment Land Use - River	Built-Up/ Open Space Ratio	Area of Water Body	Depth	Fluctuation (Pre monsoon - Post monsoon)	Water Body Storage Volume	Annual Recharge (@0.6m per year)	Category (Natural or Man-made)	Source (Rainfall/ GW Seepage/ Catchment runoff/ direct or indirect flow from river/stream or creek)	Total Water Demand @135 lpcd (Catchment)	Total Water Supply @27 lpcd as per Municipality (Catchment)	Total Waste Water Generation (@ 80% of water supply)	Total Solid Waste Generation (@0.3 Kgs per person per day as per Bhagalpur SWM Report)	100m Buffer Area	Built-Up Area within 100m Buffer Area	%age of Built Up Area within 100m Buffer Area	Slum Settlements within 10m from water bodies
	Sq.m	Persons	pph	Sq.m	Sq.m	Sq.m	Sq.m	Sq.m		Sq.m	m	m	cubic meters	cubic meters			lpcd	lpcd	lpcd	Kgs	Sq.m	Sq.m	%	Yes/No
Bhairava	2175582.595	27455	126	820399.088	127717.139	894342.027	336754.365	0.000	0.604	90511	2.6		235328.6	54306.6000	Man-made	Rainfall, Catchment Runoff	3706425	741285	593028.00	8236.50	255963	72309.97	28.25	No
Naya Tola	2175582.595	27455	126	820399.088	127717.139	894342.027	336754.365	0.000	0.604	54097	2.438		131888.486	32458.2000	Natural	Rainfall, Catchment Runoff	3706425	741285	593028.00	8236.50	54097	32963.49	60.93	Yes
University Pond	1498251.131	37756	252	1298268.296	10918.697	153177.839	41852.757	0.000	6.304	24198	2.438		58994.724	14518.8000	Natural	Rainfall, Catchment Runoff	5097060	1019412	815529.60	11326.80	24198	55007.79	227.32	Yes
W9 Pond 1	2175582.595	27455	126	820399.088	127717.139	894342.027	336754.365	0.000	0.604	23028	2.438		56142.264	13816.8000	Natural	Rainfall, Catchment Runoff	3706425	741285	593028.00	8236.50	23028	35724.53	155.14	Yes
W9 Pond 2	2036344.879	19776	97	969625.295	297878.851	698579.032	83601.606	0.000	0.898	21152	2.438		51568.576	12691.2000	Natural	Rainfall, Catchment Runoff	2669760	533952	427161.60	5932.80	21152	51940.64	245.56	No
Nathnagar	2036344.879	19776	97	969625.295	297878.851	698579.032	83601.606	0.000	0.898	28684	2.438		69931.592	17210.4000	Natural	Rainfall, Catchment Runoff	2669760	533952	427161.60	5932.80	28684	44112.11	153.79	Yes
Dhobia Ghat	2175582.595	27455	126	820399.088	127717.139	894342.027	336754.365	0.000	0.604	60592	2.438		147723.296	36355.2000	Natural	Rainfall, Catchment Runoff	3706425	741285	593028.00	8236.50	60592	53035.18	87.53	No
Tanti Tola	6031932.804	58785	97	2476875.320	1162368.822	2325934.581	76565.573	0.000	0.695	23699	2.438		57778.162	14219.4000	Natural	Rainfall, Catchment Runoff	7935975	1587195	1269756.00	17635.50	23699	28627.62	120.80	Yes
Shahjangi Peer Masjid	2175582.595	27455	126	820399.088	127717.139	894342.027	336754.365	0.000	0.604	62111	6.096		378628.656	37266.6000	Man-made	Rainfall, Catchment Runoff	3706425	741285	593028.00	8236.50	62111	41597.85	66.97	No
Shahjangi Talaab (L)	565626.9261	4202	74	238642.804	28410.257	261827.910	37791.819	0.000	0.728	33220	2.438		80990.36	19932.0000	Natural	Rainfall, Catchment Runoff	567270	113454	90763.20	1260.60	33289	77178.23	231.84	No
Ragopur Talaab	1827785.311	16948	93	739848.684	489069.595	554904.570	63123.136	0.000	0.668	34621	2.438		84405.998	20772.6000	Natural	Rainfall, Catchment Runoff	2287980	457596	366076.80	5084.40	34622	33963.15	98.10	No
Habibpur Talaab	2074295.14	47291	228	1455633.435	0.000	515631.928	109846.872	0.000	2.327	35863	2.438		87433.994	21517.8000	Natural	Rainfall, Catchment Runoff	6384285	1276857	1021485.60	14187.30	35863	56316.70	157.03	No
Dighi Talaab	1789701.684	8575	48	136354.787	1419565.718	174777.555	86983.594	21491.877	0.080	63819	2.438		155590.722	38291.4000	Natural	Rainfall, Catchment Runoff, Direct flow from river	1157625	231525	185220.00	2572.50	64098	35109.65	54.77	No

Source: SPA Delhi, Primary Survey

Table 25: Attributes of Water Body within Zone of Influence

Water Bodies	Area of Zone of Influence (ZOI)	Population within Zone of Influence (ZOI)	Population Density	Catchment Land Use - Built Up Area	Catchment Land Use - Agricultural Land	Catchment Land Use - Scrub Land/ Vegetation	Catchment Land Use - Water Bodies	Catchment Land Use - River	Built-Up/ Open Space Ratio	Area of Water Body	Depth	Fluctuation (Pre monsoon - Post monsoon)	Water Body Storage Volume	Annual Recharge (@0.6m per year)	Category (Natural or Man-made)	Source (Rainfall/ GW Seepage/ Catchment runoff/ direct or indirect flow from river/stream or creek)	Total Water Demand @135 lpcd (Catchment)	Total Water Supply @27 lpcd as per Municipality (Catchment)	Total Waste Water Generation (@ 80% of water supply)	Total Solid Waste Generation (@0.3 Kgs per person per day as per Bhagalpur SWM Report)	100m Buffer Area	Built-Up Area within 100m Buffer Area	%age of Built Up Area within 100m Buffer Area	Slum Settlements within 10m from water bodies
	Sq.m	Persons	pph	Sq.m	Sq.m	Sq.m	Sq.m	Sq.m		Sq.m	m	m	cubic meters	cubic meters			lpcd	lpcd	lpcd	Kgs	Sq.m	Sq.m	%	Yes/No
Bhairava	389519.354	2863	74	123996.112	0.000	173667.992	92305.413	0.000	0.466	90511	2.6		235328.6	54306.6000	Man-made	Rainfall, Catchment Runoff	386505	77301	61840.80	858.90	255963	72309.97	28.25	No
Naya Tola	267566.0399	2607	97	78609.114	0.000	132174.300	57130.131	0.000	0.415	54097	2.438		131888.486	32458.2000	Natural	Rainfall, Catchment Runoff	351945	70389	56311.20	782.10	54097	32963.49	60.93	Yes
University Pond	459082.0993	10901	237	335333.583	10918.697	89177.315	29163.678	0.000	2.594	24198	2.438		58994.724	14518.8000	Natural	Rainfall, Catchment Runoff	1471635	294327	235461.60	3270.30	24198	55007.79	227.32	Yes
W9 Pond 1	153835.2467	812	53	25772.233	50343.341	40580.844	38950.246	0.000	0.198	23028	2.438		56142.264	13816.8000	Natural	Rainfall, Catchment Runoff	109620	21924	17539.20	243.60	23028	35724.53	155.14	Yes
W9 Pond 2	488456.1567	1993	41	145200.703	297878.852	33044.923	23231.443	0.000	0.410	21152	2.438		51568.576	12691.2000	Natural	Rainfall, Catchment Runoff	269055	53811	43048.80	597.90	21152	51940.64	245.56	No
Nathnagar	382669.8776	2405	63	110739.234	0.000	245067.415	28684.357	0.000	0.405	28684	2.438		69931.592	17210.4000	Natural	Rainfall, Catchment Runoff	324675	64935	51948.00	721.50	28684	44112.11	153.79	Yes
Dhobia Ghat	152340.7577	2720	179	53785.813	0.000	37889.917	61043.849	0.000	0.544	60592	2.438		147723.296	36355.2000	Natural	Rainfall, Catchment Runoff	367200	73440	58752.00	816.00	60592	53035.18	87.53	No
Tanti Tola	739191.8284	9215	125	373418.322	6553.146	300778.062	58609.393	0.000	1.020	23699	2.438		57778.162	14219.4000	Natural	Rainfall, Catchment Runoff	1244025	248805	199044.00	2764.50	23699	28627.62	120.80	Yes
Shahjangi Peer Masjid	365555.6835	4693	128	96364.311	19229.750	174601.794	75481.886	0.000	0.358	62111	6.096		378628.656	37266.6000	Man-made	Rainfall, Catchment Runoff	633555	126711	101368.80	1407.90	62111	41597.85	66.97	No
Shahjangi Talaab (L)	245560.1078	1790	73	95368.654	28201.693	89746.951	33288.635	0.000	0.631	33220	2.438		80990.36	19932.0000	Natural	Rainfall, Catchment Runoff	241650	48330	38664.00	537.00	33289	77178.23	231.84	No
Ragopur Talaab	1250038.542	13706	110	572733.889	298518.328	335506.888	57975.213	0.000	0.828	34621	2.438		84405.998	20772.6000	Natural	Rainfall, Catchment Runoff	1850310	370062	296049.60	4111.80	34622	33963.15	98.10	No
Habibpur Talaab	267409.8897	4216	158	116993.963	0.000	109235.386	41326.332	0.000	0.777	35863	2.438		87433.994	21517.8000	Natural	Rainfall, Catchment Runoff	569160	113832	91065.60	1264.80	35863	56316.70	157.03	No
Dighi Talaab	1789701.684	8575	48	136354.787	1419565.718	174777.555	86983.594	21491.877	0.080	63819	2.438		155590.722	38291.4000	Natural	Rainfall, Catchment Runoff, Direct flow from river	1157625	231525	185220.00	2572.50	64098	35109.65	54.77	No

Source: SPA Delhi, Primary Survey

Table 26: Ecosystem Services of Water Bodies

Services			Ecosystem Service Identification												
			Bhairava	Naya Tola	University Pond	W9 Pond 1	W9 Pond 2	Nathnagar	Dhobia Ghat	Tanti Tola	Shahjangi Peer Masjid	Shahjangi Talaab (L)	Ragopur Talaab	Habibpur Talaab	Dighi Talaab
Provisioning	Food	Production of fish (0.5)	Yes, maintained by University & commercially supplied in market	None	None	Yes, benefits obtained from being near agricultural land	Yes, benefits obtained from being near agricultural land	Yes	None	None	Yes, community-maintained fisheries	None	Yes	Yes	Yes, benefits obtained from being near agricultural land
		Production of fruits and grains (0.5)	None, no buffer space	None, no buffer space	None, no buffer space	Yes, water is being used in agriculture production	Yes, water is being used in agriculture production	None, no buffer space	None, no buffer space	Yes, water is being used in agriculture production	None, no buffer space	None, no buffer space	None, no buffer space	None, no buffer space	Yes, water is being used in agriculture production
	Fresh Water	Storage and retention of water (0.33)	Yes, perennial	Yes, perennial	Yes, perennial	Yes, perennial	Yes, perennial	Yes, perennial	Yes, perennial	Yes, perennial	Yes, perennial	Yes, perennial	Yes, perennial	Yes, perennial	Yes, perennial
		Provision of water for irrigation (0.33)	None	None	None	Yes, water is being used in agriculture production	Yes, water is being used in agriculture production	None	None	Yes, water is being used in agriculture production	None	Yes, water is being used in agriculture production	None	None	Yes, water is being used in agriculture production
		Provision of water for drinking (0.33)	None	None	None	None	None	None	None	None	None	None	None	None	None
	Fiber and Fuel	Production of timber (0.2)	None, not used for production of timber	None, not used for production of timber	None, not used for production of timber	None, not used for production of timber	None, not used for production of timber	None, not used for production of timber	None, not used for production of timber	None, not used for production of timber	None, not used for production of timber	None, not used for production of timber	None, not used for production of timber	None, not used for production of timber	None, not used for production of timber
		Production of fuelwood (0.2)	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space
		Production of peat (0.2)	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply
		Production of fodder (0.2)	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space
		Livestock rearing (0.2)	Pisciculture	None	None	Pisciculture	Pisciculture	Pisciculture	None	None	Pisciculture	None	Pisciculture	Pisciculture	Pisciculture
	Bio-Chemical Products	Extraction of materials from biota (1)	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented
	Genetic Material	Medicine (0.33)	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented
		Genes for resistance to plant pathogens (0.33)	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented
		Ornamental species (0.33)	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented	Not well documented
Regulating	Climate Regulation	Regulation of greenhouse gases (0.5)	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space	None, absence of buffer space
		Regulation of temperature/ micro-climate (0.5)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Hydrological Regimes	Groundwater recharge and discharge (0.33)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
		Storage of water for agriculture (0.33)	None	None	None	Yes, water is being used in agriculture production	Yes, water is being used in agriculture production	None	None	Yes, water is being used in agriculture production	None	None	None	None	Yes, water is being used in agriculture production
		Storage of water for industry (0.33)	None	None	None	None	None	None	None	None	None	None	None	None	None
	Pollution Control & Detoxification	Nutrient Retention (0.33)	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies

Services			Ecosystem Service Identification												
			Bhairava	Naya Tola	University Pond	W9 Pond 1	W9 Pond 2	Nathnagar	Dhobia Ghat	Tanti Tola	Shahjangi Peer Masjid	Shahjangi Talaab (L)	Ragopur Talaab	Habibpur Talaab	Dighi Talaab
Regulating (Cont.)	Pollution Control & Detoxification (Cont.)	Removal of excess nutrients (0.33)	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies
		Removal of pollutants (0.33)	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies	Yes, chemical characteristics of water within limits considering the inflow of sewage and drains into water bodies
	Erosion Protection	Retention of soils and prevention of structural changes (such as erosion, bank slumping and so on) (1)	None, does not apply	None, does not apply	None, does not apply	None, does not apply	None, does not apply	None, does not apply	None, does not apply	None, does not apply	None, does not apply	None, does not apply	None, does not apply	None, does not apply	None, does not apply
	Natural Hazard	Flood control (0.5)	Yes, falls under flood inundation zone	Yes, falls under flood inundation zone	Yes, falls under flood inundation zone	Yes, falls under flood inundation zone	Yes, falls under flood inundation zone	None	None	None	None	None	None	None	Yes, falls under flood inundation zone
		Storm Protection (0.5)	None, does not apply	None, does not apply	None, does not apply	None, does not apply	None, does not apply	None, does not apply	None, does not apply	None, does not apply	None, does not apply	None, does not apply	None, does not apply	None, does not apply	None, does not apply
Cultural	Spiritual & Inspirational	Personal feelings and well-being (0.5)	Yes, linked to economic productivity	None	None	Yes, linked to economic productivity	Yes, linked to economic productivity	Yes, linked to economic productivity	Yes, linked to economic productivity	None	Yes, linked to economic productivity	None	Yes, linked to economic productivity	Yes, linked to economic productivity	Yes, linked to economic productivity
		Religious significance (0.5)	Yes, Hinduism	None	None	None	None	None	None	None	Yes, Muslim	None	None	None	None
	Recreational	Opportunities for tourism (0.5)	Yes, well accessible and well maintained	None	None	None	None	None	Yes, well accessible and well maintained	None	Yes, well accessible and well maintained	None	None	None	Yes, well accessible and presence of agricultural farms & plantation around
		Opportunities for recreational activities (0.5)	Yes	None	None	None	None	None	Yes	None	Yes	None	None	None	Yes
	Aesthetics	Appreciation of natural features (1)	Yes	Yes	None	Yes	Yes	Yes	Yes	Yes	Yes	Yes	None	None	Yes
	Educational	Opportunities for formal and informal education and training (1)	Yes, can be studied from the point of providing livelihoods via maintenance of water bodies	Yes, can be studied from the point of providing livelihoods via maintenance of water bodies	Yes, can be studied from the point of providing livelihoods via maintenance of water bodies	Yes, can be studied from the point of providing livelihoods via maintenance of water bodies	Yes, can be studied from the point of providing livelihoods via maintenance of water bodies	Yes, can be studied from the point of providing livelihoods via maintenance of water bodies	Yes, can be studied from the point of providing livelihoods via maintenance of water bodies	Yes, can be studied from the point of providing livelihoods via maintenance of water bodies	Yes, can be studied from the point of providing livelihoods via maintenance of water bodies	Yes, can be studied from the point of providing livelihoods via maintenance of water bodies	Yes, can be studied from the point of providing livelihoods via maintenance of water bodies	Yes, can be studied from the point of providing livelihoods via maintenance of water bodies	Yes, can be studied from the point of providing livelihoods via maintenance of water bodies
Supporting	Biodiversity	Habitats for residents or transient species (1)	Yes, habitat for fishes and recreational space for locals	Yes, recreational space for locals	None	Yes, habitat for fishes and recreational space for locals	Yes, habitat for fishes and recreational space for locals	Yes, habitat for fishes and recreational space for locals	Yes, recreational space for locals	Yes, habitat for fishes and recreational space for locals	Yes, habitat for fishes and recreational space for locals	Yes, recreational space for locals	Yes, habitat for fishes and recreational space for locals	Yes, habitat for fishes and recreational space for locals	Yes, habitat for fishes and recreational space for locals
	Soil Formation	Sediment retention (0.5)	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply
		Accumulation of organic matter (0.2)	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality
	Nutrient Cycling	Storage, recycling, processing and acquisition of nutrients (1)	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality	Yes, evidence from water quality
	Pollination	Support for pollinators (1)	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply	Does not apply

Source: SPA Delhi, Primary Survey

3.5 VALUATION OF ECOSYSTEM SERVICES

Many ecosystem services are perceived as "public goods", accruing outside monetary systems. Until recently, many went unrecognized in planning processes and they continue to be under-valued. Consequently, ecosystems are being degraded at an increasing rate.

Infrastructure built primarily to provide people with water for irrigation and domestic, commercial and industrial purposes is crucial for economic growth, for alleviating poverty and for attaining many of the proposed SDGs.

However, this infrastructure—especially dams—has impacts on aquatic ecosystems and, by altering flows of water, sediment and nutrients, can weaken the ecosystem services on which poor communities depend.

Modifying ecosystems to facilitate socioeconomic development is necessary but how can we avoid damaging important ecosystem services? As a prerequisite, we need to understand how ecosystem services contribute to people's livelihoods and wellbeing. In considering ecosystem services, the intent is to identify interventions that offer people possibilities and improve their livelihoods over the long term. There is no blueprint for finding the balance between conservation and development, but it is essential we understand who will benefit and who will lose out if ecosystem services change.

The Millennium Ecosystem Assessment found that "cross-sectoral and ecosystem-based approaches to wetland management—such as river (or lake or aquifer) basin-scale management, and integrated coastal zone management—that consider trade-offs between different wetland ecosystem services are more likely to ensure sustainable development than many existing sectoral approaches and are critical in designing actions in support of the Millennium Development Goals" (MEA, 2005). This finding remains relevant for designing the SDGs.

By focusing more on ecosystem services, land use planners can determine the values people place on different parts of the landscape in which they live. Currently, these values tend to go unrecognized by wider society, and land-use change for development often results in consequences for the poor that are not adequately compensated.

3.5.1 Relative magnitude (per unit area) of ecosystem services derived from different types of wetland ecosystem

Wetland ecosystems provide a diversity of services vital for human well-being and poverty alleviation. (See Table) It is well established that provisioning services from wetlands, such as food (notably fish) and fiber are essential for human well-being. Supporting and regulating services (such as nutrient cycling) are critical to sustaining vital ecosystem functions that deliver many benefits to people. The delivery of fresh water is a particularly important service both directly and indirectly. In addition, wetlands have significant aesthetic, educational, cultural, and spiritual values and provide invaluable opportunities for recreation and tourism.

The principal supply of renewable fresh water for human use comes from an array of inland wetlands, including lakes, rivers, swamps, and shallow groundwater aquifers. Inland waters and mountains provide water to two thirds of global population and dry-lands to one third. Inland wetlands serve 12 times as many people downstream through river corridors as they do through locally derived runoff .

Groundwater, often recharged through wetlands, plays an important role in water supply, providing drinking water to large section of population. It also serves as the source water for industrial use and irrigation. Despite its importance, sustainable use of groundwater has often not been sufficiently supported through appropriate pricing and management action.

Another important water supply is represented by the widespread construction of artificial impoundments that stabilize river flow. Today, a large number of dams have been built for municipal, industrial, hydro-power, agricultural, and recreational water supply and for flood control.

Fish and fishery products are particularly important ecosystem services derived from inland waters.

Inland fisheries are of special importance in developing countries as they are sometimes the primary source of animal protein for rural communities.

Wetlands provide an important service by treating and detoxifying a variety of waste products. Water flowing through a wetland area may be considerably cleaner upon its exit from the wetland. Some wetlands have been found to reduce the concentration of nitrate by more than 80%. Some artificially constructed wetlands have been developed specifically to treat nitrogen-rich sewage effluents. Metals and many organic compounds may be adsorbed to the sediments (that is, accumulated on their surface) in the wetlands. The relatively slow passage of water through wetlands provides time for pathogens to lose their viability or be consumed by other organisms in the ecosystem. However, wetlands can become "hotspots" of contamination— wastes can build up to concentrations high enough to have detrimental effects on wetland functions. Unfortunately, the threshold between where loadings are tolerated and where they will do damage to wetlands is not easily determined.

Wetlands are important tourism destinations because of their aesthetic value and the high diversity of the animal and plant life they contain. In some locations, tourism plays a major part in supporting rural economies, although there are often great disparities between access to and involvement in such activities. Recreational fishing can generate considerable income. The negative effects of recreation and tourism are particularly noticeable when they introduce inequities and do not support and develop local economies, and especially where the resources that support the recreation and tourism are degraded.

Wetlands play an important role in the regulation of global climate by sequestering and releasing significant amounts of carbon. Inland water systems play two critical but contrasting roles in mitigating the effects of climate change: the regulation of greenhouse gases (especially carbon dioxide) and the physical buffering of climate change impacts.

Inland water systems have been identified as significant storehouses (sinks) of carbon as well as sources of carbon dioxide (for instance, boreal peatlands), as net sources of carbon sequestration in sediments, and as transporters of carbon to the sea.

Wetlands provide many nonmarketed and marketed benefits to people, and the total economic value of unconverted wetlands is often greater than that of converted wetlands (medium certainty). There are many examples of the economic value of intact wetlands exceeding that of converted or otherwise altered wetlands. (See Table 27).

Water scarcity and declining access to fresh water is a globally significant and accelerating problem for 1–2 billion people worldwide, leading to reductions in food production, human health, and economic development. With population growth and the overexploitation and contamination of water resources, the gap between available water and water demand is increasing in many parts of the world. Scarcity of water will affect all businesses either directly or indirectly, just as increases in the price of petroleum affect the state of the global economy (Business and Industry Synthesis).

Table 27: Magnitude of ecosystem services in various ecosystems

Scale is low ● , medium ● , to high ● ; not known = ?; Blank cells indicate that the service is not considered applicable to wetland type. The information in the table represents expert opinion for a global average pattern of wetlands; there will be local and regional differences in relative magnitude

Service	Comments and Examples	Permanent and Temporary Rivers & Streams	Permanent lakes & Reservoirs	Seasonal lakes, marshes and Swamps including floodplains	Forested wetlands, marshes, and swamps including floodplains	Alpine and tundra wetlands	Springs and oases	Geothermal wetlands	Underground wetlands including caves and ground water systems
Inland Wetlands									
Provisioning									
Food	**Production of fish, wild game, fruits, grains and so on**	high	high	high	high	low	low		
Fresh Water	**Storage and retention of water; provision of water for irrigation and for drinking**	high	high	medium	low	low	low		high
Fiber and Fuel	**Production of timber, fuelwood, peat, fodder, aggregate**	medium	medium	low	high	medium	low		
Biochemical Products	**Extraction of materials from biota**	low	low	?	?	?	?	?	?
Genetic Material	**Medicine; genes for resistance to plant pathogens, ornamental species and so on**	low	low	?	low	?	?	?	?
Regulating									
Climate Regulation	**Regulation of greenhouse gases, temperature, precipitation, and other climatic processes; chemical composition of atmosphere**	low	high	low	high	low		low	low
Hydrological Regime	**Groundwater recharge and discharge of water for agricultue or industry**	high	high	medium	medium	low	low		low
Pollution Control and detoxification	**Retention, recovery and removal of excess nutrients and pollutants**	high	medium	low	medium	low	low		medium
Erosion Protection	**Retention of soils and prevention of structural change (such as coastal erosion, bank, slumping and so on)**	medium	low	low	medium	?	low		low
Natural Hazards	**Flood control; storm protection**	medium	high	high	medium	medium			low
Cultural									

Scale is low ● , medium ● , to high ● ; not known = ?; Blank cells indicate that the service is not considered applicable to wetland type. The information in the table represents expert opinion for a global average pattern of wetlands; there will be local and regional differences in relative magnitude

Service	Comments and Examples	Permanent and Temporary Rivers & Streams	Permanent lakes & Reservoirs	Seasonal lakes, marshes and Swamps including floodplains	Forested wetlands, marshes, and swamps including floodplains	Alpine and tundra wetlands	Springs and oases	Geothermal wetlands	Underground wetlands including caves and ground water systems
Spiritual and inspirational	**Personal feelings and well-being; religious significance**	● (high)	● (high)	● (medium)	● (medium)	● (low)	● (medium)	● (low)	● (low)
Recreational	**Opportunities for tourism and recreational activities**	● (high)	● (high)	● (medium)	● (low)	● (low)	● (low)	● (low)	● (low)
Aesthetics	**Appreciation of natural features**	● (high)	● (medium)	● (low)	● (medium)	● (low)	● (low)	● (low)	● (low)
Educational	**Opportunities for formal and informal education and training**	● (high)	● (high)	● (medium)	● (medium)	● (low)	● (low)	● (low)	● (low)
Supporting									
Biodiversity	**Habitats for resident or transient species**	● (high)	● (high)	● (medium)	● (medium)	● (low)	● (low)	● (low)	● (low)
Soil Formation	**Sediment retention and accumulation of organic matter**	● (high)	● (low)	● (medium)	● (high)	● (low)	?	?	
Nutrient Cycling	**Storage, recycling, processing, and acquisition of nutrients**	● (high)	● (high)	● (high)	● (high)	● (low)	● (low)	?	● (low)
Pollination	**Support for pollination**	● (low)	● (low)	● (low)	● (medium)	● (low)	● (low)		

Source: Finlayson, C.M., D'Cruz, R & Davidson, N.C. 2005. Ecosystems and Human well-being: wetlands and water. Synthesis. Millennium Ecosystem Assessment. World Resources Institute, Washington D.C. (RAMSAR Handbook)

Table 28: Valuation of Ecosystem Services based on Magnitude Values

Services			Scope		Ecosystem Service Identification												
Water Bodies/Wetlands			Water Body	Buffer Zone	Bhairava	Naya Tola	University Pond	W9 Pond 1	W9 Pond 2	Nathnagar	Dhobia Ghat	Tanti Tola	Shahjangi Peer Masjid	Shahjangi Talaab (L)	Ragopur Talaab	Habibpur Talaab	Dighi Talaab
Provisioning	**Food (1)**	Production of fish			1	0	0	1	1	1	0	0	1	0	1	1	1
		Production of fruits and grains			0	0	0	1	1	0	0	1	0	0	0	0	1
	Fresh water (1)	Storage and retention of water			1	1	1	1	1	1	1	1	1	1	1	1	1
		Provision of water for irrigation			0	0	0	1	1	0	0	1	0	1	0	0	1
		Provision of water for drinking			0	0	0	0	0	0	0	0	0	0	0	0	0
	Fiber and Fuel (1)	Production of timber			0	0	0	0	0	0	0	0	0	0	0	0	0
		Production of fuelwood			0	0	0	0	0	0	0	0	0	0	0	0	0
		Production of peat			0	0	0	0	0	0	0	0	0	0	0	0	0
		Production of fodder			0	0	0	0	0	0	0	0	0	0	0	0	0
		Livestock rearing			1	0	0	1	1	1	0	0	1	0	1	1	1
	Biochemical Products (1)	Extraction of materials from biota			0	0	0	0	0	0	0	0	0	0	0	0	0
	Genetic Material (1)	Medicine			0	0	0	0	0	0	0	0	0	0	0	0	0
		Genes for resistance to plant pathogens			0	0	0	0	0	0	0	0	0	0	0	0	0
		Ornamental species			0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Provisioning Services Value				**3**	**1**	**1**	**5**	**5**	**3**	**1**	**3**	**3**	**2**	**3**	**3**	**5**
Regulating	**Climate Regulation (1)**	Regulation of greenhouse gases			0	0	0	0	0	0	0	0	0	0	0	0	0
		Regulation of temperature/micro-climate			1	1	1	1	1	1	1	1	1	1	1	1	1
	Hydrological Regimes (1)	Groundwater recharge and discharge			1	1	1	1	1	1	1	1	1	1	1	1	1
		Storage of water for agriculture			0	0	0	1	1	0	0	1	0	0	0	0	1
		Storage of water for industry			0	0	0	0	0	0	0	0	0	0	0	0	0
	Pollution control and detoxification (1)	Nutrient Retention			1	1	1	1	1	1	1	1	1	1	1	1	1
		Removal of excess nutrients			1	1	1	1	1	1	1	1	1	1	1	1	1
		Removal of pollutants			1	1	1	1	1	1	1	1	1	1	1	1	1
	Erosion Protection (1)	Retention of soils and prevention of structural changes (such as erosion, bank slumping and so on)			0	0	0	0	0	0	0	0	0	0	0	0	0
	Natural Hazard (1)	Flood control			1	1	1	1	1	0	0	0	0	0	0	0	1
		Storm Protection			0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Regulating Services Value				**6**	**6**	**6**	**7**	**7**	**5**	**5**	**6**	**5**	**5**	**5**	**5**	**6**
Cultural	**Spiritual and Inspirational (1)**	Personal feelings and well-being (0.5)			1	0	0	1	1	1	1	0	1	0	1	1	1
		Religious significance (0.5)			1	0	0	0	0	0	0	0	1	0	0	0	0
	Recreational (1)	Opportunities for tourism (0.5)			1	0	0	0	0	0	1	0	1	0	0	0	1
		Opportunities for recreational activities (0.5)			1	0	0	0	0	0	1	0	1	0	0	0	0
	Aesthetics	Appreciation of natural features (1)			1	1	0	1	1	1	1	1	1	1	0	0	1
	Educational (1)	Opportunities for formal and informal education and training (1)			1	1	1	1	1	1	1	1	1	1	1	1	1
	Total Cultural Service Value				**6**	**2**	**1**	**3**	**3**	**3**	**5**	**2**	**6**	**2**	**2**	**2**	**4**
Supporting	**Biodiversity (1)**	Habitats for residents or transient species (1)			1	1	0	1	1	1	1	1	1	1	1	1	1
	Soil Formation (1)	Sediment retention (0.5)			0	0	0	0	0	0	0	0	0	0	0	0	0
		Accumulation of organic matter (0.2)			1	1	1	1	1	1	1	1	1	1	1	1	1
	Nutrient Cycling (1)	Storage, recycling, processing and acquisition of nutrients (1)			1	1	1	1	1	1	1	1	1	1	1	1	1
	Pollination (1)	Support for pollinators (1)			0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Supporting Services Value				**3**	**3**	**2**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
Total Value of Ecosystem Services					**18**	**12**	**10**	**18**	**18**	**14**	**14**	**14**	**17**	**12**	**13**	**13**	**18**

Source: SPA Delhi

Table 29: Total value of ecosystem services of water bodies

Water Bodies/Wetlands	Provisioning	Regulating	Cultural	Supporting	Total ESS Value
Bhairava	3	6	6	3	18
Naya Tola	1	6	2	3	12
University Pond	1	6	1	2	10
W9 Pond 1	5	7	3	3	18
W9 Pond 2	5	7	3	3	18
Nathnagar	3	5	3	3	14
Dhobia Ghat	1	5	5	3	14
Tanti Tola	3	6	2	3	14
Shahjangi Peer Masjid	3	5	6	3	17
Shahjangi Talaab (L)	2	5	2	3	12
Ragopur Talaab	3	5	2	3	13
Habibpur Talaab	3	5	2	3	13
Dighi Talaab	5	6	4	3	18

Source: SPA, Delhi

CHAPTER 4

GROUND WATER ASSESSMENT

4. GROUND WATER ASSESSMENT

4.1 INTRODUCTION

The first and foremost important thing in ground water assessment is that it should be carried out at a level of basin or sub-basin or watershed or micro-watershed best suited to the scope of study area. These hydrological unit for assessment provides better accuracy other than assessing them at block or district level.

For the purpose of assessing the ground water of the city, the micro-watersheds bounding the city is undertaken. This may include the urban and peri-urban areas as both will have direct impact on the ground water status.

There are various steps involved in assessing the ground water which includes:

a. Rainfall Data for last 5-10 years – Openly available from IMD

b. Identification of area of micro-watershed – Openly available at SLUSI, Bhuvan Portal, CGWB, WRIS or can be generated and manually corrected from DEM obtained from USGS or NASA.

c. Land Use Land Cover within the micro-watershed – Built-Up, Agricultural land, Scrub/Vegetation, Water Bodies and Rivers – Readily available with municipality or can be mapped from high resolution satellite imagery such as SENTINEL (10m res.) or Landsat 8 (30m res.) or Google Earth Satellite Imagery.

d. Agricultural Cropping Pattern and Type of Crops (Paddy/Non-Paddy) – In case agricultural land falls within the study area – Value for Crop Water Requirement is essential for estimation of ground water use in agricultural areas in case of non-availability of data.

e. Ground water draft/utilization status within the micro-watershed – agricultural use, domestic and industrial use of ground water – Can be acquired from municipality and primary survey of use of bore well, municipality water supply, etc.

f. Soil data with its specific yield – Can be obtained from Department of Agriculture, Cooperation & Farmers Welfare, CGWB, SLUSI, Bhuvan Portal, Geological Survey of India.

g. Recharge Potential of Water Bodies – In case of non-availability of data, area and depth of water bodies can be obtained from primary survey and basic assumptions can be considered as per CGWB GEC 2015 Report.

The rainfall data for Bhagalpur district have been considered due to lack of well-established data for city level. The data is obtained from IMD website.

Table 30: Rainfall data of Bhagalpur district

Rainfall (District)													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (mm)
2014	5.6	38.1	3.8	0	197.6	95.3	476.3	203.3	149.6	9	0	0.2	1178.8
2015	28.4	3.7	31.9	71.4	53.7	204.2	360.1	300.7	188	11.4	0	0	1253.5
2016	23.6	0.9	1.6	7.2	92	104.9	315.3	117.1	320.1	27.1	0	0	1009.8
2017	4	0	18.4	22.6	111.3	66.8	377.5	319.3	216	272.3	0.1	0	1408.3
2018	0	0	13.5	35.5	49.3	156	338.3	345.9	83.3	61.6	0	`3	1083.4
Avg.	12.32	8.54	13.84	27.34	100.78	125.44	373.50	257.26	191.40	76.28	0.02	0.04	1186.76

Source: IMD

4.2 UNIT FOR GROUND WATER RECHARGE ASSESSMENT

Watershed with well-defined hydrological boundaries is an appropriate hydrological unit for ground water resource estimation. In hard rock areas, the hydro-geological and hydrological units normally coincide, which may not be the case in alluvial areas where the aquifers traverse the basin boundaries. In hard rock areas which occupy about 2/3rd area of the country, assessment of ground water resources on watershed as a unit is more desirable. In many states where the development unit is either a block, taluka or a mandal, the ground water resources worked out on watershed as a unit, may be apportioned and presented finally on block/taluka/mandal-wise basis, for planning of development programmes. In case of alluvial areas where it is difficult to identify watershed considering the trans-boundary aquifer system, assessment of ground water potential on block/taluka/mandal-wise basis may prevail.

4.3 DELINEATION OF SUBAREAS IN THE ASSESSMENT UNIT

GEC - 1997 recommends identifying hilly areas where slope is more than 20% as these areas are likely to contribute more to run off than to ground water recharge. Such hilly areas should be subtracted from the total geographical area of the unit. The areas where the quality of ground water is beyond the usable limits, should also be identified and handled separately. The remaining area need to be re-delineated as (a) Non-command areas which do not come under major/medium surface water irrigation schemes and (b) Command areas which come under major/medium surface water irrigation schemes.

4.4 SEASON-WISE ASSESSMENT OF GROUND WATER RESOURCES

Ground water recharge assessment is to be made separately for the non-command, command areas and poor ground water quality areas in the assessment unit. For each of these subareas, recharge in the monsoon season and non-monsoon season is to be estimated separately. For most parts of the country receiving the main rainfall from South west monsoon, the monsoon season would pertain to kharif period of cultivation. In areas, such as Tamil Nadu, where the primary monsoon season is the North east monsoon, the period of monsoon season should be suitably modified. For the purposes of recharge assessment using water level fluctuation method, the monsoon season may be taken as May/June to October/November for all areas, except those where the predominant rainfall is due to the North east monsoon. In areas where the predominant rainfall is due to North east monsoon, the period for recharge assessment may be based on pre-monsoon (October) to post monsoon (February) water level fluctuations.

4.5 ESTIMATION OF GROUND WATER DRAFT

Ground water draft is estimated for all the ground water uses viz. Domestic, Irrigation and Industrial. Domestic draft can be estimated based on well census method or requirement method. Irrigation draft can be estimated using well census method, cropping pattern method or power consumption method. Industrial draft can be estimated using well census method, power consumption method or requirement method. Sum of all these drafts is the Gross ground water draft.

4.6 ESTIMATION OF GROUND WATER RECHARGES

Ground water recharge due to rainfall is to be estimated using ground water level fluctuation method and rainfall infiltration factor method.

4.6.1 Ground water level fluctuation method

The water level fluctuation method is applied for the monsoon season to estimate the recharge using ground water balance equation. The ground water balance equation for the monsoon season is expressed as,

$$R_G – D_G - B + I_S + I = \Delta S$$

Where,

R_G = gross recharge due to rainfall and other sources including recycled water

D_G = gross ground water draft

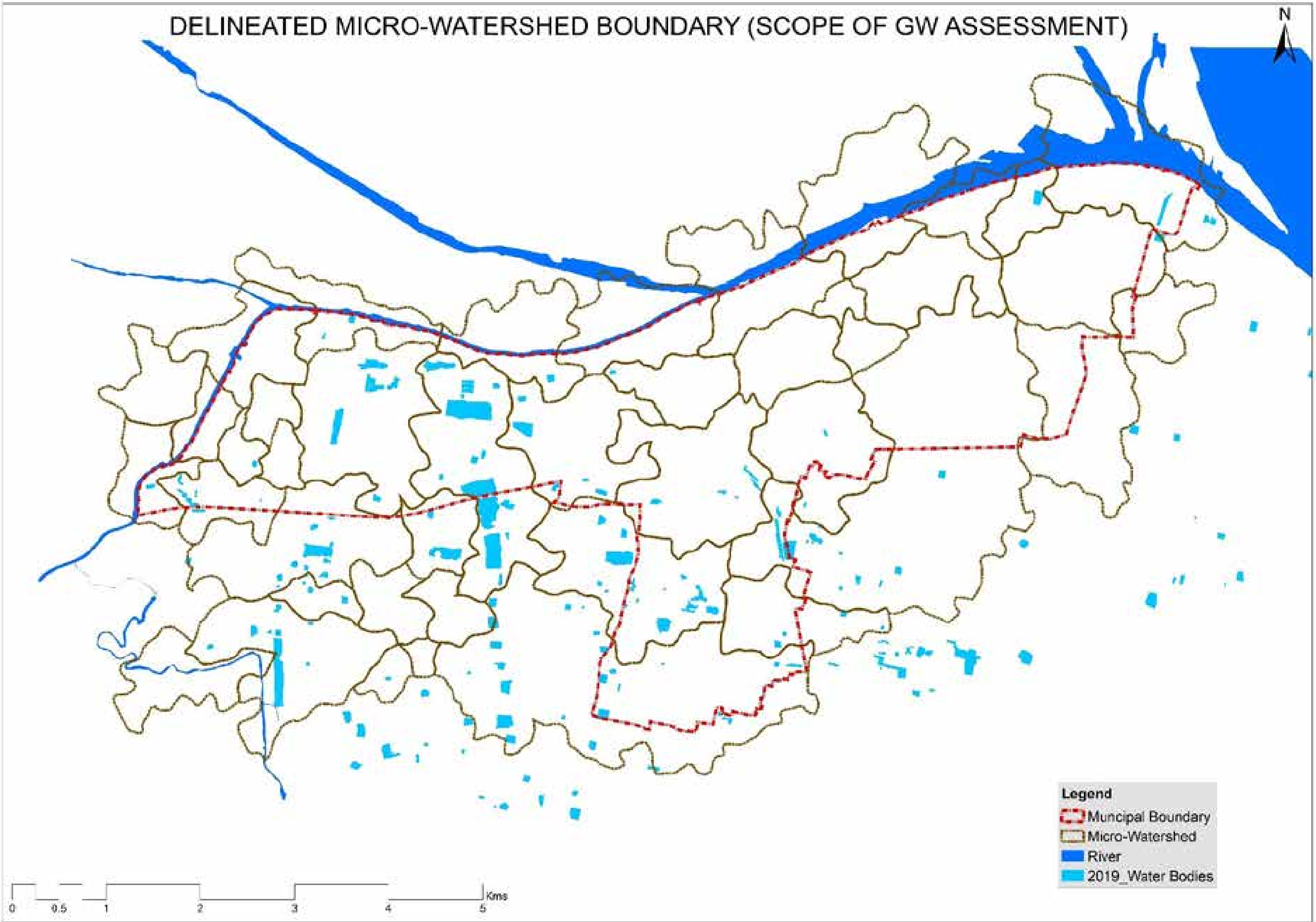
B = base flow into streams from the area

I_S = recharge from streams into ground water body

I = net ground water inflow into the area across the boundary (inflow - outflow)

ΔS = increase in ground water storage

Figure 33: Delineated micro-watershed boundary (scope of ground water assessment)



Source: SPA Delhi

For non-command areas, the recharge from other sources may be recharge from recycled water from ground water irrigation, recharge from tanks and ponds and recharge from water conservation structures. The recharge from rainfall is given by,

$R_{rf} = R - R_{gw} - R_{wc} - R_t = h \times S_y \times A + D_g - R_{gw} - R_t - R_{wc}$

Where,

R_{rf} = recharge from rainfall

R_{gw} = recharge from ground water irrigation in the area

R_{wc} = recharge from water conservation structures

h = rise in water level in the monsoon season

S_y = specific yield

A = area for computation of recharge (This will include the open areas & agricultural land)

R_t = Recharge from tanks and ponds

In command areas there are two more components in recharge due to other sources viz. recharge due to canals and return flow from surface water irrigation. Hence the rainfall recharge can be estimated using the following formula.

$R_{rf} = h \times S_y \times A + D_G - R_C - R_{sw} - R_{gw} - Rt - R_{wc}$

Where,

R_{rf} = rainfall recharge

h = rise in water level in the monsoon season

S_y = specific yield

A = area for computation of recharge

D_G = gross ground water draft in the monsoon season

R_c = recharge due to seepage from canals

R_{sw} = recharge from surface water irrigation

R_{gw} = recharge from ground water irrigation

R_t = recharge from tanks and ponds

R_{wc} = recharge from water conservation structures

4.6.2 Rainfall Infiltration Factor Method

Recharge from rainfall in monsoon season can also be estimated based on the Rainfall Infiltration Factor method and is estimated using the following equation;

Rrf = f x A x Normal rainfall in monsoon season

Where,

f = rainfall infiltration factor

A = area for computation of recharge

4.6.3 Recharge due to other sources

Recharge due to other sources constitute recharges from Canals, Applied Surface Water irrigation, Applied Ground Water Irrigation, Tanks& Ponds and Water Conservation Structures in Command areas. Whereas in Non-command areas only the recharge due to Applied Ground Water Irrigation, Tanks & Ponds and Water Conservation Structures are possible.

4.6.3.1 Recharge due to Canal (Can also be applied to river)

Recharge due to canals is estimated based on the following formula:

RC = WA * SF * Days

Where;

RC= Recharge Due to Canals

WA=Wetted Area

SF= Seepage Factor

Days= Number of Canal Running Days.

4.6.3.2 Recharge due to Applied Ground Water Irrigation

Recharge due to applied ground water irrigation is estimated based on the following formula:

RGWI =GDI*RFF

Where,

RGWI = Recharge due to applied ground water irrigation

GDI= Gross Ground Water Draft for Irrigation

RFF= Return Flow Factor

4.6.3.3 Recharge due to Tanks & Ponds

Recharge due to Tanks & Ponds is estimated based on the following formula:

RTP =AWSA*R *RF

Where,

RTP = Recharge due to Tanks & Ponds

AWSA= Average Water Spread Area

N=Number of days Water is available in the Tank/Pond

RF= Recharge Factor

4.6.3.4 Recharge due to Water Conservation Structures

Recharge due to Water Conservation Structures is estimated based on the following formula:

RWCS =GS*RF

Where,

RWCS = Recharge due to Water Conservation Structures

GS= Gross Storage= Storage Capacity X No. of Fillings.

RF= Recharge Factor

4.6.4 Recharge during Monsoon Season

The sum of Normalized Monsoon Rainfall Recharge and the recharge due to other sources during monsoon season is the total recharge during Monsoon season.

4.6.5 Recharge during Non-Monsoon Season

The rainfall recharge during non-monsoon season is estimated using Rainfall Infiltration factor Method only when the non-monsoon season rainfall is more than 10% of normal annual rainfall. The sum of Non-Monsoon Rainfall Recharge and the recharge due to other sources during non-monsoon season is the total recharge during Non-Monsoon season.

4.6.6 Total Annual Ground Water Recharge

The sum of the recharge during monsoon season and Non monsoon season is the Total Annual Ground Water Recharge.

4.6.7 Unaccounted Natural Discharges

The Unaccounted Natural Discharges are estimated based on the method with which rainfall recharge is estimated during monsoon season. If the rainfall recharge is computed using water table fluctuation method, 5% of the Total Annual Ground Water Recharge is taken as unaccounted Natural discharges else it is 10% of the Total Annual Ground Water Recharge.

4.6.8 Net Annual Ground Water Availability

The difference between total annual ground water recharge and the unaccounted natural discharges is the net annual ground water availability.

4.6.9 Stage of Ground Water Development

Stage of Ground Water Development is to be computed using the following formula.

Stage of ground water development = (Existing Gross Ground Water Draft for all uses/Net Annual Ground Water Availability) × 100

4.7 NORMS RECOMMENDED BY GEC 1997

4.7.1 Norms for specific yield

The norms for Specific yield as recommended by GEC 1997 are given in Table 31.

Table 31: Norms for specific yield

Sl.No.	Formation	Recommended Value (%)	Minimum Value (%)	Maximum Value (%)
(a)	Alluvial Areas			
	Sandy Alluvium	16	12	20
	Silty Alluvium	10	8	12
	Clayey Alluvium	6	4	8
(b)	Hard rock areas	6		
	Weathered granite, gneiss and schist with low clay content	3	2	4
	Weathered granite, gneiss and schist with significant clay content	1.5	1	2
	Weathered or vesicular, jointed basalt	2	1	3
	Laterite	2.5	2	3
	Sandstone	3	1	5
	Quartzite	1.5	1	2
	Limestone	2	1	3
	Karstified limestone	8	5	15
	Phyllites, Shales	1.5	1	2
	Massive poorly fractured rock	0.3	0.2	0.5

Note: Usually the recommended values should be used for assessment, unless sufficient data based on field study is available to justify the minimum, maximum or other intermediate values.

Source: CGWB, GEC 97, 2015 Report

4.7.2 Norms for Rainfall Infiltration Factor

The norms for Rainfall Infiltration factor as recommended by GEC 1997 are given below in Table 32.

Table 32: Norms for rainfall infiltration factor

S. No.	Formation	Recommended Value (%)	Minimum Value (%)	Maximum Value (%)
(a)	Alluvial Areas			
	Indo-Gangetic and Inland areas	22	20	25
	East Coast	16	14	18
	West Coast	10	8	12
(b)	Hard rock areas			
	Weathered granite, gneiss and schist with low clay content	11	10	12
	Weathered granite, gneiss and schist with significant clay content	8	5	9
	Granulite facies like charnockite etc.	5	4	6
	Vesicular and jointed basalt	13	12	14
	Weathered basalt	7	6	8

S. No.	Formation	Recommended Value (%)	Minimum Value (%)	Maximum Value (%)
	Laterite	7	6	8
	Semi-consolidated sandstone	12	10	14
	Consolidated sandstone, quartzite, limestone (except cavernous limestone)	6	5	7
	Phyllites, shales	4	3	5
	Massive poorly fractured rock	1	1	3

Note:1. Usually, the recommended values should be used for assessment, unless sufficient information is available to justify the use of minimum, maximum or other intermediate values. 2. An additional 2% of rainfall recharge factor may be used in such areas or part of the areas where watershed development with associated soil conservation measures are implemented. This additional factor is subjective and is separate from the contribution due to the water conservation structures such as check dams, nalla bunds, percolation tanks etc. The norms for the estimation of recharge due to these structures are provided separately. This additional factor of 2% is, at this stage, only provisional, and will need revision based on pilot studies.
Source: CGWB, GEC 97, 2015 Report

4.7.3 Norms for recharge due to seepage from canals

The norms for Recharge due to seepage from canals as recommended by GEC 1997 are given below in Table 33.

Table 33: Norms for recharge due to seepage from canals

(a) Unlined canals in normal soils with some clay content along with sand	1.8 to 2.5 cumecs per million sq.m. of wetted area (or) 15 to 20 ham/day/million sq.m. of wetted area
(b) Unlined canals in sandy soil with some silt content	3.0 to 3.5 cumecs per million sq.m. of wetted area (or) 25 to 30 ham/day/million sq.m. of wetted area
(c) Lined canals and canals in hard rock area	20% of above values for unlined canals

Notes: 1. The above values are valid if the water table is relatively deep. In shallow water table and waterlogged areas, the recharge from canal seepage may be suitably reduced. 2. Where specific results are available from case studies in some states, the adhoc norms are to be replaced by norms evolved from these results.
Source: CGWB, GEC 97, 2015 Report

4.7.4 Norms for Return flow from irrigation

The recharge due to return flow from irrigation may be estimated, based on the source of irrigation (ground water or surface water), the type of crop (paddy, non-paddy) and the depth of water table below ground level. The norms for Return flow from irrigation as recommended by GEC 1997 are given below in Table 34.

Table 34: Norms for return flow from irrigation

Source of Irrigation	Type of crop	Water Table below ground level		
		< 10m	10-25m	>25m
Ground Water	Non-Paddy	25	15	5
Surface Water	Non-Paddy	30	20	10
Ground Water	Paddy	45	35	20
Surface Water	Paddy	50	40	25

Notes: 1. For surface water, the recharge is to be estimated based on water released at the outlet. For ground water, the recharge is to be estimated based on gross draft. 2. Where continuous supply is used instead of rotational supply, an additional recharge of 5% of application may be used. 3. Where specific results are available from case studies in some states, the adhoc norms are to be replaced by norms evolved from these results.
Source: CGWB, GEC 97, 2015 Report

4.7.5 Recharge from Storage Tanks and Ponds

1.4 mm/day for the period in which the tank has water, based on the average area of water spread. If data on the average area of water spread is not available, 60% of the maximum water spread area may be used instead of average area of the water spread.

4.7.6 Recharge from Percolation Tanks

50% of gross storage, considering the number of fillings, with half of this recharge occurring in the monsoon season, and the balance in the non-monsoon season.

4.7.7 Recharge due to Check Dams and Nala Bunds

50% of gross storage (assuming annual de-silting maintenance exists) with half of this recharge occurring in the monsoon season, and the balance in the non-monsoon season.

4.7.8 Categorization of areas for ground water development

The categorization based on status of ground water quantity is defined by Stage of Ground Water Extraction as given in Table 35.

Table 35: Categorization of areas for ground water development

Stage of Ground Water Extraction	Category
≤ 70 %	Safe
> 70 % and ≤ 90 %	Semi-Critical
> 90% and ≤ 100 %	Critical
> 100 %	Over Exploited

Source: CGWB, GEC 97, 2015 Report

4.8 GROUND WATER ASSESSMENT OF BHAGALPUR CITY

Based on the above literature and approach to ground water assessment, the same has been adopted for Bhagalpur city at micro-watershed level bounding the city as identified earlier.

• The monsoon season is considered as per IMD classification i.e., May to September and non-monsoon season between Jan to April and October to December.

• The micro-watershed has been generated and manually corrected from DEM obtained from USGS/ NASA website. A well demarcated micro-watershed is essential for ground water assessment and as such help from hydrologist and geographer is necessary.

• The land use and land cover data for the micro-watershed have been demarcated through primary survey and secondary data such as Google Satellite Imagery and verified with other government portals such as Bhuvan Portal.

• Agricultural Cropping Pattern and Type of Crops (Paddy/Non-Paddy) have been obtained from Agricultural Contingency Plan for Bhagalpur district and primary survey for well demarcated between crop types, paddy or non-paddy. Major crops and fruits grown within the micro-watershed area are rice (paddy) and mangoes (non-paddy).

• Ground water draft/utilization status within the micro-watershed for agricultural use have been calculated through crop water requirement technique due to lack of well-established data and for domestic and industrial use of ground water the data have been taken from various reports of Bhagalpur city – Sewerage Master Plan, City Sanitation Plan, Solid Waste Management Plan & CDP.

• The soil data of Bhagalpur have been taken from CGWB report and cross-verified with Bhuvan portal. The map obtained from the report has been taken to ArcGIS and digitized.

• The water bodies depth and area have been obtained from primary survey and due to lack of data for their contribution to ground water recharge, the CWGB GEC 2015 assumptions have been considered.

4.8.1 Rainfall in Bhagalpur District

Table 36: Rainfall in Bhagalpur district

Rainfall (District)													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total (mm)
2014	5.6	38.1	3.8	0	197.6	95.3	476.3	203.3	149.6	9	0	0.2	1178.8
2015	28.4	3.7	31.9	71.4	53.7	204.2	360.1	300.7	188	11.4	0	0	1253.5
2016	23.6	0.9	1.6	7.2	92	104.9	315.3	117.1	320.1	27.1	0	0	1009.8

Rainfall (District)													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Total (mm)**
2017	4	0	18.4	22.6	111.3	66.8	377.5	319.3	216	272.3	0.1	0	1408.3
2018	0	0	13.5	35.5	49.3	156	338.3	345.9	83.3	61.6	0	`3	1083.4
Avg.	12.32	8.54	13.84	27.34	100.78	125.44	373.50	257.26	191.40	76.28	0.02	0.04	1186.76

Source: IMD

4.8.2 Ground water recharge estimation for monsoon season

Ground Water Draft for Irrigation is calculated as given in Table 37.

Table 37: Cropping Pattern in Bhagalpur district

Sowing window for 5 major field crops	Rice	Wheat	Maize	Lentil	Blackgram
Kharif - Rainfed	June to July		June to July		
Kharif - Irrigated	June to July		May to June		
Rabi - Rainfed		3rd week October- 2nd week November	3rd week October- 2nd week November	October - November	August to September
Rabi - Irrigated		2nd week November - 1st week January	October - November	2nd week October - 2nd week December	

Source: Agricultural Contingency Plan of Bhagalpur District

Table 38: Ground Water Draft from irrigation

Major Field Crop	Area of land covered (Sq. m)	Crop Water Requirement (ICAR) in mm/growing period	Draft in cubic meters (Draft per growing season)	Return Flow from irrigation (%)	Monsoon: Recharge from Ground water irrigation (cubic meters) - CGWB Norms	Non-Monsoon: Recharge from ground water irrigation (cubic meters) – CGWB Norms
	A	B	C=A*B	D	E=C*D	F = C*D
Rice (Paddy)	4652044.421	900-1300	6047657.747	45	2721445.986	2721445.986
Mango (Non-Paddy)	8035325.579	1250-1700	13660053.48	25	3415013.371	Not grown
Total			19707711.23		6136459.357	2721445.986

Source: SPA, Delhi

Ground Water Draft for Domestic and Industrial use is calculated as given below:

Daily ground water extracted from tube wells for domestic water supply in Bhagalpur is 11.084 MLD.

Number of days in Monsoon Season (May-September) = 153 days

Total Ground Water Draft for Domestic and Industrial Use = 153*11.084*1000 cubic meter or 1695852 cubic meters or 1.696 MCM.

Gross Ground Water Draft in Monsoon Season = Ground water draft for irrigation use (monsoon) + Ground water draft for domestic and industrial use (monsoon) = 19707711.23 + 1695852 = 21403563.232 cubic meters

The area for computation of recharge is considered as total area falling under agricultural land and water bodies.

Table 39: Land Use and Land Cover of Watershed bounding Bhagalpur City

Land Use Land Cover	Area (Sq.m)
Built-Up	21626800
Agricultural Land	12512780
Scrubland/Vegetation	13992520
Water Bodies	1108347
River	7548126
Area for computation of recharge (Agricultural land + Water Bodies + Scrubland/Vegetation)	27613647

Source: SPA Delhi; Generated in ArcGIS

The soil characteristics of within the assessment area is sandy alluvium as identified from soil map from CGWB reports. The specific yield of sandy alluvium as per GEC 2015 report is 16 percent. The rise of water level in monsoon season is 3 meters.

Area of water bodies = 1108346.97 sq.m.

Recharge from tanks and ponds @1.4 mm per day (as per CGWB report) = 1.4 * 153 days * Area of water bodies * 0.001 cubic meters = 237407.92 cubic meters

Area of river falling within the assessment unit is 1757216.55 sq.m.

Recharge from Flood Plain/River @1.8 to 2.5 cumecs/million sq.m. of wetted area = 2.5 * Area of river/flood plain * 153 days = 2887.16 cubic meters

Therefore, recharge from rainfall in monsoon season is calculated as;

Recharge from Rainfall in monsoon = (Rise in water level * Specific Yield * Area for computation of recharge) + Gross Ground Water Draft – Recharge from ground water irrigation in area – Recharge from tanks and ponds – Recharge from flood plain/river.

i.e., Recharge from rainfall in monsoon, R_{rf} = (3*0.16*27613647) + 21403563.232 - 6136459.357 - 237407.92 - 2887.16 = 34658113.79 cubic meters

Recharge from rainfall in monsoon season can also be calculated based on rainfall infiltration method estimated using the following equation:

R_{rf}= (f x A x Normal rainfall in monsoon season, where f is rainfall infiltration factor and A is area for computation of recharge) + Gross Ground Water Draft – Recharge from ground water irrigation in area – Recharge from tanks and ponds – Recharge from flood plain/river.

The rainfall infiltration factor for Bhagalpur city is 22% as per the norms provided in GEC 97 & 2015 (falls in Indo-Gangetic and Inland Areas). Therefore, the recharge from rainfall via rainfall infiltration method is computed as:

R_{rf} = (0.22 x 27613647 sq.m x 1048.38 mm x 0.001*0.000001) + 21403563.232 - 6136459.357 - 237407.92 - 2887.16 = 15026815.16 cubic meters

4.8.3 Estimation of normal rainfall recharge during monsoon season

The rainfall recharge obtained by using above equations provide the recharge in any particular monsoon season for the associated monsoon season rainfall. This estimate is to be normalized for the normal monsoon season rainfall which in turn is obtained as the average of the monsoon season rainfall for the recent 30 to 50 years. The normalization procedure requires that, a set of pairs of data on recharge and associated rainfall are first obtained. To eliminate the effects of drought or surplus years, it is recommended that the rainfall recharge during monsoon season is estimated not only for the current year for which assessment is being made, but also for at least four more preceding years.

The computational procedure to be followed is as given below:

a = [Ns4 - (S1*S2)] / [NS3 - (S1*S2)]

b = [S2-(A*S1)] / N

Where,

N = No. of datasets and

$S1 = \sum_{i=1}^{n} r,\ S2 = \sum_{i=1}^{n} R,\ S3 = \sum_{i=1}^{n} r^2\ \&\ S4 = \sum_{i=1}^{n} r * R$

Where, r is rainfall and R is rainfall recharge.

The rainfall recharge during monsoon season for normal monsoon rainfall condition is computed as below:

R_{rf} (normal) = a * r(normal) + b

Due to data limitations on rainfall recharge for last four preceding years, the calculation for recharge during normal monsoon could not be calculated. However, in case all the data is available then the process may be followed to minimize the data. For this particular process we have already taken the average of rainfall in monsoon season for various years (2014 to 2018) to bring the negate effects of drought or low rainfall season. This will provide an average value for recharge from rainfall for particular city.

In case, of data availability on recharge the further calculations may be taken as provided. After the estimation of rainfall recharge for normal monsoon season rainfall using the water table fluctuation method and rainfall infiltration factor method, Percent Deviation (PD) which is the difference between the two methods expressed as a percentage of the latter is computed as,

PD = {[R_{rf}(normal,wtfm) - R_{rf}(normal, rifm)]/R_{rf}(normal,rifm)]} x 100

Where,

R_{rf} (normal, wtfm) = Rainfall recharge for normal monsoon season rainfall estimated by the water table fluctuation method.

R_{rf} (normal, rifm) = Rainfall recharge for normal monsoon season rainfall estimated by the rainfall infiltration factor method.

Therefore, PD = [((28283574.37 - 15029030.18)/(15029030.18)] x 100 = 88.19 %

The rainfall recharge for normal monsoon season rainfall is finally adopted as per criteria given below:

• If PD is greater than or equal to -20%, and less than or equal to +20%, R_{rf} (normal) is taken as the value estimated by the water table fluctuation method.

• If PD is less than -20%, R_{rf} (normal) is taken as equal to 0.8 times the value estimated by the rainfall infiltration factor method.

• If PD is greater than +20%, R_{rf} (normal) is taken as equal to 1.2 times the value estimated by the rainfall infiltration factor method.

The sum of Normalized Monsoon Rainfall Recharge and the recharge due to other sources during monsoon season is the total recharge during Monsoon season.

Therefore, the total recharge during monsoon can now be computed as = R_{rf} from rainfall in normal monsoon (Recharge from rainfall in monsoon, R_{rf} in our case) + Recharge from ground water irrigation in the area + Recharge from tanks and ponds + Recharge from Flood Plain/River = 34658113.79 cubic meters or 34.658 MCM

4.8.4 Ground water recharge estimation for non-monsoon season

The rainfall recharge during non-monsoon season is estimated using Rainfall Infiltration factor Method only when the non-monsoon season rainfall is more than 10% of normal annual rainfall. The sum of Non-Monsoon Rainfall Recharge and the recharge due to other sources during non-monsoon season is the total recharge during Non-Monsoon season.

Recharge from rainfall via infiltration method in non-monsoon season = (f x A x Normal rainfall in non-monsoon season, where f is rainfall infiltration factor and A is area for computation of recharge)

Number of days in Non-monsoon season = 212 days

Average Rainfall during Non-Monsoon Season = 138.38 mm

Since, the average rainfall in non-monsoon season is more than 10% of the normal annual rainfall (i.e,

11.22 percent) therefore the recharge from rainfall can be calculated by infiltration method.
i.e., Recharge from rainfall in non-monsoon = 0.22 * 27613647 * 138.38 = 840,658.824 cubic meters
Recharge from tanks and ponds @1.4 mm per day (as per CGWB report) = 1.4 * 212 days * Area of water bodies * 0.001 cubic meters = 328957.39 cubic meters
Recharge from Flood Plain/River @1.8 to 2.5 cumecs/million sq.m. of wetted area = 2.5 * Area of river/ flood plain * 212 days = 4000.51 cubic meters
Recharge from GW Irrigation (non-monsoon season) = 2721445.986 cubic meters

GW draft for all uses:
GW_d = GW Draft for irrigation in non-monsoon + GW Draft for domestic Purpose in non-monsoon
GW_d= 6047657.747 + 2349808.00 = 8397465.75 cubic meters or 8.397 MCM
Therefore, total recharge of ground water in non-monsoon = Recharge from rainfall in non-monsoon season + Recharge from tanks and ponds + recharge from flood plain/river + recharge from ground water irrigation – ground water draft for all uses
= 840,658.824 + 328957.39 + 4000.51 + 2721445.986 - 8397465.75 = -4,502, 403.04 cubic meters or -4.502 MCM
Or there is no recharge during non-monsoon whereas ground water extraction is observed to be high during non-monsoon season. The reason can be pointed out to the crops being sown during non-monsoon season based on ground water. It can be minimized based with proper utilization of surface water promoting surface water irrigation and with less dependence on ground water for irrigation.

4.8.5 Ground Water Potential

Now, as the recharge of ground water during monsoon and non-monsoon is established, the total ground water availability can be estimated as:
Ground Water Potential = GW Recharge during monsoon + GW Recharge during non-monsoon
= 34.658 MCM + (-4.502) MCM (No recharge is observed during non-monsoon season however ground water extraction is more)
= 30.155 MCM
Unaccounted Natural Discharges in Non-Monsoon (5 to 10 percent of total annual ground water potential)
= 0.05 * 30.155 MCM = 1.5078 MCM
Net Annual Ground Water Availability = Ground water Potential – Unaccounted Natural Discharges in Non-monsoon Season = 30.155 - 1.5078 = 28.648 MCM
Existing Gross Ground Water Draft for irrigation (Irrigation based on ground water) = Gross GW Draft in Monsoon Season for irrigation + Gross GW Draft in Non-Monsoon Season for irrigation
= 25.755 MCM
Existing Gross Ground Water Draft for Domestic & Industrial = Gross GW Draft in Monsoon Season for domestic and industrial use + Gross GW Draft in Non-Monsoon Season for domestic and industrial use
= 4.046 MCM
Existing Gross Draft for all uses = Existing Gross Ground Water Draft for irrigation + Existing Gross Ground Water Draft for Domestic & Industrial
= 25.755 MCM + 4.046 MCM = 29.801 MCM

Stage of Ground Water Development = (Existing Gross Draft for all uses/Net Annual Ground Water Availability) x 100 = = 29.801/28.648 *100 = 104.03 % (Over Exploited)
We can observe that stage of ground water development in the assessment unit is over-exploited and as such necessary steps needs to be identified for recharge within the assessment unit.
The detailed matrix of the calculations is given in the Table 40.

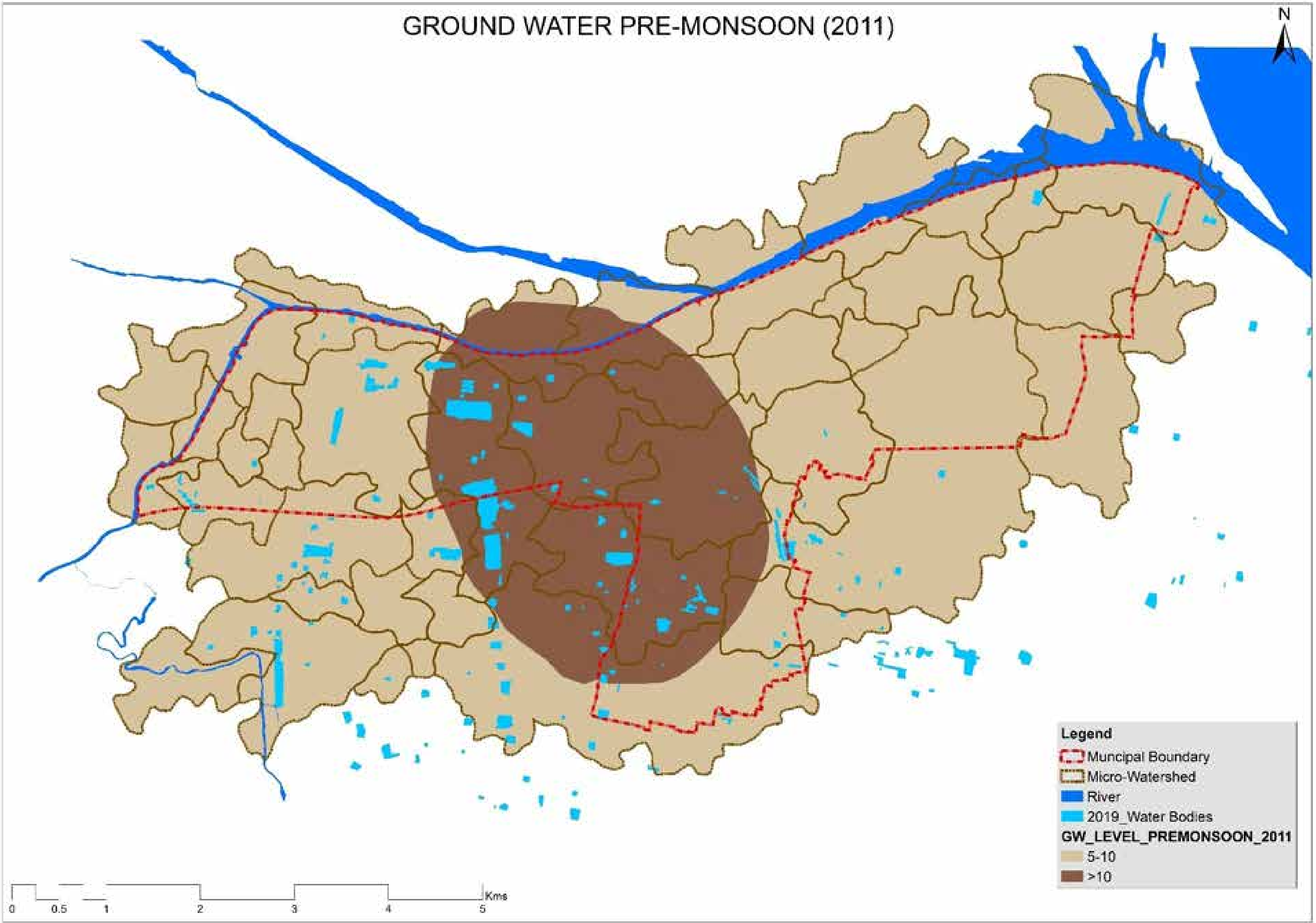
Table 40: Ground Water Assessment of Watershed bounding Bhagalpur city

Monsoon Season			
Parameters	**Unit**	**Value**	**Values**
Avg. Rainfall (Annual in mm) (May to Sept)	mm	1048.38	
Area of Watershed (A)	Sq.m	49333930.43	
Area of River	Sq.m	7548126.00	
Area of Water Bodies	Sq.m	1108347.00	
Area of Agricultural Land	Sq.m	12512780.00	
Area of Scrubland/Vegetation	Sq.m	13992520.00	
Area of Built Up	Sq.m	21626800.00	
Area for computation of recharge	Sq.m	27613647.00	
Rise in water level in monsoon season (m)	meter	3.00	
Gross Ground Water Draft (Irrigation)	cubic meters	19707711.23	19.70771123
Annual Gross Ground Water Draft (Domestic and Industrial Use)	153 days *MLD*1000 (cubic meters)	1695852.000	11.084 MLD is extracted through tube wells
Gross GW Draft Monsoon Season	cubic meters	21403563.232	21.40356323
Specific Yield (Sandy Alluvium)	percentage	0.16	
Recharge from ground water irrigation in the area	cubic meters	6136459.36	6.136459357
Recharge from tanks and ponds	1.4 mm per day	237407.93	0.237407927
Recharge from Flood Plain/River	1.8 to 2.5 cumecs/million sq.m of wetted area (cubic meters)	2887.16	
Recharge from Rainfall in Monsoon Season	cubic meters	28281359.35	28.28135935
Recharge from Rainfall Using Infiltration Method	22 percent (cubic meters)	15026815.16	15.02681516
Total Recharge during Monsoon Season		34658113.79	34.65811379
Non-Monsoon Season			
Parameters	**Unit**	**Value**	**Value in MCM**
Avg. Rainfall (Annual in mm)	mm	138.38	
Area of River	Sq.m	7548126.00	
Area of Water Bodies	Sq.m	1108347.00	
Area of Agricultural Land	Sq.m	12512780.00	
Area of Scrubland/Vegetation	Sq.m	13992520.00	
Area of Built Up	Sq.m	21626800.00	
Area for computation of recharge	Sq.m	27613647.00	
Recharge from Rainfall infiltration	22 percent	840658.8238	0.840658824
Recharge from ground water irrigation in the area	cubic meters	2721445.99	2.721445986
Recharge from tanks and ponds	1.4mm per day	328957.39	0.32895739
Recharge from Flood Plain/River	1.8 to 2.5 cumecs/million sq.m of wetted area (cubic meters)	4000.51	
GW Draft for Irrigation Purpose	cubic meters	6047657.747	
GW Draft for Domestic and Industrial Purpose	212*MLD*1000 (cubic meters)	2349808.00	2.35
Gross GW Draft Non-Monsoon	GW Draft for all Uses	8397465.75	
Total Recharge in Non-Monsoon Season	cubic meters	-4502403.04	-4.502403041

Annually			
Total GW Availability	Total Recharge in Monsoon and Non-Monsoon in MCM	30.15571075	
Unaccounted Natural Discharges in Non-Monsoon Season	5 to 10% of total annual GW Potential (MCM)	1.507785538	
Existing GW withdrawal for various uses and potential for future development	Net Annual GW Availability (MCM)	28.64792521	
Annual water requirement for domestic and industrial use, 2011	Requirement (135lpcd per person) (MCM)	19.71719415	
Annual water requirement for domestic and industrial use, 2018	Requirement (135lpcd per person) (MCM)	22.3722297	
Annual water requirement for domestic and industrial use, 2023	Requirement (135lpcd per person) (MCM)	24.71402408	
Net annual GW availability for irrigation, 2018	Net Annual GW Availability - Water Requirement for Domestic and Industrial Use	6.275695513	
Existing Gross Ground Water Draft for irrigation	Irrigation solely based of GW	25.755	
Existing Gross Ground Water Draft for Domestic and Industrial Water Supply	GW Draft in Monsoon and Non-Monsoon Season (MCM)	4.046	
Stage of GW Development (%)	**Existing Gross GW Draft for all Uses/Net annual GW availability * 100**	**104.03**	**Over Exploited**

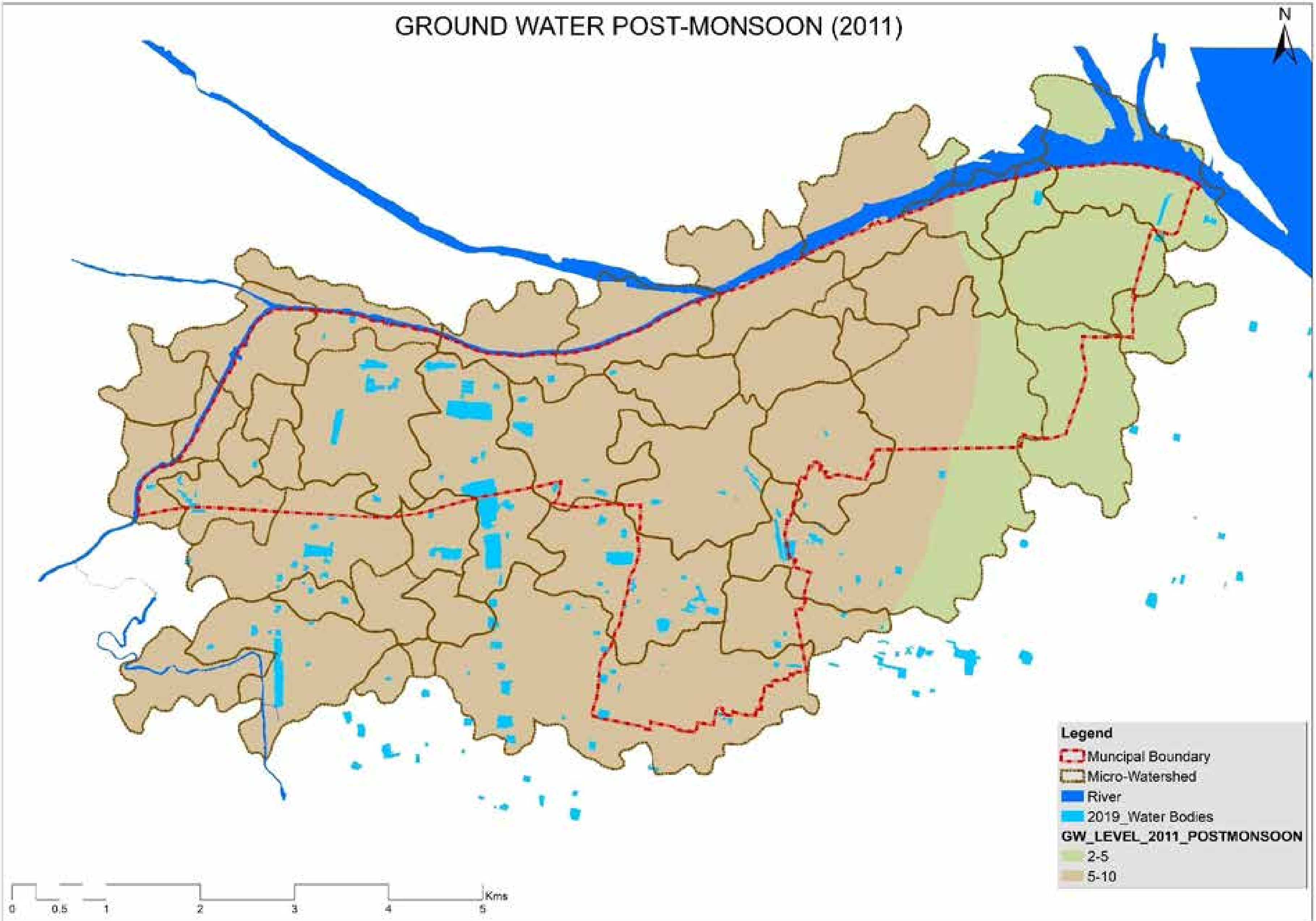
Source: Computed by SPA, Delhi

Figure 34: Ground water Pre-monsoon, 2011



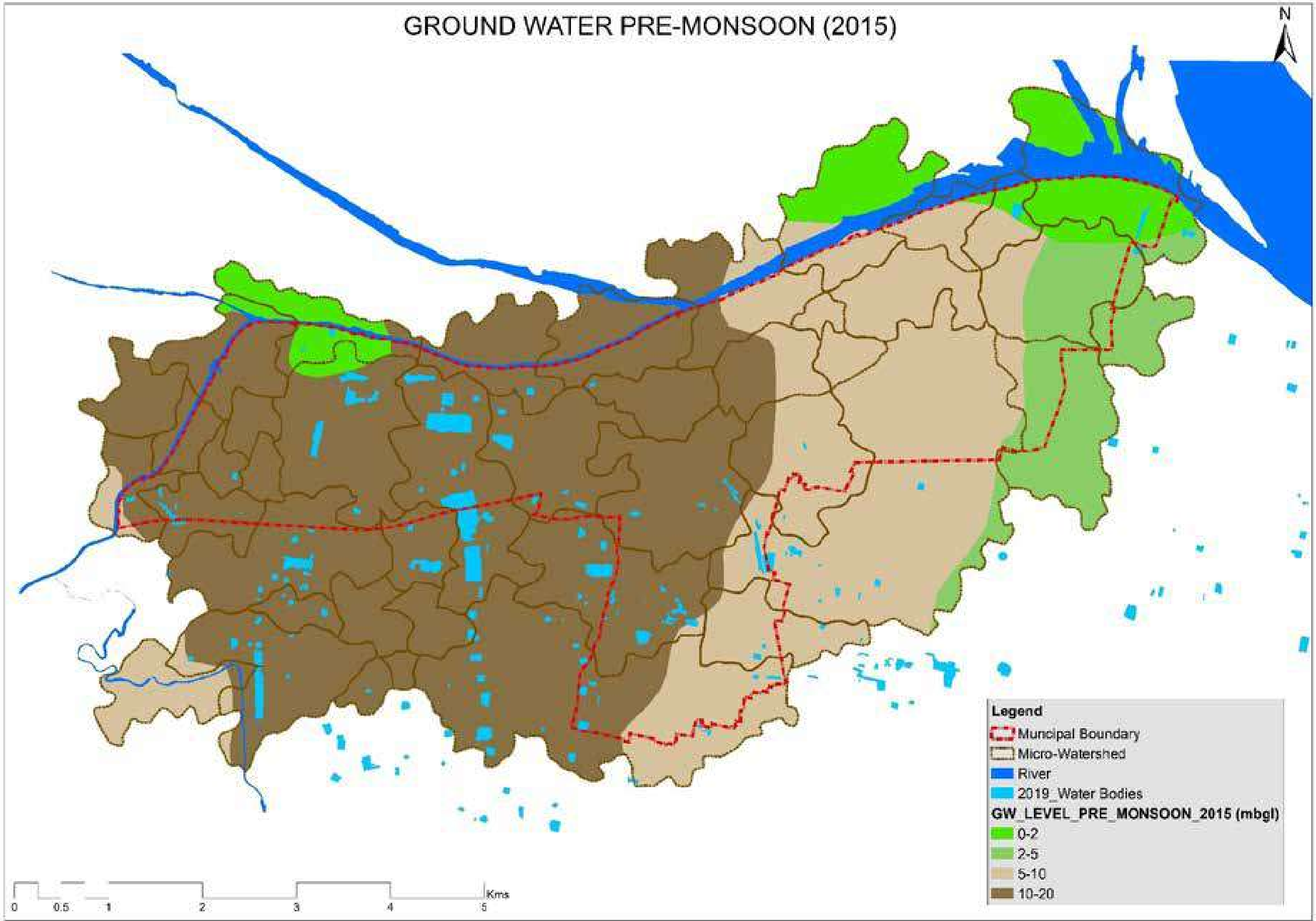
Source: CGWB, Generated in ArcGIS

Figure 35: Ground water Post-monsoon, 2011



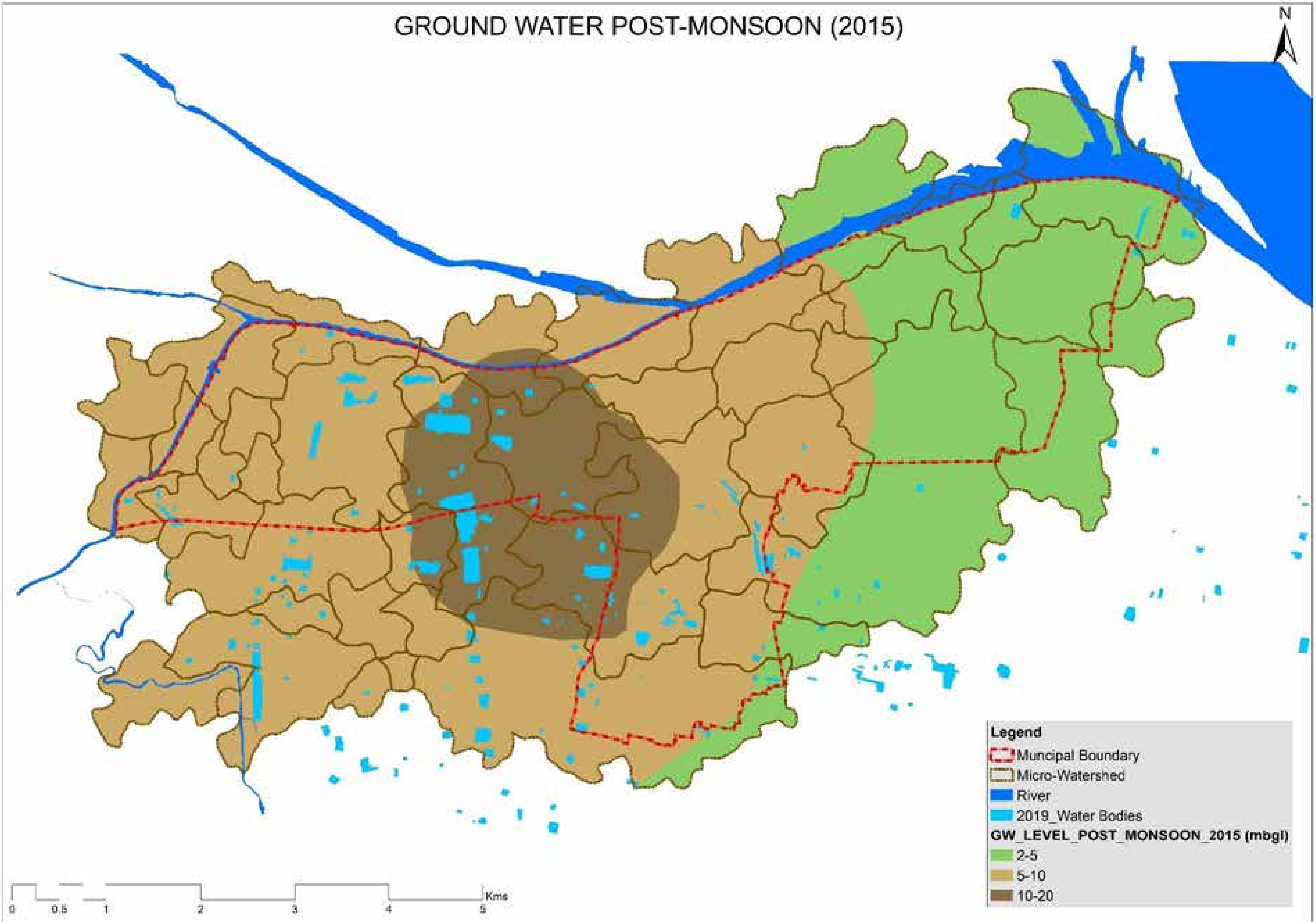
Source: CGWB, Generated in ArcGIS

Figure 36: Ground water Pre-monsoon, 2015



Source: CGWB, Generated in ArcGIS

Figure 37: Ground water Post-monsoon, 2015



Source: CGWB, Generated in ArcGIS

CHAPTER 5

LAND SUITABILITY ASSESSMENT FOR GROUND WATER RECHARGE

5. LAND SUITABILITY FOR GROUND WATER RECHARGE

5.1 INTRODUCTION

As it has been well established from the ground water assessment of Bhagalpur city, the stage of ground water development is over-exploited and also there is a declining trend in ground water level as can be seen in figure above, so there is an urgent need for ground water recharge in the assessment unit/city.

Now that the need for ground water recharge has been established, the next step is to establish the following parameters:

a. Estimation of sub-surface storage capacity of the aquifers and quantification of water required for recharge

b. Prioritization of areas for artificial recharge

c. Source water availability

d. Assessment of source water

e. Source water quality

f. Suitability of the area for recharge in terms of climate, topography, soil and land use characteristics and hydro-geologic set-up

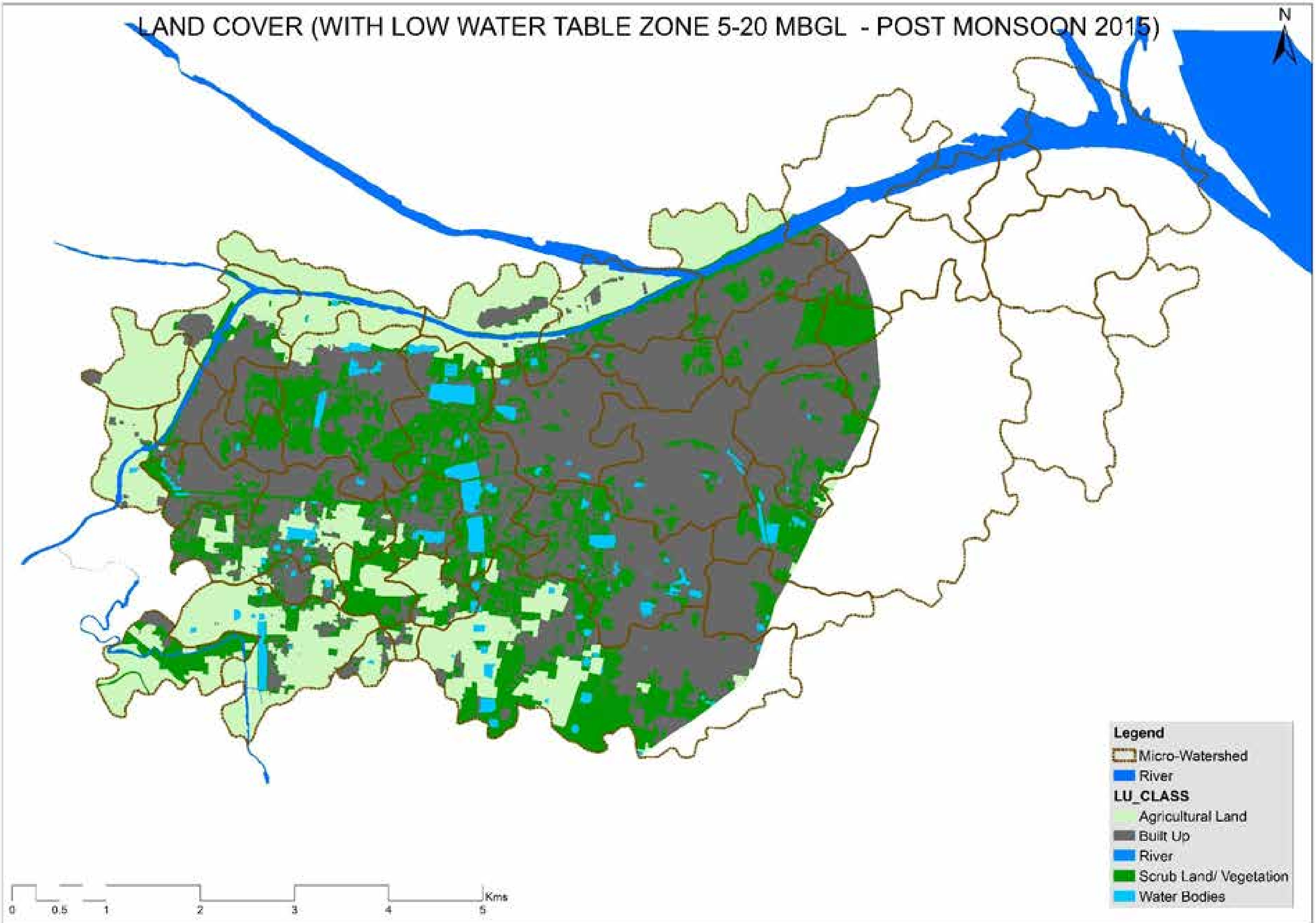
5.2 ESTIMATION OF SUB-SURFACE STORAGE CAPACITY OF THE AQUIFERS

The scope for artificial recharge in an area is basically governed by the thickness of unsaturated material available above the water table in the unconfined aquifer. Depth to water level, therefore, provides the reference level to calculate the volume of unsaturated material available for recharge. Depth to water level recorded during post-monsoon period is used for the purpose as areas where the natural recharge is not enough to compensate the ground water withdrawal, can be easily identified using the water level data. The average water levels for a period of at least 5 years is to be used in order to nullify the effects of variation in rainfall.

Contour maps prepared from the average post-monsoon water level data with suitable contour intervals can be used for assessment of available storage space. The inter-contour areas between successive contours are determined and the total area in which the water levels are below a certain cut-off level (say 3.00 mbgl in phreatic aquifers), multiplied by the specific yield of the aquifer material gives the volume of subsurface storage space available for recharge. The cut-off water level is so selected to ensure that the recharge does not result in water logging conditions in the area.

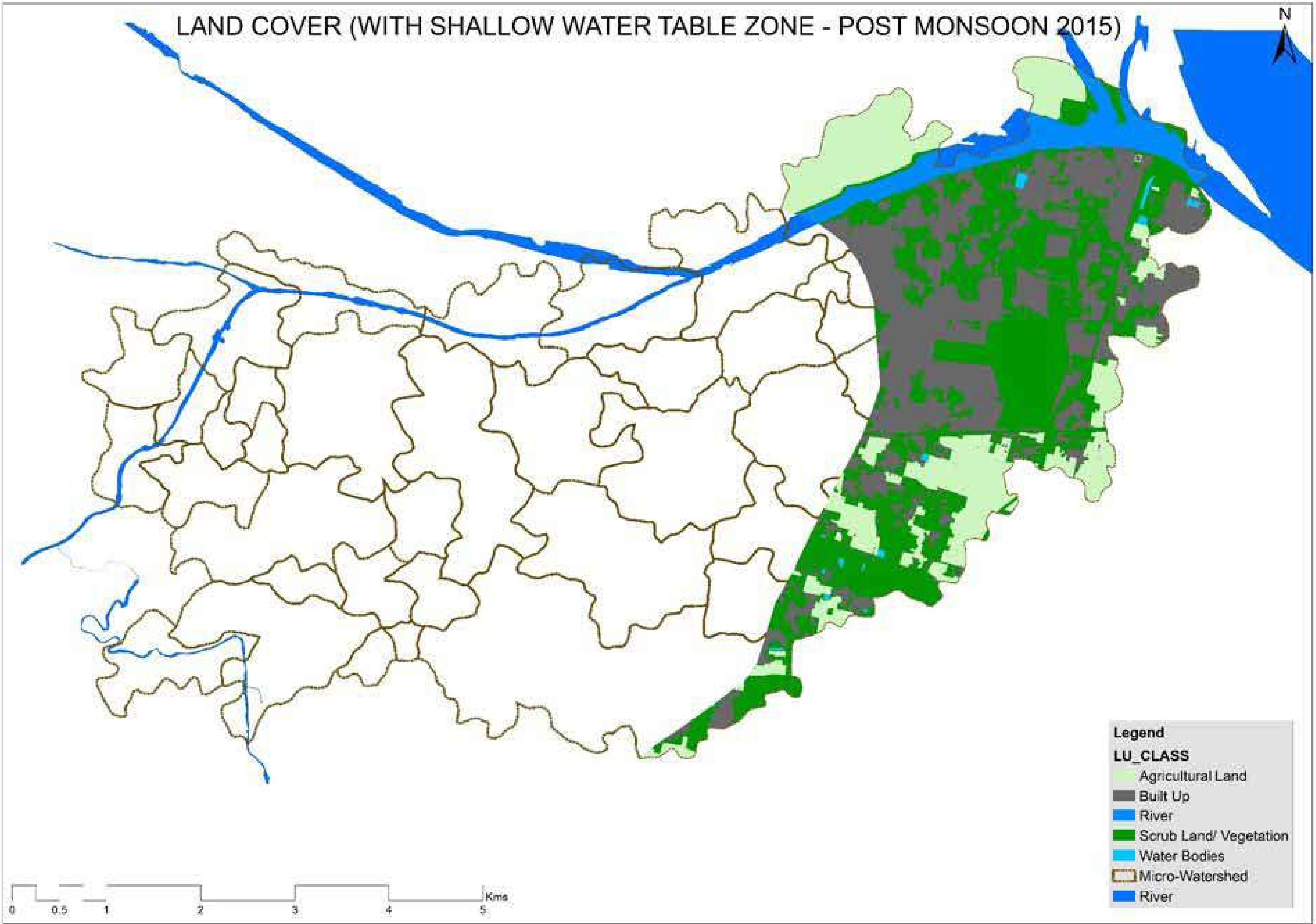
After assessing the subsurface storage space, the actual requirement of source water is to be estimated. As per CGWB Manual on Artificial Recharge of Ground Water Report, the average recharge efficiency of the individual structure is to be specified (say 60-90%). To arrive at the total volume of actual source water required at the surface, the volume of water required for artificial recharge is calculated by multiplying the volume of subsurface storage space with the reciprocal of recharge efficiency of the structure proposed.

Figure 38: Land cover (with low water table, 5-20 mbgl, Post-monsoon, 2015)



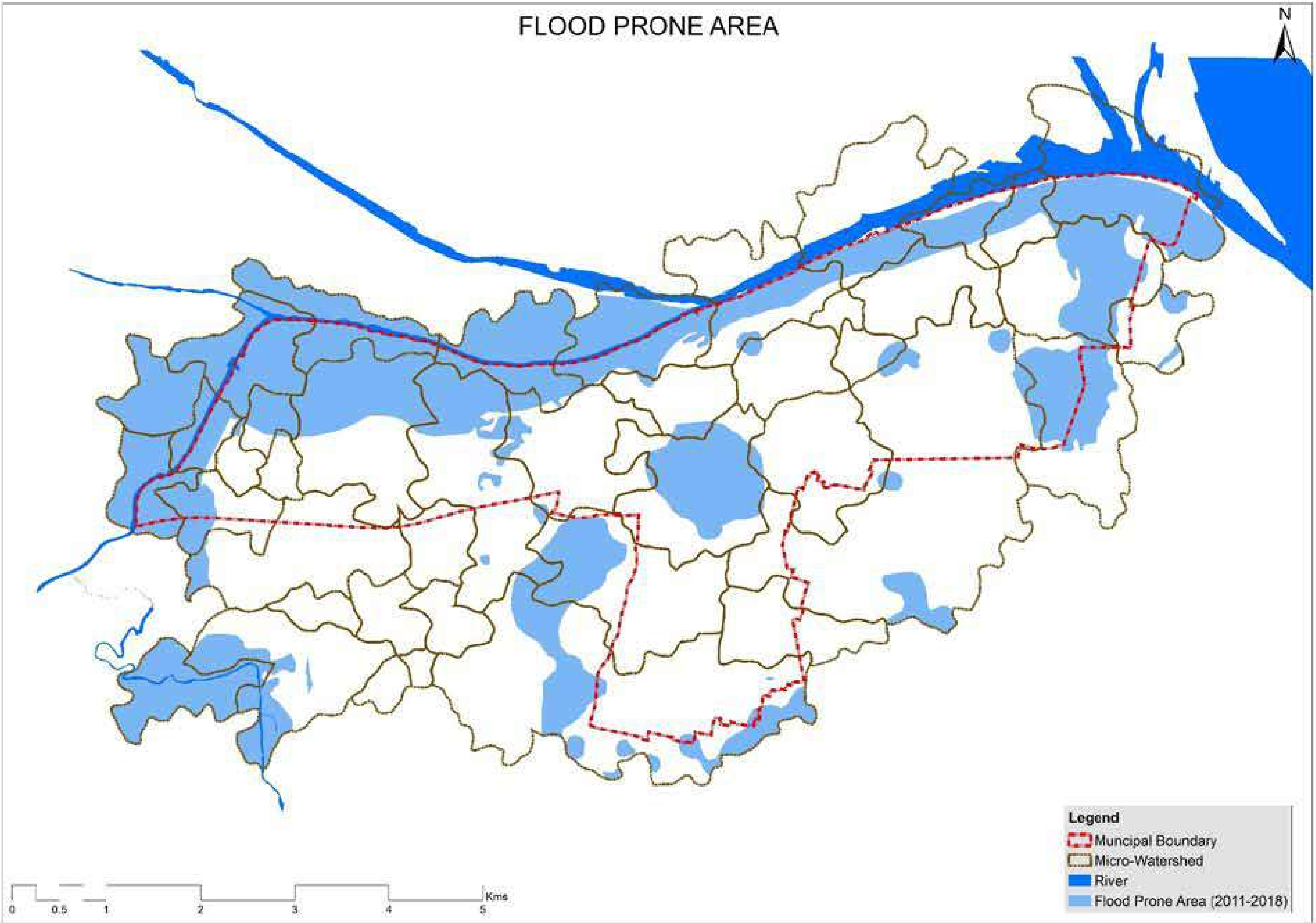
Source: SPA Delhi

Figure 39: Land cover (with shallow water table zone, Post-monsoon, 2015)



Source: SPA Delhi

Figure 40: Flood Prone Area



Source: SPA Delhi

The computation of area of land use land cover within the high-water table zone (5-20m) as per post-monsoon ground water level, 2015 is given in Table 41.

Table 41: Land Use Land Cover Under High Water Table Zone, Post-monsoon, 2015

Land Use Land Cover	Area in Sq.m.
Built Up	16182810
Agricultural Land	9222779
Scrubland/Vegetation	7887738
Water Bodies	1033442
River	685795

Source: SPA Delhi, Computed in ArcGIS

Area computed for GW recharge will include agricultural area, scrubland/vegetation and water bodies. The total area is 18143958.5 sq.m.

The area identified for ground water recharge fall within ground level of 5m -20m. So, the cut off considered here is 3mbgl. The cut-off water level is so selected to ensure that the recharge does not result in water logging conditions in the area.

The sub-surface storage capacity and volume of water required for recharge is as given below:

Area identified for artificial recharge (sq.m) = 18143958.5 sq.m

Depth to water level (Post-Monsoon) below cut-off level (m) = 3m

Volume of unsaturated zone (MCM) = (Area Identified for artificial recharge) * (Depth to water level (Post-Monsoon) below cut-off level) = 18143958.5 * 3 = 54431875.5 cubic meters or 54.4 MCM

Average Specific Yield (%) = 16 % (Specific Yield of Sandy Alluvium, as per CGWB Report)

Therefore, Total sub-surface storage potential as volume of water (MCM) = (Volume of unsaturated zone) * (Average Specific Yield) = 54.4 * 0.16 = 8.7 MCM

So, via back calculation method to meet to requirement of domestic water supply and agricultural water resource, we can calculate the area required for artificial GW recharge zone.

A. Area required to meet drinking water requirements

Population of Bhagalpur Municipality in 2011 (Census) = 400146

Population of Bhagalpur Municipality (2018) = 454028

Population of Bhagalpur Municipality (2023) = 501553

Existing Volume of water supply (2018) in MCM @27lpcd

= 454028*27*365*0.001*0.000001 = 4.47 MCM

Existing Volume of water requirement (2018) in MCM @135lpcd

= 454028*135*365*0.001*0.000001 = 22.37 MCM

Supply Gap = (22.37 - 4.47) MCM = 17.9 MCM

8.7 MCM of water can be stored within an area of 18143958.5 sq.m

Therefore, to meet the requirement of 17.9 MCM, area required is

= (18143958.5/8.7) * 17.9

Area required for GW recharge to meet the Supply Gap = 37,330,673.235 sq.m = 37.33 Sq. Km

B. Area required to meet irrigation water requirements

Existing volume of ground water draft for GW Irrigation = 25.755 MCM

Therefore, by back calculation, area required for GW to meet the demand (100 percent demand) = (18143958.5/8.7) * 25.755 = 53712373.697 Sq.m = 53.7 Sq. Km

Or area required for GW to meet the demand (60 percent demand) = (18143958.5/8.7) * 25.755 *0.6= 32227424.218 Sq.m = 32.2 Sq. Km

5.2.1 Potential Resource Due to Shallow Water Table Areas

Potential resource due to Shallow Water table areas is a one time resource which is available in the aquifers above 5.0 mbgl. This can be computed using the following formula:

PRWL = (5-DTW)* A * S

Where,

PRWL = Potential Resource in Water Logged and Shallow Water Table Areas

DTW = Average Depth to Water Level

A = Area of the Water-logged Zone

SY = Specific Yield in the zone upto 5.0 mbgl.

Area under shallow water table zone (2-5 mbgl during post-monsoon season, 2015) = 15950830.785831 Sq.m = 15.95 Sq. km

Land Use Land cover within Shallow Water table (2-5 mbgl during post-monsoon, 2015) is given in Table 42.

Table 42: Land Use and Land Cover within shallow water table, 2-5 mbgl, Post-monsoon, 2015

Land Use Land Cover	Area in Sq.m.
Built Up	5439346
Agricultural Land	3290005
Scrubland/Vegetation	6104784
Water Bodies	74904.98
River	1071423

Source: SPA Delhi, Computed in ArcGIS

Open Rechargeable area in shallow water table zone = Agricultural Land + Scrubland/Vegetation + Water Bodies = 9469692.97 Sq.m = 9.47 Sq. Kms

Potential resource in the shallow water table zone (one-time resource) = (5-Ground water depth) * Rechargeable Area * Specific Yield

= (5-2) * 9469692.97 * 0.16

= 4545452.6256 cubic meters

= 4.5 MCM

This potential resource of ground water is available only after depression of water level up to 5mbgl. This is not an annual resource and should be recommended for development on a very cautious approach so that it does not adversely affect the ground water potentials in the overall area.

5.2.2 Potential Resource in the Flood Prone Area

Potential Resource in the Flood Prone Area is a onetime resource which is available in the Flood Prone Areas only. Ground water recharge from a flood plain is mainly the function of the following parameters-

• Areal extent of flood plain

• Retention period of flood

• Type of sub-soil strata and silt charge in the river water which gets deposited and controls seepage

Since collection of data on all these factors is time taking and difficult, in the meantime, the potential resource from flood plain may be estimated on the same norms as for ponds, tanks and lakes i.e., 1.4 mm per day for the period in which the tank has water, based on the average area of water spread. This has to be calculated over the water spread area and only for the retention period using the following formula.

PRFL = 1.4 * N * A/1000

Where,

PRFL = Potential Recharge in Flood Prone Areas

N = No of Days Water is Retained in the Area

A = Flood Prone Area

Flood Prone Area in Assessment Area = 28140796.5279 Sq.m

The number of days water is retained in the area is 5 to 6 days (as recorded during primary survey)

Therefore, the Potential recharge in Flood Prone Areas = 1.4 * 6 * 28140796.5279/1000

= 236,382.6908 cubic meters = 0.236 MCM

5.3 PRIORITIZATION OF AREAS FOR ARTIFICIAL RECHARGE

Prioritization of areas for artificial recharge is normally done by overlaying post-monsoon depth to water level maps with maps depicting the long-term trend of ground water levels. From these maps, it is possible to demarcate areas with various combinations of depth to water levels and water level trends. For example, if a depth to water level map having 3 m contour intervals is combined with a water level trend map with 0.1 m/year contour interval, it is possible to demarcate areas having,

a) water levels in the range of 3 to 6 m.bgl and declining trend of 0.10 to 0.20 m/year.

b) water levels deeper than 9.00 m bgl and declining trend in excess of 0.40 m/year or

c) water levels deeper than 12.00 m bgl, but with a long-term rising trend of 0.2 to 0.4 m/year.

d) Water levels in the range of 5.0 to 10.0m with declining trends during both pre-monsoon and post-monsoon season.

Normally, areas having deeper water levels and declining water level trends are given higher priority identification of area feasible for artificial recharge. Areas having shallow water levels / rising water level trends are not considered for inclusion in artificial recharge plan.

The post-monsoon ground water level maps from 2011 and 2015 shows a declining water table in central and western parts of the city. The area thus computed based on overlay of both the post-monsoon ground water level maps is given in the Figure 41.

5.4 AVAILABILITY OF SOURCE WATER

A realistic assessment and quantification of the source water help design the storage capacity of the structure. Otherwise, there is a possibility of arriving at an improper design of the recharge structure. In cases validated data on non-committed surplus runoff / any other possible source of water and its distribution in time and space is available with appropriate agencies, the same can be considered. The quality aspects of the water to be utilized for recharge needs to be ascertained from the available data and if required through detailed analysis.

Availability of source water is one of the basic prerequisites for taking up any artificial recharge scheme. The source water available for artificial recharge could be of the following types:

i) In-situ precipitation in the watershed / area

ii) Nearby stream/ spring / aquifer system

iii) Surface water (canal) supplies from large reservoirs located within the watershed/basin

iv) Surface water supplies through trans-basin water transfer

v) Treated Municipal/industrial waste waters

vi) Any other specific source(s)

The availability of water for artificial recharge from all these sources may vary considerably from place to place. In any given situation, the following information may be required for a realistic assessment of the source water available for recharge.

i) The quantum of non-committed water available for recharge

ii) Time for which the source water will be available.

iii) Quality of source water and the pre-treatment required.

iv) Conveyance system required to bring the water to the proposed recharge site.

Rainfall and runoff available constitute the major sources of water for artificial recharge of ground water. Rainfall is the primary source of recharge into the ground water reservoir. Other important sources of recharge include seepage from tanks, canals and streams and the return flow from applied irrigation. For proper evaluation of source water availability, a thorough understanding of rainfall and runoff is essential. Collection and analysis of hydro-meteorological and hydrological data have an important role to play in the assessment of source water availability for planning and design of artificial recharge schemes.

A case of micro-watershed falling within high priority area for ground water recharge have been taken up for further analysis as given in Figure 43.

The annual average rainfall computed for Bhagalpur from 2014 to 2018 is 1186.76 mm. The land use for the selected micro-watershed is given below and the corresponding runoff values have been calculated. The runoff 'r' in cm and rainfall 'P' in cm can be correlated as R = CIA, where 'C' is the runoff coefficient, 'I' is the rainfall and 'A' is the area. The runoff coefficient depends on factors affecting runoff. Here the maximum value of runoff coefficient is considered due to city's densely built character.

Table 43: Land Use and Land Cover of selected micro-watershed, WS1

Land Use Land Cover of selected micro-watershed	Area in Sq.m	Runoff Coeff.	Runoff (r) in MCM
	A	**B**	**C=A*B*Rainfall**
Built Up	820399.088	0.3 – 0.5	0.487
Agricultural Land	127717.139	0.05 – 0.3	0.046
Scrubland/Vegetation	894342.027	0.05 – 0.2	0.212
Water Bodies	336754.365		
Total	2179212.619		0.745 MCM

Source: SPA Delhi, Generated in ArcGIS

We can observe from the drainage network map (Figure 44) of the city that the five prime water bodies i.e., Bhairava Talaab, Naya Tola Talaab, Dhobia Ghat Talaab, Shahjangi Peer Masjid Talaab and Ward 9 Pond 1, within the selected micro-watershed is fed by drains (waste water). The drainage network outside the municipal boundary is not available but on the basis of primary survey the outfall of drains in Shahjangi Peer Masjid Talaab is identified.

All the five water bodies within the micro-watershed are well drained as can be observed from drainage density and such the runoff is directed towards the water bodies.

Therefore, the sources of water for the five water bodies based on observation can be listed as:

• Precipitation (rainfall)

• Municipal waste water (drains)

• Runoff

5.5 SUITABILITY OF AREA FOR RECHARGE

The climatic, topographic, soil, land-use and hydrogeological conditions are important factors controlling the suitability of an area for artificial recharge. The climatic conditions broadly determine the spatial and temporal availability of water for recharge, whereas the topography controls the extent of run-off and retention. The prevalent soil and land use conditions determine the extent of infiltration, whereas the hydrogeological conditions govern the occurrence of potential aquifer systems and their suitability for artificial recharge.

5.5.1. Climatic Conditions

Bhagalpur city falls within the lower ganga basin with experiencing a rainfall of more than 1000mm annually. A major part of the water received during the rainy season goes as surface runoff. Only 5 to 10 percent of the total precipitation may infiltrate into the ground and reach the water table, which may be sufficient for adequate recharge. In areas of very high rainfall, the phenomenon of rejected recharge may also occur.

Most of such areas may not require artificial recharge of ground water and the best option is to store as much of the surplus water available as possible in large surface reservoirs, to be released to downstream areas during non-monsoon periods for direct use or to be used as source water for artificial recharge in suitable areas. The second and third order streams in such regions may have flow throughout the winter and the major rivers are normally perennial. The water in these streams and rivers, diverted, lifted or drawn through induced recharge may also be used as source water for artificial recharge.

The presence of numerous water bodies in Bhagalpur city can be utilized for ground water recharge as such.

5.5.2 Topographic Set-up

The topographic set-up of an area controls the retention period of surface and ground water within a topographic unit. The broad valley floors or the zone of lowest elevation occurring along the major rivers may typically have gentle to very gentle gradients. The movement of both surface and ground water in these areas is sluggish and retention time, in general, is high. These areas are generally categorized as ground water storage zones as all the water moving down the water table gradient converges in this zone. The deeper semi-confined aquifers often contribute water to the unconfined zone through upward leakage due to higher piezometric heads. The need for artificial recharge in such areas may arise only when they are located in low rainfall zones or have adverse hydrogeological conditions. In such situations, induced recharge of unconfined aquifer along the river channel will be feasible if the river has some flow. Soil Aquifer Treatment (SAT) of treated municipal waste water may also be possible in the vicinity of urban agglomerations.[1]

Bhagalpur city falls has a very gentle slope and ranging from 0-19 degrees as shown in figure. The area, being generally categorized as ground water storage zones, is observed to be over-exploited in terms of ground water development (as established in ground water assessment). The need arises in identifying potential recharge zones via augmenting existing water bodies and conserving them.

5.5.3 Soil and Land Use Conditions

Soil and land use conditions are of vital importance if artificial recharge through surface spreading methods is contemplated in an area. Various factors such as the depth of soil profile, its texture, mineral composition and organic content control the infiltration capacity of soils. Areas having a thin soil cover are easily drained and permit more infiltration when compared to areas with thick soil cover in the valley zones. Soils having coarser texture due to higher sand-silt fractions have markedly higher infiltration capacity as compared to clay-rich soils, which are poorly permeable. Soils containing minerals, which swell on wetting like montmorillonite etc. and with higher organic matter, are good retainers of moisture necessary for crop growth but impede deeper percolation.

The land use and extent of vegetation also controls the infiltration capacity of soils. Barren valley slopes are poor retainers of water as compared to grass lands and forested tracts, which not only hold water on the surface longer, but also facilitate seepage during the rainy seasons through the root systems. Similarly, ploughed fields facilitate more infiltration as compared to barren fields.

As established before during watershed delineation from the drainage texture and texture ratio, the selected micro-watershed has good infiltration capacity and is subjected to high runoff.

Drainage texture depends upon the soil type, slope and water holding capacity of the basin. More number of stream segments in a basin indicates impermeable surface.

Texture ratio depends upon the soil type, infiltration and basin relief. The high value of Rt indicates low infiltration and more run-off. It depicts the presence of large number of first-order streams in the basin that means there is a variation in topology.

5.5.4 Hydrogeological Factors

Hydrogeological conditions of the area are also among important factors in planning artificial recharge schemes. The nature of soil, subsoil, weathered mantle, presence of hard pans or impermeable layers govern the process of recharge into the unconfined aquifer. The saturation and movement of ground water within unconfined and all deeper semi-confined and confined aquifers is governed by storativity and hydraulic conductivity of the aquifer material. Aquifers best suited for artificial recharge are those, which absorb large quantities of water and release them whenever required.

Geomorphologically, the district Bhagalpur forms a part of the Mid-Ganga Foreland Basin. The north and central Bhagalpur towards the north and south of Ganga respectively forms a flat Indo-Gangetic alluvium tract (parts of the North Bihar Plains and Central Bihar Plains respectively).

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1 Manual on Artificial Recharge of Ground Water, CGWB

The soils in the district are mainly derived from the older and newer alluvium. These alluvial plain soils are light grey to dark grey in color, rather heavy and texturally fine in nature. The pH values range from neutral to acidic and the acidity of the soil gradually increases from north to south. The hilly soils are acidic with low nitrogen, medium to high potash.

The soils derived from older alluvium are mainly loamy in character with moderate to heavy texture and well drained. In low lands these are poorly drained with heavy texture. Sandy soils (Diara soils) derived from younger alluvium are light textured, well drained. These are moderate to highly fertile calcareous soils and found along the banks/course of the river Ganga. These comprise the soil association of inceptisols and entisols.

The sand layers in the Quaternary Alluvium (both newer and older) form the main source of ground water in the district. Based on the strata logs and hydrogeological properties, the aquifer system in the district can be divided into two categories;

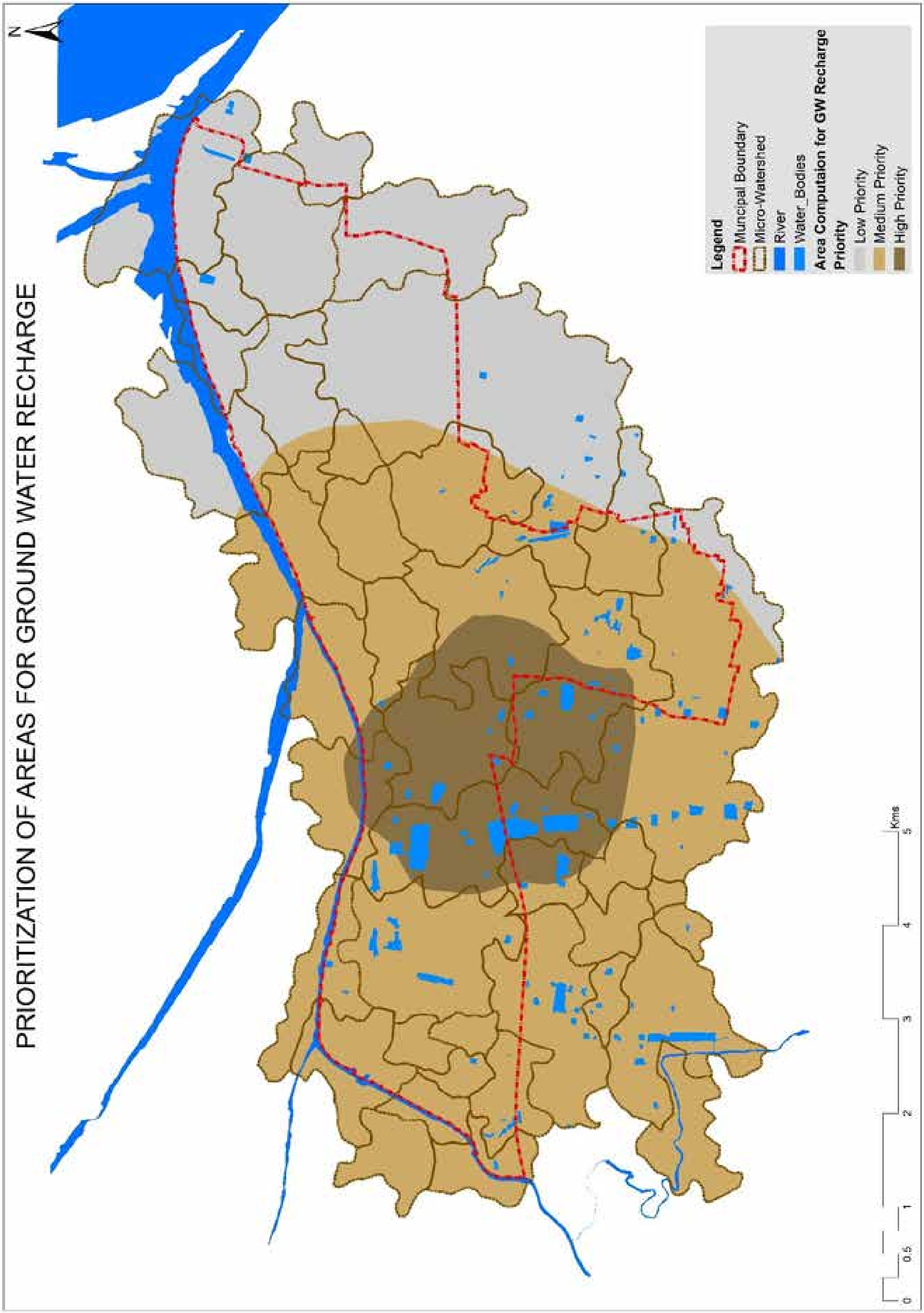
a. The shallow aquifers within 50 m depth.

b. The deep aquifers within 50 – 200 m depth.

In shallow aquifers, the ground water occurs under unconfined condition and in deeper aquifers under semi-confined to confined conditions. The shallow aquifers consisting of fine to medium sand with clay, silt and kankars are the main sources of ground water in the marginal alluvial tract in the south Bhagalpur. In general, the thickness of these aquifers varies from 13 to 18 m, being more at central parts than the eastern and western parts of the marginal alluvium. The thickness of the aquifer is controlled by the geometry of the underlying basement rock. The deeper aquifers mainly consist of sand, gravel and calcareous nodules with alternating layers of clay. The exploration data reveals the presence of four to five major aquifers with cumulative thickness 20 to 85 m. These aquifers thin out towards Sultanganj in the western part since clay dominancy increase.

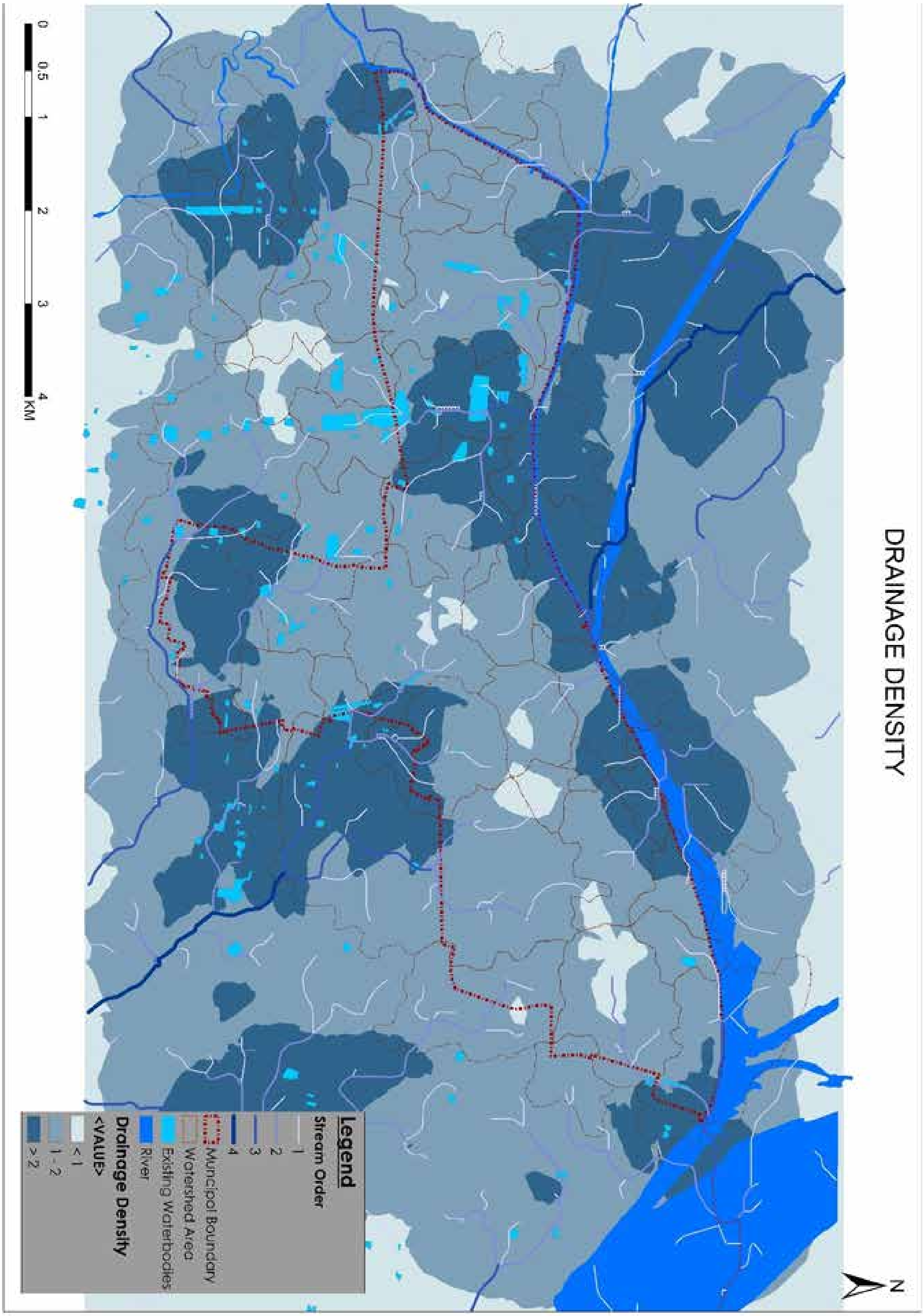
Bhagalpur city as such has younger alluvium soils with shallow aquifers consisting of fine to medium sand with clay, silt and kankars. These forms the main source of ground water in Bhagalpur city. With sandy alluvium soils having high specific yield value i.e. 16% as per GEC 1997 and 2015 Norms, the selected micro-watershed becomes a feasible for artificial ground water recharge.

Figure 41: Prioritization of areas for ground water recharge



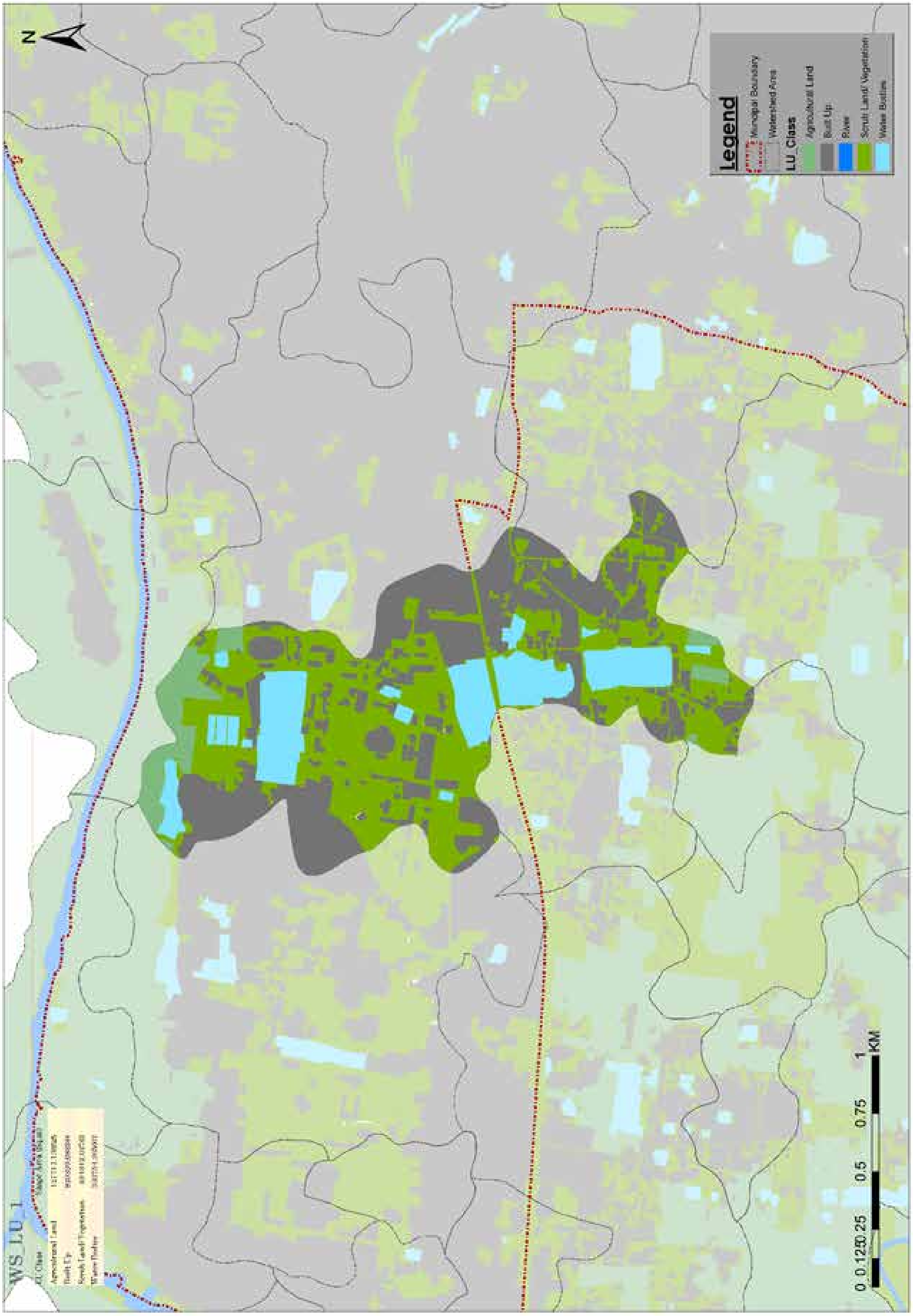
Source: SPA Delhi

Figure 42: Drainage Density



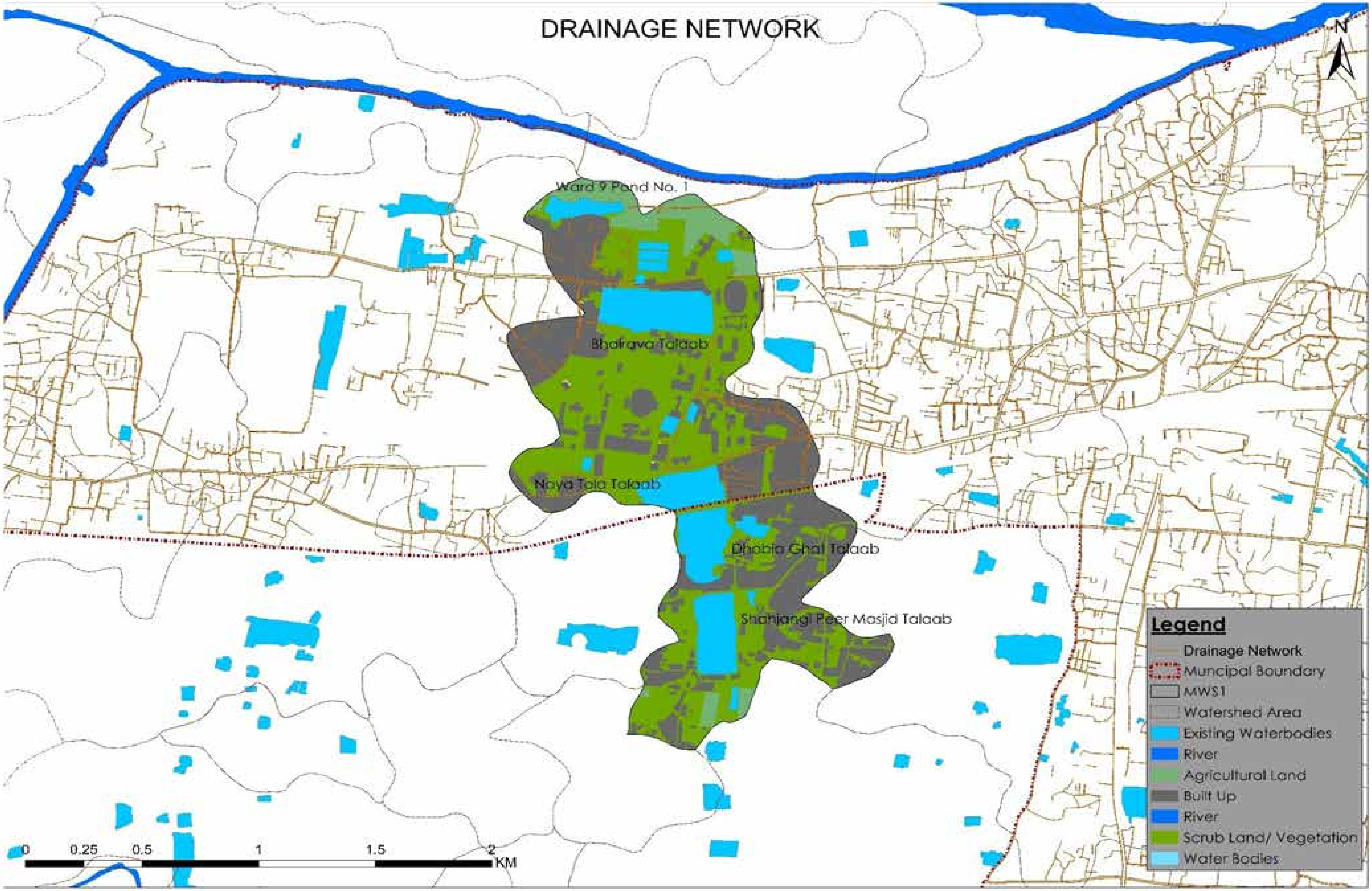
Source: SPA Delhi

Figure 43: Land Use Land Cover of Selected micro-watershed for study



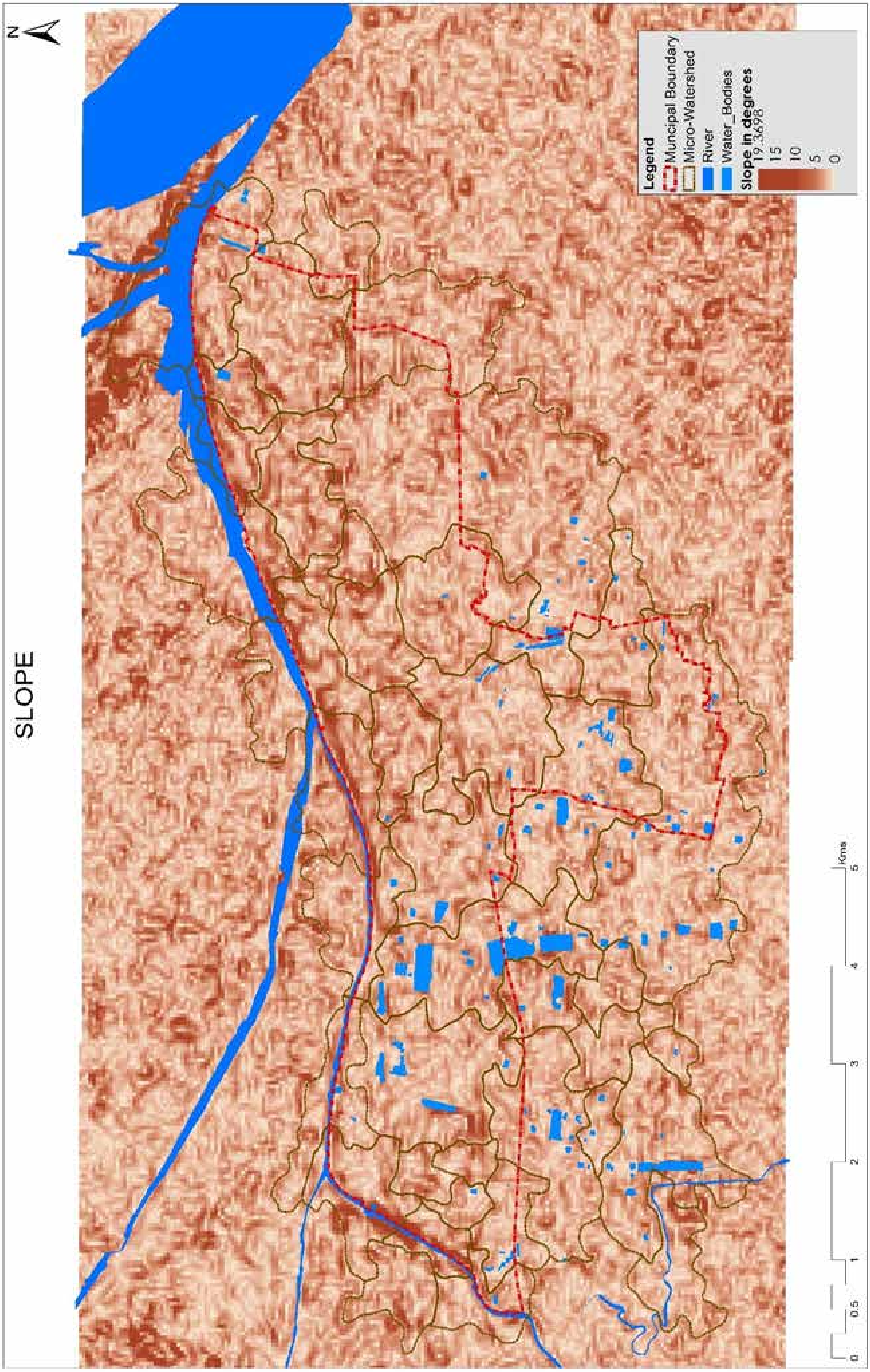
Source: SPA Delhi

Figure 44: Drainage Network



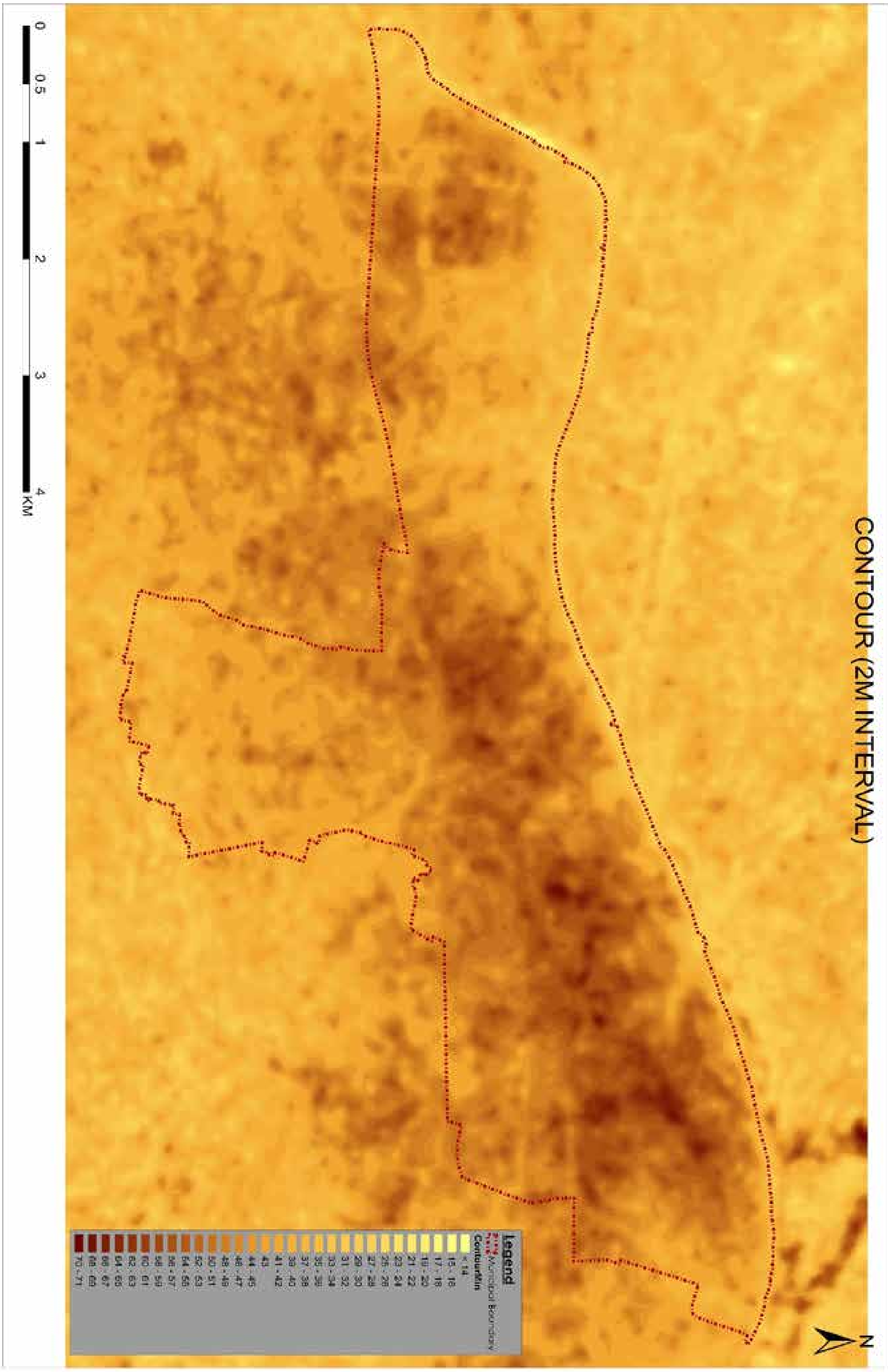
Source: SPA Delhi

Figure 45: Slope map of Bhagalpur city



Source: SPA Delhi

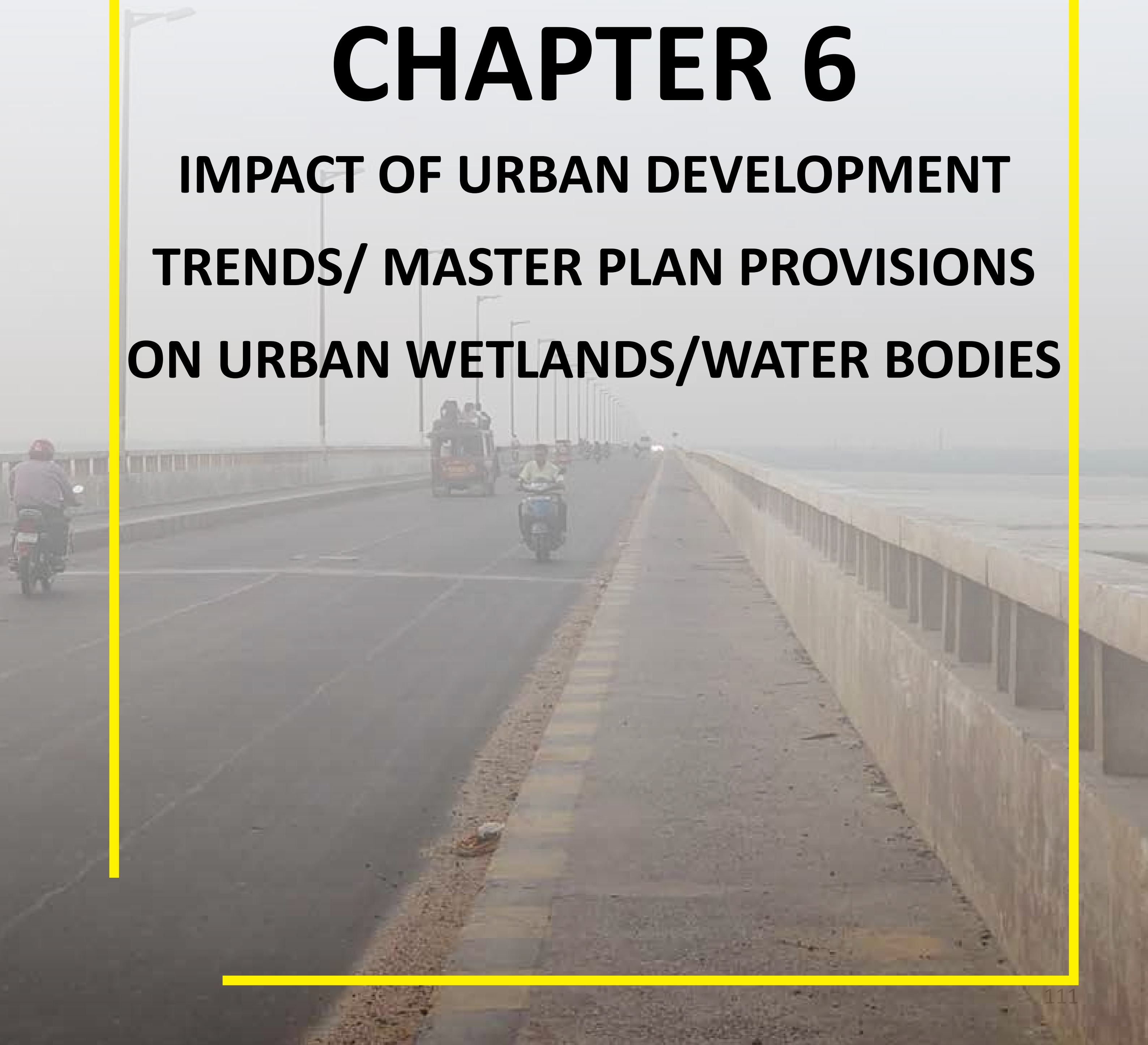
Figure 46: Bhagalpur Contour Map (2m interval)



Source: SPA Delhi

CHAPTER 6

IMPACT OF URBAN DEVELOPMENT TRENDS/ MASTER PLAN PROVISIONS ON URBAN WETLANDS/WATER BODIES



6. IMPACT OF URBAN DEVELOPMENT ON WATER BODIES

6.1 INTRODUCTION

Urban development is the social, cultural, economic and physical development of cities, as well as the underlying causes of these processes (Department of Sociology and Human Geography, UIO).

Water Bodies play multi-functional role in urban area. It can be the source of water for supply, landscaping, irrigation, fishing and eco-tourism, which add values to social benefits. They can also be used to prevent heat island effects and to improve the micro climate in cities (URDPFI 2015).

There various impacts of urban development can be described as follows:

6.2 SPATIAL DEVELOPMENT

Urban development has had a significant impact on the surface water bodies and their riparian zones either by size reduction or complete reclamation. The reduction, disappearance and pollution of surface water may contribute to the undervaluation of the water bodies' ecological potential among the general public which in turn, may further intensify the process of water-to-land conversions for urban construction. The vegetative cover on the riparian areas is limited and has decreased as a result of urban development. Finally, the priority given to fast urban economic development has led to the large-scale utilization of surface water bodies and their riparian areas for building purposes. Despite the emphasis on ecological frameworks and environment in recent policies, current planning concepts and approaches need to be challenged.

The impact of spatial development on water bodies can be clearly observed in Bhagalpur city with water bodies being covered and converted into residential buildings. A lot of water bodies from the year 2007 can now be seen under built up area while some of them are encroached upon and is under the threat of getting converted. The growth of city is towards eastern and southern parts which encompasses a large number of water bodies. As such future development should also consider the protection of water bodies in peri-urban areas those not within the purview of municipality as of now and maintain the same along with existing water bodies within the city.

6.3 FLOODS

Flood is one of the threats to urban water bodies especially during the rainy seasons. The floods repeatedly draw our attention to only one fact: our urban sprawls have not paid adequate attention to the natural water bodies that exist in them (Sushmita Sengupta, 2016). A case in point is Chennai, where each of its lakes has a natural flood discharge channel which drains the spill over. Development over many of these water bodies have blocked the flow of water.

Bhagalpur city is very similar in case of flood where the city faces flood frequently every year and the reason can be hinted towards the urban sprawl and unorganized development activities. Development and conservation should be taken hand in hand to achieve a sustainable growth and development both uplifting the economy, enriching the livelihoods of people dependent on wetlands/water bodies and providing better neighbourhood and environment to live.

6.4 POLLUTION

For the last two decades, there has been an explosive increase in the urban population without corresponding expansion of civic facilities such as adequate infrastructure for the disposal of waste. Hence, as more and more people are migrating to cities the urban civic services are becoming less adequate. As a result, almost all urban water bodies in India are suffering because of pollution and are used for disposing untreated local sewage and solid waste, and in many cases the water bodies have been ultimately turned into landfills.

In Bhagalpur city, piles of solid waste can be seen being dumped in and at the edge of water bodies destroying the natural habitats and aesthetics of the place. A lot of them are seen encroached by slum dwellers.

Figure 47: Solid waste disposal & Slum near Naya Tola Talaab

Source: Primary Survey, SPA Delhi

6.5 ENCROACHMENT

Encroachment is another major threat to waterbodies particularly in urban areas. As more people are migrating to cities the availability of land is getting scarce. Today, even a small piece of land in urban areas has a high economic value. Hence, these urban water bodies are no more acknowledged for their ecosystem services but as real estate.

A lot of slum settlements can be observed near the water bodies and many developments have been taken up by covering of water bodies in Bhagalpur as shown in Figure 47.

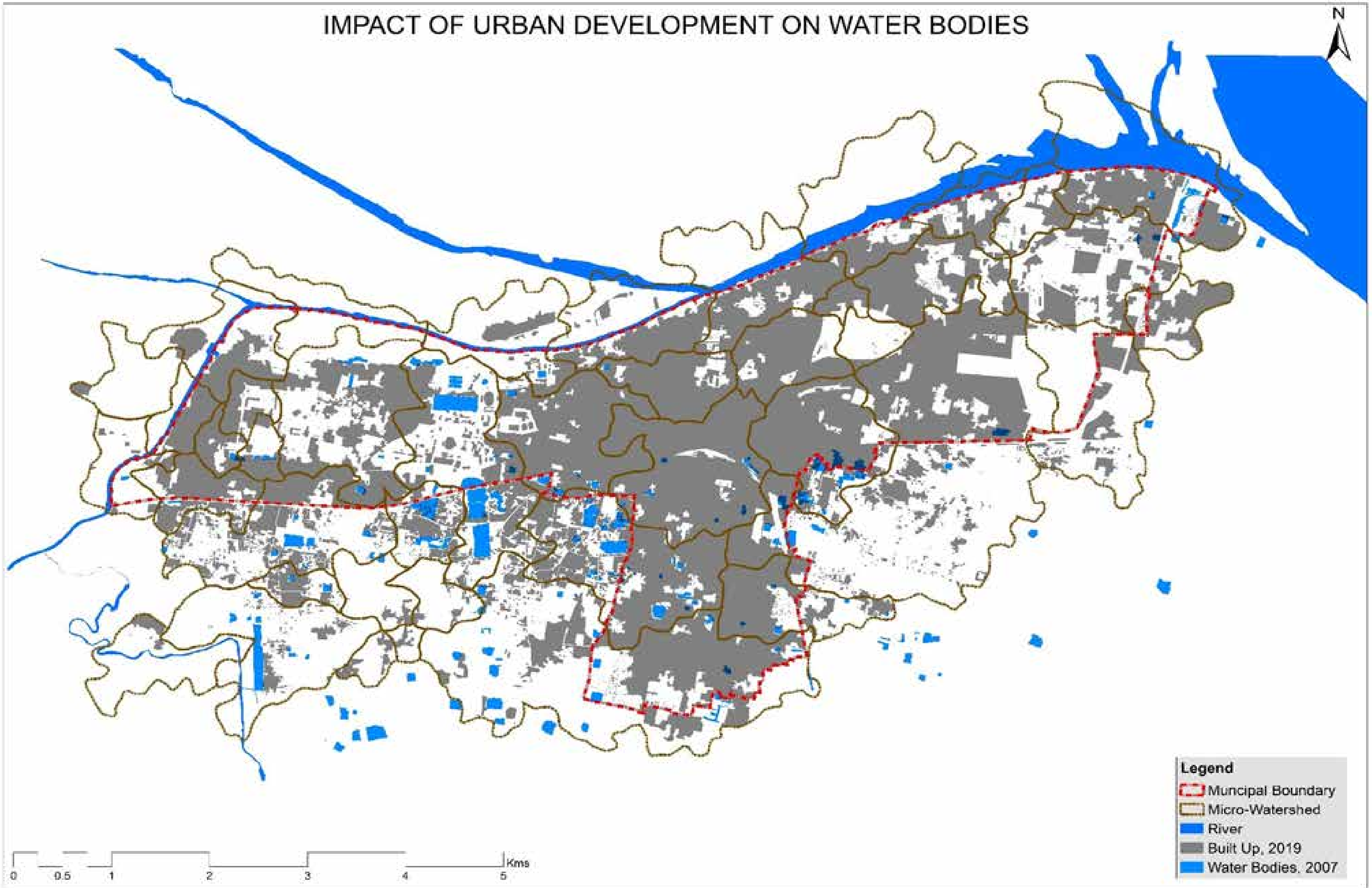
6.6 SOCIAL AND CULTURAL MISUSE

Adding to the poor state of urban water bodies is also the misuse of these water bodies by local communities for the cultural or religious festivals such the immersion of idols. These activities are particularly a source of serious pollution in lakes. Open-defecation is still prevalent in major parts of India where under privileged people who stays in the squatters, slums and other illegal settlements have no sanitary facilities. These facts be clearly justified from the water quality of wetlands/water bodies with slum settlements residing nearby.

6.7 EUTROPHICATION

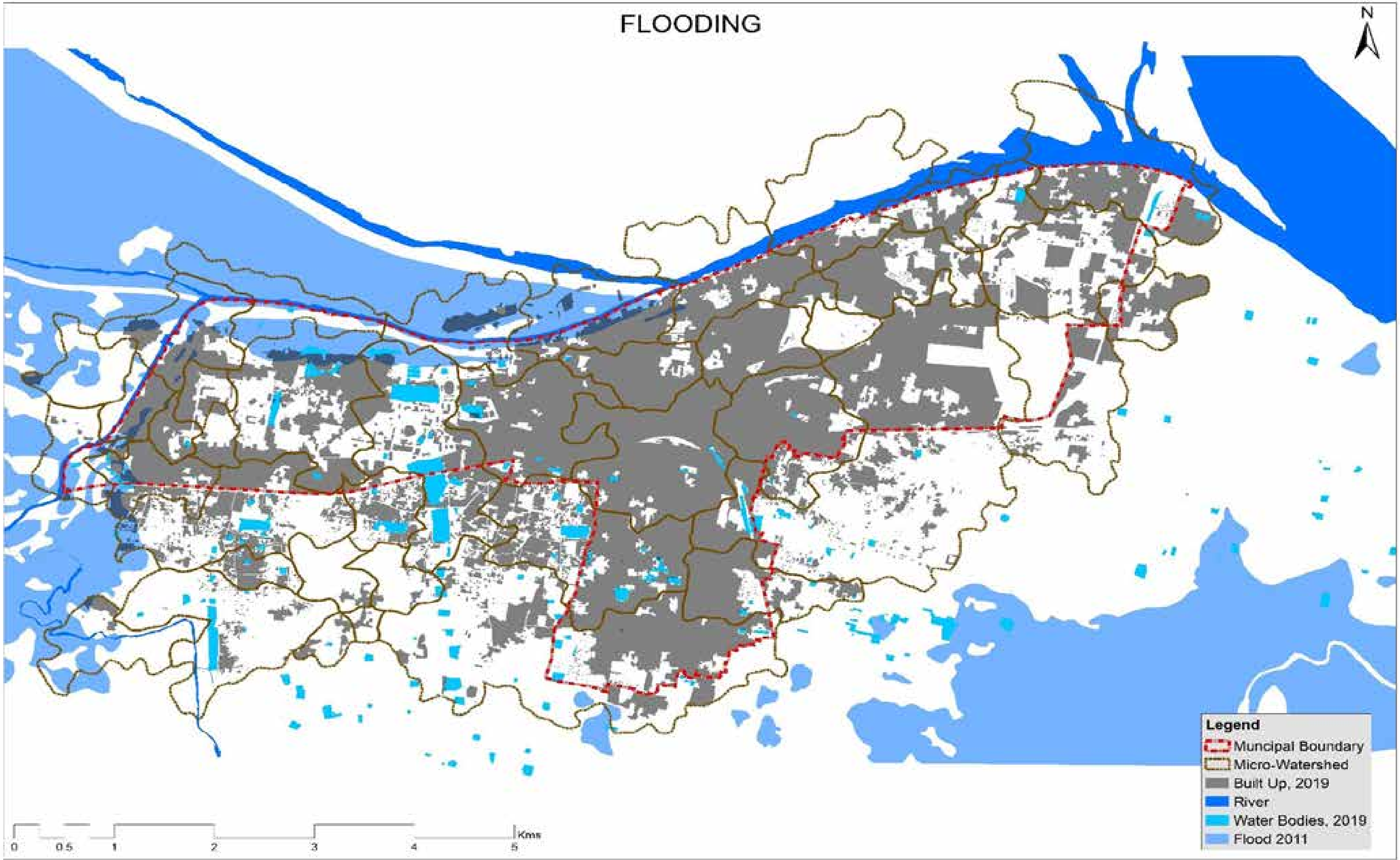
Industrial effluents, runoff from agricultural fields, refuse and sewage, domestic wastes like food remnants, soaps, detergents and sewage are dumped into lakes which break down and release nutrients in the lake water. Microscopic organisms ingest these nutrients and survive on them. Following ingestion of carbonic elements, carbon dioxide is released, while some of the elements are converted into nitrates and phosphates. This is called oxidizing and uses up a lot of dissolved oxygen. The depleted levels of dissolved oxygen in water lead to a situation where other aquatic life-forms cannot survive. This process is called eutrophication.

Figure 48: Impact of urban development on water bodies



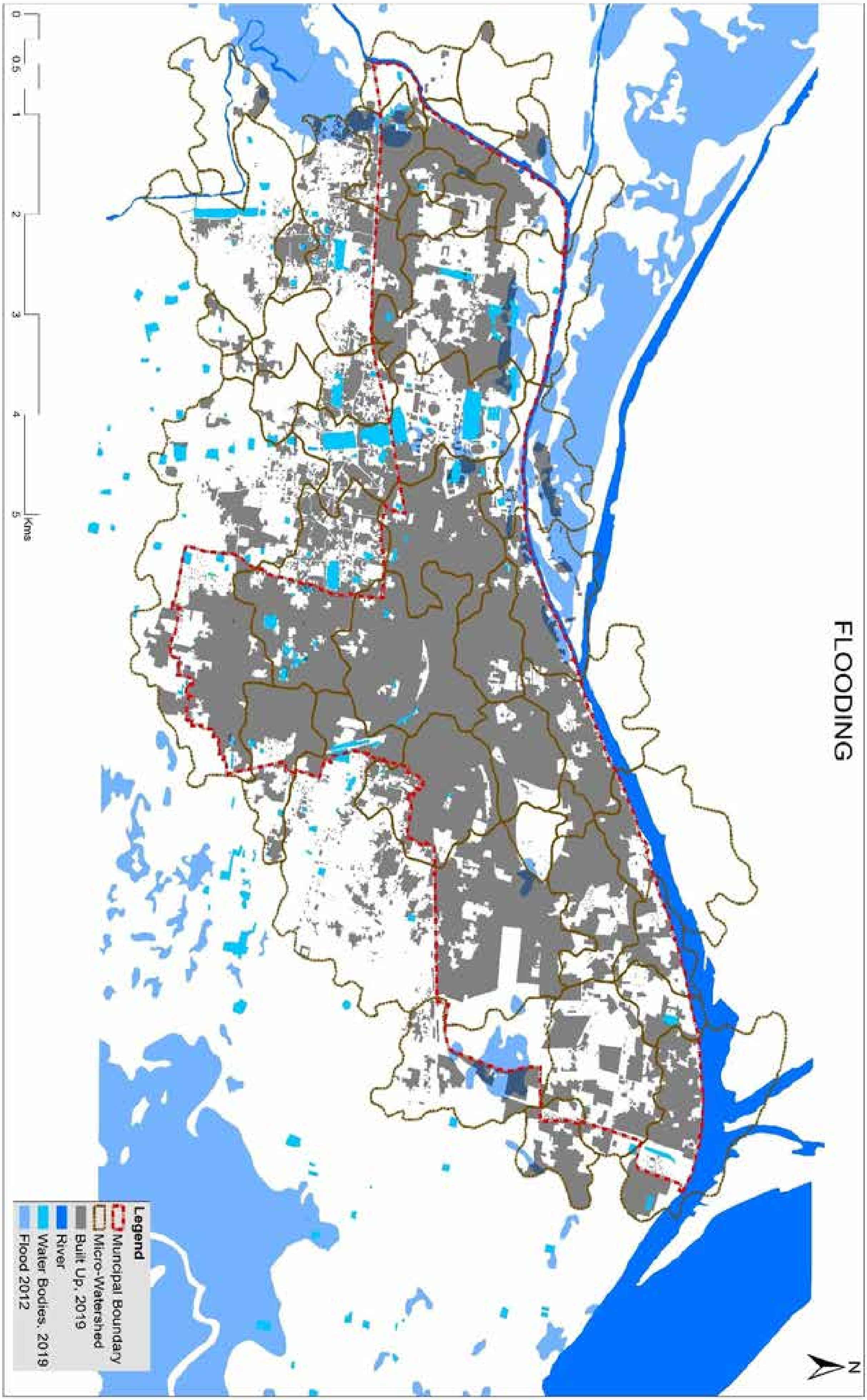
Source: Bhagalpur Municipality, SPA Delhi, Generated in ArcGIS

Figure 49: Incidence of Flood, 2011



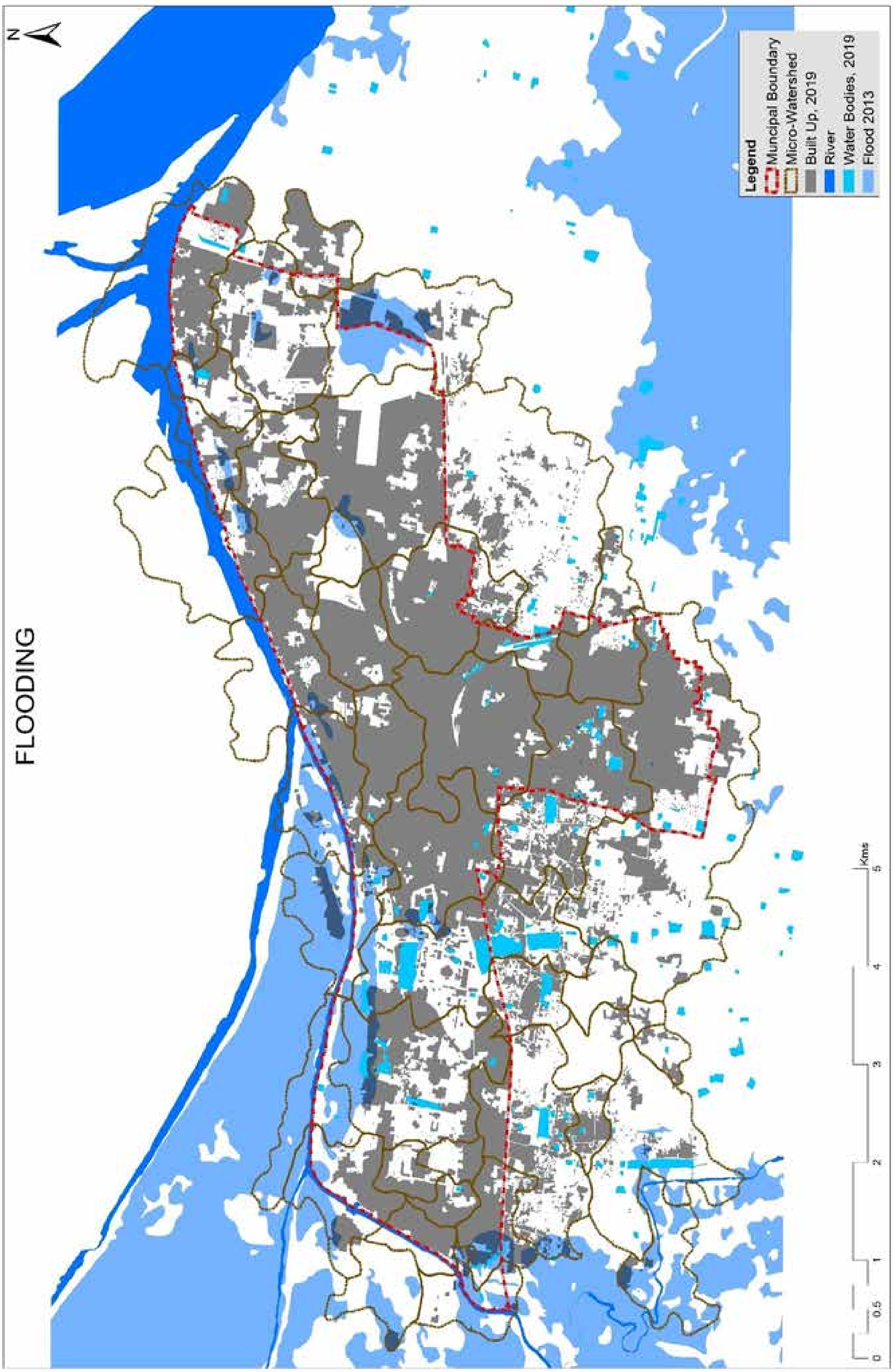
Source: BHUVAN Portal

Figure 50: Incidence of Flood, 2012



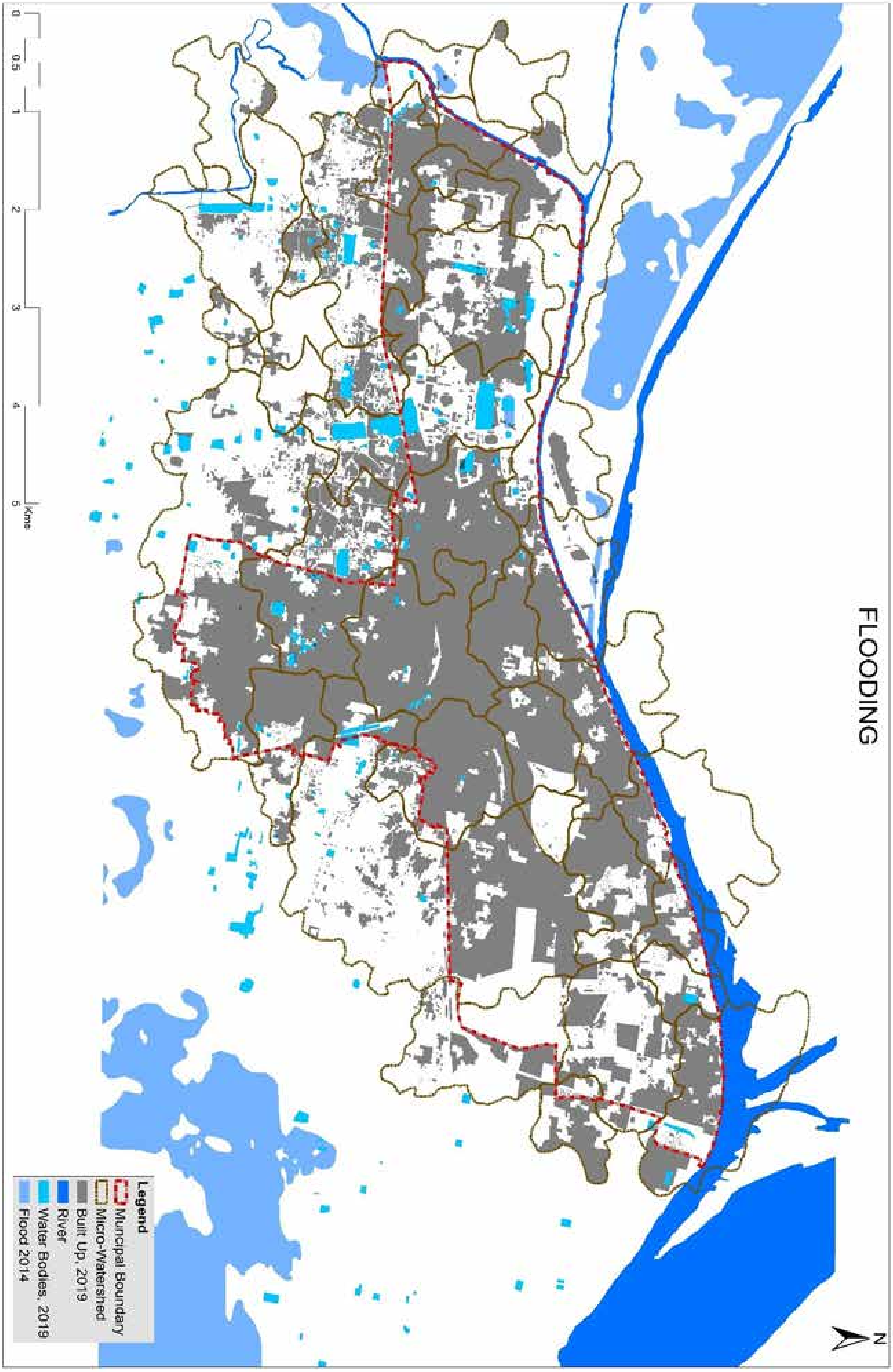
Source: BHUVAN Portal

Figure 51: Incidence of Flood, 2013



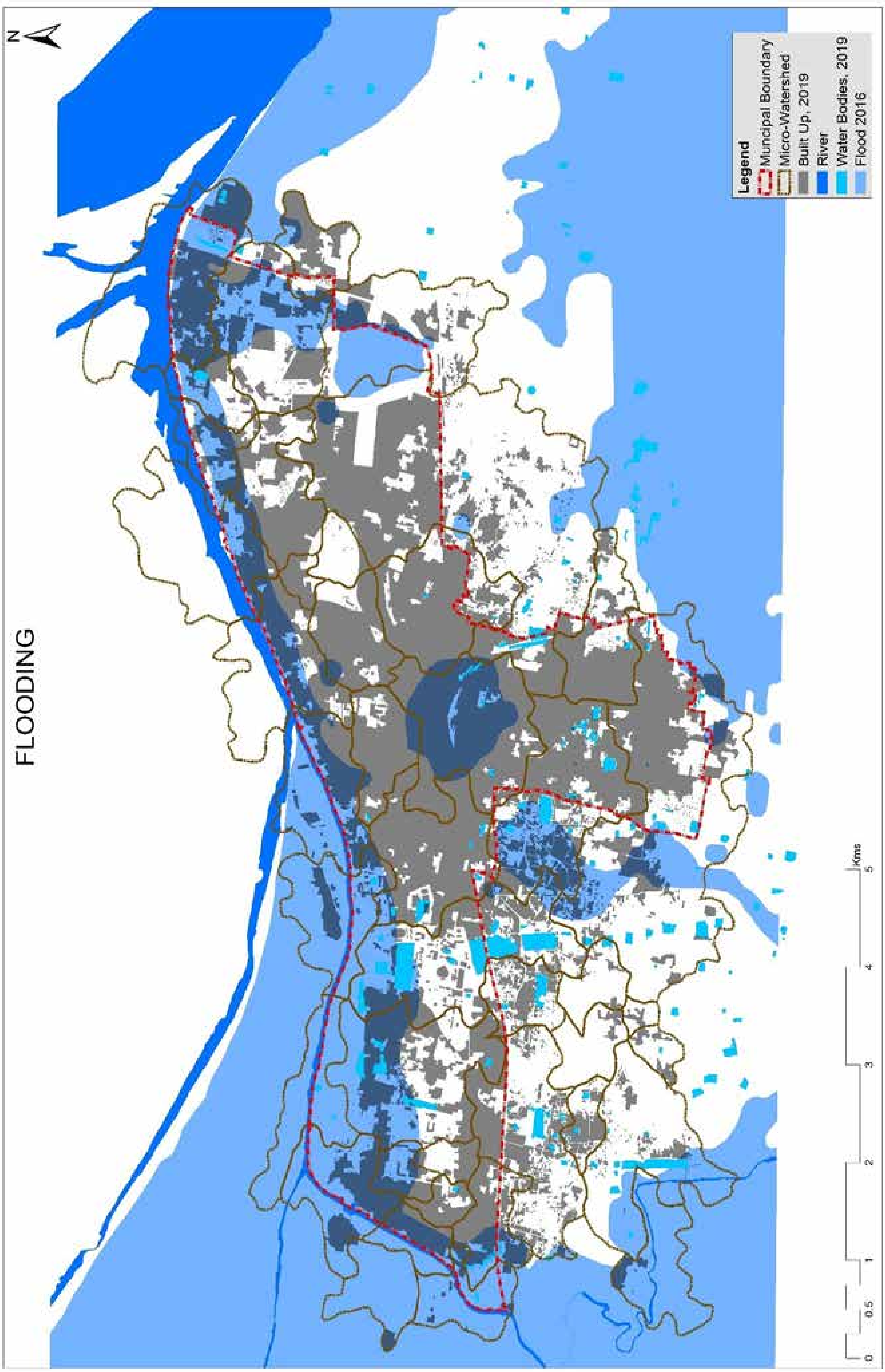
Source: BHUVAN Portal

Figure 52: Incidence of Flood, 2014



Source: BHUVAN Portal

Figure 53: Incidence of Flood, 2016



Source: BHUVAN Portal

To establish the impact of urban development on water bodies in Bhagalpur we have considered the following parameters within Catchment Area and Zone of Influence of Water Bodies:

a. Population Density: It shows the pressure on water infrastructure within the scope of study.

b. Built Up/Open Area Ratio: It shows the relative value of built up in relation to open areas i.e., how much space does built up occupy in comparison to open space within the scope of study. Higher built/ open area ration will show high runoff values.

c. Water Demand: It shows the pressure on water infrastructure.

d. Waste Water Generation: It shows the potential value of degradation of water bodies if disposed directly into it without treatment thus degrading its ecosystem services.

e. Solid Waste Generation: It shows the potential value of degradation of water bodies if disposed directly into it without treatment thus degrading its ecosystem services.

f. Built-Up Area within 100m buffer of water bodies: It shows the degree of threat of water body due to urban development activities.

g. Slums settlements within 10 meters: It shows the potential value of degradation of water bodies.

The following matrix have been prepared based on the above parameters to identify the impact of urban development on water bodies.

All the values are normalized to bring them to same scale and ranking is provided for each parameter based on the maximum value as shown in the Table 44 & 45.

Table 44: Matrix for impact of urban development on water bodies in catchment area

Units	ZOI Area (Sq.m)	Popu-lation within ZOI	Popu-lation Density (pph)	N Pop Density	Catchment LU - Built-Up Area	Catchment LU - Agricultural Land	Catchment LU - Scrub Land/ Vegetation	Catchment LU - Water Bodies	Catch-ment LU - River	Built/ Open Ratio	N B-OR	Area of Water Body(Sq.m)	Depth (m)	Annual Recharge (0.6m per year) in Cu.M	WB Storage Volume (Cubic Meters)	fluctu-ation (m) {Pre Mon-soon - Post Mon-soon	Category (Natural or Manmade)	Source (Rainfall/ GW Seepage/ Catchment runoff/ direct or indirect flow from river or stream or creek)	Total Water Demand (ZOI) 135 lpcd	N Water Demand	Total Water Supply (ZOI) 27 lpcd	Total Waste Water Generation (ZOI) 80% of water supply	N Waste Water	Total Soild Waste Generation in Kgs (0.3 kg per person)	N Solid Waste	100m buffer area	100 m Buffer BU (Sq.m)	100 m BU Percentage	N 100m BU	Slum Settlements within 10 meters from Water Bodies	N Slums	Total Nor-malization Value	Criticality
	sqm	Persons	PPH		Sq.m	Sq.m	Sq.m	Sq.m	Sq.m			Sq.m	m	m cubic meters	cubic meters	m			lpcd		lpcd	lpcd		Kgs		Sq.m	Sq.m	%		Yes/No			
Bhairava	2175582.595	27455	126	1	820399	127717	894342	336754	0	1	0	90511	3		235329	54307	Manmade	Rainfall, Catchment Runoff	3706425	0	741285	593028	0	8237	0	255963	72310	28	0	No	0	2	
Naya Tola	2175582.595	27455	126	1	820399	127717	894342	336754	0	1	0	54097	2		131888	32458	Natural	Rainfall, Catchment Runoff	3706425	0	741285	593028	0	8237	0	54097	32963	61	0	Yes	1	3	
University Pond	1498251.131	37756	252	1	1298268	10919	153178	41853	0	6	1	24198	2		58995	14519	Natural	Rainfall, Catchment Runoff	5097060	1	1019412	815530	1	11327	1	24198	55008	227	1	Yes	1	6	
W9 Pond 1	2175582.595	27455		1	820399	127717	894342	336754	0	1	0	23028	2		56142	13817	Natural	Rainfall, Catchment Runoff	3706425	0	741285	593028	0	8237	0	23028	35725	155	1	Yes	1	4	
W9 Pond 2	2036344.879	19776	97	0	969625	297879	698579	83602	0	1	0	21152	2		51569	12691	Natural	Rainfall, Catchment Runoff	2669760	0	533952	427162	0	5933	0	21152	51941	246	1	No	0	3	
Nathnagar	2036344.879	19776	97	0	969625	297879	698579	83602	0	1	0	28684	2		69932	17210	Natural	Rainfall, Catchment Runoff	2669760	0	533952	427162	0	5933	0	28684	44112	154	1	Yes	1	3	
Dhobia Ghat	2175582.595	27455	126	1	820399	127717	894342	336754	0	1	0	60592	2		147723	36355	Natural	Rainfall, Catchment Runoff	3706425	0	741285	593028	0	8237	0	60592	53035	88	0	No	0	2	
Tanti Tola	6031932.804	58785	97	0	2476875	1162369	2325935	76566	0	1	0	23699	2		57778	14219	Natural	Rainfall, Catchment Runoff	7935975	1	1587195	1269756	1	17636	1	23699	28628	121	0	Yes	1	5	
Shahjangi Peer Masjid	2175582.595	27455	126	1	820399	127717	894342	336754	0	1	0	62111	6		378629	37267	Manmade	Rainfall, Catchment Runoff	3706425	0	741285	593028	0	8237	0	62111	41598	67	0	No	0	2	
Shahjangi Talaab (L)	565626.9261	4202	74	0	238643	28410	261828	37792	0	1	0	33220	2		80990	19932	Natural	Rainfall, Catchment Runoff	567270	0	113454	90763	0	1261	0	33289	77178	232	1	No	0	2	
Ragopur Talaab	1827785.311	16948	93	0	739849	489070	554905	63123	0	1	0	34621	2		84406	20773	Natural	Rainfall, Catchment Runoff	2287980	0	457596	366077	0	5084	0	34622	33963	98	0	No	0	2	
Habibpur Talaab	2074295.14	47291	228	1	1455633	0	515632	109847	0	2	0	35863	2		87434	21518	Natural	Rainfall, Catchment Runoff	6384285	1	1276857	1021486	1	14187	1	35863	56317	157	1	No	0	4	
Dighi Talaab	1789701.684	8575	48	0	136355	1419566	174778	86984	21492	0	0	63819	2		155591	38291	Natural	Rainfall, Catchment Runoff, Direct flow from river	1157625	0	231525	185220	0	2573	0	64098	35110	55	0	No	0	1	

Ranking	Value
High	>3.5
Medium	1.4-3.4
Low	<1.5

Source: SPA Delhi

Table 45: Matrix on impact of urban development on water bodies within zone of influence

Units	ZOI Area (Sq.m)	Population within ZOI	Population Density (pph)	N Pop Density	Catchment LU - Built-Up Area	Catchment LU - Agricultural Land	Catchment LU - Scrub Land/Vegetation	Catchment LU - Water Bodies	Catchment LU - River	Built/ Open Ratio	N B-OR	Area of Water Body(Sq.m)	Depth (m)	Annual Recharge (0.6m per year) in Cu.M	WB Storage Volume (Cubic Meters)	fluctuation (m) (Pre Monsoon - Post Monsoon)	Category (Natural or Manmade)	Source (Rainfall/ GW Seepage/ Catchment runoff/ direct or indirect flow from river or strream or creek)	Total Water Demand (ZOI) 135 lpcd	N Water Demand	Total Water Supply (ZOI) 27 lpcd	Total Waste Water Generation (ZOI) 80% of water supply	N Waste Water	Total Soild Waste Generation in Kgs (0.3 kg per person)	N Solid Waste	100m buffer area	100 m Buffer BU (Sq.m)	100 m BU Percentage	N 100m BU	Slum Settlements within 10 meters from Water Bodies	N Slums	Total Normalization Value	Criticality
	sqm	Persons	PPH		Sq.m	Sq.m	Sq.m	Sq.m	Sq.m			Sq.m	m	m cubic meters	cubic meters	m			lpcd		lpcd	lpcd		Kgs		Sq.m	Sq.m	%		Yes/No			
Bhairava	389519.354	2863	74	0.31	123996.112	0.000	173667.992	92305.413	0.000	0.466	0.18	90511	2.6	54306.6000	235328.6		Manmade	Rainfall, Catchment Runoff	386505	0.21	77301	61840.80	0.21	858.90	0.21	255963	72309.97	28.25	0.12	No	0.00	1.23	
Naya Tola	267566.0399	2607	97	0.41	78609.114	0.000	132174.300	57130.131	0.000	0.415	0.16	54097	2.438	32458.2000	131888.486		Natural	Rainfall, Catchment Runoff	351945	0.19	70389	56311.20	0.19	782.10	0.19	54097	32963.49	60.93	0.25	Yes	1.00	2.39	
University Pond	459082.0993	10901	237	1.00	335333.583	10918.697	89177.315	29163.678	0.000	2.594	1.00	24198	2.438	14518.8000	58994.724		Natural	Rainfall, Catchment Runoff	1471635	0.80	294327	235461.60	0.80	3270.30	0.80	24198	55007.79	227.32	0.93	Yes	1.00	6.31	
W9 Pond 1	153835.2467	812		0.22	25772.233	50343.341	40580.844	38950.246	0.000	0.198	0.08	23028	2.438	13816.8000	56142.264		Natural	Rainfall, Catchment Runoff	109620	0.06	21924	17539.20	0.06	243.60	0.06	23028	35724.53	155.14	0.63	Yes	1.00	2.11	
W9 Pond 2	488456.1567	1993	41	0.17	145200.703	297878.852	33044.923	23231.443	0.000	0.410	0.16	21152	2.438	12691.2000	51568.576		Natural	Rainfall, Catchment Runoff	269055	0.15	53811	43048.80	0.15	597.90	0.15	21152	51940.64	245.56	1.00	No	0.00	1.77	
Nath-nagar	382669.8776	2405	63	0.27	110739.234	0.000	245067.415	28684.357	0.000	0.405	0.16	28684	2.438	17210.4000	69931.592		Natural	Rainfall, Catchment Runoff	324675	0.18	64935	51948.00	0.18	721.50	0.18	28684	44112.11	153.79	0.63	Yes	1.00	2.57	
Dhobia Ghat	152340.7577	2720	179	0.75	53785.813	0.000	37889.917	61043.849	0.000	0.544	0.21	60592	2.438	36355.2000	147723.296		Natural	Rainfall, Catchment Runoff	367200	0.20	73440	58752.00	0.20	816.00	0.20	60592	53035.18	87.53	0.36	No	0.00	1.91	
Tanti Tola	739191.8284	9215	125	0.53	373418.322	6553.146	300778.062	58609.393	0.000	1.020	0.39	23699	2.438	14219.4000	57778.162		Natural	Rainfall, Catchment Runoff	1244025	0.67	248805	199044.00	0.67	2764.50	0.67	23699	28627.62	120.80	0.49	Yes	1.00	4.43	
Shahjangi Peer Masjid	365555.6835	4693	128	0.54	96364.311	19229.750	174601.794	75481.886	0.000	0.358	0.14	62111	6.096	37266.6000	378628.656		Manmade	Rainfall, Catchment Runoff	633555	0.34	126711	101368.80	0.34	1407.90	0.34	62111	41597.85	66.97	0.27	No	0.00	1.98	
Shahjangi Talaab (L)	245560.1078	1790	73	0.31	95368.654	28201.693	89746.951	33288.635	0.000	0.631	0.24	33220	2.438	19932.0000	80990.36		Natural	Rainfall, Catchment Runoff	241650	0.13	48330	38664.00	0.13	537.00	0.13	33289	77178.23	231.84	0.94	No	0.00	1.89	
Ragopur Talaab	1250038.542	13706	110	0.46	572733.889	298518.328	335506.888	57975.213	0.000	0.828	0.32	34621	2.438	20772.6000	84405.998		Natural	Rainfall, Catchment Runoff	1850310	1.00	370062	296049.60	1.00	4111.80	1.00	34622	33963.15	98.10	0.40	No	0.00	4.18	
Habibpur Talaab	267409.8897	4216	158	0.67	116993.963	0.000	109235.386	41326.332	0.000	0.777	0.30	35863	2.438	21517.8000	87433.994		Natural	Rainfall, Catchment Runoff	569160	0.31	113832	91065.60	0.31	1264.80	0.31	35863	56316.70	157.03	0.64	No	0.00	2.53	
Dighi Talaab	1789701.684	8575	48	0.20	136354.787	1419565.718	174777.555	86983.594	21491.877	0.080	0.03	63819	2.438	38291.4000	155590.722		Natural	Rainfall, Catchment Runoff, Direct flow from river	1157625	0.63	231525	185220.00	0.63	2572.50	0.63	64098	35109.65	54.77	0.22	No	0.00	2.33	

Ranking	Value
High	>3.5
Medium	1.4-3.4
Low	<1.5

Source: SPA Delhi

As per CPCB, Buffer Zone around a lake or pond (at least 50 to 100 m periphery) should be maintained as green belt zone or no activity zone and no activity is allowed within the buffer zone by the concerned Departments in the State/UT. In case, any activity presently existing within the buffer zone (50 to 100 m), such as residential or commercial or industrial activity should take necessary measures to prevent discharge of any wastes into the water body.

Within the buffer zone, no impervious cover is allowed and mainly plantation with a dense population of deeply rooted plants, trees, shrubs and grasses should be created so as to absorb nutrients (which promotes aquatic plant growth and a shift in the water quality) that comes directly from the anthropogenic activities.

There are various rules adopted by different states in India prohibiting construction near water bodies. Some of them are listed below in Table 46.

Table 46: Rule/Norms of various States in India prohibiting construction near water bodies

Andhra Pradesh
a) 100m from the boundary of the river outside the municipal corporation / municipality / nagara panchayat limits and 50m within their limits. The boundary of the river shall be as fixed and certified by the irrigation department and revenue department.
b) 30m from the FTL boundary of lakes / tanks / kuntas of area 10Ha and above
c) 9m from the FTL boundary of lakes / tanks / kuntas of area less than 10Ha / shikam lands
d) 9m from the defined boundary of canal, vagu, nala, storm water drain of width more than 10m
e) 2m from the defined boundary of canal, vagu, nala, storm water drain of width up to 10m
Assam:
a) No construction within 15m from river and notified bodies
b) No construction within 1m from pond or other notified bodies
Madhya Pradesh:
a) 30m from Rivers or lakes/ponds/reservoirs or nala/canal or flood affected areas
Chhattisgarh
a) 100m from Mahanadi Canal is a green belt and no construction is allowed.
Bihar
No Construction or re-construction of any building shall be allowed within a strip of land of 200 m or such other higher distance as may be prescribed from time to time by the State Government from the outer boundary of the river of Ganges (as prescribed by the irrigation department) shall be permitted (except for repair and renovation of heritage buildings) and in the case of other rivers, no construction or re-construction of any building shall be allowed within a strip of land of 100 meters.
Karnataka:
A buffer of 45 m is assumed all along the flow of the river on both banks, which shall be treated as a no-development zone.
a) No building/ development activity shall be allowed in the bed of water bodies like nala, and in the Full Tank Level (FTL) of any lake, pond etc.,
b) As per the Judgement of the National Green Tribunal, Principal Bench, New Delhi in O.A.No.222 of 2014, no construction activity is allowed in Karnataka in buffer/green zone.
i) In case of lakes, 75 meters from the periphery of water body to be maintained as a green belt and buffer zone for all existing water bodies i.e., lakes/wetlands.
ii) 50 m from the edge of the primary Rajkulewas
iii) 35 m from the edge of the secondary Rajkulewas
iv) 25 m from the edge of the tertiary Rajkulewas

Maharashtra:
If the site is within a distance of 9 m from the edge of water mark of a minor watercourse (like nallah) and 15 m from the edge of water mark of a major water course (like river) shown in the development plan or village/city survey map or otherwise.

Source: Adapted from Gazette Notifications

From the various rules adopted in different states it is evident to undertake a minimum 10m buffer with no construction upto 100m from edge of water bodies.

Correlation of degree of impact of urban water bodies and ecosystem services of water bodies is shown in Table 47.

Table 47: Correlation of degree of impact of urban water bodies and ecosystem services

Water Bodies	Catchment	Zone of Influence	Ecosystem Service Score
Bhairava	Medium	Low	18
Naya Tola	Medium	Medium	12
University Pond	High	High	10
W9 Pond 1	High	Medium	18
W9 Pond 2	Medium	Medium	18
Nathnagar	Medium	Medium	14
Dhobia Ghat	Medium	Medium	14
Tanti Tola	High	High	14
Shahjangi Peer Masjid	Medium	Medium	17
Shahjangi Talaab (L)	Medium	Medium	12
Ragopur Talaab	Medium	High	13
Habibpur Talaab	High	Medium	13
Dighi Talaab	Low	Medium	18

Source: SPA Delhi

Every individual water bodies provide certain ecosystem based on their size, location, type, etc. One cannot compare the ecosystem services of one wetland/water body to other. However, to define the critical status of water body one can always justify with water quality status of wetlands/water bodies. The water quality status can be correlated with the impact of urban development.

The water quality of the above-mentioned water bodies is provided in the annexures. The figures indicate the presence of oil and grease in all the water bodies and high nitrogen content as per drinking water norms. Rest of the parameters such as pH, TDS, TSS, BOD, COD, and other chemicals like Chloride, Fluoride, Iron, Arsenic, Nitrate & Phosphate are within the limits.

The table provides a basis of formulation of necessary interventions based on whether the water body requires treatment at catchment level or at zone of influence or on site.

6.8 ASSESSING POTENTIALS AND SCOPE OF INTERVENTION

For the purpose of assessing the potential and scope of intervention, the ecosystem services of wetlands/ water bodies along with impacts of urban development have been considered.

Due to well established literature and availability of data, we shall consider a case of Bhairava and assess its potential and scope of intervention.

The final assessment would be in the format of identification of need and potential based on the five main parameters – ground water recharge, storing runoff, recreational use, fishing/cultivation & revenue generation.

Table 48: Matrix for assessment of needs, potentials and scope of intervention for water bodies

Water Body	Groundwater recharge		Storing Runoff		Recreational Use		Fishing		Revenue Generation		Total Score	Scope of Development
	P	N	P	N	P	N	P	N	P	N		
Bhairava												
Naya Tola												
University Pond												
W9 Pond 1												
W9 Pond 2												
Nathnagar												
Dhobia Ghat												
Tanti Tola												
Shahjangi Peer Masjid												
Shahjangi Talaab (L)												
Ragopur Talaab												
Habibpur Talaab												
Dighi Talaab												

NOTE: P denoted Potential and N denoted Need

Source: SPA Delhi

6.8.1 Assessment of Bhairava Pond

Ground water recharge: The water body has a good potential for ground water storage based on hydrogeological conditions and as mentioned earlier and dredging can be done upto 3m depth to increase its storage capacity. The ground water level within the catchment is 5-10m and as such there is a good potential to increase its water holding and recharge capacity.

The water body falls within the zone of declining ground water trend and as such ground water recharge through pond is a need.

Storing Runoff: The catchment falls under the flood prone areas as previously shown in map and as such the water body has good potential of minimizing the impact of flood inundation.

The water body also falls under zone of high drainage density as previously shown in map, which means the area is well drained and high runoff in the catchment. There is a need to store the excess runoff water from its zone of influence and catchment area.

Recreational Use: The size of water body is large i.e., greater than 10 ha. and is currently in pristine state. The religious significance attached to it and its locational context situated besides University has a good potential to be used as recreational space.

The water body currently has no well demarcated buffer space and is surrounded by University campus/ hostels. The need of buffer space and its utility as recreational space becomes a need.

Fishing: The water body has also inflows from waste water and sewage directly from drains as observed earlier from drainage network map. The significance of waste water fed aquaculture in East Kolkata Wetlands is already well established and as such the pond has huge potential to boost its productivity with proper utilization of already available resources.

The water body has a long history of pisciculture and the fishes from the pond in sold in wholesale market. The demand for fishes in market is high and as also Bhagalpur imports additional quantity of fishes from West Bengal to meet its daily requirements (primary survey). The need for fisheries and encouraging pisciculture activity is necessary and serves as a need as many locals are dependent on fisheries for their livelihoods.

Revenue Generation: The water body is currently under the ownership of University and lease is provided for stakeholder to undertake pisciculture. The revenue is generated by University through lease system and the lease holder from fisheries. There is direct and indirect flow of revenue already existing. The need is already well established in this case.

The water body is also listed under Smart City Plan for promoting it under tourism. The site holds religious importance too for locals in Bhagalpur and as such there is potential for collecting revenues through promotion of tourism activity while also considering the maintenance of its ecology.

The final output is shown in Table 49.

Table 49: Assessment of needs, potentials and scope of development for Bhairava Talaab

Water Body	Groundwater recharge		Storing Runoff		Recreational Use		Fishing		Revenue Generation		Scope of Development
	P	N	P	N	P	N	P	N	P	N	
Bhairava	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	Ground Water Recharge, Runoff Storage, Recreational Use, Fishing and Revenue Generation

Source: SPA Delhi

CHAPTER 7

PREPARATION OF ACTION PLAN FOR CONSERVATION OF URBAN WETLANDS/ WATER BODIES

7. PREPARATION OF ACTION PLAN FOR CONSERVATION OF URBAN WETLANDS/ WATER BODIES

7.1 INTRODUCTION

After the establishment of potential, needs and scope of development of water bodies, the next step is to develop action plans to achieve/enhance the identified services or scope of development of water body.

For this purpose, we shall be talking the same case of Bhairava and highlight the action plans necessary to achieve those goals.

The indicative actions will target interventions at site, zone of influence and within catchment area. The indicative actions for Bhairava have been shown in Table 50.

Table 50: Indicative actions for conservation of Bhairava Talaab

Components	Activities		At Site	Zone of Influence	Catchment Area
	Core	Non-Core			
Boundary Delineation & Establishing Buffer Space	a. Wetland Survey and Mapping b. Identifying activities within its zone of influence	a. Delineation of buffer space b. Removal of encroachments	a. Identification of max. extent of water body to delineate boundary	a. Identification of activities around water bodies b. Removal of encroachments	-
Water Management	a. Assessment of water requirements b. Dredging to increase storage capacity for GW recharge c. Constructed wetlands to treat pollution from diffuse sources. d. Construction of STP e. Assessment of water quality quarterly.	a. Procurement of machinery b. Capacity building	a. Dredging of water body. b. Provision of solid waste segregation chamber from drains	a. Provision of door to door solid waste management facility. b. Provision of sanitation facilities for slum dwellers c. Plantation within identified buffer space	a. Waste water and sewerage network should be linked to STP b. Control of GW extraction through private borewell. c. Rainwater harvesting mechanism for buildings.
Biodiversity Conservation & Habitat Management	a. Population assessment of wetlands dependent species b. Regulating species invasion by biological and habitat manipulation c. Economic use of harvested biomass of invasive species	Mechanical removal of invasive species biomass	a. Identification of aquatic species – flora and fauna. b. Assessment of nutrients and chemical parameters for suitability of aquatic habitats.	a. Regulating disposal of effluents or chemicals. b. Buffer space management to provide suitable environment for faunal species.	a. Waste water and sewerage network should be linked to STP.

Source: SPA Delhi

CHAPTER 8

PREPARATION OF MANAGEMENT PLAN FOR CONSERVATION OF URBAN WETLANDS/WATER BODIES

8. PREPARATION OF MANAGEMENT PLAN FOR CONSERVATION OF URBAN WETLANDS/WATER BODIES

8.1 INTRODUCTION

The management plan for conservation of water bodies should include all the necessary actions, budget and plan formulation to achieve in particular time frame and identify convergence of schemes.

Management plan should be prepared by municipality with the help of stakeholders.
A generic format for the preparation of the management plan has been provided in the toolkit (annexure).

NAMAMI GANGE
INTEGRATED GANGA CONSERVATION MISSION

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