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Remodelling Urban Spaces in the Light of Blue-Green Infrastructure: A Case Study of Guwahati, India

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Abstract

Guwahati, the fastest-growing metropolis of North East India, is surrounded by beautiful hillocks and the mighty River Brahmaputra flowing through the north. The city is endowed with rich biodiversity and blessed with pleasant weather. But since the 1990s, migration from rural Assam started; unplanned growth and expansion of the city soon followed. Unforeseen problems, like urban floods, landslides, land and water quality degradation, heat island effects and scarcity of basic amenities, are now quite common in Guwahati. The only Ramsar site of the state, the Deepor Beel, as well as other wetlands in Guwahati is under severe threat due to the encroachment and exploitation. The city falls in most vulnerable seismic zone V, but preparedness to combat big earthquakes and similar disasters is not in place. The present study has been carried out to assess the decadal changes over a period, starting from first spell of population influx, senseless expansion to environmental degradation. Data used for the study comprised of Landsat TM, ETM+, OLI and TIRS, ASTER Digital Elevation Model (DEM) and Survey of India Topomap. Data classification, analysis and mapping were carried out in GIS environment using ESRI ArcGIS 10.1 and Hexagon ERDAS 2014 software. It was found that urban expansion increased by 11.53% in 2000–1990, 16.31% in 2010–2000 and 13.64% in 2020–2010. But open spaces reduced by 14.47% in 2010–2000, waterbodies have shrunk and forest cover have reduced considerably. Based on these, suggestions have been made for restoration of existing natural resources and remodelling the city using blue-green infrastructure.

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13.1 Introduction

Rapid urbanization and unplanned growth have led to urban sprawl, water and air pollution, environmental degradation and exposure to natural and man-made hazards in many countries (Li et al. 2015; Zhang 2016). Fifty four percent of the world's population resided in urban areas in 2014, which is projected to rise to 66% by 2050. Asia and Africa will urbanize at a greater pace than all other regions of the world, where increase will be from 48 and 40% to 64 and 56%, respectively, by 2050. The world urban population has grown from 746 million in 1950 to 3.9 billion in 2014, which further will reach 6.3 billion by 2050. Africa and Asia combined will account for 90% of this rise. Though high-income developed countries have undergone urbanization for several decades, this process started much later in upper middle class countries, mainly due to collapse of rural economy, extreme climate events, people displaced by mega projects and lack of basic civic amenities in rural areas. The 57% urban population in developed countries in 1950 is expected to rise to 86% by 2050, while the same data for upper middle class countries would be from 20% in 1950 to 79% in 2050 (UN 2014).

Among the developing countries, India possesses the most characteristic features of urbanization. In 1951, India's total population was over 361 million, with 17.29% urban population which increased by 13.87% in 2011. The growth of urban population started gaining momentum after 1980. Post 1991, economic growth of the country due to Liberalization-Privatization-Globalization (LPG) brought into sharp focus the economic role of cities (Sadashivan and Tabassu 2016). Urbanization in India is referred to as pseudo-urbanization because people migrate to cities due to rural push factors and not due to urban pull (Breese 1969). Continuous concentration of population and activities in cities marks the pattern of urbanization in India (Jaysawal and Saha 2014). An example of this was the mass migration of marginal workers from cities during the nationwide lockdown period from March to June 2020 owing to COVID-19 pandemic. Urbanization in India is involuted (Mukherji 1991) and has been characterized by weak economic base and poor industrialization. Such lopsided urbanization has given rise to class I cities with massive growth of slums and denial of shelter, basic amenities such as potable water, hygiene, sanitation, electricity, etc., along with misery, poverty, unemployment, inequalities, exploitation and degradation of the environment and quality of urban life (Bhagat 1992; Kundu 1994). During the last 50 years, the urban population of the country has grown five times (Chakrabarti 2001), and the number of mega cities has increased from three (Delhi, Mumbai, Kolkata) to six including Bengaluru, Hyderabad and Chennai. As urbanization takes place and urban population increases, demand for land also increases resulting in unprecedented changes in land use-land cover, draining and filling of wetlands either to house the growing population or build urban infrastructure for industrial and commercial purpose or expansion of transport and communication, felling of trees in the forest, ploughing or grazing of grasslands and conversion of agricultural lands for other purpose.

Indian cities report of steady land cover erosion due to intense urbanization. Between 1973 and 2007, built-up area in Bengaluru has increased by 46% leading to a sharp decline from 68% to 25% in vegetation and 61% in waterbodies (Kumar et al. 2009). Disposal and management of solid waste is another matter of concern because in most of the cities there are no effective mechanisms to collect and dispose wastes. Similar evidence of urban progression from Delhi reflects that the city is developing very fast in the west, south-west and eastern sides. Urban expansion in the fringe areas has engulfed 17% of agricultural land in the Union Territory of Delhi. Considered as the lungs of Delhi, there has been considerable decrease in the famous Kamala Nehru Ridge area from 6.7% in 1992 to 5.5% in 2004 because of continuous felling of trees, construction and quarrying (Sherbinin et al. 2007).

North East (NE) India comprises of eight states, viz. Assam, Arunachal Pradesh, Meghalaya, Nagaland, Mizoram, Manipur, Tripura and Sikkim. Compared to the rest of India, NE is least urbanized where only 18% of the population reside in the 414 towns of various sizes. The only “million city” in the region is Guwahati in Assam, the gateway of the region, located on the left bank of Brahmaputra. Of the half dozen towns with population of more than 100,000, the largest number of towns falls in the group having population of 5000–10,000 people. Many of these towns are administrative or service centres with few industrial towns. The important cities or towns in the region are Guwahati, Jorhat, Dibrugarh, Tezpur and Silchar in Assam; Shillong and Tura in Meghalaya; Dimapur and Kohima in Nagaland; Agartala in Tripura; Imphal in Manipur; Aizawl in Mizoram; and Tawang and Ziro in Arunachal Pradesh. Digboi with a petroleum refinery and several hydrocarbon industries is the oil town of Assam; Itanagar is the newly planned town of Arunachal Pradesh and Agartala an upcoming urban hub. The number of towns in the NE India has increased from 30 in 1951 to 414 in 2011, and urban population has increased by 3.5% only of which highest urban pollution of 52.44% resides in Assam followed by 11.48% in Tripura, 9.82% in Manipur, 7.11% in Meghalaya, 6.85% in Nagaland, 6.71% in Mizoram, 3.74% in Arunachal Pradesh and 1.81% in Sikkim (Dikshit and Dikshit 2014).

13.1.1 Grey Infrastructure and the Challenges Within

Grey infrastructure refers to the traditional methods of managing water using man-made or constructed drainpipes, curb inlets, minor channels, manholes, roadside ditches and culverts designed or installed to remove storm water as fast as possible from sites to avoid or reduce on-site flooding. Grey infrastructure is often designed to avoid any type of ecosystem to grown on it. The grey infrastructure sewer system is of two types: combined or separate. The combined sewer system is the one in which storm water and wastewater are collected in the same pipe network, and then the mixed water is taken to wastewater treatment plant before being discharged into the nearest large waterbody or main river channel. On the other hand, in the separate sewer system, the storm water and wastewater are collected separately, and the wastewater is transported for treatment, whereas the storm water is directly discharged in nearest large waterbody or river channel if it does not contain pollutants (Jha et al. 2012; Opperman 2014).

This traditional grey infrastructure has been proved to be quite effective in collecting storm water run-off and draining it until unintended negative consequences related to quality and quantity of water started emerging in the form of changes in hydrological cycles, increased peak flows, downstream flooding risks, changes in groundwater and surface water levels causing increased climate change-related flood risks and flash floods, enhanced delivery of nutrients and toxins causing eutrophication threatening aquatic habitats in urban waterways and combined sewer overflows (CSOs) during heavy downpour or wet conditions, exposing urban populations to health risks from waterborne pathogens and toxins (Driscoll et al. 2015).

13.1.2 Dual Impacts of Urbanization and Grey Infrastructure on Urban Ecosystem

Combined impact of urbanization and grey infrastructure has pushed urban ecosystem to the edge of vulnerability. Under natural conditions, only a limited portion of the ground surface is covered by impervious layer. So, most rainwater goes down to recharge groundwater resources, filling rivers and lakes and taken up by plants and trees through the process of rainfall interception, infiltration, evapotranspiration and soil retention (Wagner et al. 2013). But in the cities, sealed surfaces like buildings, squares, sidewalks and pavements act as barriers, and instead of infiltration through the soil, the rainwater simply flows over the impervious surfaces. Secondly, urban expansion, particularly in flood-prone areas, alters the natural path of the flowing waterbodies and reduces rainwater infiltration, again increasing overland flows exceeding the capacity of drainage systems. Although urban drainage systems are designed to prevent local flooding by draining out storm water as fast as possible from the vulnerable sites, many a times urban flooding in the downstream is also observed (Jha et al. 2012). Such downstream flood risks may be amplified by ageing systems causing sewers to overflow, blocked natural flow paths and increase run-off (Grant 2010). This issue is severe in cities like Guwahati, which are facing financial challenges of developing new infrastructure, at the same time operating, maintaining, rehabilitating and ensuring environmental compliance of the current ageing infrastructure (Ozment et al. 2015).

Due to impervious surfaces and storm water systems, infiltration and evaporation are reduced in urban areas causing rise of ambient temperature resulting in urban heat island (UHI) effect (Chetia et al. 2020). This also changes the local climate parameters resulting in low precipitation, slower groundwater recharge rates and less water for the citizens. The lower groundwater levels in the urban areas can potentially lead to lower streambase flows, decreasing habitats and cover available for instream inhabitants, therefore increasing competition and vulnerability to predators. With reduced flow, there is also the likelihood of increased water temperatures and lower dissolved oxygen levels, both of which will create additional stress to stream inhabitants (Howe et al. 2011; Knight 2003).

Run-off from roads and highways frequently washes pollutants like dirt, oil, grease, toxic chemicals, heavy metals, road salts, wintertime salting and sanding deposits, sodium chloride and calcium chloride on the roads, nitrogen and phosphorus, rubbish from roadside vehicle repairing centres (brake pads, wear-related deposits include copper and zinc) and pathogens into nearby waterways including rivers, streams and lakes. Fertilizer application on agricultural strips is a source of nitrogen and phosphorus. Urban run-off also reduces visibility of water with outbreaks of blue-green algae, fish kill, piles of foam, cloudy and coloured water and oil slicks. In addition, the degradation of roads and pavements also generates pollutants, and floating inorganic debris and litter (bottles and aluminium cans, car tyres, oil drums, etc.) raises community concern. The decomposition of organic debris like leaves, twigs, timber, paper, cardboard and food waste reduces visibility of water, and nutrients released can form rich organic sediment resulting in algal blooms (Lloyd et al. 2002). The effect of these pollutants from road run-off is harmful for the human ecosystem as well as flora and fauna. Urban storm water run-off also significantly contributes to thermal pollution of waterways and waterbodies. Increased temperatures can threaten survival of aquatic species by interfering with spawning and migration patterns, promote harmful algal blooms producing toxins, raise treatment costs for drinking water and harm industries that rely on clean water, besides creating dead zones in water (Brears 2018; Stuart and Stanford 1978; Qian et al. 2019).

13.1.3 Blue-Green Infrastructure and Its Advantages

Blue-green infrastructure (BGI) is a network of strategically planned natural and semi-natural areas encompassing green spaces and blue areas concerning aquatic ecosystems and other environmental features. BGI is designed and managed to protect biodiversity and deliver a wide range of ecosystem services (Brears 2018). It is supposed to utilize natural processes to improve and manage water quality and quantity by restoring the hydrological function of any urban landscape. Spatial planning is the most effective way of implementing BGI. This allows interactions between different land use patterns over a large geographical area. Spatial planning at strategic level helps to pinpoint the best locations for habitat enhancement projects to house the increasing population load and reconnect healthy ecosystems, improve permeability of landscape and connectivity between protected areas and guide infrastructural developments away from sensitive natural areas to more robust areas that in addition may contribute to recreating and restoring green infrastructure features in the development proposal. It also helps to identify multifunctional zones where compatible land uses are favourable and support healthy ecosystems over single focus development (Foster et al. 2011).

13.1.4 Footprints of Urbanization in Guwahati City

Guwahati, the largest city of North East India, has witnessed influx of people since 1972 when the capital of Assam was shifted from Shillong to Dispur. The population of the city increased at a compound annual growth rate of 4.0% from 293,219 to 646,169 between 1971 and 1991. By the last decadal census in 2011, its population reached 968,549, and at present, the city probably has about one and a half million people. The city is of strategic and geographical significance, located at the banks of the mighty Brahmaputra River, with few tributaries flowing through the city nurtures biodiversity (Figs. 13.1 and 13.2). But rapid and unplanned urban growth has changed the land use pattern of the city. Like numerous Indian cities, Guwahati also faces problems of land use-land cover (LULC) change due to inadequate planning efforts, uncontrolled development activities compounded by urban population growth and expansion with adverse impacts on the ecology and environment of the city. The only Ramsar site of the state, the Deepor *Beel* (wetlands, lakes and ponds are commonly called "beel" in Assamese language), located in Guwahati is under severe threat due to the encroachment and unplanned urban developmental activities. The city is located on the seismic belt (Zone V) and prone to floods and

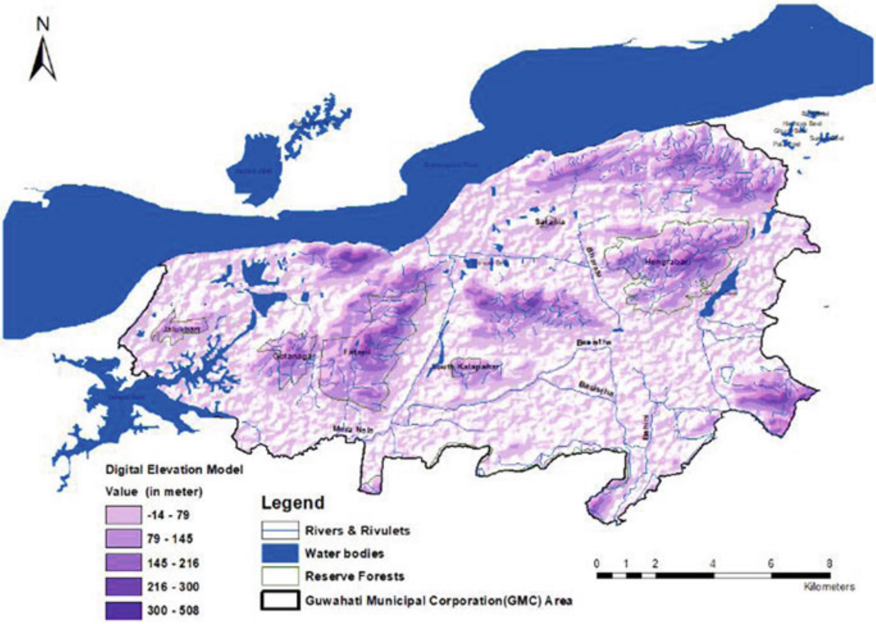

Fig. 13.1 Base map of Guwahati Municipal Corporation (GMC) area

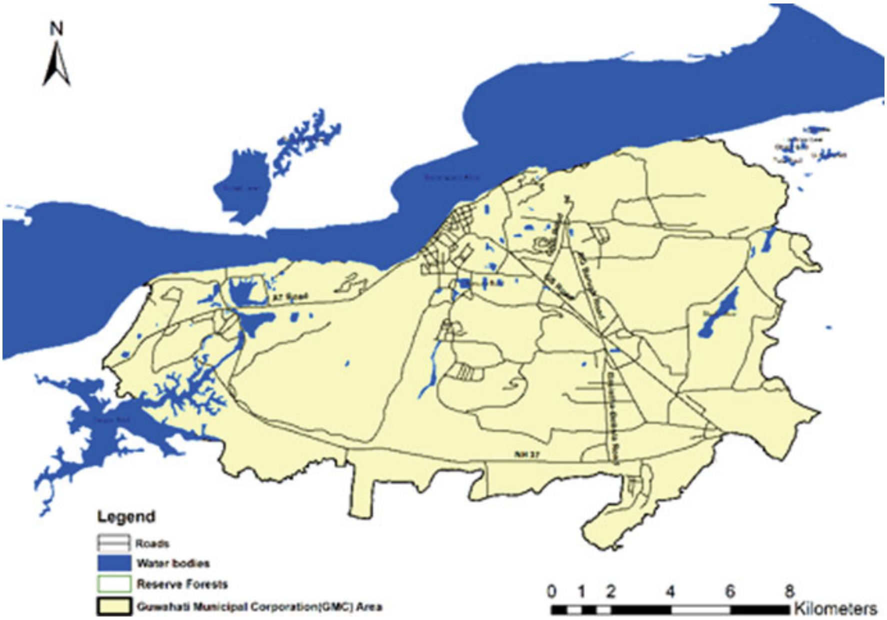

Fig. 13.2 Road network map of GMC area

landslide. The capacity and preparedness of the city to combat with such disasters and deal with its impacts are not up to the mark, which make its residents quite vulnerable.

On 25 June 2015, the Ministry of Urban Development (MoUD), Government of India under its Smart City Mission, launched an ambitious initiative to develop 100 smart cities and 500 small medium towns under Atal Mission for Rejuvenation and Urban Transformation (AMRUT). Guwahati is the only city from NE India among the top 20 cities (Round 1) to be developed as a smart city (Kaushik et al. 2015). The city is extolled as lynch pin to the gateway to Southeast Asia and India's Act East Policy (Pawe and Saikia 2018; Sarma 2012). The vision for smart city includes Solar City Guwahati Mission, Integrated Command and Control Center (ICCC) with smart electric poles for smart lightning, robust IT connectivity, skill development centres, Deepor *Beel* development project, strengthening eco-tourism in the city, flag construction at Gandhi Mandap, special road which connects Guwahati to AIIMS (Guwahati), round-the-clock electricity supply, smart metering, wastewater recycling, smart parking, etc.

This has pressed upon the need for efficient urban planning and proper environmental management of the city. Planning and management necessitate advanced methodologies like space technologies and spatial mapping which aids urban planners, environmentalists, ecologist, economists and resource managers to solve problems accompanied with urban growth (Maktav and Erbek 2005). Traditionally, in the field of geography and planning, there is research on description, characterization, mapping and measurement, understanding the morphology, form and evolution of urban environment (Taubenböck et al. 2009). The classical theories of urban morphology defined urban patterns as concentric rings with different land use types as sectors (Burgess 1935), modification of concentric zones pattern based on transportation network (Hoyt 1939) and the multiple nuclei theory model of urban patches with specialized multiple centres of land use (Harris and Ullman 1945). Meanwhile, techniques of remote sensing (RS) have been proved effective in mapping urban areas at various scales acquiring data for urban LULC analysis (Batty and Howes 2001; Donnay et al. 2001; Herold et al. 2002).

In this study, a spatiotemporal analysis of Guwahati city's LULC and its changes using time series of Landsat data has been carried out to detect the pressure of urban population growth and expansion on the forests, rivers and rivulets, and its increasing vulnerabilities.

13.2 Methodology

Methodology adopted for the study has been shown in Fig. 13.3.

13.2.1 Data

Primary Data for the study comprised of Landsat time series data (TM, ETM+, OLI and TIRS) and ASTER Digital Elevation Model (DEM) were downloaded from United States Geological Survey's interface Earth Explorer, Survey of India (SOI)

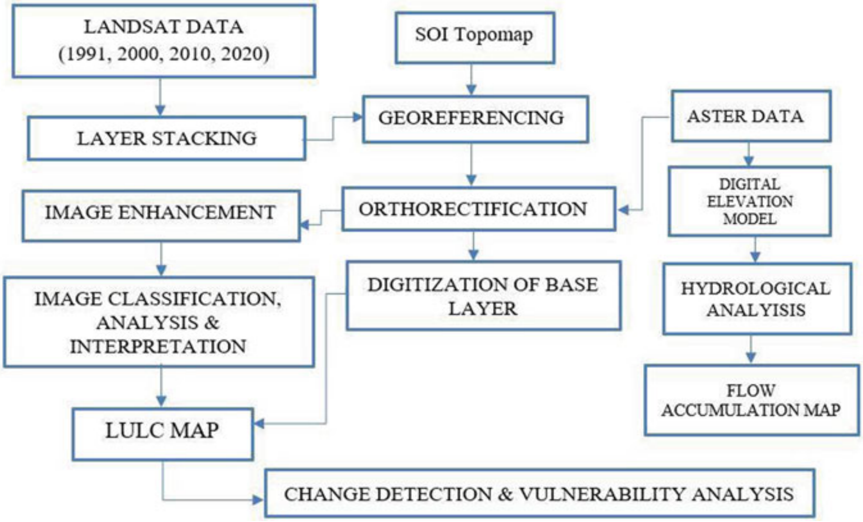

Fig. 13.3 Flowchart of methodology adopted in the study

Table 13.1 Details of satellite data used in the study

Data	Bands	Resolution	Path and row	Year
Landsat TM[a]	7	30 m	137/42	1990
Landsat ETM+[b]	8	30 m	137/42	2000, 2010
Landsat OLI and TIRS[c]	11	30 m	137/42	2020
ASTER[d]	14	30 m	–	2011

[a] Landsat Thematic Mapper
[b] Landsat Enhanced Thematic Mapper
[c] Landsat Operational Land Imager and Thermal Infrared Sensor
[d] Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)

Topomap for Guwahati city and secondary data for the consisted of flood and landslide hazards maps for Guwahati city developed by Assam State Disaster Management Authority (ASDMA), Government of Assam. Data classification, analysis and mapping were carried out in GIS environment using ESRI ArcGIS 10.1 and Hexagon ERDAS 2014 software (Table 13.1).

13.2.2 Image Classification and Accuracy

The LULC characteristics of Guwahati Municipal Corporation (GMC) were generated using supervised classification technique through maximum likelihood classifier for the Landsat time series data, while classifying it ensured that different clusters do not overlap and at least 30 numbers of observations per cluster were maintained (Saikia et al. 2013; Janssen et al. 2001). Based on the spatial resolution of the Landsat data and the multifunctional LULC pattern of Guwahati city (Borah and Bhagabati 2015), the datasets were classified into eight LULC categories. The LULC scheme adopted in this study complies with the land cover classification scheme designed by the Food and Agriculture Organization (Gregrio and Jansen 1998; Latham et al. 2002). An accuracy assessment was performed for each decade (1990, 2000, 2010 and 2020) with a set of 40 random ground points for each LULC class. Overall accuracies and Cohen's kappa coefficient (κ) for 1990, 2000, 2010 and 2020 images were 96.80% ($\kappa = 0.95$), 96.88% ($\kappa = 0.96$), 94.31% ($\kappa = 0.92$) and 92.96% ($\kappa = 0.92$), respectively. An overall accuracy of 85% is generally regarded satisfactory (Anderson 1976). The value of kappa coefficient ranges between 0 and 1, and over 0.75, it is deemed excellent (Fleiss 1981).

13.3 Results and Discussion

13.3.1 Spatiotemporal Analysis of Guwahati City

From the LULC classification of Guwahati Municipal Corporation areas for the decades 1990, 2000, 2010 and 2020, it is evident that natural areas (closed forest, open forest, aquatic vegetation, open space, riverine sand) and agriculture were the

Table 13.2 Decadal LULC statistics of GMC area (in ha)

LULC categories	Area under different LULC categories (in ha)			
	1990	2000	2010	2020
Urban built-up	3711.85	5733.71	8594.16	10986.71
Waterbodies	652.73	761.46	512.90	341.98
Aquatic vegetation	2085.00	693.24	396.24	432.92
Closed forest	1114.43	1308.12	1273.27	1255.76
Open forest	5700.47	3454.10	5788.1	4048.58
Open space	1353.49	3547.22	968.08	468.90
Agriculture land	2891.64	2030.72	0.00	0.00
Riverine sand	27.77	8.84	4.61	2.56
Total	**17,537**	**17,537**	**17,537**	**17,537**

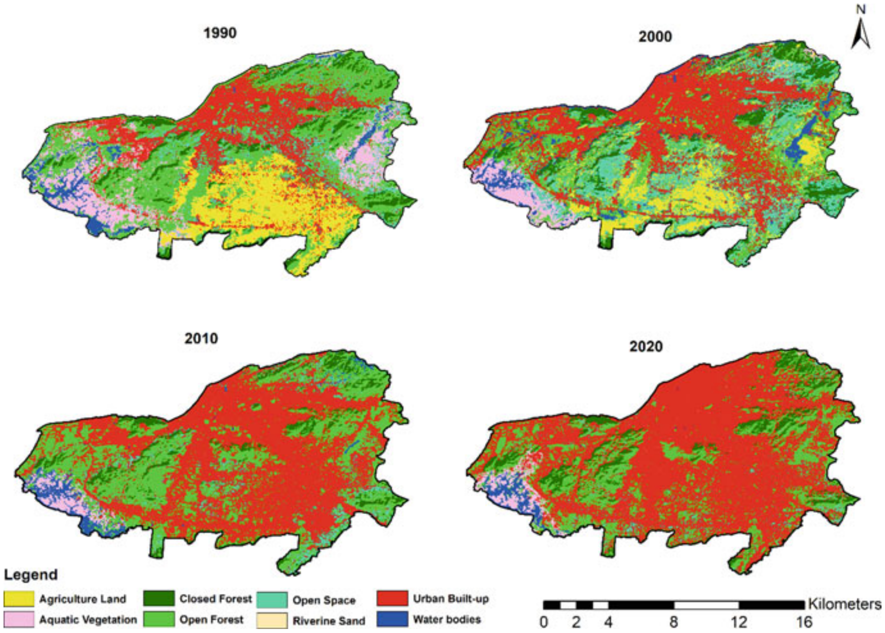

Fig. 13.4 Decadal LULC map of GMC area

predominant LULC categories during 1990 and 2000. However, with increasing urban pressure and population growth, these areas have largely been replaced by built-up areas in 2010 and 2020 (Table 13.2; Fig. 13.4).

Over the four decades under study, urban built-up increased by 11.53% in 2000–1990, by 16.31% in 2010–2000 and by 13.64% in 2020–2010 (Table 13.3). Although waterbodies have increased by 0.62%, this increase can be linked with the decrease of aquatic vegetation by 7.94% which helped the signature of water to be visible. However, both waterbodies and aquatic vegetation decreased by 1.42 and

Table 13.3 Decadal LULC change statistics of GMC area

	Decadal LULC change (in ha)			Rate of decadal LULC change (in %)		
LULC categories	2000–1990	2010–2000	2020–2010	2000–1990	2010–2000	2020–2010
Urban built-up	2021.86	2860.45	2392.55	11.53%	16.31%	13.64%
Waterbodies	108.73	−248.56	−170.92	0.62%	−1.42%	−0.97%
Aquatic vegetation	−1391.76	−297	36.68	−7.94%	−1.69%	0.21%
Closed forest	193.69	−34.85	−17.51	1.10%	−0.20%	−0.10%
Open forest	−2246.37	2334	−1739.52	−12.81%	13.31%	−9.92%
Open space	2193.73	−2579.14	−499.18	12.51%	−14.71%	−2.85%
Agriculture land	−860.92	−2030.72	0	−4.91%	−11.58%	0.00%
Riverine sand	−18.93	−4.23	−2.05	−0.11%	−0.02%	−0.01%

1.69% between 2010 and 2000. Aquatic vegetation grew by 0.21% in 2010–2000, but waterbodies continued to decrease by another 0.97%. Closed forest increased by 1.10% in 2000–1990 but continued to decline by 0.20 and 0.10% in 2010–2000 and 2020–2010, respectively, due to human pressure. Open forest reduced by 12.81% in 2000–1990 and then increased by 13.31% in 2010–2000 to witness decline again by 9.92% in 2020–2010. Clearance of open forest in the city led to the rise of open space by 12.51% in 2000–1990 which later continued to decline by 14.71 and 2.85% in 2010–2010 and 2020–2010, respectively. Rapid urbanization and need to house the growing population have created tremendous pressure on the agriculture land which reduced by 4.91% in 2000–1990 and by 11.58% in 2010–2000 which got wiped out from the land use pattern of the city (Fig. 13.5). The emergence and submergence of the riverine sand is a continuous dynamic annual episode.

13.3.2 Encroachment of the Reserve Forest by Urban Built-Up

The city is surrounded by 18 hills of which 8 are reserve forests (RF), and 6 of them are in the city, namely, Fatasil RF, Gotanagar RF, Hengrabari RF, Jalukbari RF, Sarania RF and South Kalapahar RF. Primarily, the vegetation of the city is tropical deciduous. Over the years, expansion of built-up areas occurred inside the notified reserved forests (RFs) and on the hills within the jurisdiction of GMC (Table 13.4 and Figs. 13.6 and 13.7). Such encroachments are predominantly made by the urban poor. In 2001, nearly 170,000 people were residing in the city hills (Borah and Gogoi 2012). Besides the urban poor, some pockets of land have been encroached of by commercial entities and wealthy urbanites (Borthakur and Nath 2012). Urban poor residing in informal settlements on the tenuous hill slopes of the RFs often face the problem of soil erosion or rainfall-induced landslide (Forman 2014). During 2000–2007, around 60 people lost their lives due to mudslide in the hills of Guwahati (Dutta et al. 2017). These makeshift houses often lack access to basic

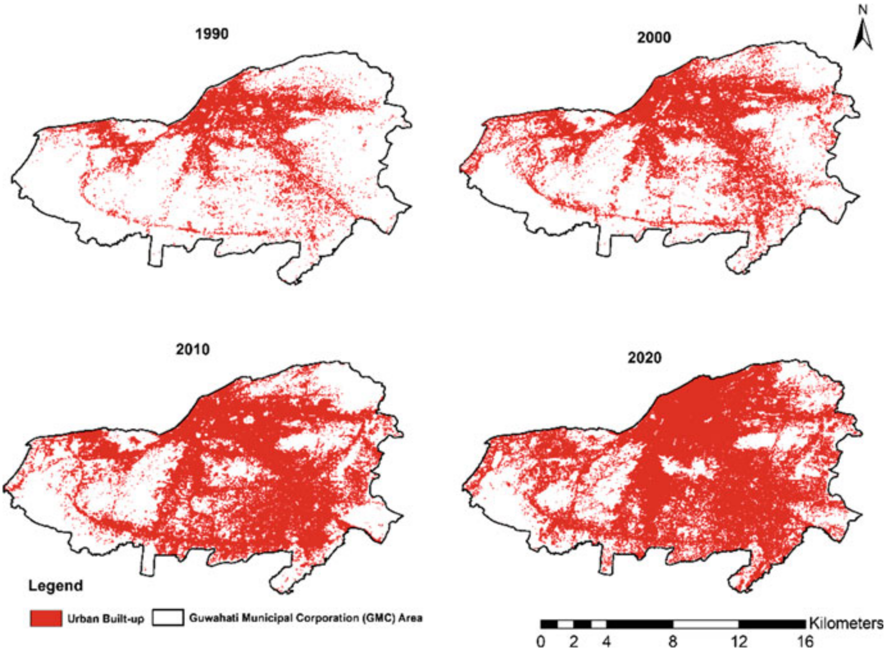

Fig. 13.5 Decadal urban expansion in GMC area

Table 13.4 Urban expansion in the reserve forests of Guwahati city

Reserve forests	Area under urban built-up in the RFs (in ha)				Decadal growth of built-up in RFs		
	1990	2000	2010	2020	2000–1990	2010–2000	2020–2010
Fatasil	9.80	26.59	79.20	132.31	16.79	52.61	53.11
Gotanagar	2.42	5.97	8.70	18.53	3.56	2.73	9.83
Hengrabari	79.09	188.80	385.12	396.73	109.72	196.32	11.61
Jalukbari	0.00	0.94	0.71	1.17	0.94	−0.23	0.46
Sarania	2.12	2.16	0.96	8.69	0.04	−1.20	7.73
South Kalapahar	1.58	2.99	7.93	45.47	1.41	4.93	37.54
Total	**2085.00**	**2227.46**	**2492.62**	**2622.89**	**132.46**	**255.16**	**120.27**

amenities such as all-weather or drivable roads, electricity and water supply and sanitation. Ever increasing population and lack of space have forced humans to settle in the vulnerable locations of the city (Forman 2014), thereby increasing pressure on the slopes, natural domain of the rivers and rivulets, wetlands and flood plains. Urban expansion changes a city’s seven basic factors—natural vegetation, water, agricultural land, housing, communities, jobs and transport (Forman and Wu 2016),

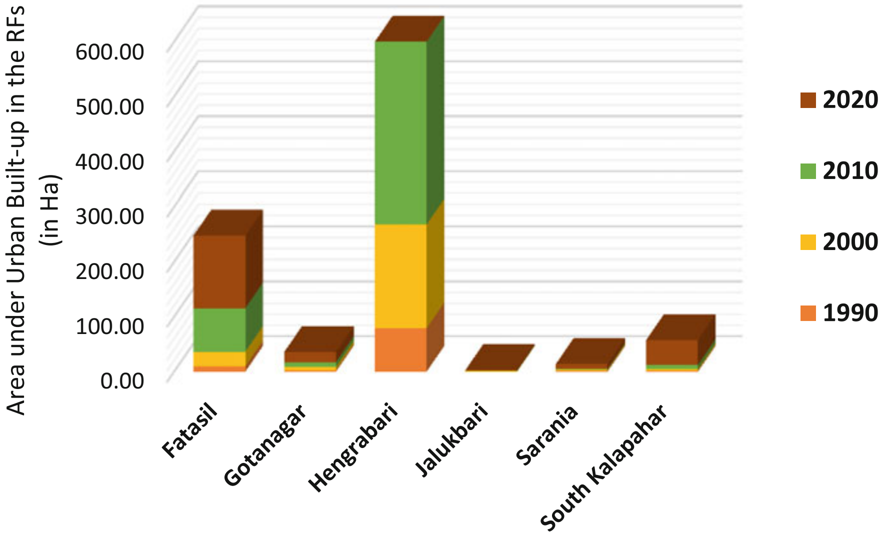

Fig. 13.6 Showing urban built-up in the reserve forests within GMC area

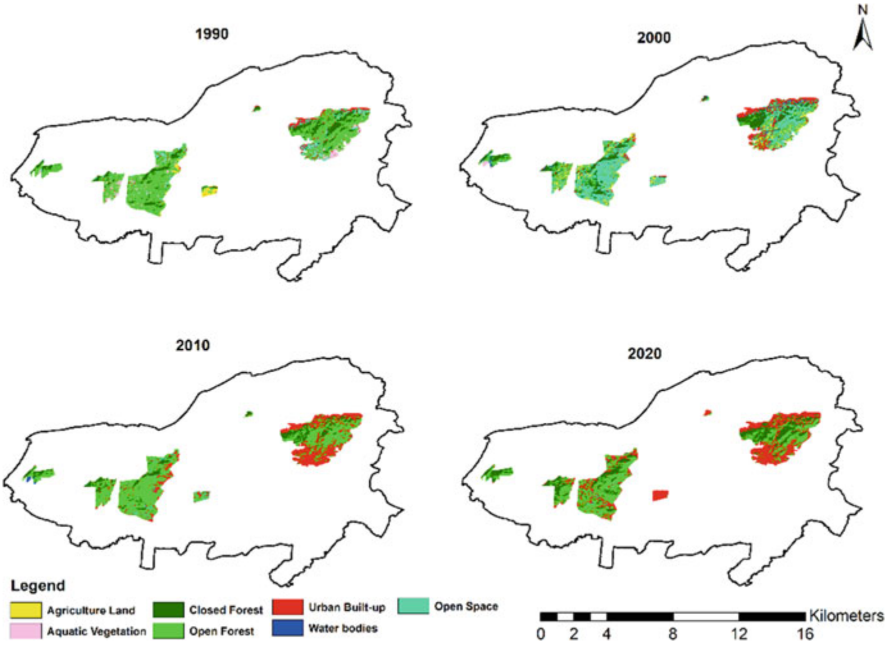

Fig. 13.7 Decadal expansion of urban built-up and reduction of forest cover in the RFs of Guwahati

although unequally on the basis of economic strata. Changes in all these have been quite significant in the case of Guwahati as well.

13.3.3 Impacts of Urban Growth in Guwahati

Change in the land use pattern and fast pace of urbanization during the past four decades has resulted in significant depreciation of the environment and ecology of the city. Growing urban settlement in and around the hills and reserve forests of the city at the cost of forest or vegetation cover have exposed the surface to landslide, soil erosion and rise in air pollution. Urban expansion and human settlement along the flood plains of Brahmaputra River and banks of other rivulets within the city and around the wetlands have led to decrease in the water retention capacity of the waterbodies exacerbating problems of flooding and water logging (Gogoi 2013). Degradation of wetlands is a notable problem of Guwahati due to shrinkage of the Ramsar Site Deepor *Beel* and complete encroachment and conversion of Silsako *Beel* and Borsola *Beel*. Water contamination and bacterial pollution in Brahmaputra River and Bharalu River have increased due to direct and untreated discharge from combined sewer systems, and biological oxygen demand (BOD) of Bharalu River has increased due to presence of various oxygen demanding organic and inorganic matter (Girija et al. 2007; Hussain et al. 2015). Deforestation and cutting of hill slopes for earth filling of low-lying areas have increased the risk of sheet-wash, slope failure, high rate of soil erosion, increased siltation and choking of drainage channels. Soil erosion and heavy siltation have raised the riverbeds, and the capacity of natural and artificial drainage network to discharge storm water has drastically reduced. Backflow of water from rivers, rivulets and wetlands also causes frequent floods during monsoons and occurrence of heavy rainfall. The growing urban population and its need of potable water has put tremendous pressure on the groundwater resources leading to lowering of groundwater table and scarcity of water (Nath et al. 2021). The groundwater of the city reports moderate mineral content with slightly higher concentration of iron and toxic elements (Das et al. 2003; Singh et al. 2019).

13.3.4 Vulnerability of Flood Hazard in Guwahati

Other than the mighty Brahmaputra River flowing through the north of the city, a number of other rivers and rivulets, namely, Bharalu, Basistha and Bahini, originating from the Khasi Hills of Meghalaya flow through the city. The river Bharalu drains into Brahmaputra River and river Basishta into the Deepor *Beel* through the Mora Bharalu channel. Besides the city is also known for its numerous wetlands such as Deepor *Beel*, Silsako *Beel* and Borsola *Beel* which sustain significant flora and fauna in the heart of the city. Based on its physiography, the city is divided into six natural drainage basins, ultimately discharging into the mighty Brahmaputra River with different drainage lines and reservoirs (Baruah and Naik

2020). These are Silsako basin, Deepor basin, Bharalu basin, Kalmoni basin, Foreshore basin and North Guwahati basin:

- Bharalu basin: Bharalu is the major river running across the city. It is heavily degraded due to haphazard construction on the natural domain of the river, unplanned commercial developmental, sewage and solid waste disposal, etc. Decline in water-holding capacity during heavy rainfall or monsoon season causes flood in the city due to backflow from Brahmaputra River. City life comes to a standstill, with frequent loss in life and property. The river has been marked as one of the most polluted rivers of the country by the Central Pollution Control Board (CPCB), New Delhi.
- Deepor basin: With a respectable tag of Ramsar site, this wetland was the storm water storage of the city. Basishta river drains into this wetland, and it is the single largest basin located in the southernmost part of the city. The basin is again subdivided into two sub-basins, viz. Bijubari and Deepor sub-basin. Deepor *Beel* used to act as a sponge retaining the excess storm water during heavy rainfall and then slowly releasing it into the Brahmaputra river.
- Silsako basin: Silsako *Beel* is located in the eastern part of Guwahati city. This basin consists of industrial estate of Bamunimaidam, IOC refinery (Noonmati) and military (Narengi) area. Silsako *Beel* is connected to Brahmaputra river through Bondajan rivulet.
- Kalmoni basin: Although the entire basin lies outside the Guwahati Municipal Corporation (GMC) area, it discharges into Brahmaputra river through Deepor *Beel* and Khanajan rivulet indirectly.
- Foreshore basin: This basin mainly consists of residential, institutional and commercial areas of the city. Due to the shallow bowl-like physiography of the city, water logging and urban floods are regular features in Guwahati during monsoon.
- North Guwahati basin: This basin discharges into the Brahmaputra river directly or indirectly through the Ghorajan rivulet.

The city suffers from the worst impact of urban floods every time after heavy rainfall with worst consequences on and in the fringes of Guwahati-Shillong (GS) Road, RG Baruah Road, GNB Road and Beltola-Basistha Road (Fig. 13.9) due to lack of planned drainage system; ageing water channels and feeder drains with reduced holding capacity due to siltation and solid waste accumulation (Sarmah and Das 2018); encroachment along the edges of the rivers, rivulets and wetlands; or blocking of the channels for construction and settlement and backflow from the channels on occasion or heavy downpour. During incidents of incessant or heavy downpour, the wetlands cannot retain storm water resulting in blockage of waterways and flooded streets with sewage water. On the other hand, clearing of slopes in an around the hills and RFs of Guwahati for settlement and other activities has either blocked or concealed the streams discharging rainwater leading to slope failure induced by downpour. This is another geoenvironmental hazard other than floods that affects the city every year (Dutta et al. 2017). Guwahati Metropolitan

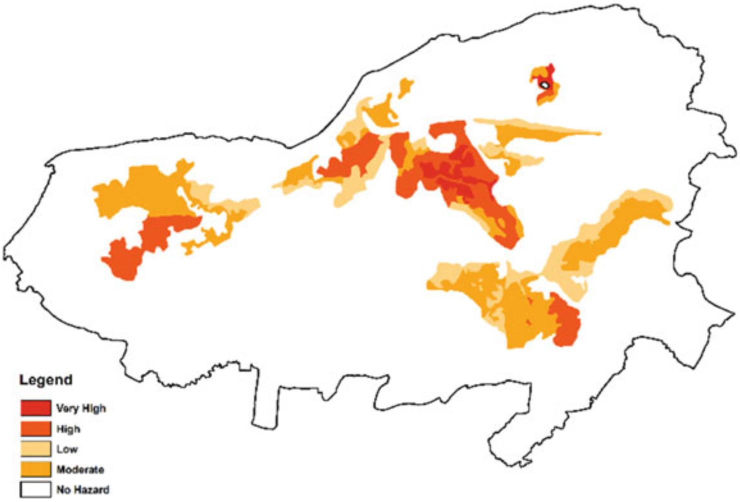

Fig. 13.8 Flood hazard map of Guwahati city (source: ASDMA)

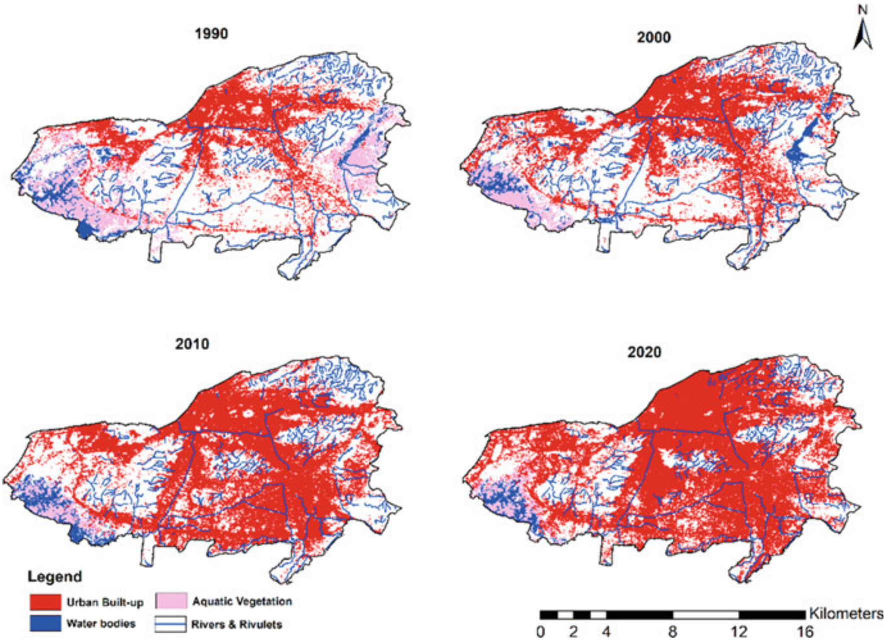

Fig. 13.9 Expansion of urban built-up in Guwahati city

Development Authority (GMDA) identified mushrooming slums as the root cause of urban floods in the city (Sarmah and Das 2018). Figures 13.8 and 13.9 shows the flood hazard zones of Guwahati city, pressure of urban built-up and population on the natural waterways of the city. Apart from Deepor *Beel*, other important wetlands of the city "Silsako *Beel*" and "Borsola *Beel*" have been gradually squeezed by urban built-up. Silsako *Beel* spreads over an area of 87.67 ha in 1990, 127.00 ha (the waterbodies spread over a considerable area due to reduction of aquatic vegetation and inundation of the nearby agriculture land by the waterbody) and 11.62 in 2010, and in 2020, it has no existence. Similarly, Borsola *Beel* was 2.86 ha in 1990, 2.63 ha in 2000 and 0.87 ha in 2010 and was wiped out in 2020. From this it is evident that the non-existence of wetlands in the city has exacerbated the vulnerability of flood hazard.

13.4 Role of Blue-Green Infrastructure in Remodelling Guwahati City

Remodelling Guwahati city in the light of BGI is the solution to reduce the risks and vulnerability to flood and landslide hazards, improve drainage network for storm water discharge and water ways, enhance green cover of the RFs and open spaces, restore and improve the existing waterbodies of the city and aid GMDA in adopting compatible and favourable building bye-laws to enrich the urban ecosystem. Some of the BGI measures proposed, based on the present study, are as follows:

- **Storm water detention and retention basin:** This is a system to store run-off storm water temporarily, which includes detention or retention basins, bioretention basins or swales that capture run-off from roadways and buildings. Unlike the traditional urban storm water pathways, this system does not interrupt the upstream storm water sewer inlets. The detention basins are systems to temporarily store storm water run-off during incidents of downpour and later release it at a controlled rate to the drainage system. Retention basin again holds permanent pool of water which is designed for peak run-off control and pre-treatment (Driscoll et al. 2015). Since the city has different depths and pockets of shallow areas, both in the plain and hill slopes, therefore, strategic configuration of these areas into retention and detention systems and connecting them with the storm water drainage will capture inflows and overflows from external and internal conveyance respectively. This will mitigate the flooding of streets and downstream localities and reduce incidents of slope failure.
- **Revival of the concealed or dilapidating rivers, rivulets and streams:** Revival of the existing, blocked or concealed rivers (Bharalu, Basistha, Bondajan), rivulets and streams (Bahini, Mora Bharalu, Khanajan) through dredging, desiltation and networking all the waterways will aid in restoring the aquatic ecosystem of the city (Fig. 13.10). Apart from, conservation of the existing wetlands and cleaning (Deepor*Beel*), desilting and restoring the dying wetlands (Borsola*Beel* and Silsako*Beel*) and reviving its connections with the drainage waterways network like Bharalu river—BorsolaBeel—Brahmaputra River, Basistha—Bahini—Mora Bharalu—Deepor*Beel*—Khanajan—Brahmaputra River and Silsako*Beel*—Bondajan will also bring back the natural retention

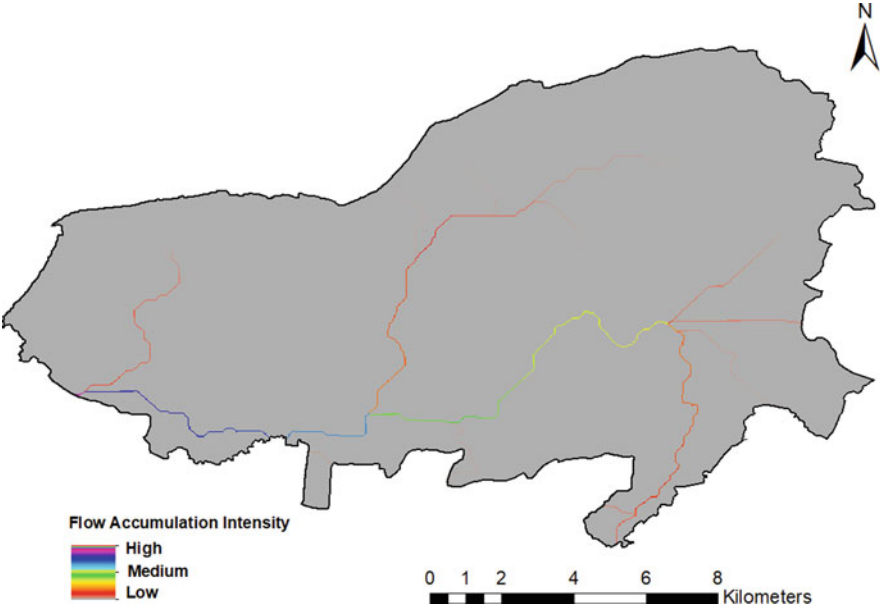

Fig. 13.10 Map showing flow accumulation intensity in the rivers and rivulets of Guwahati city

capacity of the water bodies to hold excess water, improve micro-climate, enrich the natural flora and fauna of the urban landscape, enhance groundwater recharge. During the rain-free periods, these areas can be utilized for recreational purposes (Wang et al. 2018).

- **Riparian buffers:** Riparian buffers are biological filters of vegetation between catchments and receiving pathways, preventing a significant amount of nutrients, toxins and solid wastes from entering into the water system. The vegetation and humus layers hold significant volume of water and directly uptake the contaminants; hence, the storm water run-off is slowed and filtered, allowing infiltration into the soil and releasing the run-off over a longer time period (Wagner et al. 2013). Riparian buffers also reduce erosion and preserve the function and form of the channel (Wang et al. 2021). Riparian buffers along the rivers, rivulets and wetlands of the city will not only reduce the run-off velocity of storm water but will also replenish groundwater and address to its scarcity during lean season, enhance water quality of the natural bodies, conserve the urban biodiversity, reduce man-animal conflicts and add to the aesthetic value of urban landscape.
- **Urban forests and vegetation:** The city already has eight reserve forests. Enhancing forest cover of these RFs will increase green cover of the city, absorb pollutants, improve air quality, act as windbreaks protecting urban infrastructure from wind damage, regulate urban heat island (UHI) effect, control ambient air temperature through evapotranspiration, shelter wildlife and mitigate effects of climate change by carbon sequestration.

- **Green roofs:** Flat rooftops are conducive to rainwater capture. Green roofs are permeable fabric of a growing vegetation grown on flat roofs, capable of treating storm water through retention or bioretention. Green roofs reduce storm water run-off by 50–60% and capture nearly 85% of pollutants. These also filter air pollutants, absorb carbon dioxide and reduce ambient air temperature by about 5 °C and surface temperature by 22 °C preventing UHI effect (Brears 2018; Meerow et al. 2021). Adopting green roofs in the residential housing complexes, government buildings, prestigious buildings and other flagship buildings will provide boost to the concept.
- **Downspouts and rain barrels:** In many commercial buildings and residential complexes, the rainwater is directly passed to the sewage system. Downspout disconnects the route of rainwater from the sewage system and redirects the water towards permeable areas. Besides, downspouts can be connected to rain barrels or cisterns (Foster et al. 2011). Rain barrels are small above-ground water receptacles which usually hold 50 gallons, best suited for small parcels of land as the water captured can be used for irrigation, whereas cisterns are large and can be either above or below ground. Size of the cistern range from 300 to 1000 gallons and are mostly used in large buildings. Installing rain barrels and downspouts in the commercial and residential buildings can solve the groundwater crisis of Guwahati city and improve its water regime.
- **Pervious pavement and depaving:** Pervious pavements are specially designed pavements that let water to percolate through the pavement, preventing it from becoming run-off. There are various types of porous surface such as pervious concrete, pervious asphalt and interlocking. These pavements are made of a porous surface with an underground stone reservoir. The underground reservoir stores the water temporarily before the water infiltrates into the soil. Function of interlocking pavers is different from pervious concrete and asphalt. Interlocking pavers are spaced apart with grass or gravel in between allowing water to infiltrate through the paving. Installing such pavers in the parking lots, sidewalks, frontwards and backwards or urban infrastructure has obvious advantages. On the other hand, depaving of concrete areas will liberate underutilized paved surfaces for vegetation, allowing storm water to infiltrate into the ground where it falls instead of carrying pollutants into waterways, as well as providing a habitat for insects, birds and other wildlife (Jalali and Rabotyagov 2020).

13.5 Conclusion

The present study has unfurled certain problems of Guwahati and its degrading environment and ecosystem. Urban evolution has been expeditious in the past two decades and taken the citizens by shock and surprise. But there are still scope to undertake restructuring and remodelling activities for its recovery, one major approach being building resilience to existing urban hazards by promoting urban infrastructure in the light of BGI. Urban settlement along the slopes of the hills and RFs cannot be uprooted now, but the remaining green patches, rivers, rivulets and waterbodies can be conserved. Rather than putting all loads of urban infrastructure development and settlement on the bowl shape physiography of Guwahati, the neighbouring areas of the metropolis beyond eastern and western limits should be developed into a few satellite townships to decongest the city. Financial endowments should not pose problems in this context because Guwahati is one of the 100 "smart cities" in first phase of AMRUT. Guwahati's strategic location and its importance for the country, as well as Southeast Asian countries, will be an advantage for future projects so far as government or international funding is concerned. Success of all restoration projects will largely depend on mainstreaming BGI with the masterplan for the city and going back to the basics.

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