Trans. Inst. Indian Geographers
ISSN 0970-9851
Indexed in Scopus

A study on growth and land transformation in Bhubaneswar city in Eastern India in the context of increasing urbanization and urban flood vulnerability

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Abstract

The recent trend of urbanization is the most important anthropogenic factor responsible for global climate change. In Asia, India and China are the major nations experiencing rapid urbanization. The major impact of urbanization is manifested in terms of spatio-temporal growth and land transformation in and around cities and towns. One of the most important adverse impact of land transformation in and around cities is increased runoff and increased urban flood vulnerability. A remote sensing and GIS based landuse/landcover mapping and land transformation analysis for Bhubaneswar city was carried out for a period extending over 35 years during1974 to 2010 to assess the impact of growth and land transformation in inducing flood vulnerability. Based on the analysis of stake holder focus group discussions, the most perceived impact of land transformation and increased runoff was found to be flooding and water-logging. The findings of the study point to management interventions to focus on prioritized attention for vulnerable catchment areas and conservation and protection of natural drainage channels and wetlands within the city.

Keywords: *Urbanization; land transformation; Bhubaneswar; urban flooding; GIS.*

Introduction

The recent trend of urbanization is the most important anthropogenic factor responsible for global climate change. "In 1800 there were only 2 cities larger than a million inhabitants. By 1950 there were 75 cities of this size and by 2000 there were 380 'million cities', half of these in Asia" (Satterthwaite *et al.*, 2007: 8). A study of present and projected urban population of different regions in the world indicates that the urbanization is at its highest level in Asia followed by Africa (UN Habitat, 2008). In Asia, India and China are the major nations experiencing rapid urbanization. The comparative urbanization trends in India and Odisha, in terms of number of towns, urban population and its percentage are presented in Table 1. Odisha, an eastern coastal state in India, is characterized by long coastline (around 500 Km.) and great diversity in environmental and climatic conditions amongst its 09 coastal and 21 interior districts. Odisha, earlier known as an abode of rich environment, abundant forest, diversified wild life, plenty of natural resources and moderate climate (hot summer, cold winter and pleasant coastal region), has undergone dramatic changes during the last century. At least in the last one century,

Table 1: Urban Growth in India and Orissa from 1901 to 2001

Census Year	No of Towns		Urban Population in Million		Percentage of Urban Population to Total Population	
	India	Odisha	India	Odisha	India	Odisha
1901	1916	14	25.85	0.25	10.84	2.47
1911	1908	18	25.94	0.28	10.29	2.42
1921	2048	20	28.09	0.28	11.18	2.52
1931	2220	21	33.46	0.32	11.99	2.54
1941	2427	29	44.16	0.41	13.86	3.00
1951	3060	39	62.44	0.59	17.29	4.06
1961	2700	62	78.94	1.11	17.97	6.32
1971	3126	81	109.10	1.85	19.91	8.41
1981	4029	108	159.50	3.11	23.34	11.79
1991	4689	124	217.60	4.23	25.70	13.38
2001	5161	138	285.40	5.49	27.78	14.97
2011	7935	223	377.10	7.00	31.20	16.70

Source: Compiled by Authors from Census of India

available records reveal that the state has been disaster affected for more than 90 years. All most all the extreme weather events strike the state now-a-days, which include floods, droughts, tropical cyclones, severe thunderstorms, lightning and heat waves. The data reveal that the number of towns in India has nearly doubled in the 40 years preceding 1971. In Odisha, the 2011 census enumerated 223 towns in comparison to only 14 in 1901. The urban population of Orissa has increased from 2.47 percent in 1901 to 16.70 percent in 2011. The state's highest growth rate of urban population i.e. 86.79 percent was experienced during 1951 to 1961. This declined to 29.78 percent during 1991-2001. Orissa however has a comparatively slower rate of urbanisation when compared with the national average.

A major impact of urbanization is manifested in its spatio-temporal growth and land transformation in and around cities and towns. As the rural population migrates to urban centers as a concomitant of urbanization over years, the urban population grows with a spatial expansion thrust towards the outskirts of the Central Business District (CBD) and peri-urban areas. Thus, land transformation or changes in landuse/landcover occur in urban and peri-urban areas from rural, agricultural land, forested ecosystems, flood plains, wetland area, open spaces etc. into urban uses with road, paved and built-up areas like residential colonies, institutional areas, industrial areas, roads and other built-up infrastructure. Based on the rapid population growth and urbanization trends, this urban land transformation becomes rapid and unplanned, which in turn impacts changes in heat and moisture fluxes, air quality, water resources and runoff patterns in and around cities. In this context figure 1 showing greenhouse gas emissions by source indicate that 18.2 percent of greenhouse gas emission

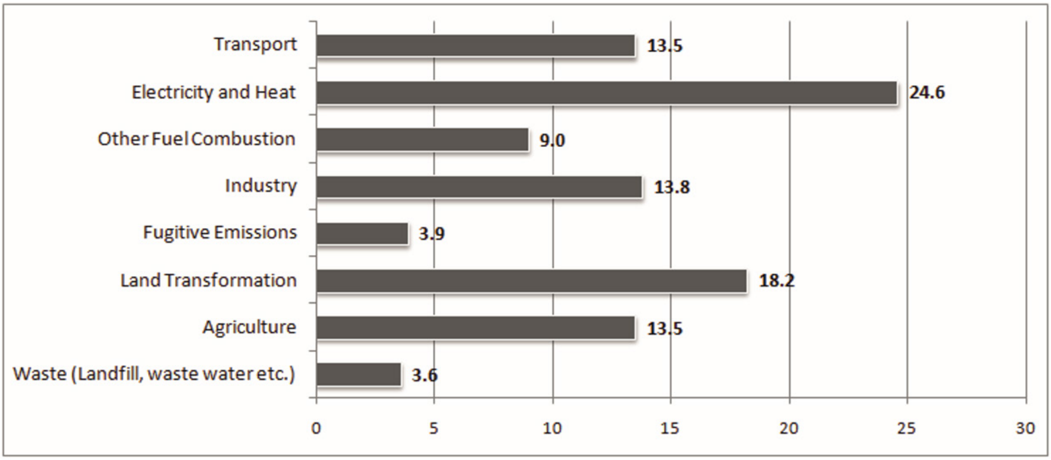

Fig. 1: Global Greenhouse Gas Emissions in 2000 by Source

worldwide is due to urbanization induced land transformation (UN-Habitat 2008).

One of the most important adverse impacts of land transformation in and around cities is increased runoff and increased urban flood vulnerability. Urban flooding refers to the inundation or water-logging caused by stagnant waters for extended periods subsequent to heavy-rainfall events in urban areas which causes runoff to exceed the capacity of the local drainage system in and around cities and towns. "Rapid urban sprawl brings significant landscape modifications of which the most pervasive hallmark is considered to be the transformation from natural lands to imperviousness" (Yao et. al. 2017: 1). "This alteration leads to negative hydrologic impacts that result in enhanced hydraulic efficiency and can thus increase storm-water runoff volumes, flow rates and peak flows and flow-time reductions in urban catchments" (Yao et. al. 2017). The four interrelated but separable effects of landuse change on the hydrology of an area are changes in peak flow characteristics, changes in total runoff, changes in quality of water and changes in hydrological amenities (Leopold, 1968). In this context the present study analyzes the land transformation that occurred in Bhubaneswar city (the capital city of Odisha) and its impacts on natural drainage in terms of changes in runoff which can help in urban flood vulnerability mapping.

Study area

Out of the total urban population of Odisha spread over 223 towns, only Bhubaneswar urban complex contributes around 24 percent (2011 census). The Bhubaneswar Urban Complex comprises two cities (municipal corporations), three other towns and many fringe villages. The capital city Bhubaneswar Muncipal Corporation (study area) constitutes the core with Cuttack Municipal Corporation (on the north), Khurda municipality (south-west), Jatni municipality (south-west) and Pipili NAC (south) located in the periphery. The fringe of these towns encompasses more than 300 villages. On the western boundary of the Bhubaneswar urban complex, there is Chandaka-Damapara Wildlife Sanctuary. The town is located between Latitude 20°51"

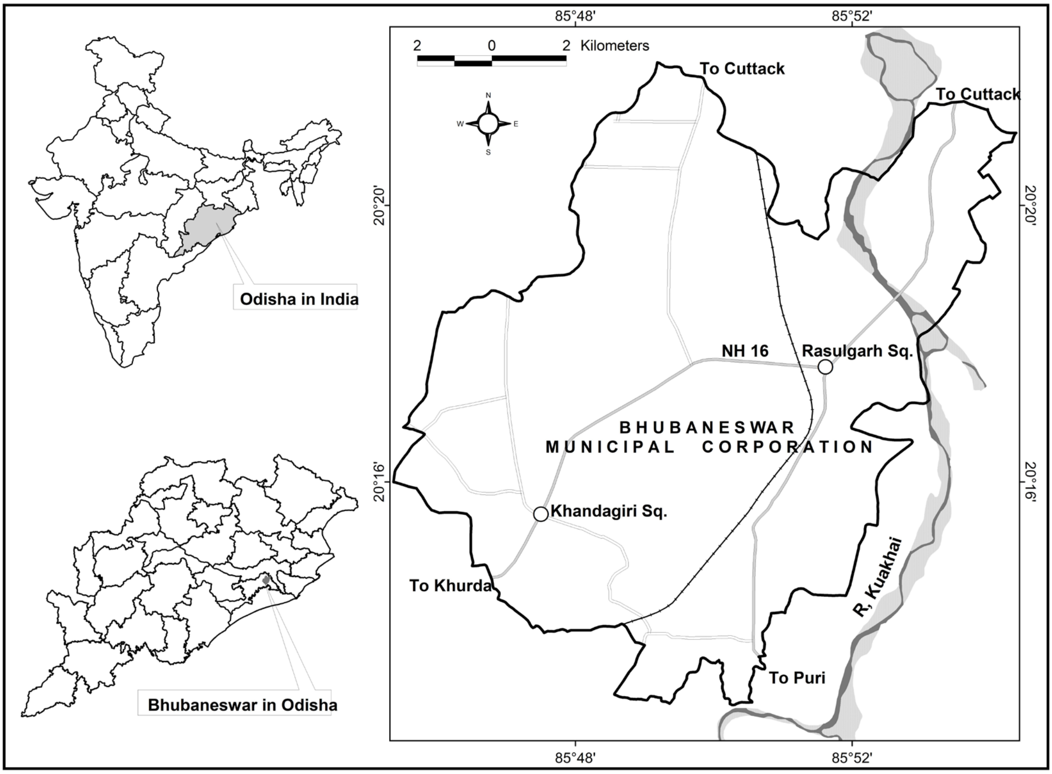

Fig. 2: Index map of the study area: Location of Bhubaneswar Municipal Corporation

to 20° 09" N and longitude 85° 58" to 85° 95" E in the eastern part of Orissa state of India (Fig. 2). The study area occupies a strategic location in regional as well as in the national context as the National Highway from Chennai and Vizag enters the city through Khurda from south and passes on north through Cuttack connecting Kolkata via Baleswar. Thus, the Bhubaneswar, the study area, forms one of the vertices along the Kolkata – Chennai corridor of the golden quadrangle transport network of the country connecting New Delhi, Kolkata, Chennai and Mumbai. The historical town of Puri lies at a distance of 40 kms south of Pipili. The Paradip port in the eastern coast of India is situated at a distance of around 90 kms east of Cuttack. The study area is hence located along one of the important growth corridors of the country and this strategic location has enhanced its potential as one of the important growths centres of the country. Bhubaneswar urban complex has of late become a centre of education, healthcare, administration, tourism, culture and economy in the state as well as in the country.

An analysis of population growth in Bhubaneswar city (Fig. 3) reveals that the city has experienced exponential growth of population from the year 1961 till 2001. The city is relatively young compared to its adjacent old city Cuttack, but its growth has surpassed Cuttack. Till 1981, the population of Bhubaneswar (2,19,211) was well below that of Cuttack (2,95,268). However, , with a

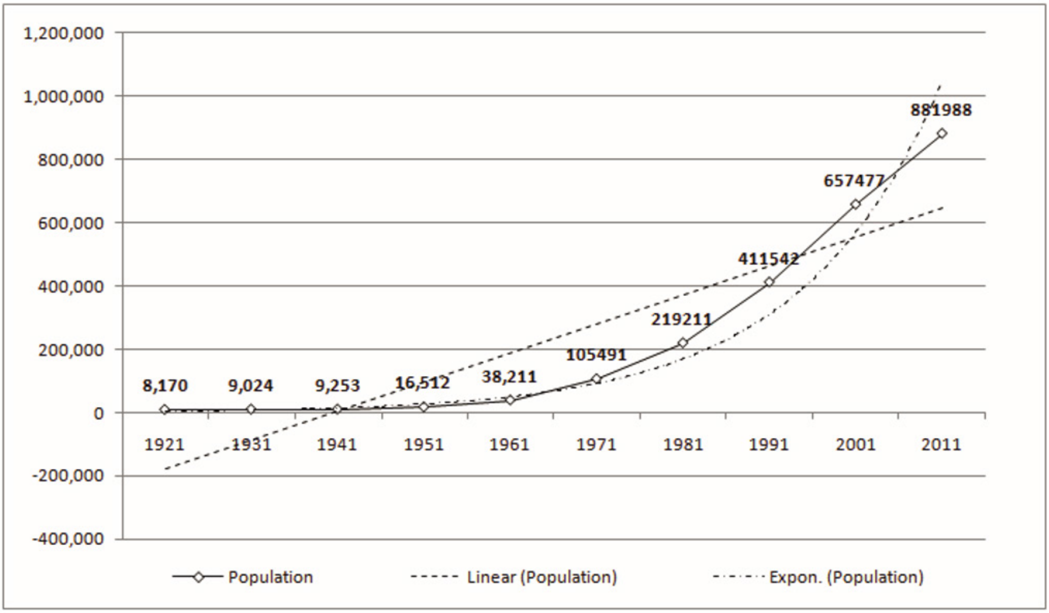

Fig. 3: Year wise Population Growth in Bhubaneswar City

population of 4,11,542 in 1991, the city's size exceeded that of Cuttack with a population size of 4,03,418. The city experienced a whopping 1720.65 percent growth in its population during 1961-2001.

Data and method

The present study is mainly based on remote sensing and GIS based data collection and analysis. The secondary data used in the research included spatial data in the form of numerous maps of varying scale and coverage, Survey of India (SOI) toposheets, masterplans of the city along with non-spatial data consisting of reports, published data, gazette notifications etc. The sources of such data included the Census of India, Bhubaneswar Development Authority, Bhubaneswar Municipal Corporation, Tehsil Office, Directorate of Town Planning-Government of Orissa, Urban Development Department-Orissa, Survey of India, Department of Forest and Environment-Orissa and numerous websites.

The primary data in this study included Global Positioning System (GPS) based field observations and recording through observation schedules. The GARMIN make Etrex Vista handheld GPS receivers have been profitably used for this purpose. The GPS were calibrated by comparing their reading with ground control points in Survey of India toposheets before their use in the present study. The GPS based field observation has also been made in the study to sample check and validate the satellite image derived landuse/landcover layers. In the present research, the multi-temporal and multi-resolution satellite images have been used to map land use/land cover in combination with GPS aided field observation results. The Landsat MSS (Multispectral Scanner) image of 1974 has been used for mapping of land use/land cover for the year 1974. The 4, 2 and 1 band of MSS assigned with red, green and blue forms the false colour composite. The Landsat MSS image has a spatial resolution of 79 metres. The digital satellite image of IRS 1D LISS-III (spatial resolution 23.5 meter) and Cartosat-1 PAN (spatial resolution 2.5 meter) has also been acquired for the year 2010 from National Remote Sensing Centre (NRSC) data centre of Department of Space, Government of India. In combination with this, the high-resolution SPOT satellite image uploaded in www.googleearth.com has also been extracted for a few specific patches needing validation at micro level. The digital images have been interpreted to derive the landuse/landcover map through digital cum visual interpretation technique. The digital enhancement techniques like 'contrast manipulation' and 'spatial filtering' were applied to enhance the image. Then it was interpreted visually 'on screen' in comparison with the SOI toposheets. The processing of IRS 1D LISS–III image involved geo-referencing, digital enhancement and visual interpretation 'on screen' to develop a vector land use layer. The Cartosat-1 PAN image was also followed with same procedure. Further, to obtain high resolution image in multispectral bands, the LISS-III image of 23.5 m spatial resolution has been merged with PAN image of 2.5 m. spatial resolution through 'resolution merge' utility in ERDAS Imagine.

Two landuse/landcover layers, for the years 1974 and 2010, have been developed in GIS for land transformation analysis. The analysis of land transformation from the year 1974 to 2010 has been carried out using 'overlaying' technique in GIS. Open source GIS 'QGIS' has been used for layer/database development, analysis and output generation. The major land transformation categories with their area statistics have been generated in GIS and have been presented in tables and maps. In order to analyse the runoff changes, the land transformation analysis has also been done on reclassified landuse/landcover layers. The reclassification has been done based on built-up area density classes. The very high-density built-up areas indicates compact built up areas coming under commercial, utility and industrial areas. The informal and formal residential areas area less densely builtup and so, are categorized as high-density built-up areas. The institutional and administrative areas have green belts, landscaped areas and garden areas within their campus and thus are categorized under medium density areas. Thus, a reclassified land transformation layer has been developed upon which the drainage catchments have been superimposed for estimation of catchment wise runoff changes from 1974 to 2010. The runoff has been estimated done using the standard formula:

Runoff = Rainfall X Catchment Area X Runoff Coefficient

The normal rainfall of Bhubaneswar has been taken as 1491.1 mm based on 69 years of average data from Indian Meteorological Department (IMD, 2002). The runoff coefficients for various landuse/landcover classes used in the study have been described in Table 2 (*Facilities Development Manual, 1997*). Finally based on these changes in runoff values over the years 1974 to 2010, an urban flood vulnerability map has been developed for the city. A few focus group discussions (FGDs) have also been carried out within Bhubaneswar amongst stake holders including researchers, planners, government officials, social workers, public

Table 2: Runoff Coefficient for various built up area density classes

Density wise Built-up Class	Runoff Coefficient	Landuse/Landcover Class
Very High-Density Built-up Area	0.7	Public Utilities / Recreational / Commercial Area
		Industrial Area
High Density Built-up Area	0.5	Formal Residential Area
		Informal Residential Area
Medium Density Built-up Area	0.3	Institutional/ Administrative/ Restricted Area
Non-Built-up Area	0.2	Green Belt / Vegetation /Agriculture / Open space
Waterbody		Waterbody

etc. for their responses on the impacts of land transformation and runoff change.

Results and discussion

Growth and Land Transformation in Bhubaneswar City

Though a number of studies have described historical growth of Bhubaneswar, the Census of India's publication, 1971, "Bhubaneswar – An Urban Study, special survey report on selected towns" (Sinha 1971) is perhaps the first attempt to describe spatio-temporal growth of the city. The report describes the changes in the spatial extent of the city and also discusses the development dynamics since 1948 up to 1972. Kalia's (1994) study is also a major landmark in describing the growth dynamics of Bhubaneswar. Routray et.al, (2000) too provided a comprehensive account on the growth and development of Bhubaneswar.

In 1948 the master plan for the new capital of Orissa at Bhubaneswar was developed for a population of only 40,000 spread over an area of 16.48 km^2. Today the area of Bhubaneswar Municipal Corporation limits has drastically increased to 135 km^2 comprising 1,44,358 households. The rapidly increasing pressure of population has been largely contributed by in-migration due to development of the city as a major centre of trade, commerce, technology and education.

The prepared landuse/landcover layers indicate that in the year 1974 (Fig. 4) the present Bhubaneswar Municipal Corporation (BMC) area was predominantly underlain by green belt (forest), vegetation, agricultural land with medium density built-up area in the core zone. However, during 2010 (Fig. 5) the core area has become highly compact with extensive development along the periphery at the cost of the green belt, vegetation, agricultural area and opens spaces. The area statistics of landuse/land-cover layers for the years 1974 and 2010 have been presented in Table 3 which reveals that the natural landcover (green belt, vegetation, agriculture and open spaces) accounted for 83.63 percent of the present BMC area during 1974, reducing rapidly to 46.72 percent by the year 2010. On the other hand, the formal residential areas have increased from 5.84 percent in 1974 to 25.95 percent in 2010. The informal residential areas have varied from 2.35 percent in 1974 to 3.26 percent in 2010. With

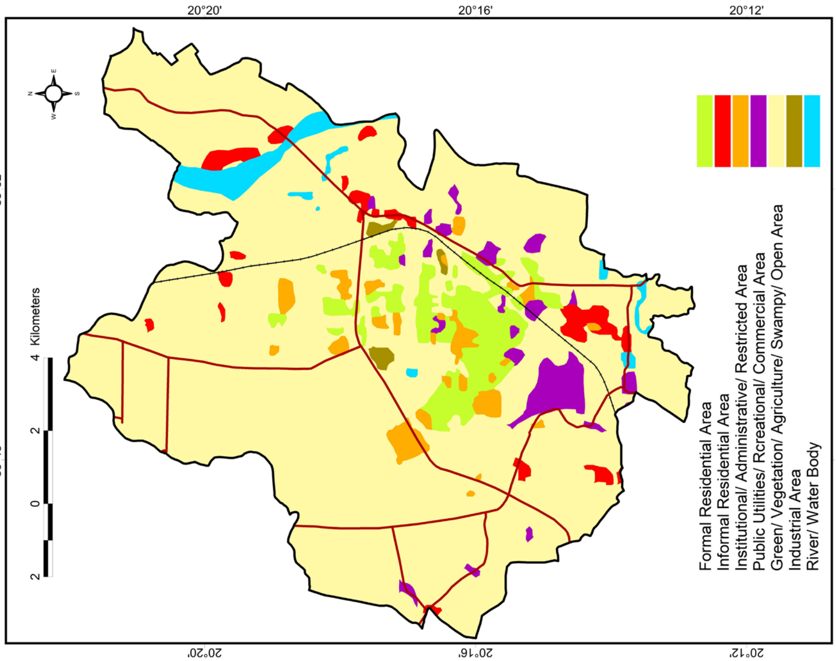

Fig. 4: Landuse/Landcover of Bhubaneswar City, 1974

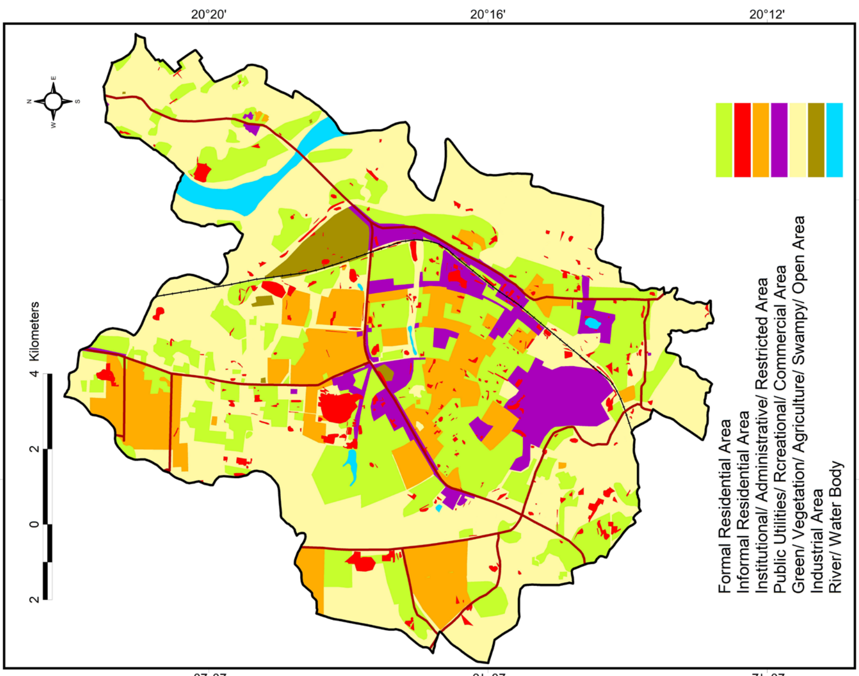

Fig. 5: Landuse/Landcover of Bhubaneswar City, 2010

Table 3: Landuse/Landcover change, 1974-2010

Landuse/Landcover Class	1974		2010	
	Area (km2)	%	Area (km2)	%
Formal Residential Area	8.51	5.84	37.84	25.95
Informal Residential Area	3.42	2.35	4.75	3.26
Institutional/ Administrative/ Restricted Area	3.95	2.71	19.28	13.22
Public Utilities/Recreational/ Commercial Area	4.11	2.82	10.77	7.39
Green Belt/Vegetation/ Agriculture/Open space	121.95	83.63	68.12	46.72
Industrial Area	0.58	0.40	2.55	1.75
Waterbody	3.30	2.26	2.51	1.72
Total	145.82	100.00	145.82	100.00

Source: GIS analysis by Researcher

the growth of the city as an administrative and academic town in the region, the area under institutional and administration has increased from 2.71 percent in 1974 to 13.22 percent in 2010.

A detailed landuse/landcover change analysis from 1974 to 2010 has been carried out on GIS platform through overlaying technique, the result of which has been presented in Fig. 6 and Table 4. The results reveal that the major land transformation has occurred from the green belt (forest/ vegetation/ agriculture /open area) to built-up area. Around 40 percent of the existing BMC area has been converted under this category of change covering an area of 57.17 km^2. The highest land transformation from green belt is for formal residential areas (20.57 % of the total area covering 30 km^2) followed by that for institutional /administrative area (9.94 % covering an area of 14.5 km^2), for public utilities /recreational /commercial area (4.31 % covering an area of 6.28 km^2) and for informal residential area (2.72 % over an area of 3.96 km^2). It is also observed that substantial area has been transformed from informal residential area to green/ vegetation/agriculture/open area (1.21 km^2) which indicates development of parks and green belts in encroached areas. The resultant reclassified land transformation layer (based on built-up area density) indicates that a major part of land has been transformed from non-built up area to high-density built-up area (33.95 km^2– 23.28 % of total BMC area) (Table 5).

Natural drainage

Bhubaneswar city and its fringe area are surrounded by distributaries of Mahanadi River in the north, east and south. The rivers Kuakhai and Daya are fourth and third order distributaries of River Mahanadi respectively. A network of channels and streams, which originate on the west of the city and flow across the city to east, joins Kuakhai and Daya rivers and drains the city and its fringe area. The Mahanadi River bifurcates into several distributaries once it reaches the Cuttack district. The Mahanadi takes about

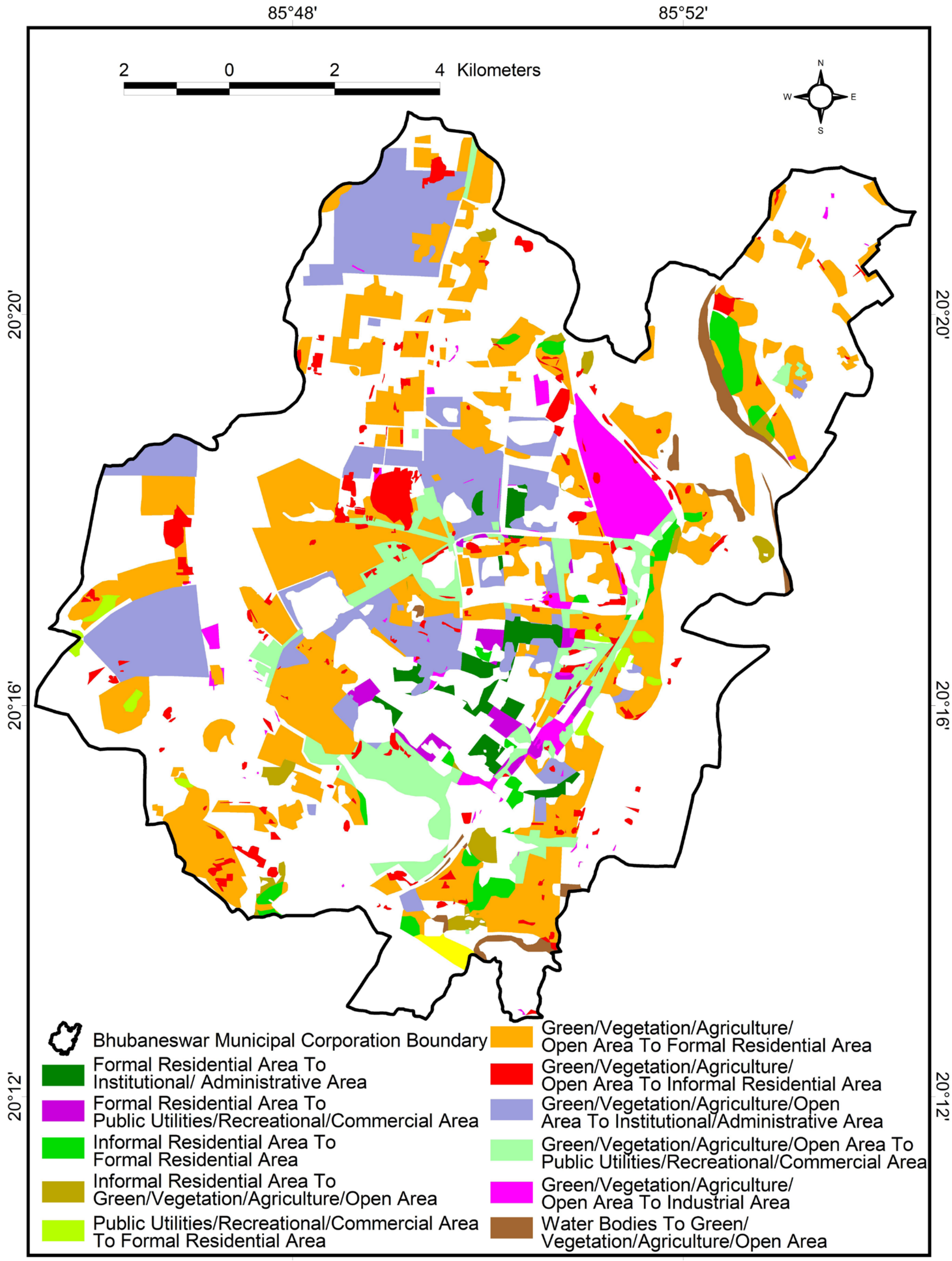

Fig. 6: Land transformation of Bhubaneswar city, 1974 to 2010

Table 4: Major land transformation, 1974 to 2010

Landuse/Landcover Change	Area (km2)	%
Green/Vegetation/Agriculture/Open Area to Formal Residential Area	30.00	20.57
Green/Vegetation/Agriculture/Open Area to Institutional/Administrative Area	14.50	9.94
Green/Vegetation/Agriculture/Open Area to Public utilities, Recreational, Commercial Area	6.28	4.31
Green/Vegetation/Agriculture/Open Area to Informal Residential Area	3.96	2.72
Green/Vegetation/Agriculture/Open Area to Industrial area	2.43	1.66
Sub Total: Green/Vegetation/Agriculture/Open Area to Bultup Area	**57.17**	**39.21**
Formal Residential Area to Institutional/Administrative Area	1.86	1.27
Informal Residential Area to Formal Residential Area	1.57	1.08
Water bodies to Green/Vegetation/Agriculture/Open Area	1.36	0.94
Informal Residential Area to green, Vegetation, Agriculture, Open Area	1.21	0.83
Formal Residential Area to Public utilities, Recreational, Commercial Area	1.16	0.79
Public utilities, Recreational, Commercial Area to Formal Residential Area	1.06	0.72

Source: GIS analysis by the researcher

Table 5: Reclassified land transformation from 1974 to 2010

Land Transformation categories	Area km^2	%
Non Builtup Area to High Density Builtup Area	33.95	23.28
Non Builtup Area to Medium Density Builtup Area	14.49	9.93
Non Builtup Area to Very High Density Builtup Area	8.70	5.97
High Density Builtup Area to Very High Density Builtup Area	1.65	1.13
Waterbody to Non Builtup Area	1.36	0.94

Source: GIS analysis by the researcher

49 percent water from the main stream and the rest going into Kathajori River. This river has been bifurcated further north of the Bhubaneswar to form Kuakhai River. The Kuakhai is bifurcated into Kushabhadra and Kuakhai east of Bhubaneswar near Pandara. Then further at Lingipur on the south of the city, the Kuakhai is bifurcated to form River Bhargavi and River Daya. The Kushabhadra joins Bay of Bengal whereas the rivers Daya and Bhargavi deposit their waters into the Chilika lagoon. From Kuakhai some water moves into the Gangua *nala* (stream) that flows in the eastern side of the Bhubaneswar city through the Mancheswar escape.

Physiographically, Bhubaneswar has been broadly divided into western uplands and eastern alluvial lowlands. The western uplands consist of 10 valleys, each containing a natural drainage channel at the lowest contour through which rain water gets discharged into Gangua *nala* and ultimately to Daya river. The Bhubaneswar Development Authority prepared a Drainage Development Scheme (DDS) that has been published under Rule-25 of the Orissa Development Authorities Rules,

Table 6: Length and catchment area of master drains in Bhubaneswar

Master Drain No.	Starting and Outfall Point	Length (Km.)	Catchment Area (km2)
1	Start: Budha Park Outfall: Budhi Nalla near Daya West Branch Canal Crossing	6.50	15.88
2	Start: Back side of Sainik School Road Culvert Outfall: Confluence point of Drain No-3 near VSS Nagar, Railway Bridge.	1.63	2.90
3	Start: OSAP Colony, (Gajapati Nagar) Outfall: Gangua Nalla	4.2	6.64
4	Start: Ekamrakanan Outfall: Gangua Nalla	8.8	17.69
5	Start: Near Gurudwar Culvert on Janapath Road. Outfall: Gangua Nalla	3.4	6.63
6	Start: Railway Bridge Outfall: Gangua Nalla	1.1	3.29
7	Start: Culvert at Airport Road Outfall: Gangua Nalla	4.7	17.65
8	Start: Jokalandi Road Outfall: Confluence point of Drain No- 9	8.51	11.69
9	Start: Ghatikia Outfall: Drain no – 8 near Dumduma	6.34	10.58
10	Start: CRP Colony Lake near Mamtaj Ali High School. Outfall: Gangua Nalla	5.9	12.50

Source: GIS based mapping

1983 in the Orissa Gazette on 6th December 1994. This scheme has defined 10 master drains in Bhubaneswar city (Table 6). As per the DDS, the width of the master drains varies from 2 m. to 4 m. at starting points and 4m. to 13m. at outfall points. The average velocity of water flow in these drains vary from 2.5 to 3 m./sec. The depth of the drains is about 1.5m. at the start and about 3m. at outfall points. The drain 01 discharges maximum water at outfall followed by the drain 04 and drain 10 (BDA, 1994).

Impact of Land Transformation on Natural Drainage: Changes in Runoff and Urban Flood Vulnerability in Bhubaneswar

As has been observed in Bhubaneswar, the rapid land transformation from non-built up to high density built-up areas has disrupted the natural drainage pattern. In fact, rapid land use changes like unplanned development of residential areas, institutional campuses and industrial areas (especially along river banks of Kuakhai river) have resulted in uncontrolled and haphazard disposal of solid wastes and garbage into the existing drainage system, and blockage of natural drainage channels. These urban anthropogenic activities are related to the disappearance of natural drainage system and the creation of impervious surfaces resulting in increased runoff.

Table 7: Master Drain Catchment wise runoff (in Million Cubic Meter-MCM) increase, 1974-2010

Drain No	Annual Runoff in MCM in 1974	Annual Runoff in MCM in 2010	Increase in Runoff in MCM
D1	4.81	6.82	2.01
D2	1.02	1.38	0.36
D3	2.07	3.46	1.39
D4	5.96	10.95	4.99
D5	2.99	3.73	0.74
D6	1.47	1.67	0.2
D7	8.98	11.81	2.83
D8	4.34	6.53	2.19
D9	3.33	4.78	1.45
D10	4.91	10.56	5.65

Source: Analysis by Researcher

Table 8: Respondents' opinion on causes of increased runoff & land-use change

Issue	% of Respondents
Flooding and Waterlogging	96
Water Pollution	94
Damage of Vegetation and Aquatic Habitats	42
Traffic Problems	90
Disruption of Normal Life and Impact on Poor	95
Damage of Infrastructure	75
Increase of Water Born Diseases & Mosquito Breeding Sites	90

Source: Field FGDs by Researcher

Rainstorms generate runoff, and its occurrence and quantity are dependent on the characteristics of the rainfall event, i.e. the intensity, duration and distribution. Apart from these rainfall characteristics, there are number of catchment specific factors, which have a direct effect on the occurrence and volume of runoff. This includes soil type, vegetation cover, slope and catchment type. However, in an urban area the predominant catchment characteristic that determines the runoff volume is the landuse/landcover.

In the present study, the master drains and their catchment layers have been superimposed on earlier derived reclassified land transformation layer in GIS for estimating catchment wise runoff for the both time periods (1974 and 2010) (Fig. 7). The estimated runoff for individual catchments of master drains has been summarized in Table 7 which indicates that the quantity of annual runoff has increased in all the 10 catchments within Bhubaneswar. The highest increase is in catchment of Drain 10 (5.65

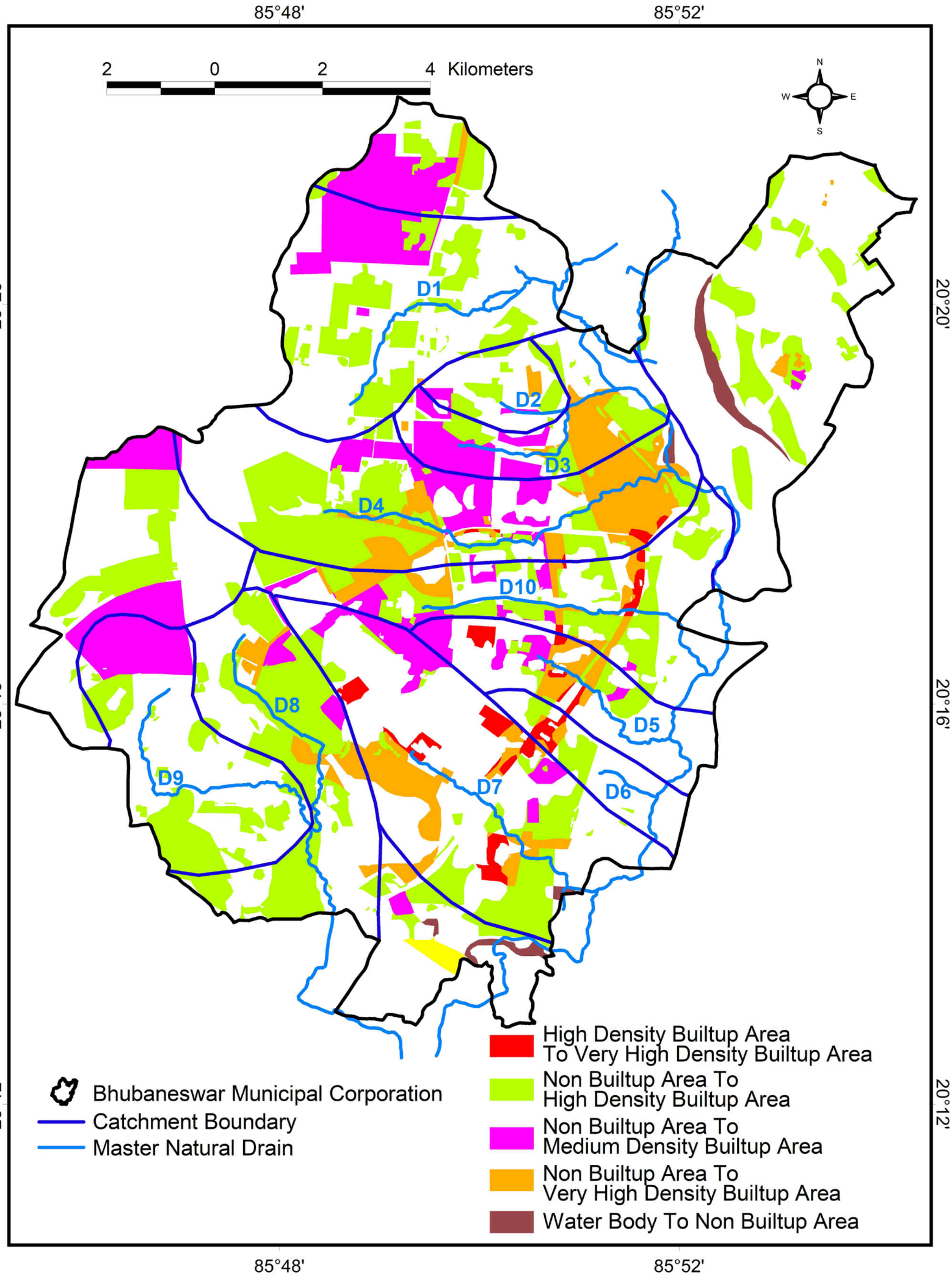

Fig. 7: Master Drains, catchments and reclassified land transformation in Bhubaneswar, 1974 - 2010

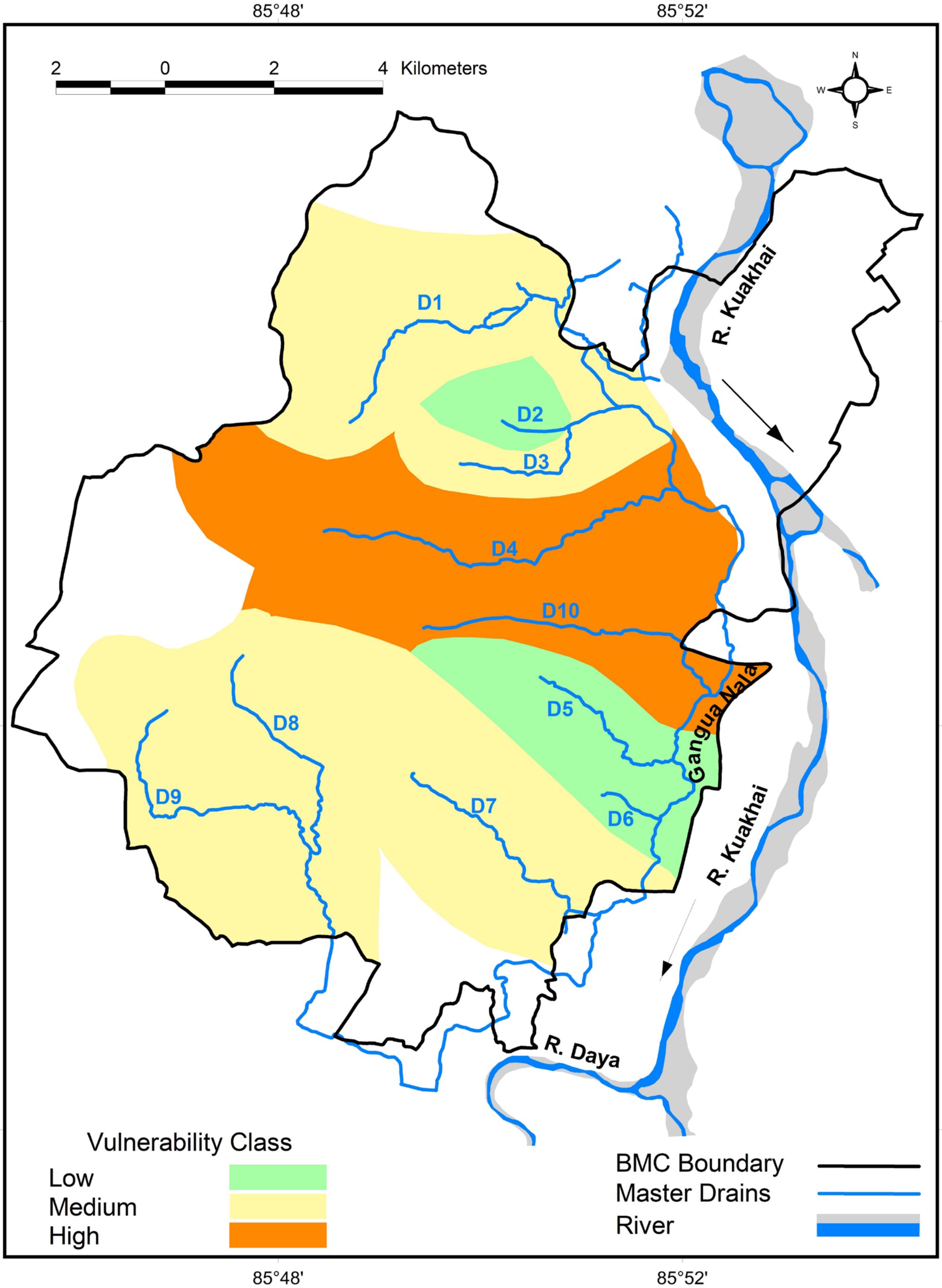

Fig. 8: Urban flood vulnerability map for Bhubaneswar City

MCM) followed by Drain 4 (4.99 MCM), where the volume of estimated annual runoff has doubled in 2010 compared to 1974. The lowest increase is in the catchment of Drain 6 (0.2 MCM) followed by Drain 2 (0.36 MCM) and Drain 5 (0.74 MCM). Based on these runoffs, an urban flood vulnerability map has been developed (Fig. 8), which indicates that the catchments of Drain 4 and Drain 10 are highly vulnerable and catchments of Drain 2, 5 and 6 are less vulnerable areas with the remaining catchment areas coming under medium vulnerability.

The results of focus group discussions (FGDs) with stake holders in Bhubaneswar indicate that 'flooding and water-logging' is the most important environmental and social issues that is affecting urban residents of Bhubaneswar (Table 8).

Conclusion

Urban centers are rapidly growing worldwide and India is no exception. The Odisha state of late is experiencing higher urbanization, but the urban population is largely concentrated in its capital city region giving rise to a very unbalanced and unplanned urbanization pattern and spatio-temporal growth in the state. The remote sensing and GIS based landuse/landcover mapping and land transformation analysis for Bhubaneswar city shows that much of the city area has been transformed from non-built-up area to excessive built-up area over the 40 years since 1970. An integrated GIS based analysis of land transformation along with the master drain catchment areas has provided input for catchment wise estimation of changes in runoff for the reference period. The results reveal that the catchment of Drain 04 and Drain 10 have become highly vulnerable to urban flooding and water logging caused by land transformation for urban uses/built-up areas.

Major impacts of land transformation and increased runoff as identified by the stakeholders (in decreasing order of importance) are: flooding and waterlogging, disruption of normal life and having its serious adverse impacts on the urban poor, water pollution, traffic problems and increase in incidence of growing water borne diseases and mosquito breeding sites.

In this context the management interventions need prioritized attention on incorporation of drainage development plan in a comprehensive development plan of the city and preparation of an integrated development plan of the city and its vicinity with greater horizon year and focus on compliance of drainage issues. At the field level, the municipal and development authorities should enforce the laws for conservation and protection of the master drains, regulation of unplanned landuse alterations, adjustment of drainage capacity of the drains and regulation of waste disposal into natural drains of the city. Further studies may also be carried out in highly vulnerable catchments for exploring micro level drainage problems and same study may be replicated for other very old cities of the state like Puri and Cuttack, which are also suffering from similar issues.

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