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A REMOTE SENSING AND GIS-BASED ANALYSIS ON THE IMPACT OF DAM CONSTRUCTION TOWARDS THE LAND USE LAND COVER PATTERN OF BAKRESWAR WATERSHED, INDIA

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Abstract
The present study evaluates the impact of dam construction on the land use and land cover (LULC) pattern of the Bakreswar Watershed in the Birbhum District, West Bengal, India during 1990-2020. Landsat 5 TM and Landsat 8 OLI data were used to analyze the LULC pattern during the pre- and post-dam construction period. Supervised image classification using the maximum likelihood algorithm was done to generate LULC and change detection maps in ArcGIS. LULC dynamic attitude and transfer matrix were prepared based on the LULC maps of four years. The results show that the dam construction significantly influenced the LULC pattern of the region. The highest rate of increase is seen in the waterbody class (86.37%) during 1990–2000 due to dam construction. The cultivated land class also increased by 12.31% during this period. After the dam construction, the conversion rate from fallow land to cultivated land is higher in the downstream area rather than the upstream area. The area under the barren land class decreased by 53.28% in 1990–2000 and by 41.23% during 2009–2020 due to its conversion to built-up area. The built-up area class rapidly increased during the past 20 years, by 34.57% and 45% during 1990–2000 and 2009-2020, respectively. Major change is seen along the Panagarh–Morgram Highway which connects two urban centers, Suri and Dubrajpur. Settlement concentration is also high around the Bakreswar Thermal Power Plant (BkTPP) and BkTPP Township. This study provides a useful approach to understanding the impacts of dam construction on cultivated area change and how transportation facility influences urban agglomeration.

Keywords: Bakreswar Dam, LULC pattern, LULC dynamic attribute, transfer matrix, remote sensing

1. Introduction

Analysis of LULC dynamics is important for monitoring and managing natural resources and urban development because it provides quantitative analysis of the spatial distribution of various LULC types on the earth's surface. It has diverse applications such as the assessment of deforestation, changes in vegetation distribution, seasonal changes in crop production, damage assessment, disaster monitoring, etc. In LULC change analysis, the terms land cover conversion and modification are very important. Land cover conversion means a change from one land cover to another; the term modification involves the alteration of structure or function without a complete change. Primarily, land cover change is a natural process consequent upon climatic variation, volcanic eruption, change in river channels or sea level, etc. But in the present and recent past, most of the land cover changes are due to human actions such as crop production, settlement, and others, which affect the hydrological balance of any area, increase the risks of flood and landslide, cause air and water pollution, etc. Other local impacts of land use change include soil erosion, sedimentation, soil and groundwater contamination, extinction of indigenous species, etc. (Briassoulis, 2020). The earth's surface has experienced a variety of changes in the past 50 years due to population explosion, which primarily encourages the conversion of arable land to built-up areas. The extension of urbanization tremendously influences the LULC pattern (Digra, et al., 2022). The growing population and increase in the socio-economic necessities create pressure on the land with unplanned and uncontrolled LULC change (Reis, 2008). Two major causes behind the LULC change in a river basin area are forest clearance and urbanization which modify the hydrological as well as the morphological characteristics of the river (Biswas, 2014). Construction of various water infrastructures such as multipurpose dams, reservoirs, check dams, etc. provide direct and indirect benefits for farmers, rural and urban poor people, and agricultural workers. The direct economic impact of dam construction includes increased agricultural production, providing water for households and industries, hydropower generation, reduction in droughts and floods as well as reduce the poverty level of those regions (Bhatia, et al., 2007).

LULC change has a greater impact on soil erosion (Kaul and Sopan, 2012), spatial redistribution of rainfall (Woldemichael, et al., 2012) geodiversity as well as biodiversity loss (Datta, 2022), and other environmental parameters (Rahaman, et al., 2020), and hence needs to be assessed for planning and development of any region. Remote sensing data analysis using GIS software has been widely used as it helps in an almost accurate assessment of LULC patterns and changes at coarse to very fine spatial and temporal scales. Supervised image classification using the maximum likelihood algorithm has been mostly used for the preparation of LULC maps (Choudhury et al. 2019; Datta and Deb, 2012; Kaul and Sopan, 2012; Abd and Alnajjar, 2013; Kayet, et al., 2019; Patel, et al., 2019; Jamal and Ali, 2021; Mandal and Chatterjee, 2023). ArcGIS and ERDAS Imagine software have been widely used for LULC mapping and change detection analysis (Datta and Dev, 2012; Karwariya and Tripathi, 2012; Hassan, et al., 2016; Zope, et al., 2016; Meer and Mishra, 2020; Jamal and Ali, 2021; Parihar, et al., 2022). The LULC of an area is greatly influenced by the construction of the dam (Cho and Qi, 2021; Samsudin, et al., 2020; Qi, et al., 2020). Dams are necessary for agricultural development at the national as well as regional level, flood management, and power generation systems, and to ensure the availability of water resources for various agricultural, industrial, and power generation purposes. Man-made dams and reservoirs have massive benefits in terms of flood control, irrigation, water supply, and hydropower generation but there are also some negative impacts of dam construction like sedimentation which influences the natural river system (Bonnema and Hossain, 2017). Changes in LULC classes and the alteration of the LULC over the catchment area are also seen due to the construction of hydroelectric dam which is associated with land clearing and dam impoundment activities (Samsudin, et al., 2020). LULC change occurs in the different stages of a dam construction period (Cho and Qi, 2021). The climate of a region is influenced by the LULC change and these conditions play a key role in hydrological drought whose effect can be modified by river dam construction as well as reservoir construction (Qi, et al., 2020).

The Bakreswar Dam was constructed across the Bakreswar River at Chinpai, Birbhum District, West Bengal, primarily to meet the water requirements of the

Bakreswar Thermal Power Plant (BkTPP) in Birbhum. The Bakreswar Dam, locally known as the ‘Nil Nirjon’ Dam, construction started in the year 1996 and was completed in July 2000. The present study thus aims to (i) identify the LULC pattern of the Bakreswar watershed during the pre-dam construction period, i.e., prior to 2000, and post-dam construction period, i.e. after 2000, and (ii) analyze the change in the LULC pattern during 1990–2020.

2. Materials and Methods

Study area

The Bakreswar watershed extends from 23°44’22” N to 23°56’22” N latitude and87°16’52” E to 87°48,’26” E longitude covering an area of 725.52 km^2 (Fig. 1). The Bakreswar River originates in Jamtara (23°55’22.13” N, 87°17’18.46” E), Santhal Parganas, Jharkhand and flows eastward through the hot spring of Bakreswar into the Birbhum District of West Bengal. It meets the Kopai River at Milanpur, Birbhum (23°47’06.3” N and 87°48’26.09” E) and flows further east as Kuiya River, which joins the Mayurakshi River in the Murshidabad District of West Bengal. The total length of the Bakreswar River is 86.38 km of which 13.87 km is perennial (Ghosh, 2016).

The watershed is mostly underlain by the Archaean Granite-Gneiss Complex. The Gondwana of the Carboniferous-Permian Age underlies the central part, and the Laterite of the Cenozoic Era is predominant in the western and southwestern parts of the watershed (Ghosh, 2016). High-plain metamorphic rocks like gneiss, schist, and varieties of phyllites are predominant in this watershed (GoWB, 2021). There are a lot of hot springs in Bakreswar (Mukhopadhyay and Sarolkar, 2012). Physiographically, the entire Birbhum district is divided into four sub-micro regions viz. Nalhati Plain, Brahmani-Mayurakshi Basin, Suri-Bolpur Plain, and Bakreswar Upland (Census of India, 2011). The Bakreswar watershed lies in the Bakreswar Upland and the Suri-Bolpur Plain area. It is a part of ancient Rarh Bhumi of Bengal which is an extension of the Chotanagpur Plateau to the south and southeast. The elevation ranges from 24m

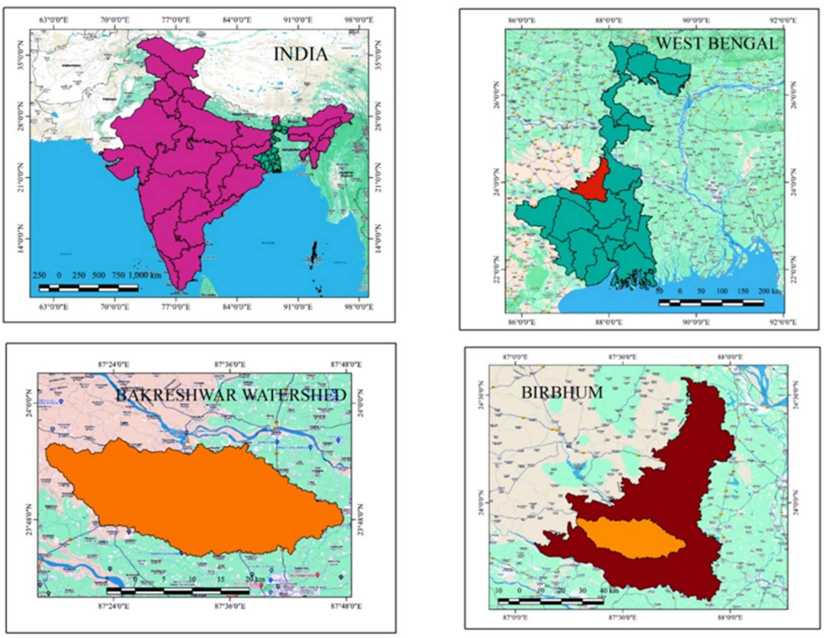

Fig. 1. Location map of Bakreswar watershed

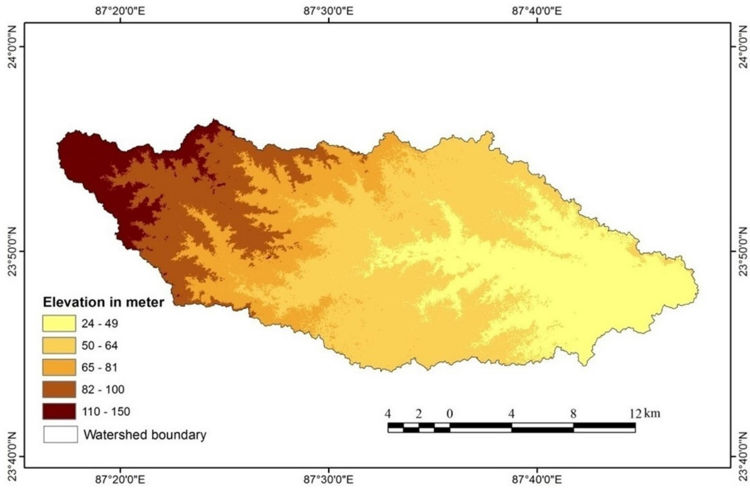

Fig. 2. Elevation map based on DEM data

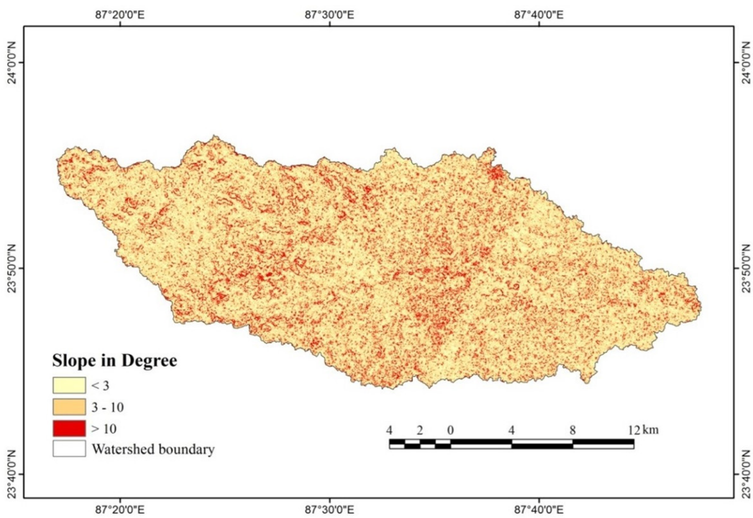

Fig. 3. Slope map of the Bakreswar Watershed

to 150m (Fig. 2). The average slope is 3-5° in the upstream area and decreases to <1° in the downstream area (Fig. 3).

The area experiences a subtropical sub-humid monsoon climate. Temperatures rise rapidly up to 48°C during summer. The winter months of this region extend from December to February. January is the coldest month with the mean daily maximum temperature of about 25°C and the minimum temperature decreases to 5–6°C. The region receives 79% rainfall during the summer monsoon period (June-September). Annual rainfall varies from 828.8 mm to 1917.1 mm. Fig.4 shows the monthly distribution of mean annual temperature and rainfall at the India Meteorological Department (IMD) station in Suri, Birbhum District (IMD, 2008).

The area is covered mostly by reddish, loose, friable, and sterile laterite soil with ferruginous concretions (O'Malley 1910). The forest area abounds with Shorearobusta (Sal), Terminalia Arjuna (Arjun), Madhucaindica (Mahua), Butea monosperma (Palash), Awava Spo. (Sisal), Barassusflabellife (Palm), Phoenix Sylovostris (date palm), Syzgiumcumini (Jamun), Dalbargiasissoo (Sissoo), Acacianilotica (Babul) (Census of

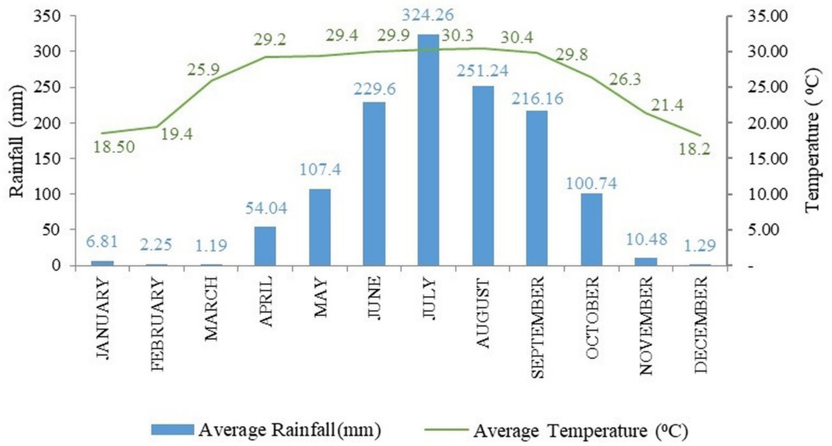

Fig. 4. Temperature and rainfall graph, Suri (Source: IMD, Pune)

India, 2011). Crop cultivation is the main economic activity of the watershed, followed by fishing. The construction of the Bakreswar Dam enhanced tourism in the region. The establishment of the BkTPP provided opportunities for people to get engaged in secondary as well as service sectors.

The Bakreswar Dam and Reservoir, locally called the 'Nil Nirjon' Dam, is constructed across the river Bakreswar (Plate 1). Actual construction work for the dam started in November 1996 (GoWB, 2012). The Bakreswar reservoir has a storage capacity of about 2.29 Mm3 and covers an area of about 6.38 km2 (data collected from BkTTP, WBPDCL, Bakreswar). The BKTPP (Plate 2) is owned by the West Bengal Power Development Corporation Limited (WBPDCL) and is one of the "most significant, reliable, and prestigious coal-fired power plants in West Bengal which generates electricity around 1050 MW" (Census of India, 2011). The water of the reservoir is used for the dual purpose of supplying fresh water to the power plant as well as to the surrounding villages; fishing is also common here.

Data source

Topographical maps of 73M/5, 73M/9, and 73M/10 on a 1:50,000 scale were downloaded from the website of the Survey of India (https://onlinemaps.surveyofindia.gov.in/). The SRTM DEM data was downloaded from the United States Geological Survey (USGS) portal (https://earthexplorer.usgs.gov.in/). Four multi-temporal cloud-free Landsat 5 and 8 images for the agricultural years (June-May in India)

Plate 1. Bakreswar Dam, Birbhum, West Bengal India

Plate 2. Bakreswar Thermal Power Plant, Birbhum, West Bengal, India

Table 1. Satellite data characteristics

Sl. No.	Satellite	Sensor	Path & Row	Date	Bands used	Spatial Resolution
1.	Landsat 5	TM	139 & 043	December 23, 1990	1-5 and 7	30 m
2.	Landsat 5	TM	139 & 043	December 2, 2000	1-5 and 7	
3.	Landsat 5	TM	139 & 043 139 & 044	November 25, 2009	1-5 and 7	
4.	Landsat 8	OLI-TIRS	139 & 043	November 23,2020	1-7	

– 1990-91, 2000-01, 2009-10, and 2020-21 were also downloaded from the USGS portal (Table 1). Such a selection of years helped in the analysis of the LULC pattern during the pre-dam construction period, i.e., 1990. The period 2000-2020 represented the post-dam construction phase. Landsat 5 has seven bands and Landsat 8 has eleven bands. Visible and infrared bands 1-5 and 7 of Landsat 5 with 30m spatial resolution, and visible and infrared bands 1-7 of Landsat 8 with 30m spatial resolution were used. The images for the months of November and December were downloaded that corresponded to the sowing or post-sowing period of the Rabi crop in the area. Mosaicking was applied to join the two adjacent scenes of the 2009 Landsat image into one large radiometrically balanced image; the study area was then extracted from the mosaic.

LULC mapping

Fig.5 shows the methodology for the present study. Supervised image classification with a maximum likelihood algorithm was done using ArcGIS 10.3 software, to prepare the LULC maps of 1990, 2000, 2009, and 2020. A group of training sets were selected to represent the LULC classes; for each class, about 30 training sets were selected. Seven LULC classes were visually identified: barren land; built-up area that included settlement and transport, and other built-up areas; cultivable land that included cultivated and fallow land; natural vegetation; and waterbody.

Accuracy Assessment

A classification accuracy assessment was performed based on the 48 ground truth points (Fig.6) representing different LULC classes in the study area. The LULC maps of the pre-and post-dam construction period showed a major change of LULC pattern in the west-central part of the watershed, especially near the dam, BkTPP, BkTPP Township area, and along the major roadways. These areas were, therefore, verified through field observation. The accuracy assessment of the LULC map of 2020 was done based on

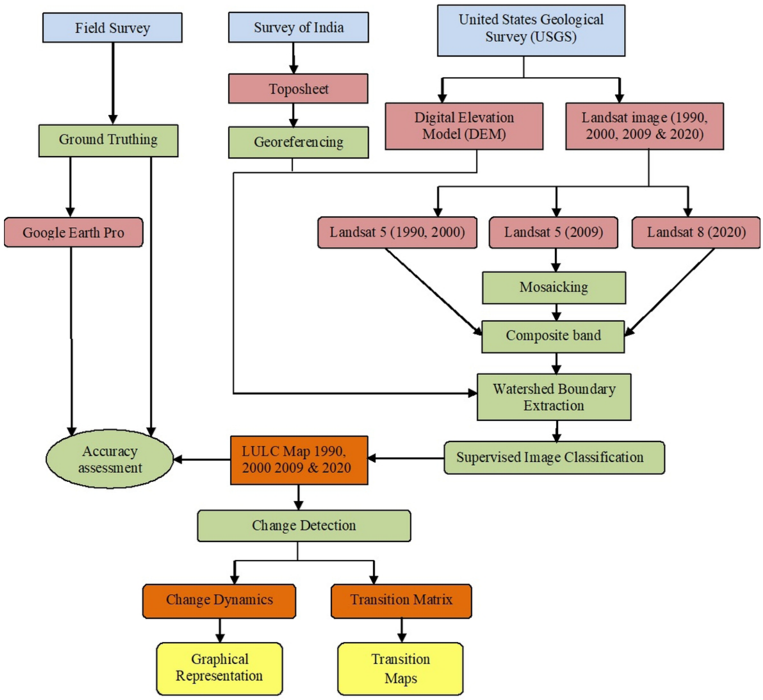

Fig. 5. Methodological flowchart of the study

the ground truth points. The accuracy of the LULC maps of 1990, 2000, and 2009 were assessed using Google Earth Pro. The ground truth points were identified on each map, saved in .kml format, and verified in Google Earth Pro for each year.

Statistical analysis was done to determine overall, user's and producer's accuracy, and Kappa analysis was based on the error matrix (Table 2 a-d). The overall accuracy represents the accuracy of the whole classification and was calculated using equation 1:

$$Overall\ accuracy = \frac{Total\ no.\ of\ correctly\ classified\ pixels}{Total\ no.\ of\ reference\ pixels} \times 100 \qquad (1)$$

The kappa analysis indicates the probability of chance agreement between the ground truth point and the classified LULC map (Datta et al., 2012). The kappa coefficient is theoretically expressed as the difference between observed accuracy and chance agreement divided by (1–chance agreement). It was calculated using equation 2:

$$K = \frac{(TS \times TCS) - \sum(column\ total - row\ total)}{TS2 - \sum(column\ total - row\ total)} \qquad (2)$$

LULC change detection

LULC dynamic attitude and transfer matrix were prepared based on the LULC maps of four years to analyze the LULC change during 1990-2020. LULC dynamics attitude refers to the quantitative change of certain land use types and reflects the positive (increase) or negative (decrease) change of all land use types within a specific time in a particular area. LULC dynamic attitude in the present study represented the changing status of the LULC classes in three different periods viz. 1990–2000, 2000–2009, and 2009–2020. The change in area under different LULC classes was calculated using equation 3:

$$Percentage\ of\ change = \frac{(Area\ in\ present\ year - Area\ in\ previous\ year)}{Area\ in\ previous\ year} \times 100 \qquad (3)$$

Land use transfer matrix is the application of the Markov model in land use change analysis. The transition matrix or confusion matrix is a table that shows the LULC change from the initial stage to the final stage (Yao, 2021). The Markov model shows the conversion from one land use to another as well as the transfer rate between the different

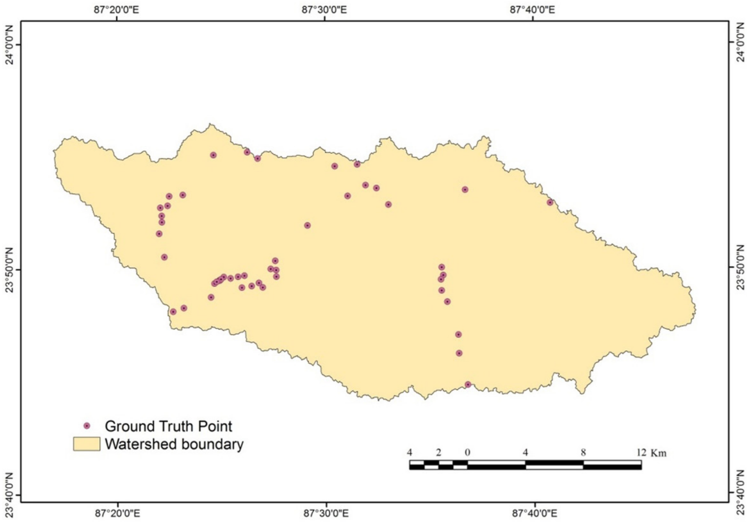

Fig. 6. Ground observation points

Table 2a. Error Matrix resulting from data analysis, 1990

Classification Data	Waterbody	Other built-up area	Natural vegetation	Settlement & transport	Cultivated land	Fallow land	Barren land	Total (User Accuracy)
Waterbody	4	0	1	0	0	0	0	5
Other built-up area	0	4	1	0	0	0	0	5
Natural vegetation	1	0	6	0	0	0	0	7
Settlement & transport	1	0	1	7	0	0	0	9
Cultivated land	0	0	0	0	8	1	0	9
Fallow land	0	0	0	0	0	6	0	6
Barren land	1	0	0	0	1	0	5	7
Total (Producer Accuracy)	7	4	9	7	9	7	5	48

Table 2b. Error Matrix resulting from data analysis, 2000

Classification Data	Waterbody	Other built-up area	Natural vegetation	Settlement & transport	Cultivated land	Fallow land	Barren land	Total (User Accuracy)
Water body	5	0	0	0	0	0	0	5
Other built-up area	0	4	0	0	0	0	0	4
Natural vegetation	0	0	7	0	0	1	0	8
Settlement & transport	0	0	0	3	1	0	0	4
Cultivated land	0	0	1	0	15	0	0	16
Fallow land	0	0	0	0	1	5	1	7
Barren land	0	0	0	0	0	0	4	4
Total (Producer Accuracy)	5	4	8	3	17	6	5	48

Table 2c. Error Matrix resulting from data analysis, 2009

Classification Data	Waterbody	Other built-up area	Natural vegetation	Settlement & transport	Cultivated land	Fallow land	Barren land	Total (User Accuracy)
Water body	5	0	0	1	0	0	0	6
Other built-up area	0	4	0	0	1	0	0	5
Natural vegetation	1	0	6	0	0	0	0	7
Settlement & transport	0	1	0	6	0	0	0	7
Cultivated land	0	0	0	0	11	1	0	12
Fallow land	0	0	0	0	0	6	1	7
Barren land	1	0	0	0	0	0	3	4
Total (Producer Accuracy)	7	5	6	7	12	7	4	48

Table 2d. Error Matrix resulting from data analysis, 2020

Classification Data	Waterbody	Other built-up area	Natural vegetation	Settlement & transport	Cultivated land	Fallow land	Barren land	Total (User Accuracy)
Waterbody	4	0	0	0	0	0	0	4
Other built-up area	0	15	1	0	0	0	0	16
Natural vegetation	0	0	7	1	0	0	0	8
Settlement & transport	0	0	0	6	1	0	0	7
Cultivated land	0	0	0	1	5	0	1	7
Fallow land	0	0	1	0	0	3	0	4
Barren land	0	0	0	0	0	0	2	2
Total (Producer Accuracy)	4	15	9	8	6	3	3	48

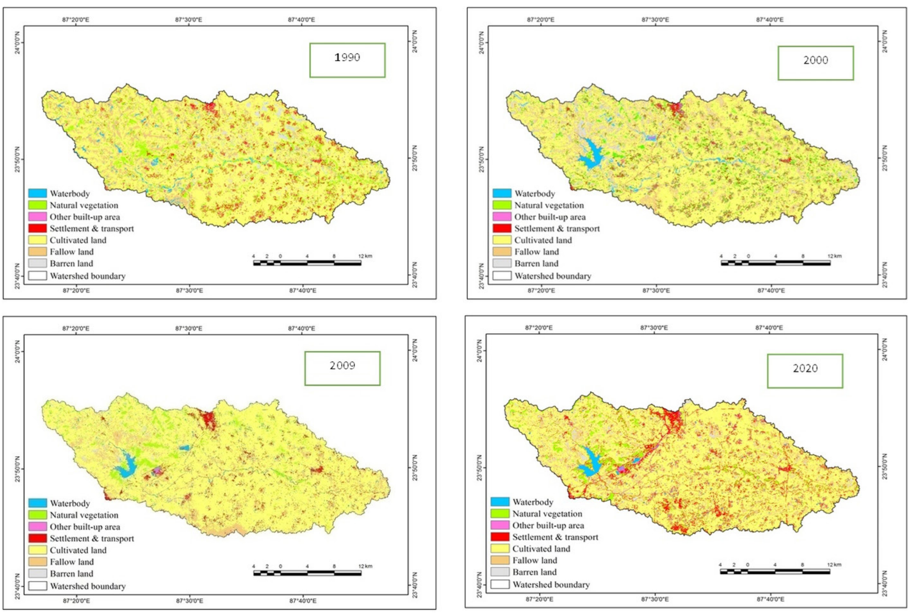

Fig. 7. LULC maps of Bakreswar watershed

classes. Transfer matrix of three different periods viz. 1990–2000, 2000-2009, and 2009–2020 of the present study area was prepared.

3. Results and Discussion

LULC pattern

The maps (Fig. 7) show that the area is largely agrarian in character with about 76% of the area being cultivable.

Table 3 (a-d) shows that the overall classification accuracy ranges from 83.3% to 89.5% and the kappa coefficient from 0.80 to 0.87, indicating a good interpretation accuracy for all the years of analysis.

In 1990 the area under waterbody class was 1.35% (9.76km^2), natural vegetation class constituted 13.7% (99.42 km^2) area, other built-up area class 1.96% (14.24 km^2), settlement & transport class 4.24% (30.76 km^2), cultivated land class 55.2% (400.5 km^2), fallow land class 12.95% (93.98 km^2) and barren land class was 10.6% (76.86 km2) (Table 4); dispersed settlement is observed in the watershed (Fig.7).

Table 3a. Different error and accuracy measurements from error matrix, 1990

Omission error	Producer's Accuracy	Commission error	User's Accuracy
Waterbody =3/7= 42.8%	Waterbody = 4/7 = 57.1%	Waterbody = 1/5 = 20%	Waterbody = 4/5 = 80%
Other built-up area = 0/4 = 0%	Other built-up area = 4/4=100%	Other built-up area = 1/5 = 20%	Other built-up area = 4/5 = 80%
Natural vegetation = 3/9 = 33.3%	Natural vegetation = 6/9=66.6%	Natural vegetation = 1/7 = 14.2%	Natural vegetation = 6/7 = 85.7%
Settlement & transport = 0/7 = 0%	Settlement & transport = 7/7 = 100%	Settlement & transport = 2/9 = 22.2%	Settlement & transport =7/9 = 77.7%
Cultivated land = 1/9 = 11.1%	Cultivated land = 8/9 =88.8%	Cultivated land = 1/9 = 11.1%	Cultivated land = 8/9 = 88.8%
Fallow land =1/7= 14.2%	Fallow land = 6/7 =85.7%	Fallow land = 0/6 = 0%	Fallow land = 6/6 = 100%
Barren land = 0/5 = 0%	Barren land =5/5 = 100%	Barren land = 2/7= 28.5%	Barren land = 5/7 = 71.4%
Overall Accuracy = 83.3 %			
Kappa Coefficient = 0.80			

Table 3b. Different error and accuracy measurements from error matrix, 2000

Omission error	Producer's Accuracy	Commission error	User's Accuracy
Waterbody = 0/5 = 0%	Waterbody = 5/5 = 100%	Waterbody = 0/5 = 0%	Waterbody = 5/5 = 100%
Other built-up area = 0/4 = 0%	Other built-up area = 4/4=100%	Other built-up area = 0/4 = 0%	Other built-up area = 4/4 = 100%
Natural vegetation = 1/8 = 12.5%	Natural vegetation = 7/8=87.5%	Natural vegetation = 1/8 = 12.5%	Natural vegetation = 7/8 = 87.5%
Settlement & transport = 0/3 = 0%	Settlement & transport = 3/3 = 100%	Settlement & transport = 1/4 = 25%	Settlement & transport =3/4 = 75%
Cultivated land = 2/17 = 11.7%	Cultivated land = 15/17 =88.2%	Cultivated land = 1/16 = 6.2%	Cultivated land = 15/16 = 93.7%
Fallow land = 1/6 = 16.6%	Fallow land = 5/6 = 83.3%	Fallow land = 2/7 = 28.5%	Fallow land = 5/7 = 71.4%
Barren land =1/5 = 20%	Barren land = 4/5 = 80%	Barren land = 0/4 = 0%	Barren land = 4/4 = 100%
Overall Accuracy = 89.5 %			
Kappa Coefficient = 0.87			

Table 3c. Different error and accuracy measurements from error matrix, 2009

Omission error	Producer's Accuracy	Commission error	User's Accuracy
Waterbody = 2/7 = 28.5%	Waterbody = 5/7 = 71.4%	Waterbody = 1/6 = 16.6%	Waterbody = 5/6 = 83.3%
Other built-up area = 1/5 = 20%	Other built-up area = 4/5=80%	Other built-up area = 1/5 = 20%	Other built-up area = 4/5 = 80%
Natural vegetation = 0/6 = 0%	Natural vegetation = 6/6=100%	Natural vegetation = 1/7 = 14.2%	Natural vegetation = 6/7 = 85.7%
Settlement & transport = 1/7 = 14.2%	Settlement & transport = 6/7 = 85.7%	Settlement & transport = 1/7 = 14.2%	Settlement & transport =6/7 = 85.7%
Cultivated land = 1/12 = 8.3%	Cultivated land = 11/12 =91.6%	Cultivated land = 1/12 = 8.3%	Cultivated land = 11/12 = 91.6%
Fallow land = 1/7 = 14.2%	Fallow land = 6/7 = 85.7%	Fallow land = 1/7 = 14.2%	Fallow land = 6/7 = 85.7%
Barren land=1/4 = 25%	Barren land=3/4 = 75%	Barren land = 1/4 = 25%	Barren land = 3/4 = 75%
Overall Accuracy = 85.4 %			
Kappa Coefficient = 0.82			

Table 3d. Different error and accuracy measurements from error matrix, 2020

Omission error	Producer's Accuracy	Commission error	User's Accuracy
Waterbody = 0/4 = 0%	Waterbody = 4/4 = 100%	Waterbody = 0/4 = 0%	Waterbody = 4/4 = 100%
Other built-up area = 0/15 = 0%	Other built-up area = 15/15=100%	Other built-up area = 1/16 = 6%	Other built-up area = 15/16 = 93.75%
Natural vegetation = 2/9 = 22%	Natural vegetation = 7/9=77.7%	Natural vegetation = 1/8 = 13%	Natural vegetation = 7/8 = 87.5%
Settlement & transport = 2/8 = 25%	Settlement & transport = 6/8 = 75%	Settlement & transport = 1/7 = 14%	Settlement & transport =6/7 = 85.7%
Cultivated land = 1/6 = 17%	Cultivated land = 5/6 =83.3%	Cultivated land = 2/7 = 29%	Cultivated land = 5/7 = 71.4%
Fallow land = 0/3 = 0%	Fallow land = 3/3 = 100%	Fallow land = 1/4 = 25%	Fallow land = 3/4 = 75%
Barren land=1/3 = 33%	Barren land=2/3 = 66.6%	Barren land = 0/2 = 0%	Barren land = 2/2 = 100%
Overall Accuracy = 87.5 %			
Kappa Coefficient = 0.85			

Table 4. Area under different LULC classes

LULC classes	1990		2000		2009		2020	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Waterbody	9.76	1.35	18.19	2.51	21.14	2.91	19.7	2.72
Natural vegetation	99.42	13.7	70.89	9.77	45.79	6.31	56.77	7.82
Others built-up area	14.24	1.96	21.4	2.95	15.74	2.17	21.71	2.99
Settlement & transport	30.76	4.24	31.33	4.32	42.16	5.81	60.75	8.37
Cultivated land	400.5	55.2	449.25	61.92	496.39	68.41	489.78	67.51
Fallow land	93.98	12.95	98.55	13.58	75.51	10.41	59.89	8.25
Barren land	76.86	10.6	35.91	4.95	28.79	3.98	16.92	2.33
Total	725.52	100	725.52	100	725.52	100	725.52	100

After the completion of the Bakreswar dam construction in July 2000, the area under waterbody class increased, especially in the western part of the watershed (Fig.7), and constituted 2.51% (18.19 km^2) of the total area. Natural vegetation class constituted 9.77% (70.89 km^2), other built-up areas 2.95% (21.4 km^2), and settlement & transportation 4.32% (31.33 km^2) of the total area. The watershed area has been mostly put to cultivation such that the cultivated land class constituted 61.92% (449.25 km^2), followed by the fallow land class, 13.58% (98.58 km^2). The barren land class was 4.95% (35.91 km^2) area in the watershed.

In 2009, the area under the waterbody class was 2.91% (21.41 km^2), and 6.31% (45.79 km^2) was under the natural vegetation class. Area constituted by other land use included 2.17% (15.74 km^2) of the class other built-up area, 5.81% (42.16 km^2) under the settlement & transport class, 68.41% (496.39 km^2) was cultivated land class, 10.41% (75.51 km^2) was fallow land class and 3.98% (28.79 km^2) was barren land class. In 2009, the northern part of the watershed experienced an expansion of Suri Town, and another major settlement expansion, Ahmadpur, is noticeable in the eastern part of the watershed (Fig.7).

In the year 2020, the area under waterbody class constituted 2.72% (19.7 km^2), natural vegetation class was 7.82% (56.77 km^2), 2.99% (21.71 km^2) was other built-up area class, 8.37% (60.75 km^2) was the settlement & transport class. The cultivated land class constituted 67.51% (489.78 km^2), fallow land class was 8.25% (59.89 km^2) and barren land class was 2.33% (16.92 km^2) in the watershed. This year also experienced settlement expansion in the central part of the watershed (Fig.7), near BkTPP along the Pangarh-Moregram Highway which connects the two urban centers, Suri in the north and Dubrajpur in the south of the watershed.

Overall, during 1990-2020, there has been an urban growth along the Panagarh-Moregram Highway which is likely to sprawl over the coming years and hence might lead to the development of an urban corridor between Suri and Dubrajpur. This has been due to the construction of the BkTPP which not only provides power supply to the area but also provides employment to the people, leading to the development of the BkTPP Township along the Highway. Moreover, the Bakreswar Dam serves as a major tourist spot in the area. This location may grow into an urban agglomeration in the future.

Single LULC dynamic attitude

Table 5 shows the change in each LULC during the three assessment periods: 1990–2000, 2000–2009, and 2009–2020.

The period 1990-2000 marked the construction of the Bakreswar Dam and hence witnessed an increase in the area under waterbodies by 86.37% (Fig.8). The Dam served as an assured source of irrigation water; thus, cultivation did not necessarily remain rainfed. Hence, cultivated area increased by 12.17%. There was a corresponding decline in barren

Table 5. Area under different LULC classes

LULC classes	1990 - 2000		2000 - 2009		2009 - 2020	
	Area (km^2)	%	Area(km^2)	%	Area (km^2)	%
Waterbody	8.43	86.37	2.95	16.22	-1.44	-6.81
Natural vegetation	-28.53	-28.70	-25.1	-35.41	10.98	23.98
Others built-up area	7.16	50.28	-5.66	-26.45	5.97	37.93
Settlement & transport	0.57	1.85	10.83	34.57	18.59	44.09
Cultivated land	48.75	12.17	47.14	10.49	-6.61	-1.33
Fallow land	4.57	4.86	-23.04	-23.38	-15.62	-20.69
Barren land	-40.95	-53.28	-7.11	-19.83	-11.88	-41.23

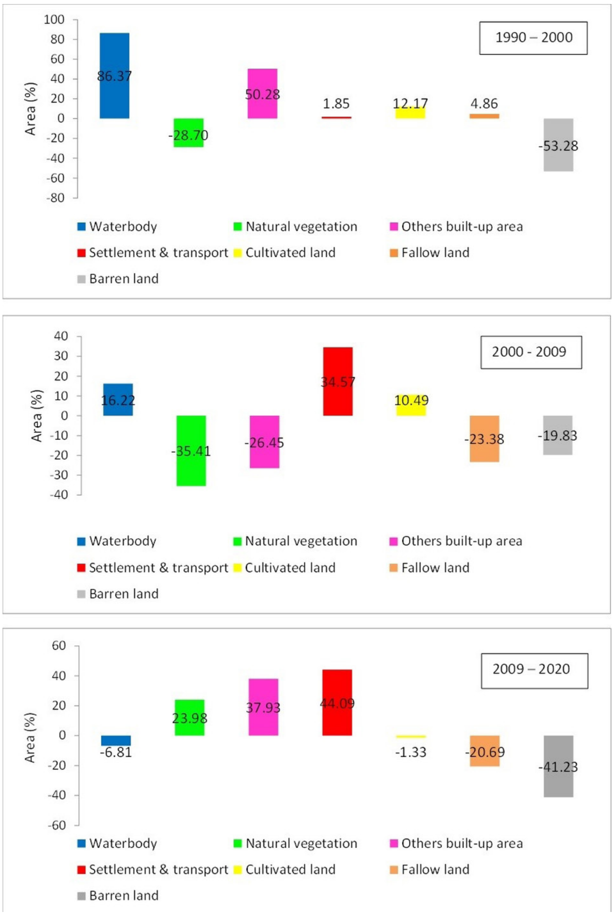

Fig. 8. LULC change during 1990-2000, 2000-2009, and 2009-2020

land (-53.28%) and areas under natural vegetation (-28.70%). The built-up area also increased by 50.28% during the period, especially other built-up areas that included the construction of the Dam and the BkTPP.

The cultivated land area increased by 10.49% during 2000-2009. The availability of reservoir water for irrigation probably reduced the fallow period as there was a decline in the fallow land area by 23.38% (Table 5). The barren land area also declined by 19.83%. The area under natural vegetation continued to decline (-35.41 %) during the period. The growth of built-up area is also noticeable during the period. The construction of the BkTPP in 1999 enhanced the urbanization process in the region. The area under settlement and transport increased by 34.57% (Fig.8).

The rapid growth of settlement and transport (44.09%) characterized the LULC dynamics of 2009–2020 (Fig.8). There was a corresponding decline in the fallow (-20.69%) and cultivated land (-1.33%) areas, and barren land (-41.23%). The area under waterbody also declined by 6.81% which may be attributed to the marked seasonality of the Bakreswar River downstream as it is devoid of its headwaters due to the Dam obstruction. The area under natural vegetation, however, increased (23.98%). This can be due to plantations around the Dam as well as the creation of green belts around the urban settlements.

LULC transfer matrix

During 1990–2020, there was a huge change in the cultivated land, fallow land, barren land, as well as built-up area. The conversion area of cropland to waterbody due to the Bakreswar Dam at Chinpai was the most noticeable among all. After the dam construction, the availability of irrigation water for agricultural production increased the conversion rate of fallow and barren land to cultivated land.

Major conversion between cultivable land and waterbody (5.69 km^2) marked the site of the Bakreswar Dam at Chinpai in 1996. The conversion of 59.93 km^2 of the natural vegetation to cultivated land was another significant change during 1990-2000 (Table 6). Almost 57 km^2 of the barren land area was converted to cultivable land, especially on the eastern part of the watershed, i.e., downstream of the Dam (Fig. 9).

The period 2000-2009 corresponds to the post-dam construction period and is characterized by an increase in the area under cultivation. Table 7 shows a major transition between the natural vegetation to cultivated land (52.05 km^2) as well as fallow land to cultivated land (53.41 km^2). There was also a huge change from cultivated land to built-up area (19.57 km^2) due to the growth of the BkTPP township in 1997 and other settlements around BkTPP (Fig.10).

Table 6. Transition matrix of LULC change of Bakreswar watershed from 1990 to 2000

LULC 1990 (km^2)	LULC 2000 (km^2)						
	Waterbody	Other built-up areas	Natural vegetation	Settlement & transport	Cultivated land	Fallow land	Barren land
Waterbody	3.20	0.10	0.13	0.12	2.21	1.40	2.57
Other built-up areas	4.23	8.26	0.67	0.74	0.2	0.04	0.01
Natural vegetation	1.92	0.96	21.15	4.10	59.93	8.80	2.53
Settlement & transport	0.32	9.02	8.94	9.92	2.40	0.11	0.03
Cultivated land	5.69	1.26	25.72	6.45	296.23	51.93	13.10
Fallow land	0.75	1.63	10.82	9.38	48.18	18.59	4.58
Barren land	2.05	0.15	3.42	0.61	39.90	17.60	13.05

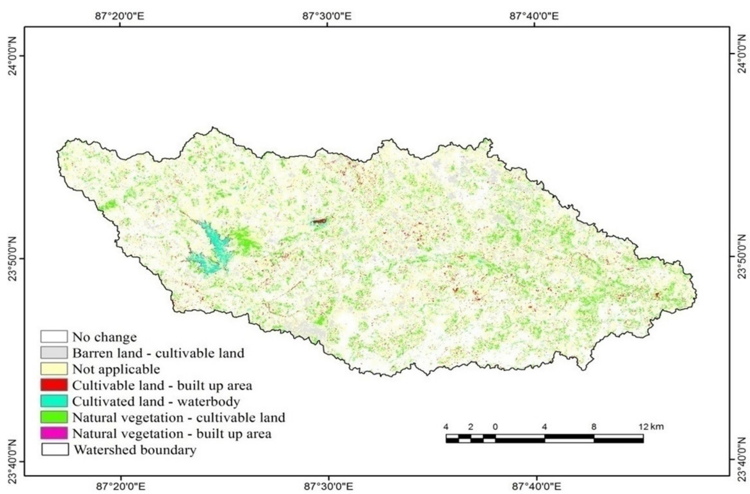

Fig. 9. LULC transition during 1990–2000

Table 7. Transition matrix of LULCC of Bakreswar watershed from 2000 to 2009

LULC 2000 (km^2)	LULC 2009 (km^2)						
	Waterbody	Other built-up area	Natural vegetation	Settlement & transport	Cultivated land	Fallow land	Barren land
Waterbody	9.05	3.62	0.56	0.51	2.51	1.38	0.55
Other built-up area	0.74	8.64	1.01	3.67	7.28	0.04	0.01
Natural vegetation	0.19	0.88	11.18	5.58	52.05	0.55	0.45
Settlement & transport	0.05	1.66	1.56	8.52	19.40	0.10	0.03
Cultivated land	1.93	0.80	26.59	19.57	350.59	34.52	15.17
Fallow land	2.77	0.05	3.37	3.14	53.41	26.64	9.13
Barren land	6.38	0.51	1.51	1.17	11.05	12.24	3.44

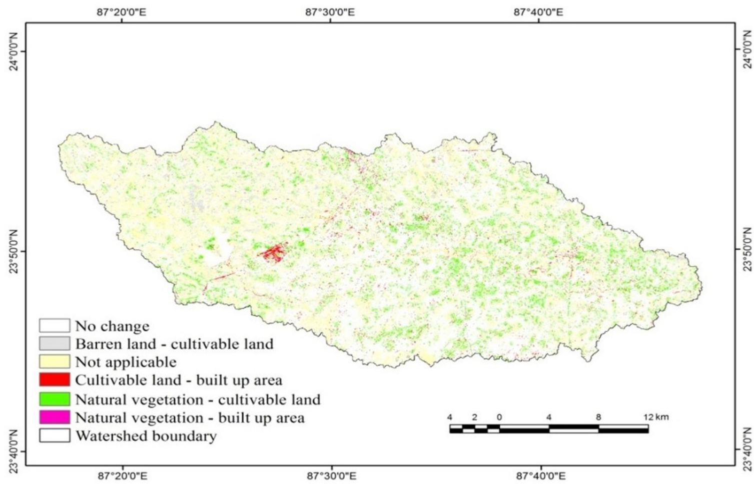

Fig. 10. LULC transition during 2000–2009

The conversion from natural vegetation to cultivated land continued and was high (26.92 km^2) during 2009–2020 (Table 8). A major transition is seen between the fallow land to cultivated land and from cultivated land to built-up area (Fig.11). The increase in the land under settlement and transport implies that the study area getting urbanized.

LULC dynamic attitude and LULC transfer matrix of the study area show that the rapid LULC change started after the year 2000. A higher conversion rate was seen in the period of 2009–2020. The results imply that the cultivated land and fallow land are predominant in the eastern and western parts, respectively in the watershed, and post-dam construction, the transfer rate of fallow land to cultivated land was greater in the eastern portion than in the western portion. The conversion of cultivated land to built-up area was also high between 2009 and 2020, and settlement concentration is more along the highway around the BkTPP.

Table 8. Transition of LULC of Bakreswar Watershed between 2009 and 2020

LULC change 2009 (km²)	LULC change in 2020 (km²)						
	Waterbody	Other built-up area	Natural vegetation	Settlement & transport	Cultivated land	Fallow land	Barren land
Waterbody	9.83	0.47	1.72	0.68	4.53	2.64	4.26
Other built-up area	3.98	7.79	2.11	0.96	0.90	2.01	0.01
Natural vegetation	0.26	0.80	4.20	1.28	26.92	1.87	0.46
Settlement & transport	0.36	4.68	5.25	9.12	20.95	1.47	0.32
Cultivated land	1.21	7.68	29.51	43.75	366.73	31.81	5.61
Fallow land	1.76	0.22	1.98	4.78	48.91	15.72	4.81
Barren land	2.31	0.07	1.99	1.17	19.77	4.35	1.45

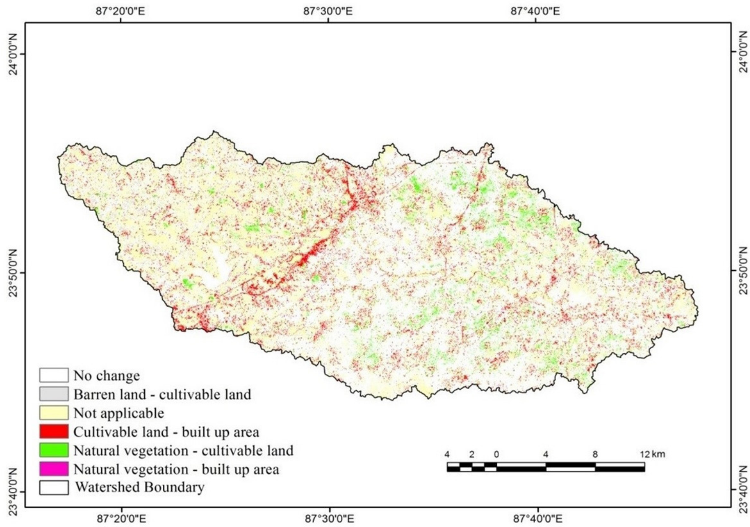

Fig. 11. LULC transition during 2009–2020

4. Conclusion

Land use dynamics of the study area during the pre-and post-construction of the Bakreswar Dam show that the LULC pattern in the Bakreswar watershed area has remarkably changed from 1990 to 2020. The increase in cultivated land, settlement & transport, other built-up areas, and waterbody has corresponded with a significant decrease in vegetation cover, fallow land, and barren land. This pattern is almost the same throughout the three decades (1990–2020). In 2020, however, the area under vegetation slightly increased near the dam, BkTPP and BkTPP Township. It is also observed that there is an unequal distribution of agricultural land in this watershed due to the disparity in terms of water supply. The western part of the watershed is characterized by fallow and barren land while the eastern portion of the watershed is characterized by cultivated land with some areas of fallow. This is because the eastern portion receives water from the Bakreswar Dam and also from the Mayurakshi Canal. It may be mentioned here that although initially, the dam construction led to an increase in the cultivated land area, over the years the growth has been stagnant, and since 2009, it is showing a decline. This has been due to the marked seasonality of the Bakreswar River downstream as it is devoid

Plate 3. Bakreswar Township

of its headwaters due to the Dam obstruction, as well as rapid urban expansion. After the establishment of BkTPP and the growth of BkTPP Township (Plate 3), the area under settlement has increased along the Panagarh–Morgram Highway connecting Suri to Dubrajpur. Given the trend of LULC dynamics in the area, the two urban centers are likely to grow into an agglomeration in the near future. Thus, the present study opens up an arena for future research on the urbanization pattern and prediction, the prospects of agricultural development, and the nature of overall regional development in the Bakreswar watershed.

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