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Monitoring Land Use and Land Cover Changes Prospects Using Remote Sensing and GIS for Mahanadi River Delta, Orissa, India

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Abstract

Geographic information systems (GIS) and remote sensing (RS) were employed to monitor land use changes utilizing quantum ArcGIS, and ERDAS Imagine was done to predict LULC changes in India. This research studied the variations in LULC in the Mahanadi River basin delta, Orissa, for the years 2010, 2015, and 2020. Landsat satellite pictures were employed to track the land use changes. For the categorization of Landsat images, maximum-likelihood supervised classification was applied. The broad categorization identifies four primary groups in the research region, including (i) waterbodies, (ii) agriculture fields, (iii) forests, (iv) barren lands, (v) built-up areas, and (vi) aquaculture. The findings indicated significant growth in forests from 2010 to 2020, but a substantial increase in barren lands had happened by 2020, while built-up land use has witnessed a quick climb. The kappa coefficient was used to measure the validity of identified photos, with an overall kappa coefficient of 0.82, 0.84, and 0.90 for the years 2010, 2015, and 2020, respectively. However, a significant drop will occur in agriculture fields in the predicted years. The study effectively demonstrates LULC alterations showing the substantial pattern of land use change in the Mahanadi delta. This information might be valuable for land use management and future planning in the region.

1. Introduction

The method of finding changes in any process or item through study at distinct periods is known as change detection (Singh, 1989; Sejati et al., 2020). Over time, humanity has substantially modified the earth's surface to generate food through agricultural systems. Nearly one-third of the world's surface is considered agricultural, and over half of the earth's surface has been transformed throughout the previous several years (Houghton, 1994). This shift from naturally emerging farming land to agricultural land is currently happening (Hathout, 2002). These considerable changes have drawn the attention of land use administrators and academics to the effect of land use changes on hydrological processes (Fei et al., 2018).

Land use managers and decision-makers can better comprehend the connections between human and natural activities by evaluating the trends in change detection. Assessing LULC changes at various levels, such as global and regional, includes examining changes within river basins (Guzha et al., 2018). The massive expansion in the pace of population is the primary determinant at the worldwide scale in the shift of land use, according to (López et al., 2001). The substantial changes in land cover, especially in emerging nations, are primarily attributable to vast urban expansion and the transformation of natural regions into industrial or agricultural fields (Jat et al., 2008). The degradation of natural land, dense forests, and watersheds puts enormous pressure on river basins' hydrological regimes and processes (Guerra et al., 1998). It is vital to offer multi-temporal sets of data to evaluate changes in the spatial properties of land (Amici et al., 2017).

Using multi-temporal datasets makes it straightforward to describe the key LULC changes together with their pattern (Hanif et al., 2015). The growth of computer technology and the launch of Landsat satellites have made it easy to trace the changes and advances that have happened over the many previous decades. Remote sensing technology coupled with a GIS has been advantageously utilized in the detection of numerous environmental features, i.e., vegetation covering, urban sprawls, transition in forests, and specific variations in LULC changes over specified periods (Roy & Roy, 2010). It has been noted that remote sensing and GIS techniques give more accurate and cost-efficient data assessment compared to other traditional procedures and surveys.

Remote sensing is described as perceiving spatial differences in specific things without direct interaction. Remote sensing employs space-borne satellites to identify the numerous properties of the planet. Because of their constant monitoring of the earth's characteristics, they can aid in tracking changes on the land surface (Hussain et al., 2013). The knowledge collected on temporal and spatial levels helps scientists and researchers to detect large-scale changes in the pattern of land and permits regional policymakers and authorities to make future judgments.

The application of remote sensing in natural disaster management has been described in various research. It has been utilized for monitoring floods in India (Singh et al., 2013). Geomorphic parameters were explored for the creation of a decision support system by (Alexakis et al., 2013) to avoid the formation of landslides using remote sensing. Furthermore, it has been beneficial in recognizing changes in agricultural patterns, land cover changes, and urban sprawls (Yatoo et al., 2020). GIS is recognized as vital for identifying the changes in remotely sensed pictures (Vibhute & Gawali, 2013). It gives the capacity to combine data from numerous resources to identify change.

The combined effect of the hydrological maps, soil and topographic maps, and classed pictures generated by GIS may provide valuable information in extracting land use for a specific region. In addition, it may demonstrate the trends of land use changes because of its capacity to create the model by using specified statistics and facts. Moreover, GIS and remotely sensed pictures are commonly applied to identify LULC alterations (Jiang et al., 2018; Liang et al., 2018; Rahman et al., 2012). For tracking land cover changes, the combined use of GIS and remote sensing has been proven to be a reliable and lucrative strategy (Hazarika et al., 2015; López-Granados et al., 2013; Serra et al., 2008).

The usefulness of space-borne imaging in mapping LULC alterations has been proven in various research (Chowdhury et al., 2020; Mohamed, 2017). Several Landsat photos of different time intervals (1972–2008) have been utilized by (Gammal et al., 2010) to explore the land use and land cover changes in Egypt. To evaluate LULC variations in Rwanda, (Akinyemi, 2017) utilized Landsat imagery from several years (1987–2016). The latest work by Cheruto et al. (2016) evaluated LULC variations in Kenya by employing GIS and remote sensing methods. Similarly, various research has been reported to find LULC variations in different catchments in Malaysia (Hanif et al., 2015; Noh et al., 2019; Yusof et al., 2016).

The Mahanadi River basin delta is an essential asset to the people in the region and the principal supply of raw water. Hence, the sustainability of the environment in and around the Mahanadi River basin delta is crucial since urbanization is one of the possible barriers to the sustainable expansion of the region. Therefore, the purpose of this study was to evaluate the LULC changes in the Mahanadi River basin delta of Orissa from the years 2010, 2015, and 2020 with the particular aims of quantifying the extent and causative elements of land use in the Mahanadi River basin delta throughout the specified period.

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2. Data and Methods

2.1. Study Area

The Mahanadi Basin is one of the five sedimentary basins in the Indian subcontinent. The Mahanadi River Delta (80°28' to 86 ° 43' E longitudes and 19°8' to 23°32' N latitude) extends for over 9,810.7642 km² in Odisha. The complex delta was formed due to integrating three water bodies: the Brahmani River in the northeast and Chilika Lake in the southwest suburbs, the Mahanadi River in the middle of the Mahanadi Delta, and the Devi River in the south (see Figure 1). This delta has four main types of mainland territories: fluvial, fluvio-marine, marine, and Aeolian landforms. The accurate delta shape has four stages due to sea violations and regression processes. Rout et al. (2018) identified four phases of delta progradation based on strandline and pylidolidic lobbies. However, limited regional studies have been conducted using geospatial technology in this delta.

2.2. Data and Pre-Processing

Data Acquisitions and Preparation Landsat images taken from Landsat 7 and Landsat 8 satellites were employed to examine the LULC changes, whilst dates were picked, emphasizing the quality and accessibility of Landsat data and weather conditions. The data for Landsat 7 and Landsat 8 exhibited a modest consistency issue from the standpoint of spatial composition. These difficulties were resolved during the pre-classification phase of the study and have been effectively handled by some prior research (Fei et al., 2018; Guzha et al., 2018) as well. The visible bands (red, green, and blue) were selected for land use categorization. The bands used for Landsat 7 classification were 4, 3, and 6, whereas 4, 5, and 6 bands were chosen for Landsat 8 image classification obtained from USGS in 2021. Four Landsat photos were gathered from 2010, 2015, and 2020 from the USGS earth explorer website. The datasets were uploaded to ArcGIS to produce LULC maps. The ArcGIS 10.8 software package was utilized during the different stages of the investigation. The photos collected from the satellite were detected at various periods of the year, and all had the same spatial resolution (30 m). The resulting four photos were cut to extract the research region after confirming the Landsat scene by date.

2.3. Image Classification

The land cover classification was carried out using the widely used supervised maximum likelihood classification algorithm (MLC) (Churches et al., 2014; Mubako et al., 2018; Rawat & Kumar, 2015; Srivastava et al., 2012) and post-classification change detection analysis approach. The classification was conducted by identifying features and selecting training regions, evaluating and analyzing training signature statistics and spectral patterns, and categorizing the pictures. Google Earth pictures and published maps were employed for training and validation samples. Training and validation samples for 2010 to 2020 imageries were created using Google Earth images. This method was used for this investigation due to the applicability of this categorization system and its efficiency in mapping from high-altitude images such as Landsat. Six key land cover categories were mapped in the Mahanadi River Basin in this study.

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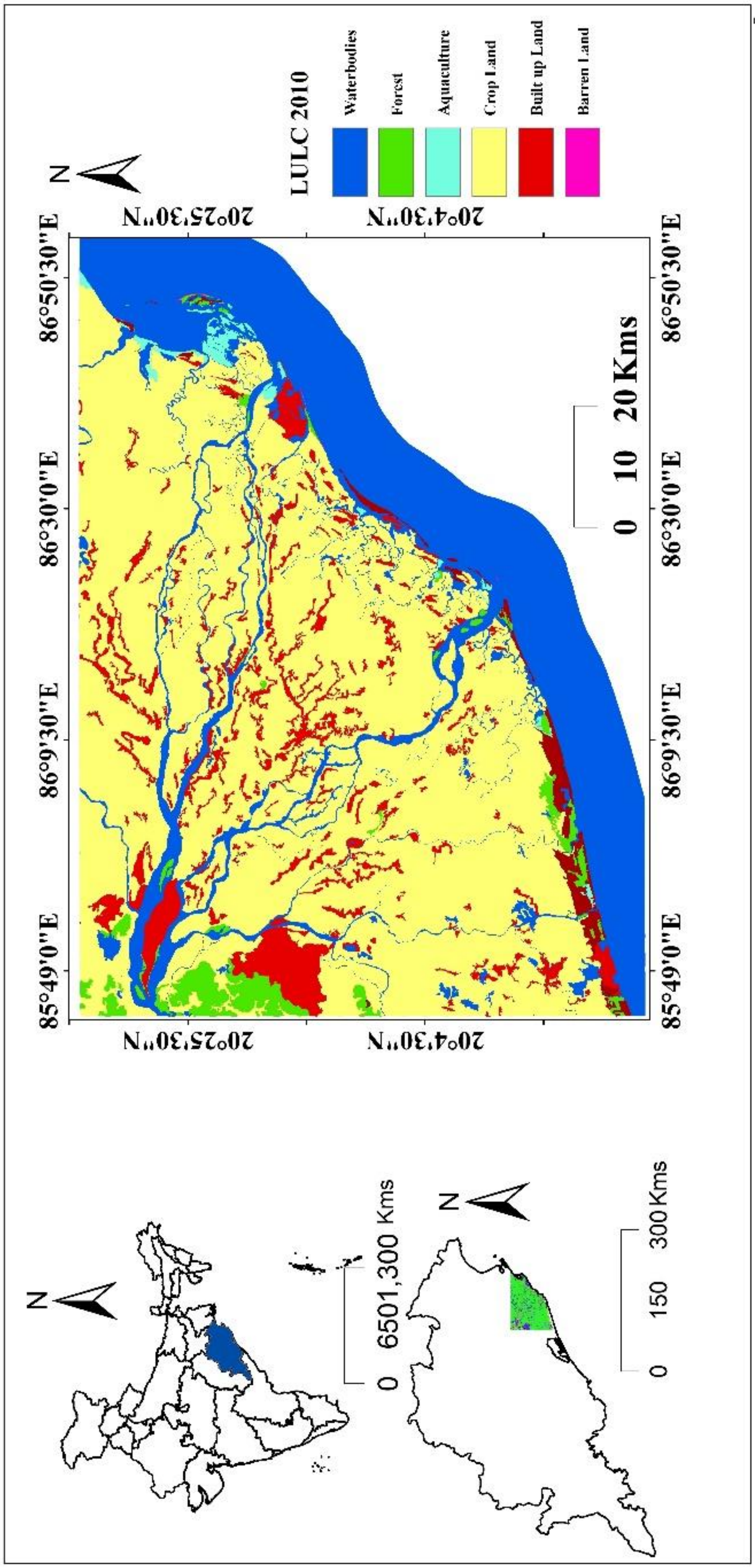

Source: Analysis, 2022

Figure 1. Location Map: Mahanadi River Basin

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2.4. Change Detection

Change detection is considered a primary method for identifying the variations in land use patterns of different classes (i.e., waterbodies, barren and urban lands, agricultural lands, and dense forests) in distinct periods. The essential characteristic of this method is the capacity to identify the changes in data from various sources and periods (Zhang et al., 2022). Change detection was calculated by finding the difference in the area covered by different land use classes between the two periods of 2010 to 2015 and 2015 to 2020. For the calculation of the area covered by other land use classes, the "attribute table" was obtained after the land use classification was analyzed. The pixels covered by each type were divided by the total pixels of the study area to get a percentage change in cover for each class (Kumar et al., 2021).

2.5. Accuracy Assessment

An accuracy assessment was performed for the classified images of 2010, 2015 and 2020. The accuracy assessment of the image classification, as an integral part of the image classification process, was done in this study following the method described in Congalton & Green (2008) and Congalton et al. (1983). This method is often considered to be effective in preparing consistent land use/cover data over time, regardless of the spatial, spectral and radiometric resolution of the satellite data differences. This approach involves the construction of an error matrix of omission and commission (representing non-existent ground features for each region of interest (ROI). Statistic measures of overall accuracy known as the Kappa coefficient, which indicates the level of accuracy classification assessment, user's accuracy (probability of a pixel classification matching the ground feature) and producer's accuracy, which describes probability, are then computed.

The accuracy of satellite imagery interpretation can vary depending on several factors, such as image resolution, interpreter expertise, and the specific purpose of using the imagery. In general, however, the accuracy of satellite imagery interpretation can be very high, especially when compared to other forms of remote sensing in detail. Accuracy assessment for land use change is a process used to evaluate the accuracy of land use maps produced from satellite imagery or other remote sensing data. This process typically involves comparing the land use maps with ground truth data, such as field surveys or aerial photographs, to determine how well the maps reflect the actual land use on the ground.

Furthermore, Model validation is an essential step in developing and applying land use change models. It involves testing the model against real-world data to determine how well it predicts land use change. This can be done in several ways, such as comparing the model's predictions with actual land use change data or using cross-validation techniques to assess the model's performance. Model validation helps to ensure that the model is accurate and reliable and can help identify any potential biases or limitations in the model.

Generally, the processing is performed using the method depicted in Figure 2. The data used in this study are Landsat 7 and Landsat 8, obtained from Landsat Satellite Imagery. Then the data that has been obtained is accurate, and a georeferencing process is carried out to get the study location, namely the Mahanadi River. The next step is to carry out the image classification process to obtain the LULC Map classification results for 2010, 2015 and 2020. After this process is carried out, it is necessary to carry out change detection to determine land use and land cover changes in the Mahanadi River Delta, Orissa, India, by utilizing the GIS Spatial Analyzes. From this process, the results of changes to the land use and land cover of the Mahanadi River will be obtained. To find out the potential for a flood disaster, it is necessary to compare the results of LULC Changes with the flood disaster on the Mahanadi River.

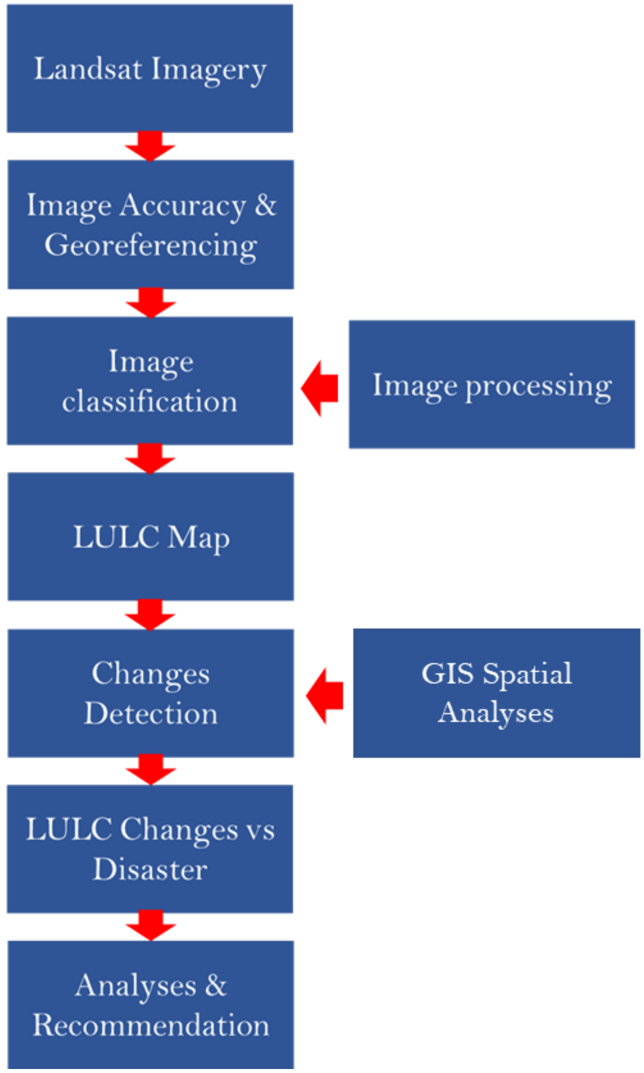

Figure 2. Monitoring Land Use and Land Cover Changes Process

3. Result and Discussion

Because of its capability to provide descriptive information, the post-classification comparison technique for the detection of land cover changes was applied to independently compare and produce classified land use/cover maps for the years 2010, 2015 and 2020. Trend analysis was carried out in ArcGIS to determine the changes' nature, size, and spatial location. The spatial and temporal distributions and differences of different land cover types of the Mahanadi River delta over the one decade are shown in Figures 3, 4 and 5, respectively. Statistics regarding land cover types are given in Table 1. Firstly, for the composition of the band, Landsat images were inputted into an image analysis tool. Then, by using Landsat images, the signatures of all the spectral classes were identified. To supervise classification, the classes with the same spectral signatures were merged. This allows all the pixels that are included in an image to be automatically assigned to the land cover classes. The maximum-likelihood classifier was employed by applying training sets developed from Landsat images. In this analysis, several steps have been carried out to conduct an assessment of changes in land use and their impact on flood disasters. The results show that from several Spatiotemporal image processing, there are significant changes. The results of the changes can be seen in Table 1.

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Table 1. Land Use/Landcover Outcomes the Area and Percentage years 2010, 2015 and 2020

LULC Categories	2010		2015		2020	
	Km²	%	Km²	%	Km²	%
Forest	318.13	3.24	358.46	3.65	378.89	3.86
Crop Land	8157.55	83.15	7830.56	79.82	7585.62	77.32
Waterbodies	177.00	1.80	220.89	2.25	248.83	2.54
Built-up Land	1031.38	10.51	1145.44	11.68	1236.65	12.61
Barren Land	87.90	0.90	208.56	2.13	292.36	2.98
Aquaculture	38.79	0.40	46.85	0.48	68.41	0.70

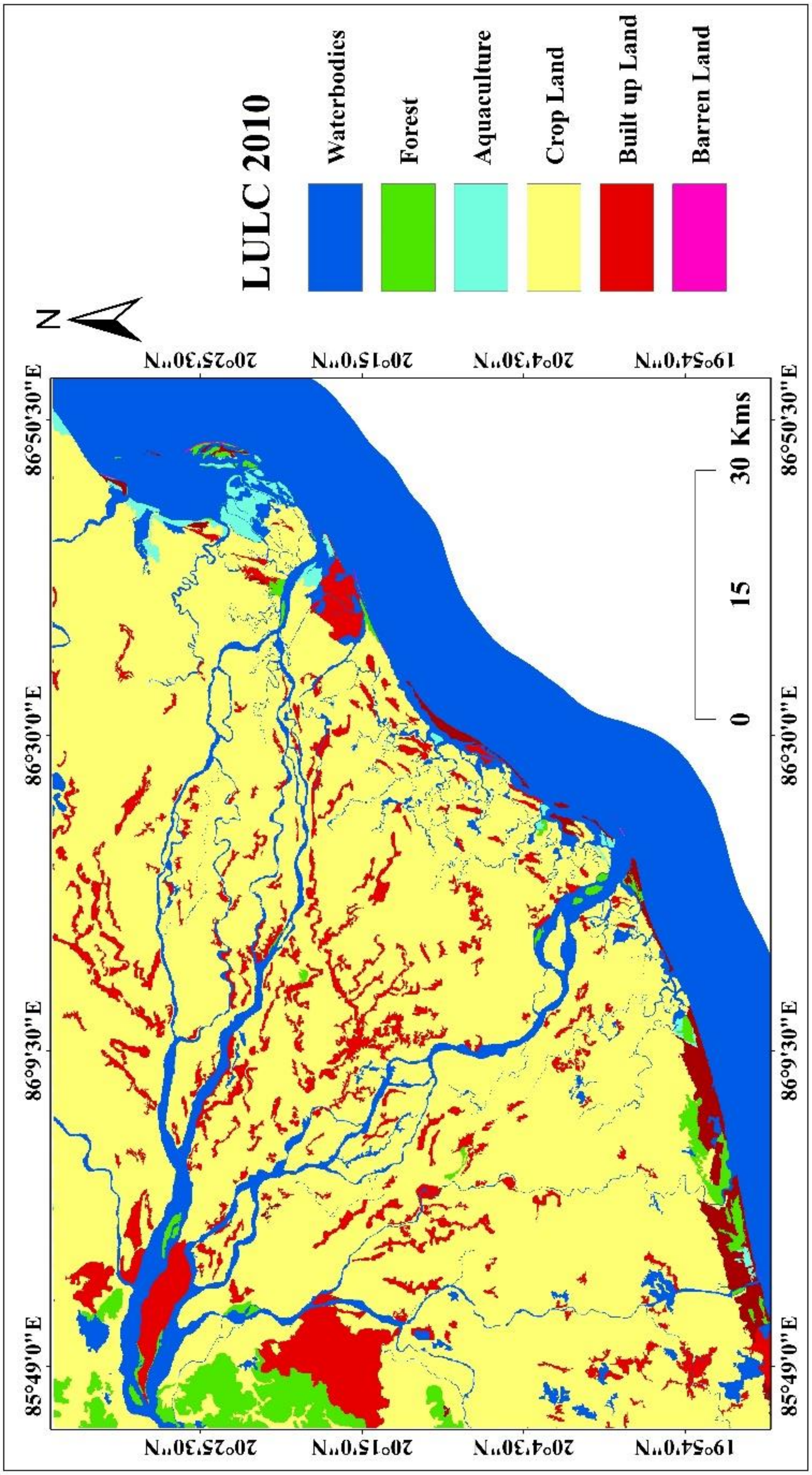
Source: Analysis, 2022

Table 1 shows that the largest change in land use in the Mahanadi River Basin in 2010, 2015 and 2020 was Crop Land, which amounted to 83.15% in 2010, 79.82% in 2015 and 77.32% in 2020. Meanwhile, the smallest land use in the Mahanadi River Basin in 2010, 2015 and 2020 was Aquaculture, namely, 0.40% in 2010, 0.48% in 2015, and 0.70% in 2020. The results indicate that during the study period, croplands decreased by 83.15% to 77.32%, while forest land, water bodies and built-up lands and barren lands areas increased by 3.24% to 3.86%, 1.80 % to 2.54%, 10.51 % to 12.61 % and 0.90 % to 2.98 % respectively (see Table 1). However, the rate of change was not uniform over the study period (2010 to 2020). The spatiotemporal dynamics of the land use/cover types are shown in Figure 6. The barren lands, including wastelands and fallow lands, have given way to expanding agriculture and built-up area (see Figure 6).

Land use change analysis for a river area involves studying the patterns and trends of land use over time, focusing on the changes that have occurred along the river and its surrounding landscape. This can be done using a combination of satellite imagery, ground surveys, and other forms of data to create land use maps and analyze the changes that have occurred. This type of analysis aims to understand the factors that have contributed to land use change in the area and to develop strategies for managing and conserving the river and its surrounding landscape.

There is a strong relationship between land use change and flood risk in river areas. When land is converted from natural vegetation to developed or agricultural use, it can affect the ability of the land to absorb and store water. This can increase the runoff and the risk of flooding during heavy rainfall events. In addition, removing natural vegetation can also reduce the amount of sediment and nutrients transported downstream, which can affect the health of the river and the surrounding ecosystem. It is important for land use planning and management to consider these potential impacts and to incorporate measures to reduce flood risk and protect the river and its surrounding landscape.

There are several steps that can be taken to address the relationship between land use change and flood risk in river areas—for instance, implementing land use planning and management strategies that prioritize the conservation and restoration of natural vegetation and consider the potential impacts of development on flood risk. Moreover, it also needs to implement structural measures, such as levees and floodwalls, to reduce the risk of flooding in areas where development is inevitable. In addition, Developing and implementing early warning systems and evacuation plans to prepare for and respond to flood events are essential, especially in Engaging with local communities and stakeholders to raise awareness about the link between land use change and flood risk and to involve them in decision-making and planning processes.



Source: Analysis, 2022

Figure 3. Land Use/Land Cover Classifications of Mahanadi River Basin in the year 2010

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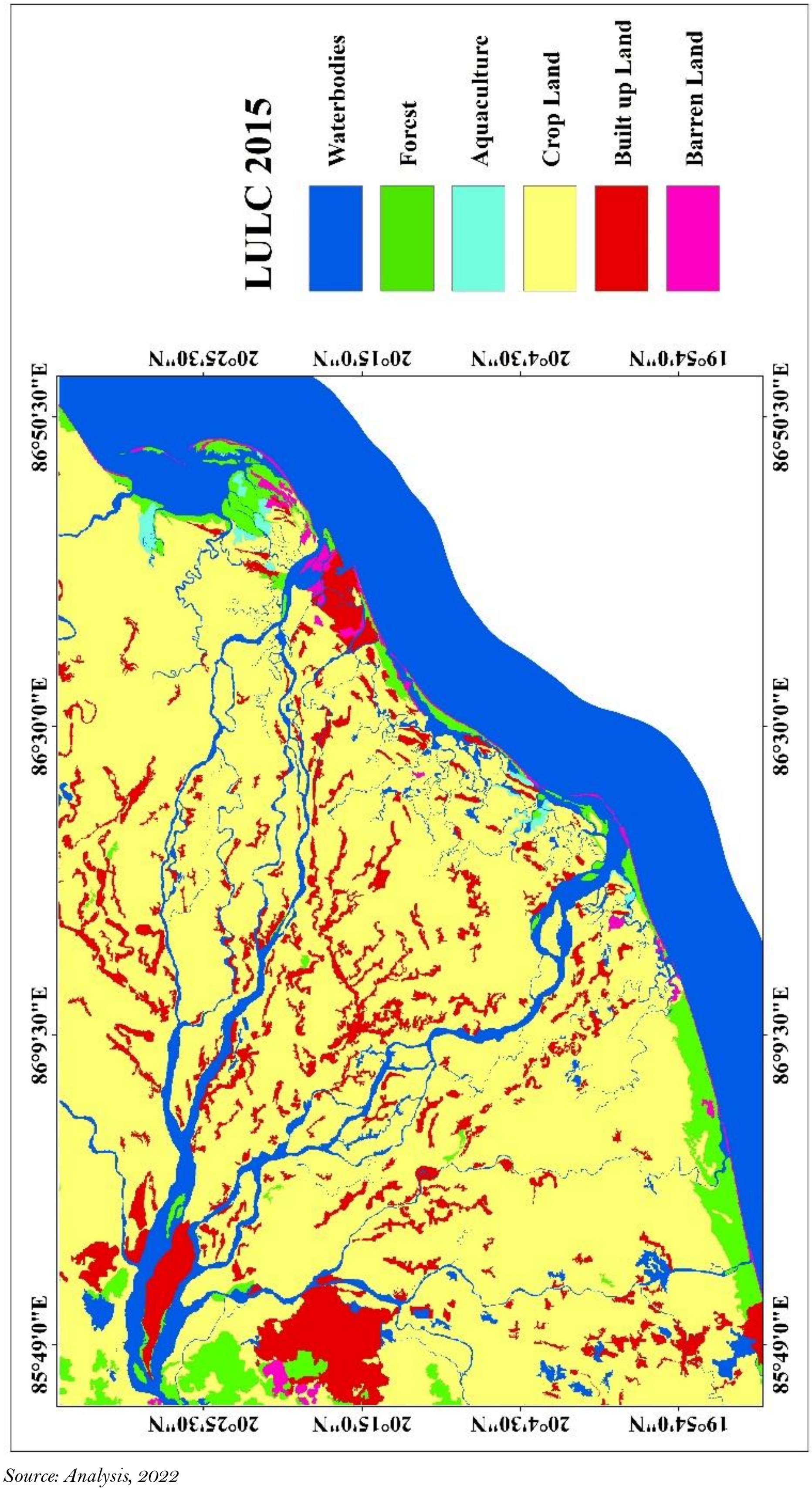

Source: Analysis, 2022

Figure 4. Land Use/Land Cover Classifications of Mahanadi River Basin in the year 2015

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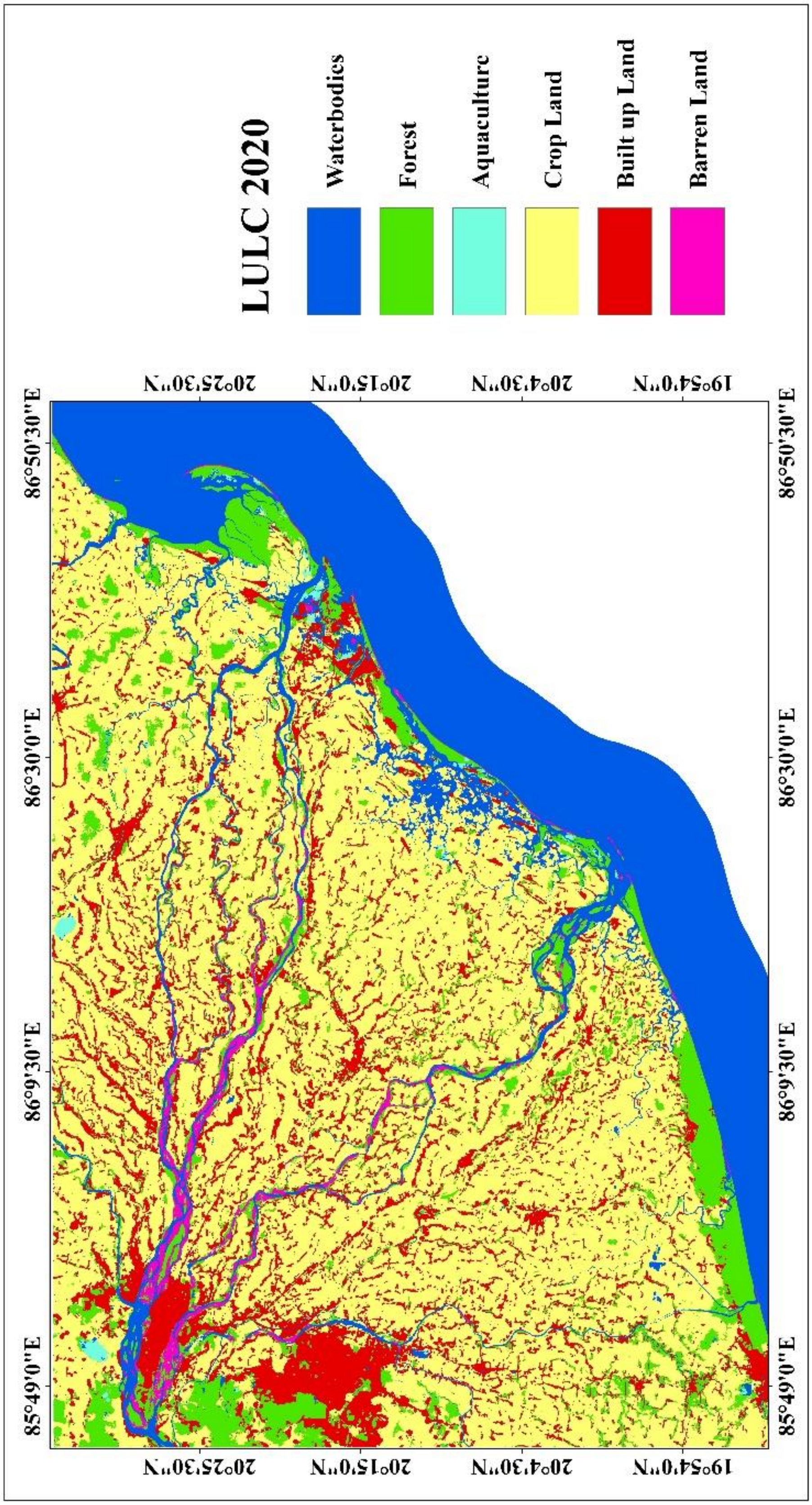

Source: Analysis, 2022

Figure 5. Land Use/Land Cover Classifications of Mahanadi River Basin in the year 2020

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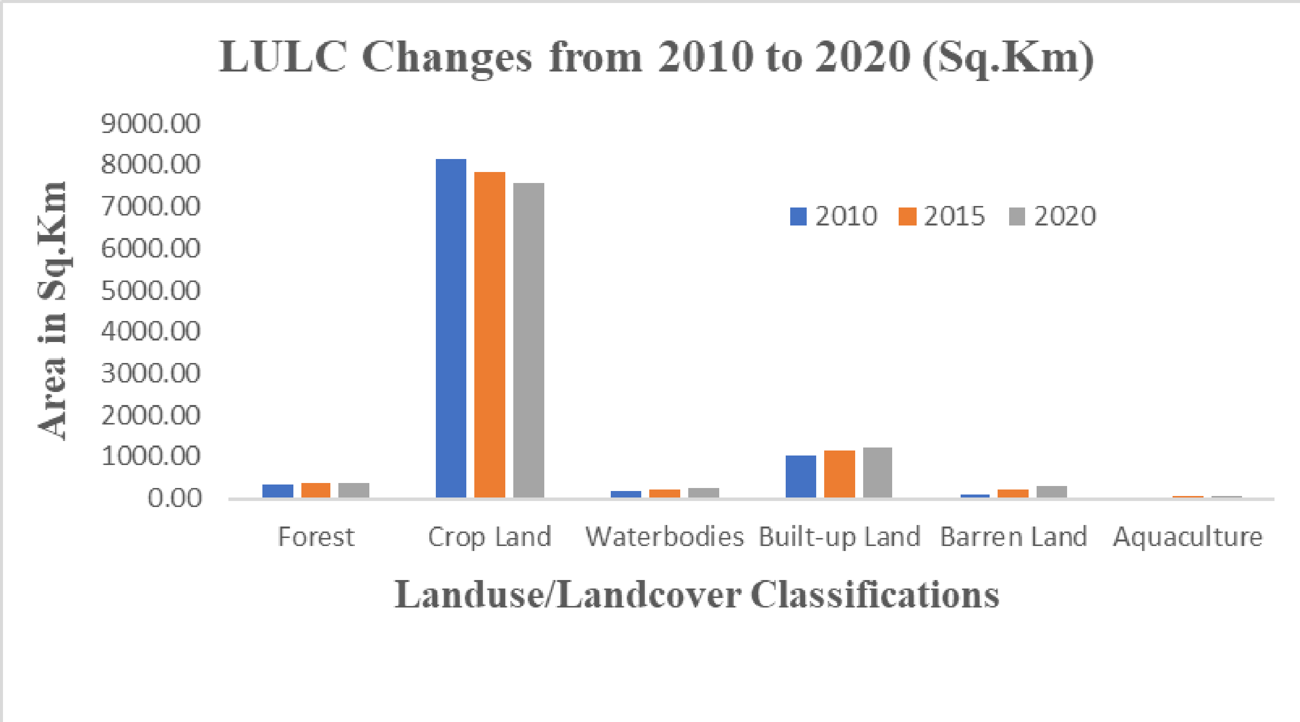

Source: Analysis, 2022

Figure 6. Land Use/Landcover Changes from 2010 to 2020

In Figure 6, it can be seen that the forest shows that the ratio of forest land use has increased from 2010 to 2015 and is constant from the 2015-2020 range. Then land use for waterbodies, barren land, and aquaculture has risen from 2010, 2015, and 2020 but the amount is not significant, and built-up land increases every year, but the amount does not affect the amount of cropland use. So, it can be seen that cropland still dominated from 2010, 2015 and 2020.

The main factors contributing to the increase in barren and urban lands in the Mahanadi River basin were a rapid expansion of urban development, the decrease in the growth of agricultural cultivation that eventually contributed to forest degradation, and the variation in the amount of annual rainfall. Changes in land use and disasters, especially floods, have indeed been widely predicted by previous studies. This is in line with the thinking of Singh et al. 2013 where land use changes influenced the incidence of flooding in India. However, the findings from Mahanadi River show that mismanagement contributes to disaster events, such as the development of urban areas that should be controlled by policy. Referring to this, it should be necessary to have decision support systems developed by the government in managing the Mahanadi River. This corroborates the study of Alexakis et al. (2013), where one of the weaknesses of the land use change monitoring system starts from poorly implemented policies.

Such LULC change analysis is essential for a deeper understanding of how these developments were changing the hydrological process of the Mahanadi River basin. Remotely sensed image integration with GIS can provide a reasonable basis for comparing the influencing factors to the dynamics of the river basin. The outcomes obtained from the analysis have shown that the land use in the study area has changed in one decade. The main components of the river basin have decreased dramatically, such as dense forests. Barren land, by comparison, has seen more changes and increased considerably more than any other class of land use. Due to the increase in barren and urban land, a huge number of light forests have been converted into development zones, and thus the area of impermeable surfaces has been enhanced. Deforestation due to land use change can be analyzed using GIS according to needs (Jiang et al., 2018; Liang et al., 2018; Rahman et al., 2012). However, what is weak is the follow-up of the results of the analysis using GIS. Even though spatial analysis has been carried out to explain the phenomena of land use change and disasters, the sophistication of GIS to try to formulate strategies needs to be enriched and must be more applicable in assisting policy formulation. In more detail, research from (Hazarika et al., 2015; López-Granados et al., 2013; Serra et al., 2008) states the need for GIS development to support development strategy planning that is reliable and has better accuracy.

The rapid urbanization was mainly due to industrial development and growth in the rate of population. A slight positive increase was detected in the class of waterbodies in the year 2020, which can be attributed to the rise in water bodies, such as reservoirs that perform the function of retention ponds in the season of floods. Increases in barren lands and rainfall played significant roles in changing the hydrological system of the river basin. According to various studies, precipitation over recently built areas results in increased runoff rates, creating floods in the low-lying region. Additionally, heavy rainfall may also increase stagnant water in urban areas where flood retention and drainage capacity are inadequate. Factors influencing the river basin, i.e., changes in climate, land use, and soil infiltration rate, may also result in significant deterioration of the river basin hydrological process. Therefore, the analysis of land use changes can also provide necessary details on potential improvements to the hydrology of the river basins. With the ability to analyze land use changes and hydrological aspects of the river Basin, it is advisable to develop flood disaster predictions based on the type of land use change. This is to the results of research from Yatoo et al. (2020), where land use patterns can be modelled to analyze the impact of changes such as land conversion and population growth.

4. Conclusion

The present study has successfully applied supervised classification in ERDAS Imagine for monitoring LULC changes and spatial distribution patterns. The growth in LULC changes and future prediction of the Perak River basin were analyzed by using multi-temporal data from the year 2010 to 2020. The LULC changes maps classified for 2010, 2015, and 2020 demonstrated significant changes in the study area. Furthermore, measurements of various LULC classes were calculated to monitor decadal changes in each category. According to the findings, barren and built-up lands in the Mahanadi River basin multiplied between 2010 and 2020. In 2010, the region's total area of barren and urban lands was 87.90 km2, which had increased to 292.36 km2 by 2020, leading to extreme soil erosion risk in the catchment. It shows an approximately five-fold increase in barren and built-up lands during this period.

The decadal change in LULC mapping of the Mahanadi River basin indicated that the dense forests significantly increased from 318.13 km2 in the year 2010 to only 378.89 km2 in 2020. However, a slight increase was observed in the areas of water bodies, from 177.00 km2 in 2010 to 248.83 km2 in 2020, and agricultural lands decreased from 8157.55 km2 in 2010 to 7585.62 km2 in 2020. Dense forests near the Mahanadi River basin were transformed into non-agricultural lands initially and later converted into a developed built-up area. The outcomes of this study on LULC changes and its future prediction might be helpful for regional policymakers and authorities in developing sustainable urban planning and improving living standards.

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