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Geospatial approach for developing an integrated water resource management plan in Rajshahi, Bangladesh

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Abstract

The integrated water resource management (IWRM) plan plays a substantial role in addressing institutional problems and capacity building for the use, control, preservation, and sustainability of water systems, especially for developing countries like Bangladesh. Bangladesh is facing massive land cover/land use (LC/LU) change, mainly influenced by rapid urbanization. Urbanization converts the natural resources (water bodies) into impervious surfaces (urban areas and roads). Rajshahi is one of the largest metropolitan cities in Bangladesh, and its urban sustainability is affected by the demolishment of water bodies influenced by rapid LC/LU change. Satellite images at different spatial resolutions are extensively used for extracting water body information at various periods. Using multi-temporal Landsat TM/OLI satellite images, the study aimed to estimate the spatiotemporal LC/LU change and identify the most influential LC/LU parameters that contributed to the reduction of surface water body from 1989 to 2019. The support vector machine, matrix union, and image difference algorithms were applied to estimate LC/LU classification, conversion of LC/LU, and water body to other LC/LU classes. Results revealed that a massive increase in the built-up area (16%) and infrastructural development was the primary cause for water body reduction, and loss of water bodies was estimated at around 8% in the last 30 years. Key informant's interviews were conducted to identify effective management and technical strategies for developing a sustainable IWRM plan using modern technology and hydro-geomorphological (modelling flow direction, stream network, flow accumulation, and surface water potential zones) information which might be helpful for any developing countries. This study will help to establish effective strategies to preserve the existing water bodies and ensure ecological and environmental sustainability by improving the plant's biodiversity and reducing heatwave effects.

Keywords: Urbanization; Land cover/land use change; Water body reduction, Remote sensing; Water resource management.

1. Introduction

Water resources play a significant role by providing an adequate food supply and sustainable environment for all living organisms globally (Kötter, 2019). The availability of worldwide freshwater is only 2.5%, and over two-thirds of this is frozen in polar ice caps and glaciers (Santamouris, 2020). Worldwide, 70% of water was used for irrigation purposes in the agricultural sector (Islam et al., 2019; Kafy et al., 2021a). From the beginning of civilization, communities have invented many different ways to catch, store, clean, and redirect freshwater resources to reduce the vulnerability of intermittent fluvial flows and erratic rainfall (Rahaman et al., 2018). Due to rapid urbanization, pressure on water and water resources are growing, and many of the world's major aquifers are becoming depleted. A remarkable decrease in surface and groundwater is hampering the hydrological cycle dramatically and increasing climate change consequences (Hossain et al., 2020). Hence, a new proto-type aims to preserve the available freshwater, and efficient use of the water resources to meet the increasing demand is needed with the help of integrated water resources management (IWRM) plan for ensuring ecological health and environmental sustainability.

Underdeveloped and developing countries mainly face rapid and unplanned urbanization due to their lack of proper initiative. These countries significantly damage the groundwater and surface water bodies by uncontrolled extractions for aquifers and disposal of pollutants such as sewage, solid waste, and industrial pollutants (Broberg, 2020; Chakroborty et al., 2020). Bangladesh is a developing country, and its primary water sources are groundwater, surface water which are categorized as rainfall, transboundary flow, water storage in reservoirs (lake, pond, and river), water on seasonal wetlands, and in-stream storage (Van Schendel, 2020). Bangladesh faces frequent flooding and inundation challenges during the monsoon season and water shortages due to drought in the dry season (Faisal and Khan, 2018). Bangladesh mainly consists of low-lying flatlands at the conflux of the Bramhaputra (Jamuna), Ganges (Padma), and Meghna (Borak) rivers and their tributaries. The country has 405 rivers, out of which 57 are perceived as transboundary rivers, including the rivers mentioned above (Van Schendel, 2020). So, it can be said that Bangladesh is a water-abundant country having plenty of rivers, innumerable small lakes, and water bodies. The importance of water bodies in Bangladesh's economic, social and overall development process should be emphasized (Al Rakib et al., 2020; Kafy, 2018). Focuses need to be given to improve drinking water quality by reducing salinity in the coastal belt, minimizing contamination of manganese and iron, and groundwater depletion in the northwest regions of Bangladesh (World Bank, 2016; Rahman, 2010). Rajshahi is situated in the northwest part of Bangladesh and mainly an agricultural-based region. Due to the gradual decrease in groundwater layers, surface water significantly contributing to irrigation activities (Ahammad et al., 2020; Kafy et al., 2019a; Mim and Zamil, 2020). Groundwater depletion is directly linked to food production and health issues, which are subsequently related to human capital (Mostafa et al., 2017). Its high time to revise existing water management policies by using the latest farming technology to develop a sustainable IWRM plan for Rajshahi.

IWRM is the strategy to make water resources more sustainable and capable of meeting future demand (Chandra S. P. Ojha et al., 2017). IWRM is a dynamic mechanism involving resource sharing between competing uses and users and thus involves political push. Due to rapid urbanization, tremendous pressure has been imposed, which significantly reduces water resources

and societal resilience with respect to water limitations, leaving fewer options available to cope with IWRM (Rahman et al., 2018; Smith and Jønch Clausen, 2015). IWRM can help to meet global water scarcity by ensuring a sufficient quantity of water storage through effective decision-making by analyzing watershed distribution, strategical guideline establishment by engaging local communities, and implementing effective ones in water scarcity regions (Katusiime and Schütt, 2020). Components such as integrated planning, regulatory measures, community engagement, and management of the undertaking programs through financing help to manage water resources and implement the IWRM plan (Attwa et al., 2021). The IWRM planning process incorporates an overview of the existing and upcoming problems based on the community needs assessment, short out the most crucial ones, designing a program to achieve the goals, and implementing organizational and community support programs (Attwa et al., 2021; Katusiime and Schütt, 2020; Smith and Jønch Clausen, 2015). During the Environment and Development conference held in Rio, four principles are identified which need to be considered during the preparation of the IWRM plan. The principles are a) freshwater is a finite and scarce resource essential for life, development, and the climate; b) a participative strategy involving all relevant parties should be used to ensure water production and water conservation; c) women have a crucial role in water supply, management and security; d) The water has an economic significance to its all competing users that have unlimited users (McCammon, 1992).
The integration of Geographic Information System (GIS) and Remote sensing (RS) technique in water resources monitoring and management have been achieved throughout the years (Asif et al., 2018; Kafy and Ferdous, 2018; Kafy et al., 2020b; Rahaman et al., 2018). Change identification in the LC/LU scenario, such as water bodies, built-up areas, vegetation cover, and bare lands, is lengthy, labor-intensive, and error-prone by direct field visits (Hart and Sailor, 2009; Kafy et al., 2020c; Lilly Rose , Devadas, M.D., 2009). The combination of RS and GIS technologies saves time and provides accurate information that enables LC/LU changes to be evaluated, monitored, and modelled (Fu and Weng, 2018; Niyogi, 2019; Trolle et al., 2019). Also, due to the increased flexibility of statistical algorithms with remotely sensed data, the spatiotemporal modelling and historical data analysis of LC/LU dynamics has resulted in significant exposures in solving the problems associated with water resources (Celik et al., 2019; Gaur et al., 2018; Kafy et al., 2020a; Mansour et al., 2020; Rahman, 2016; Zine El Abidine et al., 2014). Several studies have been conducted in different parts of Bangladesh describing the changing pattern of LC/LU classes and their impacts on the environment using RS and GIS techniques. Kafy et al. (2021) estimate and simulate the LC/LU changes using RapidEye images and identifies their impacts on the urban environment in Dhaka city, Bangladesh (Kafy et al., 2021b). Arefin, Meshram, & Seker (2021), assess the Padma river shifting related effects on LC/LU (Arefin et al., 2021). Islam, Uddin & Hossain (2021) detect the land cover changes with shoreline shifting in Nijhum Dwip of Bangladesh (Islam et al., 2021). Ahammad et al. (2020) and Mim and Zamil (2019) detect surface water body changes from Landsat images in Rajshahi city (Ahammad et al., 2020; Mim and Zamil, 2020). Kafy et al. (2020) modelling the LC/LU changes and identified the future impacts of water bodies and vegetation cover loss in the urban climate of Rajshahi City (Kafy et al., 2020c). The spatiotemporal changes of LC/LU and identification of the most influential LC/LU parameters contribute to the reduction of surface water bodies using the Landsat images in Rajshahi city was also estimated by (Kafy et al., 2019a).

Although several studies have been conducted to demonstrate the changing pattern of LC/LU classes, there is an absence of research describing the influential parameters that impact the reduction of surface water bodies and overcome those problems using the IWRM plan. Based on this consideration, this study aims to a) integrate RS datasets and GIS applications to detect decadal water bodies reduction due to massive LC/LU changes from 1989 - 2019, b) identify significant driving forces in reducing surface water bodies, and c) to provide effective recommendations in the preparation of the IWRM plan based on expert opinions for ensuring sustainable water resource development and reducing its impacts on the urban environment, biodiversity and climate change in Rajshahi City Corporation (RCC).

2. Materials and Method

2.1 Study area

The RCC, located on the bank of River Padma, is one of the key administrative divisions of Bangladesh. The area is geographically located between 24°07″ latitude to 24°43′ N and 88°17″ to 88°58′ E longitude, covering an area of 48 km^2 approximately (BBS, 2013) (**Fig 1**). Rajshahi is located within the Barind Tract and 23 meters above the mean sea level. The city is located on the alluvial planes of River Padma, which flows through the southern side of the city (BMD, 2013). As per the city corporation, the current population for the year 2020 is approximately 800,000. Large-scale rural-to-urban migration and rapid urbanization are among the most significant reasons for population growth in the RCC area (Kafy et al., 2019b). Under the Köppen climate classification, Rajshahi has a tropical wet and dry climate (Belda et al., 2014; Ferdous and Baten, 2011). The climate is generally marked with high temperature, considerable humidity, and moderate rainfall. The hot season commences early in March and continues till the middle of July. The maximum mean temperature observed is about 32 °C to 36 °C during April - July, and the minimum temperature recorded in January is about 7 °C to 16 °C. The highest rainfall is observed during the months of monsoon. The annual rainfall in the district is about 1,448 mm (BMD, 2013). Typically, the city witnesses four seasons across a year (a) winter from mid-December to February, (b) pre-monsoon with minimal rainfall, high temperatures, and evaporation from March to May, (c) monsoon with moderate rain and high temperatures between June to mid-October and (d) post-monsoon with slight decreases in rainfall and temperatures between mid-October to December (Haque et al., 2012; Kafy et al., 2020c). Geological stability of the RCC area includes hard rocks with unfavorable hydraulic pressure and low to moderate groundwater potential (Haque et al., 2012; Rasel et al., 2015).

Due to the rapid increase in population, indiscriminate land disposal, and unplanned urbanization, a total of 4,000 ponds were filled in the last five decades in the Rajshahi area (RDA, 2008, 2003). It had 4,238 reservoirs, canals, and wetlands in the city in 1961, 2,271 in 1981, 729 in 2000, and only 214 water bodies in 2019 (Clemett et al., 2006; Kafy et al., 2019a; RDA, 2008, 2003). Vast urban migration and rapid urban development constitute some of the essential factors for RCC population expansion. The past 50-year land-use history of this region indicates that more than 30% of the water bodies have been demolished due to infrastructural development (Kafy et al., 2019a; Kafy et al., 2020c; RDA, 2003, 2008).

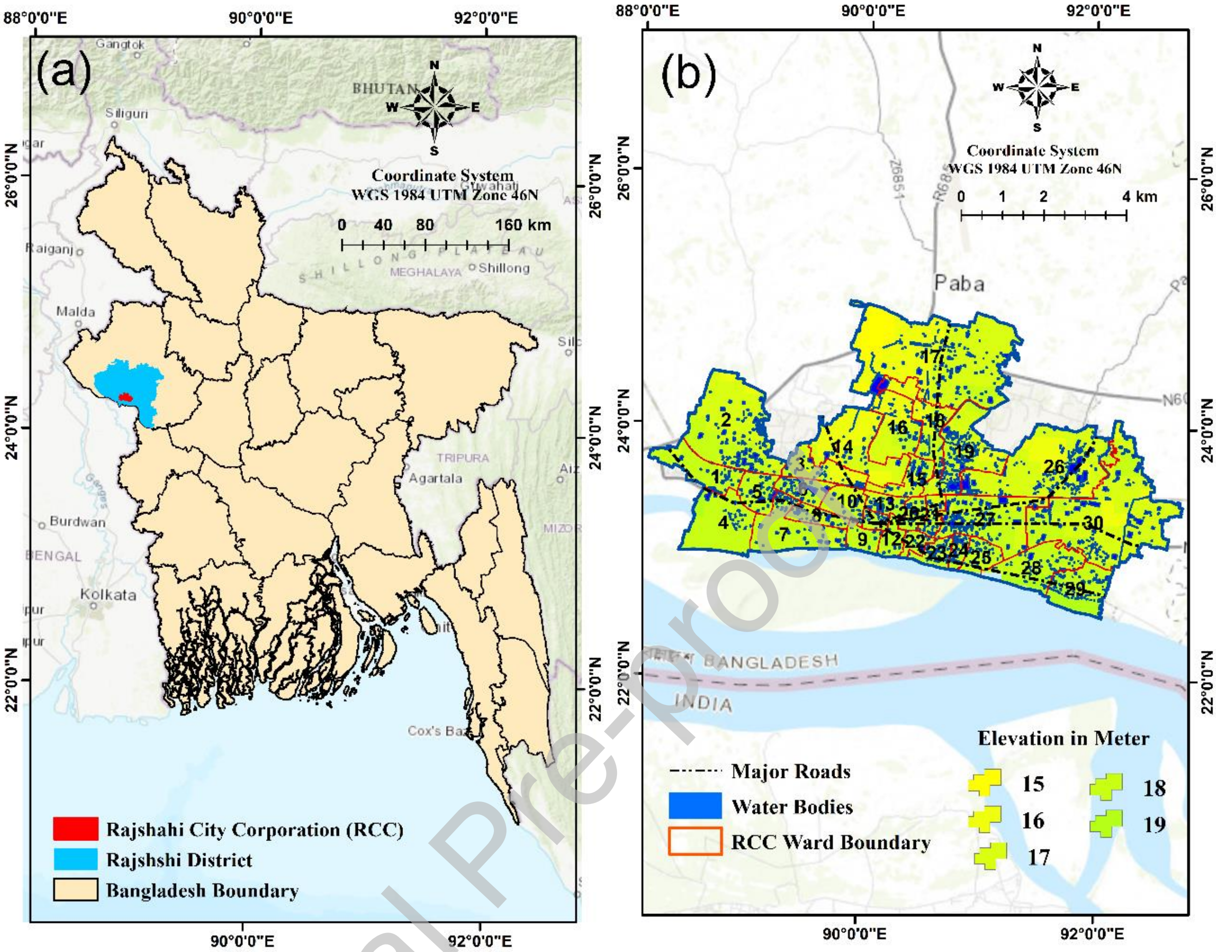

Figure 1 Location map of the study area a) In Bangladesh and Rajshahi District b) Elevation, water bodies, and road network of RCC

2.2 Description of data sets and processing approach

The study was directed based on primary and secondary data. Primary data collected from Key Informants Interviews (KIIs). The secondary data comprise of multi-temporal Landsat 4-5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) satellite images collected from US Geological Survey (USGS) website (https://earthexplorer.usgs.gov) where the scene path was 138 and row was 43 (**Table 1**) for the years, 1999, 2009 and 2019. The images had a spatial resolution of 30 m. The images were downloaded for December at ten years intervals to assess LC/LU variations in the study region. For avoiding seasonal variation, all the images were downloaded for the same month (Kafy et al., 2020e; Naim and Kafy, 2021). The images were dokafykafykwnloaded in less than 10% cloud coverage for ensuring better classification accuracy (Kafy et al., 2020b; Kafy et al., 2021a). **Table 1** contains information about the images obtained from the USGS online data portal.

Table 1 Description of downloaded satellite images

Date (d/m/y)	Sensor	Cloud Cover	Path / Row
13 / 12 / 1989	Landsat 5 TM	~0%	138/43
25 / 12 / 1999		~0%	
04 / 12 / 2009		~8%	
30 / 12 / 2019	Landsat 8 OLI	~0%	

2.3 Primary data collection

For primary data collection, a field visit was conducted in the study area in January 2020. Global Positioning System (GPS) was used to collect the ground truth data for accuracy assessment of classified LC/LU maps. Thirty KIIs (**Annex I**) were conducted from January 2020 to February 2020 through online, offline, and phone calls to identify the possible impacts of LC/LU shifts and strategies to develop IWRM plan for RCC. The KIIs consisted of urban planners, university professors, agricultural officers, environmental engineers, policymakers, local community leaders, and decision-makers. The outputs from KIIs have been discussed in **section 3.6.**

2.4 Classification of LC/LU maps

The images obtained from the Landsat satellite were classified into four broad LULC classes such as i) Built-up Area (industrial/residential/commercial and transportation network); (b) Vegetation and agricultural land (green lands, agricultural lands, and vegetation); (c) Water Bodies (rivers, wetlands, reservoirs, canals, and streams; and (d) Bare Land (fallow land, sand, playground, landfill sites, and vacant soil) for the year 1999, 2009, and 2019 using the Support Vector Machine (SVM) algorithm in ENVI 5.3 software. The SVM is a powerful supervised classification technique derived from statistical learning theory that frequently produces accurate classification results when the data is complex or noisy (Maulik and Chakraborty, 2017). The SVM is called a non-parametric classifier, and its success is greatly dependent on training procedures. The use of linearly separable classes is one of the easiest ways to train SVM. The expression of 2 hyper-planes to discriminate the data points in the respective classes are mentioned in **Eq. (1)** and **Eq. (2)** (Osuna, 1998):

$$WX_i + b \geq +1 \text{ for all } y = +1, \text{ i. e. a member of class 1} \quad (1)$$

$$WX_i + b \leq -1 \text{ for all } y = -1, \text{ i.e. a member of class 2} \quad (2)$$

Here, K number of samples are represented as (X_i, Y_i) =1,2,...,k; X € Rn is an n-dimensional space; y € (−1, +1) = class label; W = perpendicular to the linear hyper-plane (which determines the direction of the discriminating plane); **a** scalar **b** showing the offset of the discriminating hyperplane from the origin; Class 1 and class 2 represents -1 and +1, respectively.

The images were classified using the Land Cover Classification System (LCCS), developed by FAO, which provides a consistent framework for the classification and mapping of LULC (FAO, 2012; Latham et al., 2002). Based on their spectral and areal profiles, the images were analyzed to establish additional training information and background data from local knowledge and multiple secondary sources. The more sample data for each class, the more accurate the classification will be.

Around 30 samples were collected for each LC/LU class in order to produce LC/LU maps. The classified maps' accuracy was evaluated through 200 field level and 100 Google Earth image random sampling ground truth data. For accuracy assessment, the overall accuracy (**Eq.** 3), user accuracy (**Eq.** 4), producer accuracy (**Eq.** 5), and kappa statistics (**Eq.** 6) were calculated, and one of the best quantitative procedures for image classification accuracy was used (Rahman et al., 2018).

$$\text{Overall accuracy} = \frac{\text{Total number of corrected classified pixelx (diagonal)}}{\text{total number of reference pixels}} * 100 \quad (3)$$

$$\text{User Accuracy} = \frac{\text{number of correctly classified pixelxs in each catagory (diagonal)}}{\text{total number of reference pixels in each category (row total)}} * 100 \quad (4)$$

$$\text{Producer Accuracy} = \frac{\text{number of correctly classified pixelxs in each category (diagonal)}}{\text{total number of reference pixels in each category (column total)}} * 100 \quad (5)$$

$$\text{Kappa Coefficient (T)} = \frac{\text{Total number of Sample} * \text{Total Number of Corrected Sample} - \sum(\text{col.tot} * \text{row tot})}{(\text{Total number of Sample})^2 - \sum(\text{col.tot} * \text{row tot})} * 100 \quad (6)$$

2.5 Change detection analysis

Change detection analysis was conducted using matrix union (MU) and image difference (ID) tools in Erdas Imagin V15. MU analyzes two input thematic raster files and produces a new file. The new file contains class values that indicate how the LC/LU class values from the original files overlap. MU helps to identify the most influential LC/LU parameters, which significantly converted the water bodies pixels to other classes. In **Fig 2**, one example is given for the conversion of LC/LU from 1989-2019 using the MU tool to identify the influential parameters that reduce the surface water bodies.

ID is used for change analysis with imagery that depicts the same area at different points in time. ID can highlight specific areas of change in whatever percentage is chosen. Two images are generated from this image-to-image comparison; one is a continuous grayscale image, and the other is a five-class thematic image. The first image generated from ID is the difference image. The Difference image is a grayscale image composed of single-band continuous data (Erdas Imagin help-V15, 2021). This image is the direct result of subtraction of the before image (1989, 1999, 2009, and 2019) from the after image (1989, 1999, 2009, and 2019). Since ID calculates the change in brightness values over time, the difference image simply reflects that change using a grayscale image. Brighter areas have increased in reflectance. This may mean the clearing of vegetation and water bodies areas by buit-up and bare land areas. Dark areas have decreased in reflectance. This may mean an area has become more urban by replacing the green cover, water bodies, and bare lands. The highlight difference image divides the changes into three categories. The five categories are decreased, unchanged, and increased. The decreased class represents negative change areas (darker) greater than the threshold for change and is red in color. The Increased class shows positive (brighter) change areas greater than the threshold and is green in color. Other areas of positive and negative change less than the thresholds, and areas of no change are transparent. For your application, you may edit the colors to select any color desired for your study. An example of the ID work process from 1989-2019 is shown in **Fig 3**.

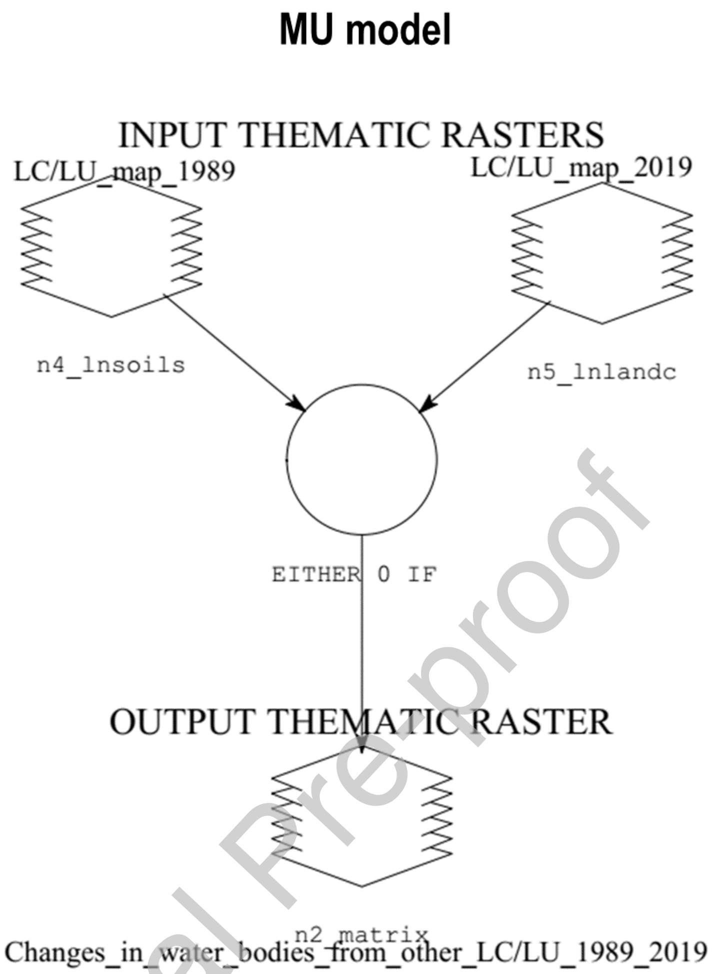

Figure 2 Graphical representation of MU tool working process in Erdas Imagine

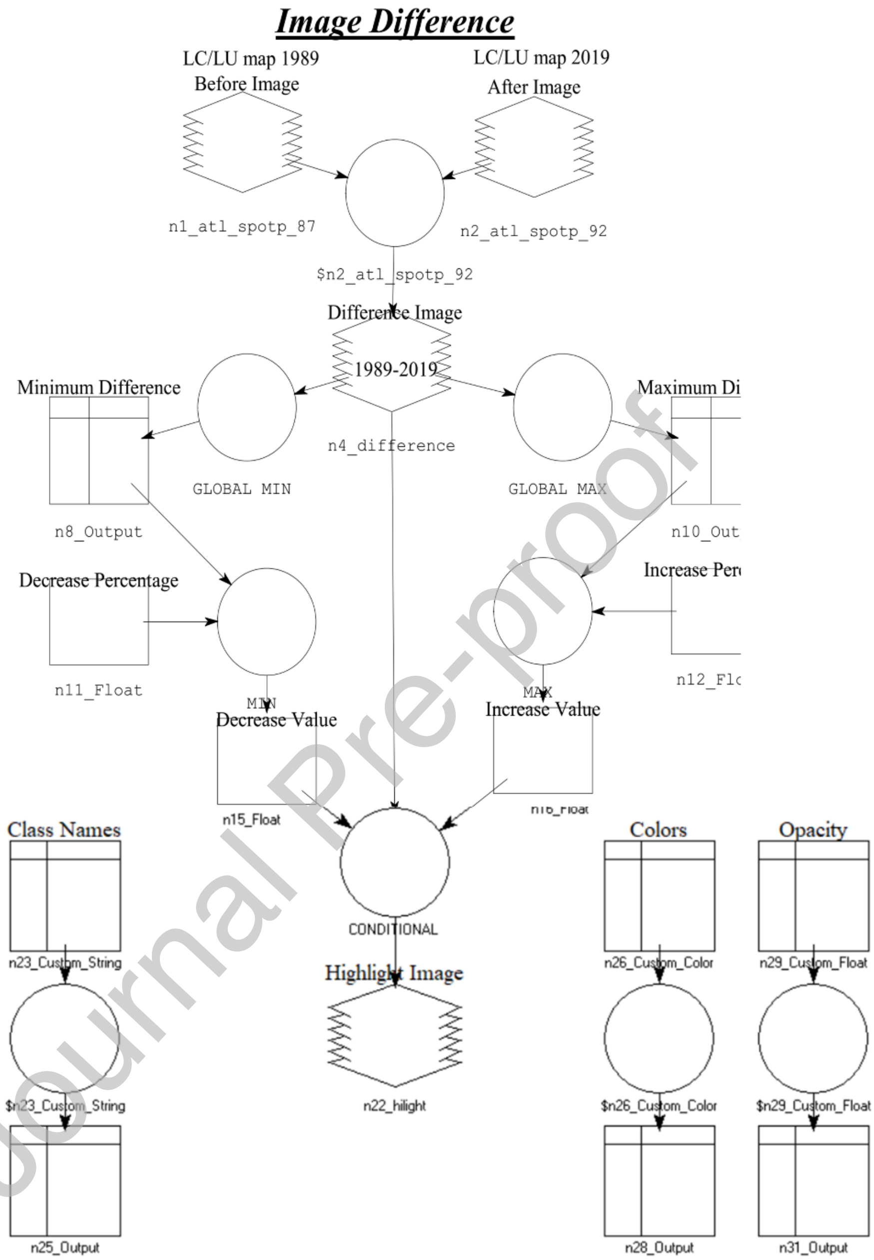

Figure 3 Graphical representation of ID tool working process in Erdas Imagine

2.6 Flow direction and accumulation estimation of surface water bodies

Flow direction (FD) and Flow accumulation (FA) estimation played a significant role in establishing a sustainable IWRM plan. One of the keys to deriving hydrologic characteristics of a surface is the ability to determine the direction of flow from every cell in the raster. This was done with the Flow Direction (FD) tool in Arc GIS 10.6. This tool takes a surface as input and outputs a raster showing the direction of flow out of each cell. If the output drop raster option is chosen, an output raster is created showing a ratio of the maximum change in elevation from each cell along the direction of flow to the path length between centers of cells and is expressed in percentages. If the force of all edge cells to flow outward option is chosen, all cells at the edge of the surface raster will flow outward from the surface raster. The FD is determined by the direction of steepest descent, or maximum drop, from each cell. If all neighbours are higher than the processing cell, it will be considered noise, be filled to the lowest value of its neighbours, and have FD toward this cell (Arc GIS help-10.6, 2021). However, if a one-cell sink is next to the physical edge of the raster or has at least one no data cell as a neighbour, it is not filled due to insufficient neighbour information. To be considered a true one-cell sink, all neighbour information must be present. If two cells flow to each other, they are sinks and have an undefined flow direction. This method of deriving FD from a digital elevation model (DEM) is presented in Jenson and Domingue in 1988 (Jenson and Domingue, 1988). Cells that sink can be identified using the Sink tool. To obtain an accurate representation of FD across a surface, the sinks should be filled before using a flow direction raster. FD creates a raster direction from each cell to its downslope neighbour, or neighbours, using D8, Multiple Flow Direction (MFD), or D-Infinity (DINF) methods. The MFD output, when added to a map, only displays the D8 flow directions. As MFDs have potentially multiple values tied to each cell which corresponds to the proportion of flow to each downslope neighbour and is not easily visualized. However, an MFD output raster is an input recognized by the FA tool that would utilize the MFD flow directions to proportion and accumulate flow from each cell to all downslope neighbours. **Fig 4** illustrates the working process of FD collected from the Arc GIS 10.6 help platform.

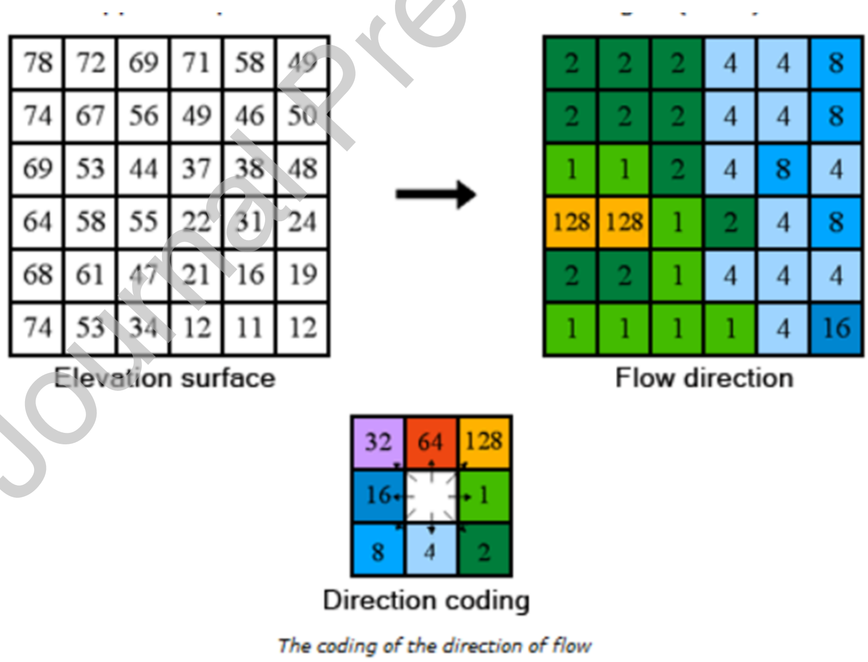

Figure 4 Illustration of FD process

The FA tool calculates accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster. If no weight raster is provided, a weight of 1 is applied to each cell, and the value of cells in the output raster is the number of cells that flow into each cell (Arc GIS help-10.6, 2021). In **Fig 5,** collected from the Arc GIS 10.6 help platform, the top left image shows the direction of travel from each cell and the top right the number of cells that flow into each cell. Cells with a high flow accumulation are areas of concentrated flow and may be used to identify stream channels. Cells with a flow accumulation of 0 are local topographic highs and may be used to identify ridges. Sample usage of the FA tool with an input weight raster might determine how much rain has fallen within a given watershed. In such a case, the weight raster may be a continuous raster representing average rainfall during a given storm. The output from the tool would then represent the amount of rain that would flow through each cell, assuming that all rain became runoff and there was no interception, evapotranspiration, or groundwater loss. This could also be viewed as the amount of rain that fell on the surface, upslope from each cell. The results of FA can be used to create a stream network by applying a threshold value to select cells with a high accumulated flow. Jenson and Domingue present this method of deriving accumulated flow from a DEM in 1988 (Jenson and Domingue, 1988). An analytic method for determining an appropriate threshold value for stream network delineation is presented by Tarboton et al. in 1991 (Tarboton et al., 1991).

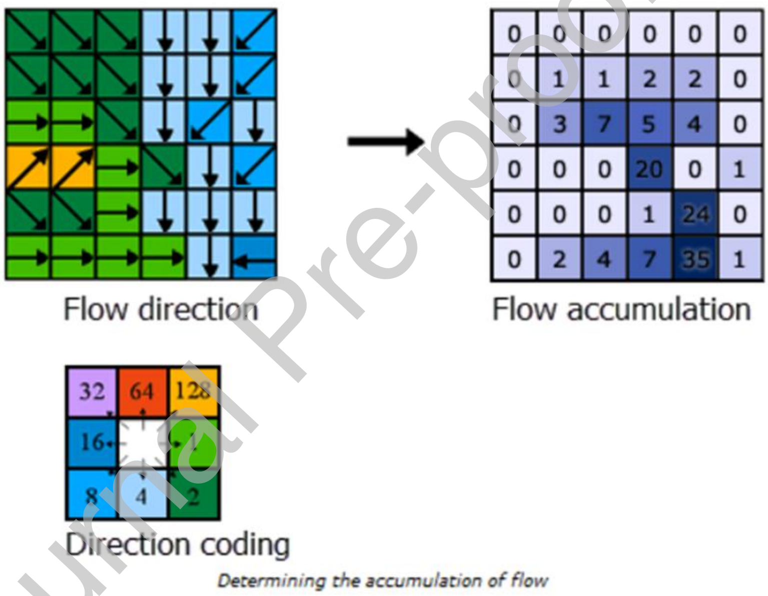

Figure 5 Illustration of FA process

3 Results and Discussion

This section describes the results estimated from the methodology presented in section 2.2. The LC/LU changes, conversion of surface water bodies to other LC/LU classes, urbanization impact on water body losses, impacts of water body losses on the urban environment, biodiversity and recommendations to develop a sustainable IWRM plan for the RCC.

3.1 Changes in LC/LU classes

The past patterns (1989-2019) of LC/LU variations were estimated from Landsat images using SVM methods are presented in **Fig. 6**. The SVM-based classification producer and overall classification accuracy was more than 95%, where the kappa coefficient estimated was more than 85% for 1989, 1999, 2009, and 2019 (**Table 2**) denotes excellent classification accuracy for all the LC/LU maps.

Table 2 Accuracy assessment of the classified images.

Year	Classified Class	Validation points for different LULC classes					
		Water Body	Built-up area	Vegetation Cover and agricultural land	Bare Land	Total	User Accuracy
1989	**Water Body**	60	0	0	0	60	100.00
	Built-up area	0	98	0	3	101	97.03
	Vegetation Cover and agricultural land	0	2	68	0	70	97.14
	Bare Land	0	4	1	64	69	92.75
	Total	60	104	69	67	300	
	Producer Accuracy	100.00	94.23	98.55	95.52	**Overall Accuracy 96**	**Kappa Coefficient 86.45**
1999	**Water Body**	45	1	0	0	46	97.83
	Built-up area	0	100	0	6	106	94.34
	Vegetation Cover and agricultural land	0	1	78	0	79	98.73
	Bare Land	0	3	0	66	69	95.65
	Total	45	105	78	72	300	
	Producer Accuracy	100.00	95.24	100	91.67	**Overall Accuracy 95**	**Kappa Coefficient 86.02**
2009	**Water Body**	56	0	0	0	56	100.00
	Built-up area	0	91	3	3	97	93.81
	Vegetation Cover and agricultural land	0	0	70	0	70	100.00
	Bare Land	0	2	0	75	77	97.40
	Total	56	93	73	78	300	
	Producer Accuracy	100.00	97.85	95.89	96.15	**Overall Accuracy 97**	**Kappa Coefficient 85.87**
2019	**Water Body**	52	0	0	0	52	100.00
	Built-up area	0	103	1	4	108	95.37
	Vegetation Cover and agricultural land	0	3	72	0	75	96.00
	Bare Land	0	1	0	64	65	98.46
	Total	52	107	73	68	300	
	Producer Accuracy	**86.67**	**96.26**	**98.63**	**94.12**	**Overall Accuracy 98**	**Kappa Coefficient 86.04**

Four LC/LU maps (**Fig 6**) were developed using the Landsat 4-5 TM and Landsat 8 OLI images. The built-up area was increased by 22% to 43% (10 km^2 to 17.7 km^2) from 1989–2019 due to the upsurge of urbanization (**Table 3**). Bare land was also recorded a significant increase from 16% to 25% in the last 30 years. Green cover and water bodies were significantly reduced in the last 30 years from 54% to 28% and 8% to 4%, respectively. Rapid urban growth dominates other LC/LU classes by replacing them significantly (**Fig 7**). In the last 30 years, unchanged built-up land recorded 10.94%, where 15.55% and 5.94% vegetation and bare land and 1.19% water bodies have been reduced due to the massive unplanned infrastructural development in the RCC area (Fig 8). Water bodies were reducing gradually and replaced by built-up areas, vegetation, and bare soil during the urbanization process to fulfill the need of city's rapid population, retail and industrial development. The total amount of water bodies were 6.12 km^2 in 1989, and the urban area was 10 km^2. No change in the water body was noticed from 1999 to 2009, which stayed at 3 km^2. A significant change was observed in the last decade. The human settlement was encroached upon the water body and reduced it to 2 km^2. The urban area was increased to 17.7 km^2, which was almost double compared to 1989 (**Table 3**).

The data displays an unprecedented increase in the built-up area and a noticeable decline in the vegetation cover, agricultural land, and water bodies. The main reason behind this is rapid and unplanned urbanization. The vegetation cover and water bodies were dynamically converted to impervious infrastructures to fulfill the demand for rapid population growth. Reduction in agricultural land forces the farmers to cultivate their land intensively, which increases the use of chemical fertilizer and pesticides that causes pollution of air, water, land, and other elements of the environment (Islam et al., 2019).

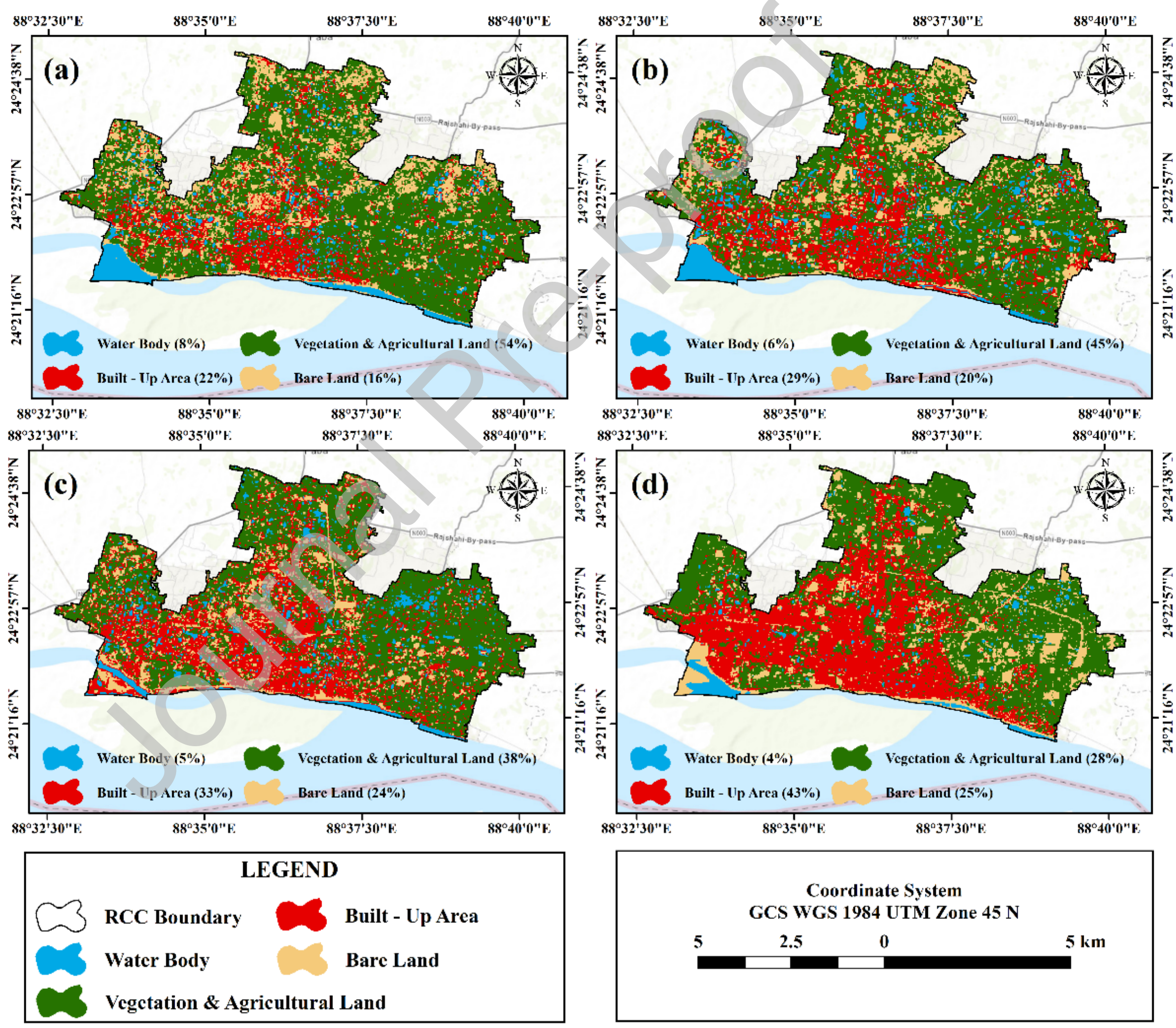

Figure 6 Land cover map of Rajshahi City Corporation in (a) 1989; (b) 1999; (c) 2009; and (d) 2019.

Table 3 LC/LU change statistics from 1989-2019

Land use	Year				
	1989 (km^2)	1999 (km^2)	2009 (km^2)	2019 (km^2)	1989-2019 (km^2)
Water Body	6.0	3.0	3.0	2.0	-4
Built-Up Area	10.0	12.0	15.0	17.7	8
Vegetation & Agricultural Land	27.0	25.0	19.0	13.7	-13
Bare Land	6.0	9.0	12.0	15.6	10

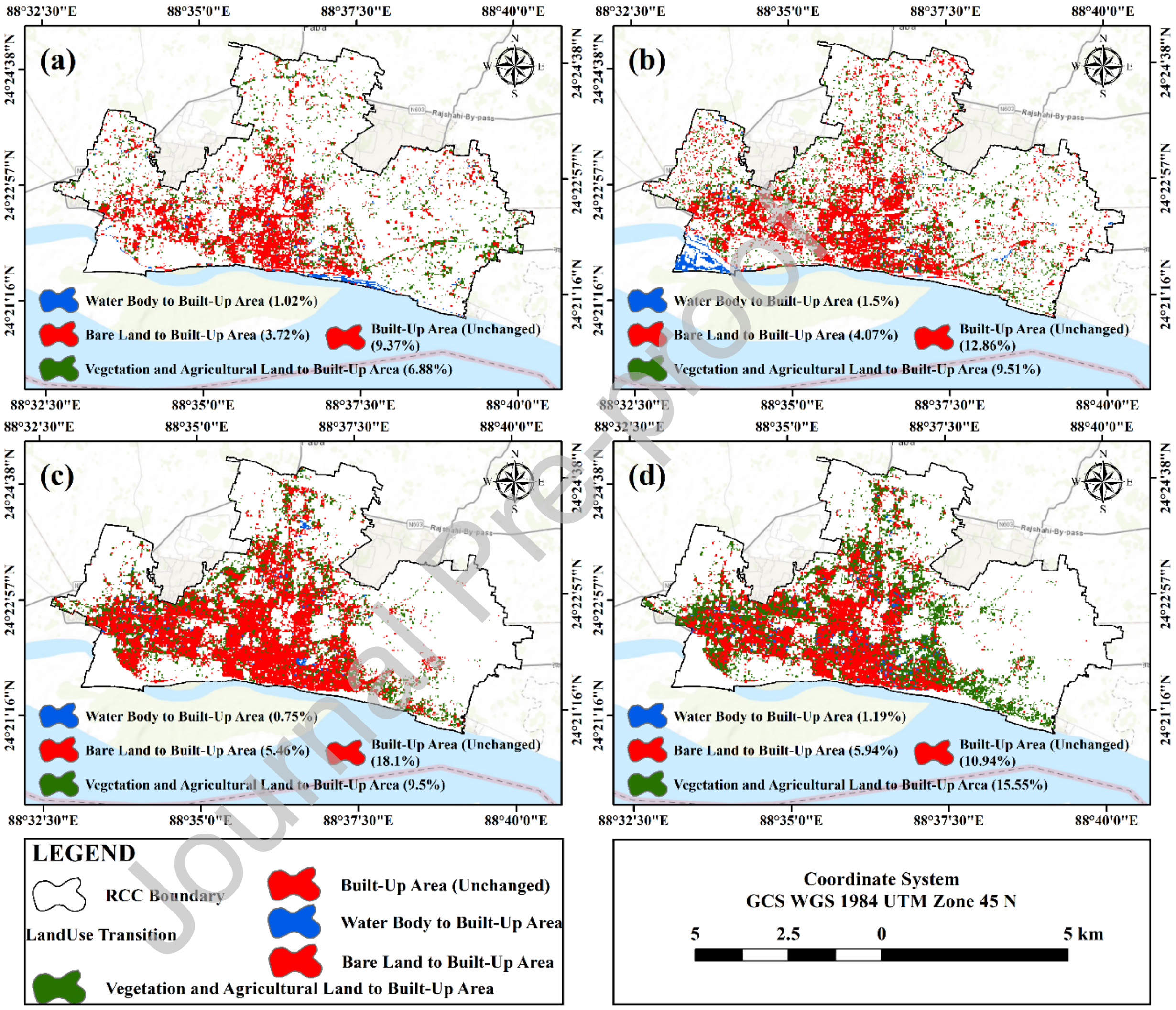

Figure 7 Transition of different LC/LU classes in the study area from a) 1989-1999 b) 1999-2009 c) 2009-2019 and d) 1989-2019

3.2 Conversion of surface water bodies to different LC/LU

A transformation detection technique, i.e., MU tool, was applied to examine the converted water body locations associated with different LC/LU changes. The location of water body losses due to different LC/LU classes in the last 30 years (1989 – 2019) is illustrated in **Fig 8**. The maps show that the built-up area plays the most significant role in reducing surface water bodies compared to other LC/LU classes. From 1989-1999, 4.91% of the water body was converted to the built-up areas, which is 5.02% and 5.87% from 1999-2009 and 2009-2019, respectively. From 1989-2019, almost 10 km^2 water bodies were converted from the built-up area with the highest changing rate compared to other LC/LU (**Table 4**). All the intervals show the influence of the built-up area in converting the water bodies, and the highest conversion occurred in 2009-2019. Lack of water body conservation projects, unplanned urbanization, and irregulated monitoring in the infrastructural development activities around the cities by replacing natural resources are the main reason behind this massive decrease in the surface water bodies in the RCC area.

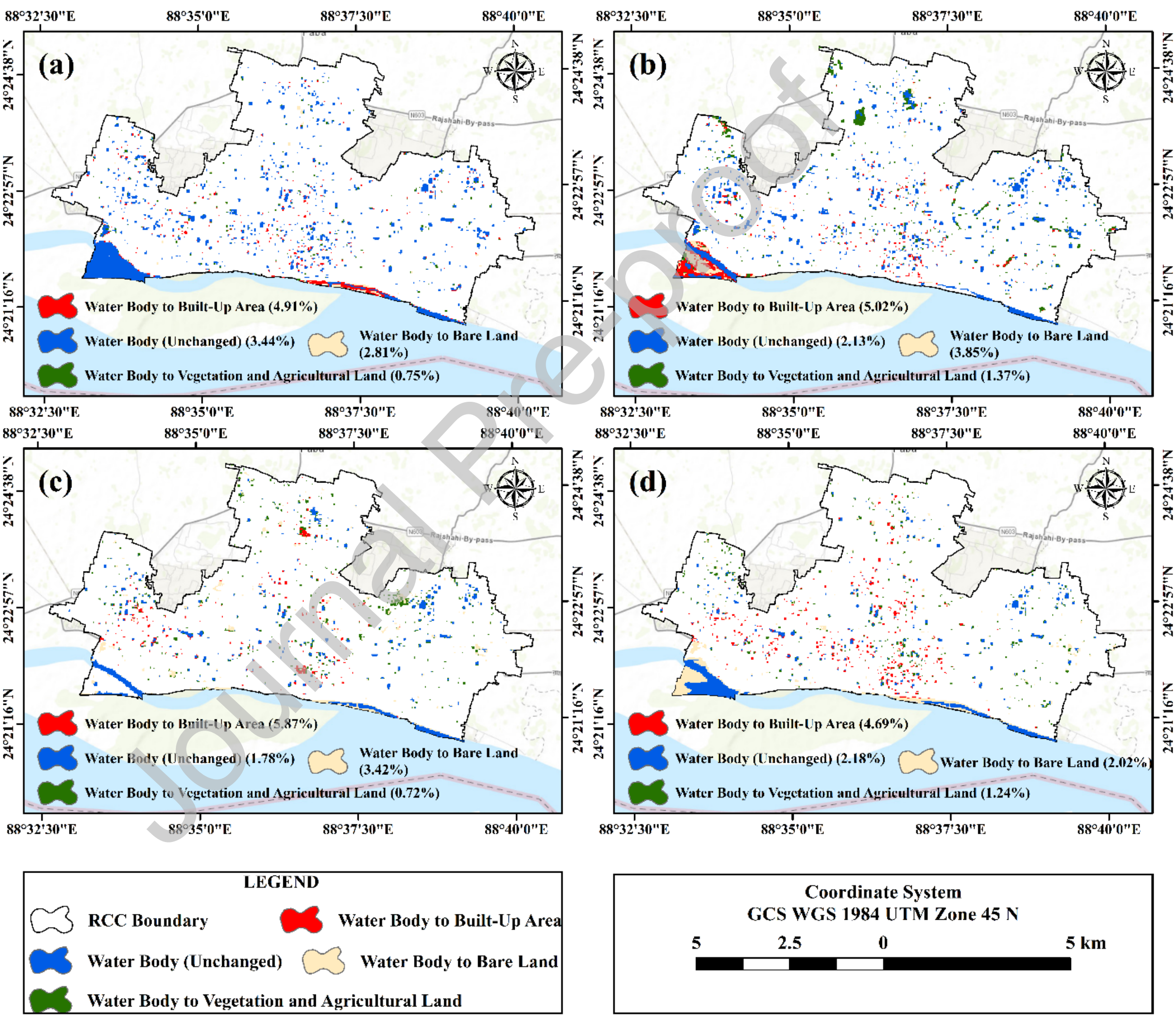

Figure 8 Conversion of water bodies to other LC/LU from a) 1989-1999 b) 1999-2009 c) 2009-2019 and d) 1989-2019

Table 4 Area (km^2) of water bodies transformation into different LC/LU classes from 1989-2019

Transformation of Waterbodies to other LC/LU classes	Year			
	1989-1999	1999-2009	2009-2019	1989-2019
	(km^2)			
Waterbody to Waterbody	1.65	1.02	0.86	4.54
Waterbody to Built-up area	2.36	2.41	2.82	9.76
Waterbody to Vegetation Land	0.36	0.66	0.35	2.58
Waterbody to Bare land	1.35	1.85	1.64	4.20

3.3 FD and FA for runoff monitoring of surface water bodies

Hydrologists use FD and FA maps to model surface runoff characteristics to determine the water flow, which significantly contributes to the urban water supply. FD calculates the direction of water flow using slope data from neighboring cells, where FA calculates the accumulated flow of all cells flowing into each downslope cell and is used to identify stream channels. The study area's water flow network was primarily influenced by the Padma river, with a significant amount of small and large water bodies (**Fig 9a**). The FA (**Fig 9b**) and FD (**Fig 9c**) greatly influenced by rapid urbanization and faces disruption due to uncontrolled use. Maximum flow network recorded in the range of 591 to 885 km (35.24%) followed by 21.69% within the range of 886 to 1180 km (**Table 5**). The Padma river is the main influential factor contributing to the FD of water in the city area. As the river was situated comparatively in the lower elevation, the water generated from rainfall, small and medium surface water bodies flow towards the river. Besides this, the study area was experienced enormous soil degradation due to inadequate tree coverage in the riverside areas and negligence of available fallow land. The research area geologically consists of rocks with unfavorable hydraulic characteristics and low to moderate groundwater potential. As shown in **Fig 9b**, the watershed (FA) has a high drying density, causing excessive earth erosion and surface rush.

Monitoring the earth's surface water through satellite imagery is a powerful way to measure discharge, FD and FA. The Rajshahi city is situated in a lower elevation with less streamflow, and it is easy to demolish vegetation cover and water bodies for residential and commercial purposes. Although a significant amount of vegetation and agricultural covers and water bodies are present in the study area, large-scale consumption of vegetation cover and water bodies took place in the last few decades due to unexpected management issues. Also, streamflow and potential groundwater resources are time-bound and highly localized. There is a need for a considered approach to improve recharge through structures for water harvesting. The streamflow rate is calculated by measuring the amount of water that passes downstream at several points along the stream called discharge per unit of time. Monitoring the stream flow rate is essential as it contributes to assess the effects of human activity and associate environmental degradation. It is also essential to control vegetation losses around surface water bodies and river. Vegetation removal, either by disasters like fires or human-made problems like deforestation, can negatively affect the surface water. Vegetation consumption may lead to escalated runoff and erosion, and the risk of urban flooding can increase. The performance of flow network, FD and FA will be increased if the restriction is applied in the demolishment of surface water bodies using proper rules, policies, and plans. The increase in FD and FA will save the city from unwanted urban flooding.

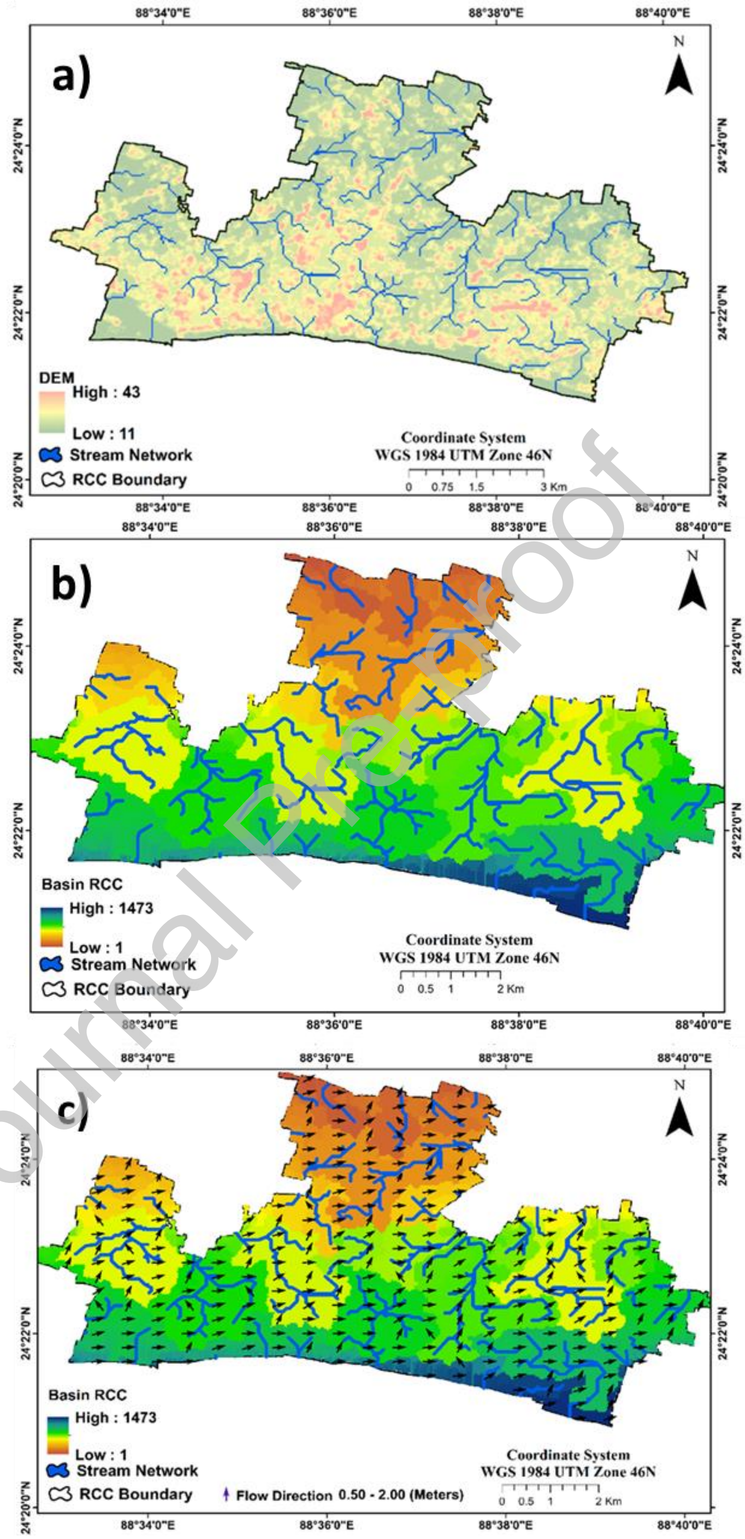

Figure 9 Characteristics of surface water bodies runoff a) Elevation based stream network b) FA and c) FD

Table 5 Ranges of network flow in the study area

Length of the flow network in km	Percentage
1 - 295	17.26
296 - 590	14.56
591 – 885	35.24
886 – 1180	21.69
1181 - 1473	11.25

3.4 Major driving forces contribute to the surface water body demolishment

Surface water bodies have been transformed into other land covers every year. Activities, such as agricultural, industrial, domestic, and municipal sources, continuously receive pollutants and damage surface water bodies. Significant factors for surface water demolishment are discussed below.

3.4.1 Influenced by LC/LU

The transformation rate between different LC/LU categories is an essential aspect to identify the influential factors that significantly contribute to the water body reduction in the RCC area. To identify the water body transformation in different LC/LU classes, LULC transformation maps were estimated using the ID approach. In the LC/LU transformation maps, decreased class denotes vegetation cover and water bodies to built-up areas, where the expansion of built-up areas by replacing vegetation cover, water bodies, and bare land classes indicates an increase. Unchanged category illustrates class to class (i.e., water-water, bare-bare etc.) unchanged pixels during four different years interval (**Fig. 10**).

From **Fig 10**, it is cleared that water bodies experienced negative growth; hence, positive growth was seen in built-up areas. Most of the LC/LU units were changed over the period with a positive change in built-up areas (6.8% per year) followed by bare land (3.4% per year). Also, strong and negative change rates were estimated for water bodies (2.01% per year) and vegetation cover (3.4% per year). Out of the total area, 51% area was experienced as positive, 37% area was experienced as negative, and the rest of the proportion was unchanged by 12% from 1989-2019 (**Fig 10**). The highest positive increase was recorded in built-up areas, and the negative decrease was recorded in water bodies. Almost 4% of surface water bodies were filled up due to the massive increase in the built-up areas.

A substantial portion of water areas has significantly reduced and converted to urban areas and bare land. The intense change dynamics were noticed in neighboring urban areas with the steady transformation of different LC/LU classes took place in the outer parts of the city center. The water bodies adjacent to the built-up areas are highly susceptible to transformation either by the construction of infrastructure or expanding bare land for future construction activities (Kafy et al., 2020d; Kafy et al., 2019a) The map illustrated in Fig 11 reflects unplanned developments and the importance of planned and sustainable LC/LU distribution for ensuring IWRM in Rajshahi City.

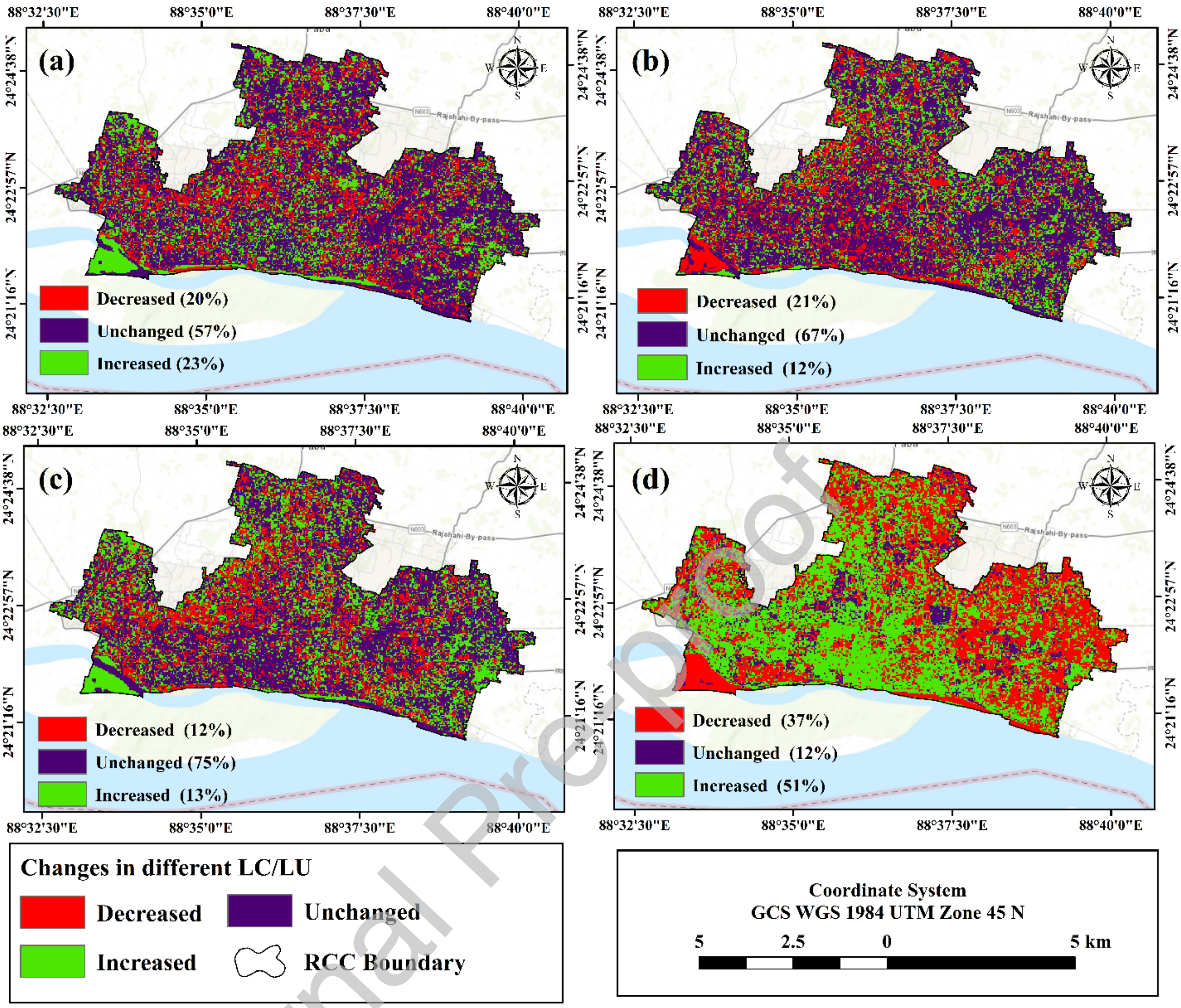

Figure 10 Transformation of different LC/LU classes from a) 1989 to 2009 b) 2009 to 2019

3.4.2 Population growth and water demands

RCC doesn't have an independent water supply system. Rajshahi Water Supply and Sewerage Authority (RWASA) is currently responsible for providing water supply and water treatment facilities for the RCC area. The major source of freshwater in RCC is from groundwater tube wells. As per the RWASA records, in 2018, the freshwater demand for RCC was estimated to be 118 million liters per day (MLD), and the RWASA supplies only 77.88 MLD. Water shortage is estimated to be about 40 MLD, which is expected to be about 67 MLD in 2031 (Rana and Adhikary, 2020). RWASA produces 77.88 MLD water, in which 74.88 MLD water is extracted from underground water, and only 3 MLD is from surface water. This has resulted in a significant and rapid decrease in the groundwater table. As per one study, groundwater in the Rajshahi district was receding at a rate of 0.23 m/year during 2000-2014 (Hasan et al., 2019). Underground water is extracted from 103 tube wells, and surface water is collected from the Padma river. According to the RWASA, the estimated population is 5,51,630, and they are providing water supply to 4,63,370 people which is 84% of the estimated population. The increasing gap between demand and supply in Rajshahi becomes more challenging during the summers due to increased water demand. RWASA produces around 192.67 lcpd of water, of which residents get around 126.3 lcpd of water, rest is lost due to leakages. RWASA has six water treatment plants with a capacity of 27 MLD is located at different wards in the RCC area, but the quantity of treated water produced daily is 18 MLD on average. It's happening due to the technical issues with the pumps, and some of them are not running for the last 6 months.

Increasing population and water demand are putting tremendous pressure on the water supply system. Further, limited availability and uncertainty of supply of surface water is also a major issue for the city due to water diversion on the upstream of Padma River. Total dependence on groundwater, increasing per capita water demand coupled with water losses & uneven distribution throughout the city is likely to have a significant impact on the residents in the future, especially during dry seasons. Therefore, it is inevitable that the currently practiced groundwater use policy in those areas needs to be revised to make groundwater use more sustainable. Strategies such as artificial recharge to the aquifers and rainwater harvesting along with water-saving technologies and IWRM need to be adopted.

3.4.3 Development pressures

Not only naturally occurring conditions such as hazards, disasters but also different actions of humans create significant pressure on water resources (Cosgrove and Rijsberman, 2014). As water demand in the development of different sectors such as industrial, agricultural, housing etc., are increasing across the world, this situation is creating pressure on freshwater availability in many regions (Amore, 2012; Connor, 2015). There is a massive threat of urbanization on the living environment, human life, human health, and in Rajshahi city, rapid urban growth accelerates due to the increase of residential and commercial activities bringing tremendous pressure on local resources of water as well as the ecological environment (Kafy et al., 2019a; Xiang, 2017). In the last few years, urbanization in RCC has increased job opportunities and economic development. Urban planning for the city is looked after by Rajshahi Development Authority (RDA), which is authorized to undertake local urban planning and infrastructure and site development activities for housing, commercial and industrial use. A recent study on RCC identified higher growth rates of urban areas during 2009–2019 and minor decreasing rates during 1999-2009 (Kafy et al., 2020c). The decadal observation demonstrates that the built-up area was 16% in 1999, which was expanded to 21.98% in 2009 with 5.3% growth, mainly in the northeast regions on the RCC area. In 2019, it was increased to 32.6%, with 10.61% of growth. The total increase in the built-up area was identified as 15.95 % from 1999-2019. Also, one of the most important natural resources, water bodies was decreased 3.77% in the last 20 years (1999-2019). Based on the current master plan conducted by RDA, percentages of major land use for RCC area in 2020 are – residential 48.3%, water bodies including river, pond, ditch 5%, agriculture 0.1%, open space 3.8%, roads 12%, educational and research land use covers 11.7%, industry and storage together comprise 1.2%, and mixed-use 11.5%. Compared to RDA data 2004, residential and mixed-use areas have been increased by 14.84% and 9.3%, mostly by replacing water bodies. From 2004-2020, 5.78% of surface water bodies have been reduced due to residential and commercial infrastructural development (RDA, 2008). However, RDA doesn't give no objection certificate (NOC) to any infrastructural development that falls in any surface water bodies. RCC has also taken a water conservation project for conserving potential 19 surface water bodies in the city area. For ensuring the orderly growth of the city, RCC and RDA is working together. But in some cases, there is an issue of inter-departmental coordination between RCC and RDA. Although RDA and RCC take initiatives to preserve surface water bodies, lack of proper monitoring in the development activities is one of the major issues that help the city residents establish infrastructure by demolishing surface water bodies. RCC doesn't have its individual master plan yet. A detailed area plan needs to be established by RCC for monitoring micro-level infrastructural development, which helps in orderly development and conservation of surface water bodies.

3.5 The impacts of water body losses on urban environment, biodiversity, and climate change

Water is an essential natural resource that is significantly impacted by human consumption, crop irrigation, fisheries, transport, and conservation. Due to rapid urbanization faced by RCC in the last two decades, hydropower, industrial and commercial demands have been increased, which significantly hampering the groundwater recharge and surface water body losses. The number of small and medium-sized ponds in the RCC area was 373 in 2011, which is found only 130 in 2019 (Kafy et al., 2019a). The water cycle (hydrological cycle) is the continuous exchange of water between land, water bodies, and the atmosphere. When precipitation falls over the land, it follows various routes. Some of it evaporates, returning to the atmosphere, some seeps into the ground, and the remainder becomes surface water, travelling to oceans and lakes by way of rivers and streams. Impervious surfaces associated with urbanization alter the natural amount of water that takes each route. The consequences of this change are a decrease in the volume of water that percolates into the ground and a resulting increase in volume and decrease in quality of surface water. These hydrological changes have significant implications for the quantity of fresh and clean water available for use by humans, fish, and wildlife.

During the KII interviews, experts have also mentioned the impacts of surface water body losses on the environment, biodiversity, and climate change (**Fig 11**). From all the experts, 22% agreed that reducing surface water bodies significantly increases the temperature and accelerates the heat waves effects in Rajshahi city. Water bodies are working as air cooling parameters, and residents living close to a water body feel less heat than others. Kafy et al. (2020) also validate the information by showing that from 1999-2019, 4% of water bodies have been reduced in the RCC area, which leads to an increase in the average temperature by almost 10 ^{0}C (Kafy et al., 2020c).

The reduction of surface water bodies also reduces the biodiversity of the urban environment. During the interviews with the experts, 23% agreed that demolishing urban water bodies negatively impacts the ecological system by reducing plant health and animal species. Surface water bodies serve as the main source for groundwater recharge and help the plants and animals by supplying water during the dry season, which ensures the growth of the plants and food for the animal species. Also, the reduction of surface water bodies increases the pressure on groundwater, according to 18% of experts. A study conducted by Schueler (2003) found that more than 10% of impervious cover (built-up areas) create stream degradation by streams channel degradation, reduce groundwater recharge, increase flood frequencies, decrease movement of groundwater to surface water, loss of tree cover around streambanks and overall degrade aquatic habitat (Schueler, 2003).

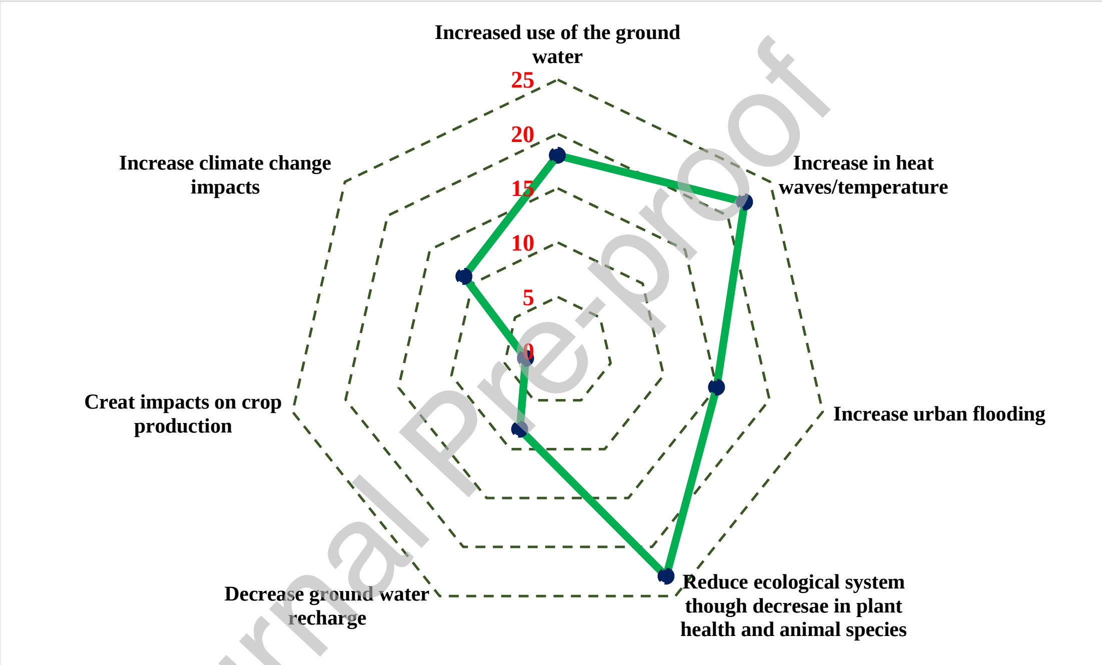

Figure 11 Impacts of water body reduction on the environment, biodiversity, and climate change based on expert opinions.

It is also evident that water body losses create an impact on the climatic condition, and during the KII interviews, 11% of experts agree with the statement. Experts (15%) also mentioned that climate change significantly impacts the rainfall pattern and increases irregular rainfall, creating unwanted urban flooding. The water bodies in the RCC area are decreasing rapidly, which restricted the flooded water flow to the nearest water bodies and increased the suffering for community people. As already discussed, the contribution of water bodies for lower temperature, climate change is also induced by the increased in temperature. According to the Intergovernmental Panel on Climate Change (IPCC), the sea level is anticipated to rise by 7 to 23 inches by 2100 (IPCC, 2014), and this change accelerates due to the massive rise in temperature (Chandra S. P. Ojha et al., 2017; Li and Qian, 2018; Timmerman, 2015; Yan et al., 2019). The rising seawater pushes the saltwater to the agricultural land that causes less production and infertility of the agricultural lands. A prediction is given by scientists that warmer temperatures will lead to more stormwater runoff, large winter steam flow, and hotter, drier summers. Large stormwater runoff will increase urban flooding, and drier summers negatively impact plant growth and food productivity in the study area. In the meantime, the increased temperature will result in a loss of moisture from rivers, lakes, and oceans because of evapotranspiration. The fundamental changes in local rivers and lakes significantly reduce fish productivity. As water is a fundamental need for the human being, and that is why water is becoming a conflicting topic among competitive users, which turns to the water war globally.

3.6 IWRM plan for sustainable water resource development

The problems related to the IWRM in Bangladesh are diverse and complex. There is a severe shortage of good quality water during the dry season, while flood causes during the monsoon. Besides, riverbank erosion, iron contamination in the groundwater etc., aggravate the water management situation in the Rajshahi region. To address these issues, a holistic and IWRM approach is essential. Although the Water Resources Planning Organization (WARPO) established the Bangladesh National Water Policy and Management Plan with the support from the Government of Bangladesh (GoB) has formally recognized the concept of IWRM, which needs to be updated for ensuring sustainability in water resource management. With the help of experts such as urban planners, environmental engineers, hydrologists, policymakers, and city officials, useful recommendations are stated below to develop a sustainable IWRM plan applicable for all developing countries.

3.6.1 Management strategies

Managing water resources is one of the essential parameters for ensuring the successful implementation of IWRM projects. To ensure sustainable water resource management, all responsible authorities, including local to regional and private sectors, need to work collaboratively to manage this scarce resource. Some of the most important management strategies are mentioned below suggested by the experts.

i. Need to strictly follow the rules of the Bangladesh Water Act (2013) by ensuring the best use of water resources, an optimal, efficient way of using scarce water resources and control of unaccounted abstraction, diversion, and pollution of water resources.
ii. Need to address all sources of surface water development, conservation, and management issues in the local level development schemes
iii. Institutional development and strengthening the capacity of the local government on water resource development and management
iv. Consultation and participation with beneficiaries before finalizing and developing water resource management schemes.
v. Accelerate a sustainable public and private water delivery system with appropriate legal and financial measures and incentives, including delineating water rights and water pricing.
vi. Develop a legal and regulatory environment by bringing institutional changes to control groundwater use and conserve the existing surface water resources for environmental

management and improve the investment scenario for the private sector in water resource development.

vii. New rules and legislation, particularly a local level water resource act and a regulatory framework for private sector participation.

viii. Decentralization and distribution of responsibilities to local government and community water management groups to successfully implement the water resource management schemes.

ix. Private sector participation in the development, financing, management, and operations of the water schemes at the local, city, and regional levels.

3.6.2 Technical Strategies

Applying technical strategies by integrating the use of latest technologies will ensure the proper monitoring and effective utilization of available water resources for the successful implementation of the IWRM plan in any developing city. Nowadays, location and logical specific activities, modelling using advanced technologies like GIS, RS, Global Positioning Systems, and various logic-based algorithms are the simplest and best-known category to estimate the best water resource management plan. There are no specific technical strategies related to the use of modern technology mentioned in the Bangladesh water act – 2013. Based on the expert's suggestion, some of the effective technical strategies are mentioned below, which will help to achieve the IWRM plan for Rajshahi city.

i. Modelling potential surface water zones and flow directions of runoff water using GIS and RS technologies for ensuring water availability during the dry season

ii. Increase efficient use of available surface water bodies by treatment for using in irrigation and secondary household activities.

iii. Comprehensively develop and manage Padma river water for multiple functions

iv. Wastewater treatment using modern technologies for watering the green covers and plants instead of fresh ground or surface water.

v. Smart watering systems and water audits of the non-revenue water need to be established for reducing water losses and fulfill the water demands of the citizens by utilizing treated surface and fresh groundwater.

vi. Identification of vulnerable flood-affected zone in the city areas using satellite image and ground-based data and determine suitable locations for surface water bodies (ponds, wetlands etc.) development for ensuing proper runoff of the flooded water.

vii. Identified existing potential surface water bodies using satellite image monitoring and took effective actions to conserve them to reduce urban flooding and water scarcity in the dry season.

viii. Develop hydropower and recreational facilities such as walking paths, sitting arrangements etc., in and around the surface water bodies.

ix. Feasibility study for using treated faecal sludge/wastewater water in watering the trees and preparing an effective sewerage/faecal sludge management plan to reduce stress in the surface water bodies.

x. Training of the city officials on effective water resources management using modern technologies and arranging peer-to-peer learning workshops between different cities for exchanging IWRM plan-related knowledge.

xi. Awareness building programs for the local community people to notify the importance of the IWRM plan, which will help to reduce temperature, unwanted urban flooding and ensure ecological and environmental sustainability.

4 Conclusion

This study aims to identify the most influential LC/LU parameters that significantly reduce the surface water bodies and identify sustainable strategies for the IWRM plan for Rajshahi city based on the expert's opinions. The IWRM plan is strongly associated with the distribution of LC/LU change. In the last few decades, the LC/LU distribution is changing rapidly, especially from water bodies to built-up areas. Results suggest that, from 1989-2019, almost 8% of the water bodies have been reduced and from this 5% due to an increase in built-up areas. The infrastructural development by reducing surface water bodies increases the probability of urban flooding due to the obstacles taking place during surface runoff and altering the stream network flow directions. Reduction in surface water bodies also damages the landscape dynamics associated with ecosystem services, climate change, and environmental sustainability by reducing plant health, increase temperature, and irregular rainfall. Effective management strategies, including collaboration between local-regional-private sectors, consultation with the beneficiaries, and ensuring community participation during finalizing water resource management projects and strengthening the institutional capacity of the local government, need to be taken to reduce water management-related issues. Technical strategies such as modelling potential surface water zones, flow directions of runoff water using GIS and RS technologies, wastewater treatment for the use of watering trees and green areas, smart watering system for reducing water wastage, established recreational facilities around water bodies, train city officials about the effective management of water resources and awareness-building program for community people describing the importance of the surface water bodies will ensure the successful implementation of IWRM plan for any developing countries. To accomplish these technical and management strategies recommendations, government, policymakers, city mayors, local and community leaders need to take proper actions with close collaboration between BWDB and local government actors to develop long term planning mechanisms, identify various investment channels and low-cost treatment facilities for promoting effective water governance through the development of IWRM.

Conflict of interest

The authors declare no conflict of interest.

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Authors Contributions

Abdulla - Al Kafy, conceived and designed the experiments; performed the experiments; analyzed and interpreted the data; contributed reagents, materials, analysis data; wrote the paper, proofreading the manuscript; **Abdullah-Al-Faisal**, performed the experiments; analyzed and interpreted the data; contributed reagents, materials, analyzed data; wrote the paper, proofreading the manuscript; **Vinay Raikwar**, analyzed and interpreted the data; contributed reagents, materials, analyzed data; wrote the paper; **Abdullah Al Rakib**, contributed reagents, revised the paper and analyzed and interpreted the data; **Marium Akter Kona,** contributed reagents, materials, analysis data; wrote the paper; **Jannatul Ferdousi** analyzed and interpreted the data; wrote the paper;

Annexe I: List of Key Informant Interviews (KIIs)

No	Key Informants	Organization	Total
1	Chief Engineer	Rajshahi City Corporation, Rajshahi, Bangladesh	1
2	Superintending Engineer	Rajshahi City Corporation, Rajshahi, Bangladesh	1
3	Assistant Engineer	Rajshahi City Corporation, Rajshahi, Bangladesh	3
4	Town Planner	Rajshahi City Corporation, Rajshahi, Bangladesh	1
5	Environmental Development Officer	Rajshahi City Corporation, Rajshahi, Bangladesh	1
6	Urban Planner	Rajshahi Development Authority, Rajshahi, Bangladesh	3
7	Secretary (Incharge)	Barind Multipurpose Development Authority, Rajshahi, Bangladesh	1
8	Executive Engineer	Barind Multipurpose Development Authority, Rajshahi, Bangladesh	2
9	Professor (Environmentalist)	University of Rajshahi, Rajshahi, Bangladesh	1
10	Professor (Geology and Mining)	University of Rajshahi, Rajshahi, Bangladesh	1
11	Professor (Civil Engineer)	Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh	1
12	Assistant Professor (Urban Planner)	Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh	1
13	Executive Engineer	Rajshahi Water Supply and Sewerage Authority (RWASA)	3
14	Additional Chief Engineer	Bangladesh Water Development Board	3
15	Superintending Engineer	Bangladesh Water Development Board	2
16	Assistant Director	Department of Environment (DoE)	1
17	Research Officer	Department of Environment (DoE)	1
18	NGO Representatives	BRAC and UNDP	3

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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