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The impacts of land-use and land-cover change on wetland ecosystem service values in peri-urban and urban area of Bahir Dar City, Upper Blue Nile Basin, Northwestern Ethiopia

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Abstract

Background: Even though wetlands are essential in enhancing water quality and providing recreation and entertainment opportunities in urban areas, their values are overlooked by the decision-makers. Underestimation of the economic value of wetland ecosystem services contributes to their continuing deterioration and inevitable loss. Investigating the changes in ecosystem service values (ESV) can provide crucial information for decision-making. This study, therefore, analyzes the temporal and spatial land-use/land-cover (LULC) change patterns over 35 years (1984–2019) intending to evaluate its impact on wetland ecosystem service values in Bahir Dar City, Ethiopia. Estimation and change analyses of ESVs were conducted by employing ArcGIS using LULC inputs of the year 1984, 1994, 2004, 2014, and 2019 with their corresponding global value coefficients that were developed earlier and our own modified value coefficients for the studied landscape.

Results: The results showed that wetlands and water bodies of the city and its peripheries had decreased by 75.71% (−1618 ha) within 35 years, while built-up area increased by 216.24% (+2599 ha). Cultivated land had increased slightly from 1984 to 1994 and then gradually declined since 1994. Changes in LULC had resulted in a decline of the total ESV. The total ESV had decreased from USD 29.73×10^6 to USD 20.84×10^6 in 35 years. This indicates the loss of nearly USD 8.9×10^6 ESV from 1984 to 2019. A sensitivity analysis suggested the robustness of ESV estimation in the study area. All individual ecosystem services experienced a negative change. However, a greater reduction in ESV was observed for services such as water regulation, waste treatment, and habitats for maintaining biodiversity. The expansion of built-up area of Bahir Dar City was the major factor that contributed to the loss of ESV provided by wetlands.

Conclusions: The loss of ESV resulting in LULC changes has a negative implication on local climate, waste management, and the livelihoods of the poor community. Thus, interventions should be made for the restoration and sustainable management of wetlands in the urban and peri-urban areas of Bahir Dar City.

Keywords: Ecosystem service, Economic valuation, Land use/land cover, Landscape change, Urban wetland

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Introduction

Wetlands are highly biodiverse and the most valuable ecosystems on our planet (Mitsch and Gosselink 2000, 2015). They deliver a wide range of direct and indirect benefits both locally and globally (Costanza et al. 2014, 1997; de Groot et al. 2012; MEA (Millennium Ecosystem Assessment) 2005; Russi et al. 2013; Van der Ploeg et al. 2010). These include supporting (e.g., nutrient recycling, soil formation, biodiversity support), regulating (e.g., hydrological flows, erosion regulation), provisioning (e.g., fish and fiber, genetic materials), and cultural services (e.g., tourism, source of inspiration) (MEA (Millennium Ecosystem Assessment) 2005). The most significant ecological services provided by urban wetlands are water supply, waste treatment, local climate regulation, and flood control (MEA (Millennium Ecosystem Assessment) 2005; Huang et al. 2019). Despite providing vital services, wetlands are declining at alarming rates faster than any other ecosystems (MEA (Millennium Ecosystem Assessment) 2005). Half of the world's wetlands have been lost since the beginning of the twentieth century (Davidson 2014) and more than 60% of the remaining wetland ecosystems were being degraded or used unsustainably (MEA (Millennium Ecosystem Assessment) 2005). The loss of wetlands in Ethiopia is also considerable (Teferi et al. 2010; Shewit et al. 2017). Urban encroachment, agricultural expansion, sedimentation, and excessive water extraction for agriculture are accountable for substantial loss of wetlands in Ethiopia (Ethiopian Wildlife and Natural History Society (EWNHS) 2018; Wondie 2018; Assefa et al. 2020). Changes in LULC have in turn resulted in changes in the economic and ecological values of various ecosystem services (Leh et al. 2013; Wang et al. 2017; Sadat et al. 2019; Sun et al. 2018; Sun et al. 2019; Hasan et al. 2020).

Estimating ESV and its changes over time is fundamental in providing valuable information about the impact of LULC dynamics on ecosystem services (Costanza et al. 1997; Anaya-Romero et al. 2016; Ferreira et al. 2019). It will also be a guidance for a comprehensive evaluation of the trade-offs among alternative land uses (de Groot et al. 2012; Yi et al. 2017). Cognizant of this fact, several studies valued the loss of ecosystem services in relation to land-use changes (Liu et al. 2012; Zhang et al. 2015; Kindu et al. 2016; Balthazar et al. 2015; Tolessa et al. 2017; Zhao et al. 2017; Gashaw et al. 2018; Paudyal et al. 2019). Some of these studies estimated the impact of LULC on forest ecosystem service values (Balthazar et al. 2015; Kindu et al. 2016; Tolessa et al. 2017). Some others (Song et al. 2015; Arowolo et al. 2018; Gashaw et al. 2018) estimated the loss of different terrestrial ecosystem services caused by LULC dynamics. The effect of LULC on ecosystem services provided by wetlands was also documented (Zhao et al. 2004; Zorrilla-Miras et al. 2014; Gaglio et al. 2016; Badamfirooz and Mousazadeh 2019; Huang et al. 2019; Rojas et al. 2019; Liu et al. 2020). The findings of some of these studies revealed the negative effect of LULC change on ecosystem services (Zhang et al. 2015; Yirsaw et al. 2017; Aneseyee et al. 2019; Liu et al. 2020). The reports of few others (e.g., Badamfirooz and Mousazadeh 2019) showed the gains of ecosystem service values due to LULC. Even though these studies provide information on how the LULC affected the ecosystem service values, most of them were conducted in specific regions (South East and East Asian). The economic losses or gains of ecosystem services associated with LULC in Africa including Ethiopia are not adequately estimated. Only a few studies (Kindu et al. 2016; Tolessa et al. 2017; Gashaw et al. 2018; Aneseyee et al. 2019) estimated the effect of LULC on ecosystem services. The scopes of these studies, however, were micro-watershed in rural landscape or forest ecosystem. The impact of LULC as a result of urban expansion on ecosystem services is not adequately addressed.

In Ethiopia, urban areas have been highly expanded for the last two or more decades (Terfa et al. 2019). The rapid urban expansion poses enormous effects on ecosystem services. It alters wetland hydrology and water quality (Ehrenfeld 2000; Kentula et al. 2004; Ethiopian Wildlife and Natural History Society (EWNHS) 2018) and connectivity (Heintzman and McIntyre 2019), which in turn results in biodiversity loss (Yi et al. 2018). Previously, few studies have been done in relation to Bahir Dar City expansion and its impacts on LULC. Admasu et al. (2020) conducted a study on the ecosystem services of expropriated land in Bahir Dar City. This study was mainly focused on the ecosystem services of three land-use types such as cropland, agroforestry, and grassland that are threatened by Bahir Dar City expansion. Besides, they evaluated the ecosystem services of expropriated land use types using community perception and expert judgments only. The wetland ecosystem services that are threatened by city expansion were not addressed and the values of ecosystem services were not quantified. Two other studies (Haregeweyn et al. 2012; Fitawok et al. 2020) were also conducted on the LULC of Bahir Dar City and the underlining factors for its LULC dynamics. But, the impact of LULC on ecosystem services and ecosystem services values lost or gained by LULC were not the focus of these studies. Moreover, in their LULC classification, they did not treat wetlands separately; rather they mixed wetlands with other land cover classes such as forests, rangelands, and water. Giving scant attention to wetland ecosystem services that are provided to urban areas by research and development projects contributes to their underestimation. McInnes (2013) argues that creating the awareness of users, planners, and decision-makers on the benefits of wetlands is the cornerstone for their sustainable utilization and management in urban and peri-urban environments. Valuation of wetland ecosystem services can be helpful to raise the awareness of decision-makers (Costanza et al. 1997).

This study thus aimed to analyze the impacts of spatial-temporal land-use change of Bahir Dar City from 1984 to 2019 on wetland ecosystem services through a monetary valuation approach. The results of this study will contribute to the overall environmental management, spatial planning, and policy-making for the protection and sustainable management of wetlands and water bodies in the study area.

Materials and methods

Study area description

Bahir Dar is the capital city of Amhara National Regional State. It is located in the northwestern highlands of Ethiopia at 37° 10′ E longitude and 11° 38′ N latitude and its average altitude is 1830 m above sea level (Fig. 1). Topographically, the city lies on a flat surface with almost no slope gradient except for small increases in elevation in the eastern and western peripheries. Based on the simplified traditional agro-climatic classification system, Bahir Dar falls within the Woina-Dega climatic condition. The mean annual atmospheric temperature of the city ranges from 15 to 21°C and its average annual rainfall was 1445 mm, of which about 84–90% occurs from June to September (Addisu et al. 2015).

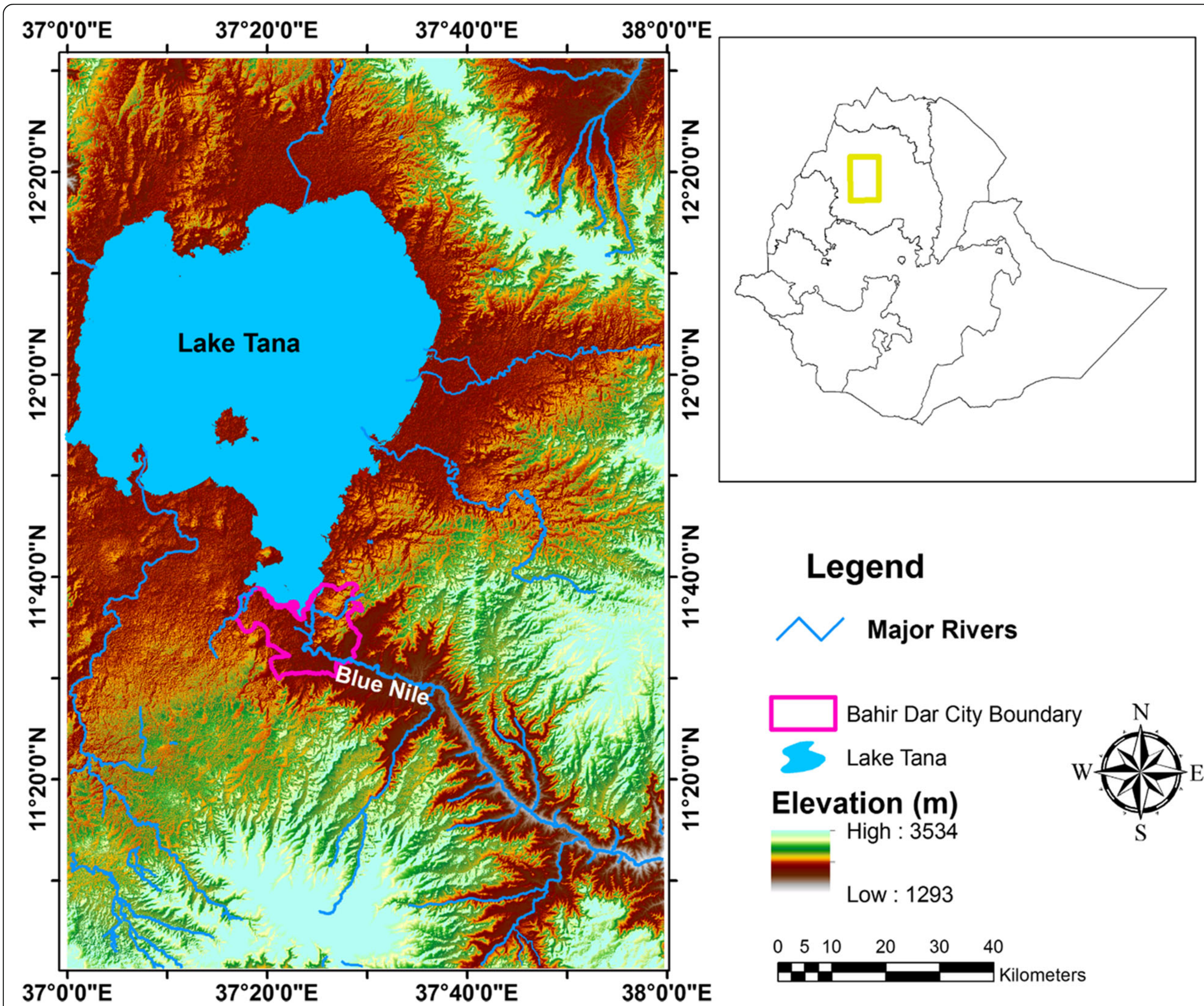

Fig. 1 Location and topography map of the study area. The background is a digital elevation model-based hill-shade obtained from USGS, https://www.usgs.gov/

The historical foundation of Bahir Dar City is associated with the establishment of Saint Kidane Miheret Church in the present site of St. Giorgis Church around the fourteenth century (Seyoum 1988). However, it was a small village until the Italian occupation (Seyoum 1988). The village was transformed into a modern township during the Italian occupation (1928–1933). During this period, the town was used as a major military base for expeditions in the region. Immediately after the Italian evacuation, Bahir Dar was selected as the Awuraja capital in 1948. The town went through a rapid transformation in the 1960s and 1970s and became the capital of the West Gojjam Province in 1987. In 1993, it was selected as an administrative seat of Amhara National Regional State, and consequently, it has been rapidly expanded into four rural *kebele* administrations adjacent to the main urban center (Adam 2014). Based on CSA projection, the total population of Bahir Dar City in 2017 was estimated to be over 396,000 (CSA 2007). Currently, the city is the political and economic center of Amhara National Regional State. Besides, it is one of the major tourist centers in the country because of its cultural heritage such as the Lake Tana Monasteries and natural attractions such as the Blue Nile Falls, birds, and hippos. Since the city is situated on Lake Tana shore and riverbank of Abbay, there are lacustrine and riverine wetlands in the city and its peri-urban kebele administrations (Wondie 2018).

Data collection, image processing, and classification

Time series data of LULC of the study area were analyzed using Landsat imagery (TM, ETM+, OLIS/TIRS) obtained from the United States Geological Survey (USGS, https://www.usgs.gov/). All the images were cloud-free and acquired in 1984, 1994, 2004, 2014, and 2019 (Table 1). They were level 1 products that were already geographically projected to UTM zone 37N WGS84. Their acquisition times were the dry season (between December and March) for each study year to make sure that the vegetation and hydrology of the study area were in similar conditions. The images, then, were converted to top-of-atmosphere (TOA) reflectance values based on Chander et al. (2009) algorithm. Dark Object Subtraction (DOS) approaches were applied to all Landsat data for atmospheric correction (Chavez 1996; Zhang et al. 2010) using the Semi-Automatic Classification Plugin of QGIS 3.8. The strips in the 2004 image were also removed using Scan Line Corrector (SLC). The images were composited and extracted using the study area boundary shapefile in ArcGIS 10.4. The years in which population and housing census took place in Ethiopia and availability of quality satellite images are used as reference study periods.

After image enhancements (standard false-color composition and standard deviation stretch), sufficient training polygons were collected to identify LULC categories using the training sample manager in ArcGIS 10.4 (Lillesand et al. 2015). Based on these data, the five images were classified into six land-use categories (built-up area, cultivated, vegetation, grazing land, wetland and water body) using the Random Forest image classification algorithm (Table 2). Random Forest was proposed by Breiman (2001) and has been increasingly used by professionals. This is because it is more robust than the traditional image classification algorithms and provides high classification accuracy for using unbalanced and small training data sets (Jin et al. 2018).

The extent of individual LULC change over time was evaluated using percent change (PC; Eq. 1) (Fenta et al. 2017; Berihun et al. 2019) and transition matrix model (Gashaw et al. 2017; Berihun et al. 2019).

$$PC = \frac{Ub - Ua}{Ua} \times 100\% \tag{1}$$

where PC= LULC rate of changes, Ua= area of start date LULC type, and Ub= area of end-date LULC type.

A land-use transition matrix was used to illustrate the direction and area of different LULC types change within a given time. This was performed between different periods using cross-tabulation and overlay-intersection in ArcGIS 10.4 software. The attribute tables obtained from these analyses were exported to Microsoft Excel to compute area change and rate of change of different years.

The accuracy of the output map was verified by performing classification accuracy assessment (Kappa coefficient and overall accuracy) using field GPS data, aerial photos, group discussion, key informant interviews, and

Table 1 Description of satellite image data that are used for the land use/land cover study of Bahir Dar City

Year	Satellite sensor	Date acquired	Spatial resolution	Path/Row	Bands used
1984	Landsat 5 TM	31/12/1984	30 m × 30 m	170/52	1, 2, 3, 4, 5 & 7
1994	Landsat 5 TM	25/01/1994	30 m × 30 m	170/52	1, 2, 3, 4, 5 & 7
2004	Landsat 7 ETM+	26/01/2004	30 m × 30 m	170/52	1, 2, 3, 4, 5 & 7
2014	Landsat 8 OLIS/TIRS	12/02/2014	30 m × 30 m	170/52	1, 2, 3, 4, 5 & 7
2019	Landsat 8 OLIS/TIRS	28/03/2019	30 m × 30 m	170/52	2, 3, 4, 5, 6 & 7

Table 2 The land use/land cover (LULC) categories of Bahir Dar City and their descriptions

LULC categories	Descriptions
Cultivated land	Areas covered with annual crops, vegetables, fruits, Khat plantations, including irrigated land
Grazing land	Land covered primarily with grasses having scattered trees serving as pasture and grazing cattle
Vegetation	Land covered with relatively dense forest, open forest, shrubs, church forests, trees scatted in the city, riverine forests and Eucalyptus plantations
Water body	Refers to river and stream courses, lakes, ponds and open water in the wetland. Irrigation canals also included
Built-up area	Areas covered with buildings constructed for residential, commercial and industrial purposes, and transport facilities such as roads and airport. Sport fields and stadiums are also part of this category.
Wetland	Areas consisted of papyrus and phragmites swamps along with the river banks and the lakeshore areas. Swampy areas, meadows, either or seasonal or permanent waterlogged, supporting hydrophytic plants degraded with human activities considered as wetlands

reference images (Congalton 1991). Data from field surveys, interviews, and Google earth were used to train and validate the image in 2019. About 50 to 60 ground truth points were collected in the field and Google Earth-Pro images for each LULC category (Lillesand et al. 2015). However, the sample size of wetlands was 60 points to increase its separability from vegetation and agriculture as they show similar spectral signatures. An accuracy assessment confirmed the resulting LULC maps fulfilled the required standards (overall classification accuracy ranged from 86.3 to 93.4% with Kappa coefficient of 0.83–0.91) to do a further ESV estimation on different LULC categories (Monserud and Leemans 1992).

Estimation of ecosystem service values (ESV)

There are several approaches for the estimation of ecosystem service values, including the direct market-based valuation approach (market price approach, cost-based approach and production function approach), revealed preference approach (travel cost method and hedonic pricing), and stated preference approach (such as contingent valuation method and choice modeling (Adamowicz et al. 2008). In this study, the Kindu et al. (2016) equivalent coefficient of ESV for the terrestrial environment was adopted for the analysis of ESV. Considering Ethiopian local conditions, Kindu et al. (2016) developed ESV for 11 biomes based on Costanza et al. (1997) approach. Of these, we select only five LULC categories that are appropriate proxy for our LULC types: (1) cropland for cultivated land, (2) tropical forest for vegetation, (3) grassland for grazing land, (4) urban for the built-up area, and (5) water body for water body (Tables 3 and 4). The tropical forest biome was not a perfect proxy for vegetation types in the study area because the vegetation in our study area includes open forests, dense forests, riverine forests, church forests, and eucalyptus plantations (Table 2). However, by assuming the similarity of the services provided by tropical forest and the vegetation of our study area, we have taken the biome as the closest proxy. On the other hand, the value coefficient of built-up area is assigned to zero value following Kindu et al. (2016) value coefficients that was modified based on Costanza et al. (1997) because Costanza et al. (1997) did not recognize ecosystem services such as carbon sequestration in urban areas. Change in ESV of the study area were calculated using the LULC data classified for the years 1984, 1994, 2004, 2014, and 2019 based on Kindu et al. (2016) ecosystem valuation model.

However, locally modified ecosystem service coefficients for inland wetland biomes were not considered in the Kindu et al. (2016) study. The monetary values established per unit area from other geographically

Table 3 The six land use/land cover (LULC) categories, their biome equivalents and valuation coefficients used for ecosystem service values estimation in USD/ha/year

LULC categories	Equivalent Biome	Ecosystem service coefficients USD/ha/year (1994)
Cultivated land	Cropland	225.56[a]
Grazing land	Grassland	293.25[a]
Vegetation	Tropical forest	986.69[a]
Built-up area	Urban	0.00
Water body	Water body	8103.50[a]
Wetland	Inland wetlands	4204.02[b]

[a]Value coefficients adopted from Kindu et al. (2016). [b]Own modified value coefficient using the Economic of Ecosystem and Biodiversity valuation database (Van der Ploeg et al. 2010)

Table 4 The land use/land cover categories and their corresponding ecosystem sub-service values (USD/ha/year) for six representative biomes

Ecosystem services	Biome					
	Cropland[a]	Tropical forest[a]	Urban[a]	Grassland[a]	Water body[a]	Wetland[b]
Provisioning services						
Water supply		8.00		117.45	2117.00	280.73
Food production	187.56	32.00			41.00	171.10
Raw material		51.24				198.54
Genetic resources		41.00				45.64
Medicinal resources						33.10
Regulating services						
Water regulation		6.00		3.00	5445.00	981.84
Waste treatment		136.00		87.00	431.50	1153.95
Erosion control		245.00		29.00		63.14
Climate regulation		223.00				208.36
Biological control	24.00			23.00		
Gas regulation		13.68		7.00		67.35
Disturbance regulation		5.00				
Supporting services						
Nutrient cycling		184.40		25.00		103.72
Pollination	12.00	7.27		1.00		
Soil formation		10.00				48.50
Habitat/refugia		17.30				716.51
Cultural services						
Recreation		4.80			69.00	76.89
Cultural		2		0.80		54.65
Sum	**225.56**	**986.69**	**0.00**	**293.25**	**8103.50**	**4204.02**

[a]Value coefficients adopted from Kindu et al. (2016), [b]Own modified value coefficient using the Economic of Ecosystem and Biodiversity valuation database (Van der Ploeg et al. 2010)

similar places were translated into our study area using benefit transfer approach as it was applied in previous research works (Kubiszewski et al. 2013; Camacho-Valdez et al. 2014; Richardson et al. 2014; Johnston et al. 2015). This method is crucial for developing countries like Ethiopia where resources and expertise are limited to do detailed data collection on the ground (Plummer 2009; Kubiszewski et al. 2013; Camacho-Valdez et al. 2014). Despite limitations in terms of data availability, reliability and distribution, and variation in socioeconomic and spatial heterogeneity, prominent scientists (Costanza et al. 1997, 2014; de Groot et al. 2012) used

Table 5 The total estimated area (ha) and percentage of each land use/land cover (LULC) category of Bahir Dar City from 1984 to 2019

LULC categories	1984		1994		2004		2014		2019	
	ha	%	ha	%	ha	%	ha	%	ha	%
Cultivated land	12,151	51.13	12,333	51.90	11,440	48.14	11,373	47.85	10,850	45.66
Built-up area	12,031	5.06	1424	6.00	2239	9.42	2843	11.96	3802	16.00
Grazing land	12,711	5.35	2002	8.43	1574	6.62	2088	8.79	2838	11.94
Vegetation	4413	18.57	3467	14.59	4716	19.84	4024	16.93	3165	13.32
Water body	612	2.58	461	1.94	543	2.29	505	2.12	350	1.47
Wetland	4116	17.32	4078	17.16	3253	13.69	2933	12.34	2760	11.61

the same method to estimate the global unit values of ecosystem services.

Thus, we developed valuation coefficients for each sub-service of wetland systems using expert knowledge of the study landscape conditions, literature review, and valuation database of Economics of Ecosystems and Biodiversity (TEEB) (Plummer 2009; Van der Ploeg et al. 2010; Kindu et al. 2016). Care was taken to ensure that the value from TEEB valuation database can be used as a good approximation of our study area. About 44 values were selected among 1350 unique value data points from the TEEB world database complied by Van der Ploeg et al. (2010). The values were taken from tropical areas of LULC categories similar to our geographical setting and comparable socioeconomic status (Kubiszewski et al. 2013; Kindu et al. 2016). ESVs were standardized to 2007 USD/ha/year and then converted into 1994 USD/ha/year to facilitate the estimation process of ESV changes to that of Kindu's value coefficients following previous study methods (Camacho-Valdez et al. 2014; Kindu et al. 2016; Yi et al. 2017). However, the standard error (N=44; SD=364.04) and deviation of the mean (SEM=54.9, Mean=280.3) that are modified for the wetland valuation coefficients are found to be in large ranges. This observation agrees with other similar studies (de Groot et al. 2012; Kubiszewski et al. 2013; Temesgen et al. 2018). Despite such limitation, many authors have used the global valuation coefficients that was developed by Costanza et al. (1997) by modifying based on the local conditions (e.g., Li et al. 2007; Hu et al. 2008; Kindu et al. 2016; Tianhong et al. 2010; Tolessa et al. 2017; Woldeyohannes et al. 2020).

The ESVs of each LULC category and the total ESVs of the study area over the study periods are estimated using Eqs. (2) and (3), respectively (Kreuter et al. 2001).

$$\mathrm{ESV}_k = \sum (A_k * VC_k) \tag{2}$$

$$\mathrm{ESV}_f = \sum (A_k * VC_{fk}) \tag{3}$$

where ESV_k and ESV_f are ESV of LULC type "k" and ESV service function "f", respectively; A_k is the area (ha) of LULC type "k"; VC_k is the value coefficient of LULC type "k" (USD /ha/year); and VC_{fk} is the value coefficient of function "f" (USD/ha/yr) for LULC type "k".

Equation 3 was also applied to calculate the values of the 17 individual ecosystem services. Locally modified valuation coefficients used in this study are shown in Tables 3 and 4.

$$\text{Pecrent of ESV change} = \left(\frac{\mathrm{ESV}_{\text{recent year}} - \mathrm{ESV}_{\text{previous year}}}{\mathrm{ESV}_{\text{previous year}}} \right) * 100 \tag{4}$$

The percent changes of the ESV across different periods (1984–1994, 1994–2004, 2004–2014, 2014–2019, and 1984–2019) are calculated using the formula shown in Eq. 4.

Ecosystem service sensitivity analyses

The proxy biomes for LULC types and their corresponding value coefficients used in this study were not perfect matches. Thus, it is important to conduct sensitivity analyses to ascertain the percent change in ESV over time by adjusting the value coefficients (VC). The VC of each land use type was adjusted by 50% up and down (Kreuter et al. 2001; Li et al. 2010). Here, we calculated coefficient of sensitivity (CS) using Eq. 5 (Kreuter et al. 2001; Zhao et al. 2004; Kindu et al. 2016; Yi et al. 2017):

$$\mathrm{CS} = \frac{(\mathrm{ESV}_j - \mathrm{ESV}_i)/\mathrm{ESV}_i}{(\mathrm{VC}_{jk} - \mathrm{VC}_{ik})/\mathrm{VC}_{ik}} \tag{5}$$

where ESV is the estimated ecosystem service value, VC is the value coefficient, i and j are the initial and adjusted values, respectively, and k is the land cover class (Kreuter et al. 2001). The greater the CS value is (CS always <1), the more critical the accuracy of the ecosystem service value index (Kreuter et al. 2001; Li et al. 2010).

Results

Extent and trends of land use/cover changes during 1984–2019

Temporal analysis of land use/cover change

The LULC maps of urban and peri-urban areas of Bahir Dar City produced for five reference years (1984, 1994, 2004, 2014, and 2019) are presented in Fig. 2 and Table 5. The major types of LULC of the peri-urban and urban areas of Bahir Dar City included cultivated land, built-up area, grazing land, vegetation, water body, and wetland. Cropland (51.13%) was the dominant LULC type of peri-urban and urban areas of the city in 1984 followed by vegetation (18.6%) and wetlands (17.3%). The proportion of grazing land, built-up area, and water body was 5.4%, 5.1%, and 2.3%, respectively. In 2019, the cultivated land remained a dominant land use type (45.7%) of the peri-urban and urban areas of the city followed by built-up area (16%) and vegetations (13.3%).

The pattern of LULC change

The LULC change trend analysis made for the four consecutive periods showed considerable land-use changes in the peri-urban and urban areas of Bahir Dar City (Table 6). As can be seen in Table 6, built-up area and grazing land had increased by 216.1 % and 123.2%, respectively over 35 years period. In contrast, cropland, wetlands, vegetations, and water body showed a declining trend of 10%, 42.8%, 28.3%, and 33%, respectively. The comparison of four study periods indicated that built-up area increased by 18.4% in the first period

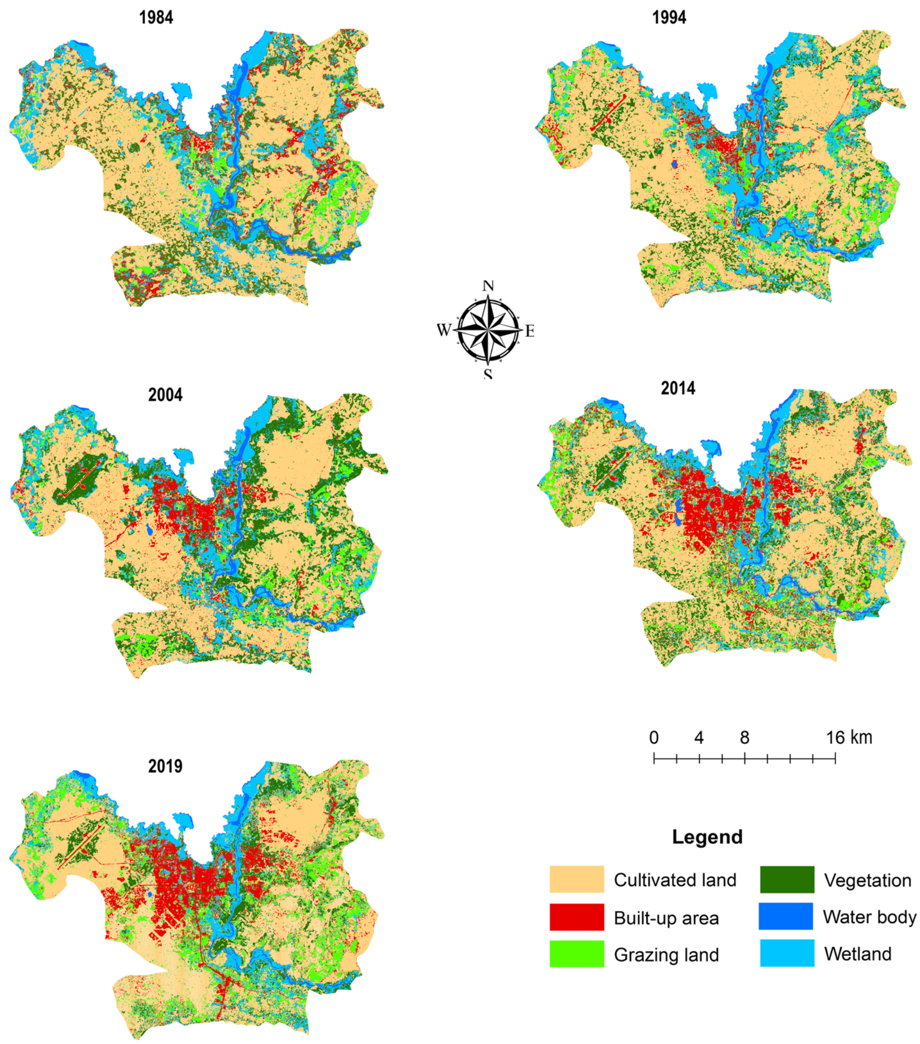

Fig. 2 The land use/land cover (LULC) map of the study area from 1984 to 2019. The LULC map is derived from the Landsat Thematic Mapper (TM), Enhanced Thematic mapper Plus (ETM^+) and Operational Land Imager (OLI) satellite data

Table 6 The land use/land cover (LULC) changes (gain, loss, and rate of change) between 1984 and 1994, 2004 and 2014, and 2014 and 2019, where G=gain, L=loss and PC= rate of change

LULC categories	1984–1994		1994–2004		2004–2014		2014–2019		1984–2019	
	G/L ha	PC %	G/L ha	PC %	G/L ha	PC %	G/L ha	PC %	G/L ha	PC %
Cultivated land	182	1.50	− 892	− 7.24	− 68	− 0.59	− 523	− 4.60	− 1301	− 10.70
Built-up area	221	18.37	815	57.26	604	26.95	959	33.75	2599	216.07
Grazing land	731	57.54	− 428	− 21.39	514	32.67	749	35.89	15676	123.24
Vegetation	− 945	− 21.43	1248	36.01	− 692	− 14.66	− 859	− 21.34	− 1247	− 28.27
Water body	− 151	− 24.69	82	17.87	− 39	− 7.14	− 154	− 30.56	− 262	− 42.76
Wetland	− 38	− 0.92	− 825	− 20.24	− 320	− 9.84	− 173	− 5.90	− 1356	− 32.95

(1984–1994), 57.3% in the second period (1994–2004), 27% in the third period (2004–2014), and 33.8% in the last period (2014–2019). It can be observed from Table 6 that the largest rate of increase of the built-up area per year was recorded in the last period (6.8% per year) followed by the second period (5.7%). Although grazing land showed a tremendous increase over the whole study period, it had declined by 21.4% in the second period then increased during two consecutive periods by 32.7% (2004–2014) and 35.9% (2014–2019). The rate of wetland area decline also varied across the study periods; the highest rate of decline was observed in the second period (2.03%/year) followed by the third period (1.2%/year); in the first period, the wetland area was insignificantly declined. Similarly, vegetation and water body showed a significant decline in both study periods. The highest rate of vegetation reduction was noticed in the second period (36%), whereas the highest reduction for water body was observed in the fourth period (30.6%).

Transformation patterns of land use types

The change matrix analysis shows the shift of LULC from one type to the other. The highest proportion of transition occurred among cultivated, built-up area, wetlands, grassland, and vegetation LULC types over the study period. For instance, during the period between 1984 and 2019, 22.8%, 25.1%, and 13.14% of the wetland was changed to cultivated land, built-up area, and grazing land, respectively. This suggested that 61% of the wetland area was lost in the past 35 years. Likewise, 56.6% and 17.6% of built-up area growth was mainly the result of the shift from cultivated land (12.1%) and grazing land (10.4%). It was also observed that 11% of grazing

Fig. 3 A high-resolution Google-Satellite image showing part of the Bahir Dar City, where infrastructure development, residential and hotel construction are devastating lacustrine wetlands (Source: SASPlanet in 2020)

land and 22% of vegetation land were converted to cultivated land. Generally, the largest transition was observed from cultivated land to built-up area, from wetland to built-up area, cultivated land and grazing land, and from grazing land to built-up area and cultivated lands. This implied that built-up area and cultivated land expansion have been the major threats to the deterioration of wetlands in the Bahir Dar area (Figs. 3, 4 and 5).

Changes in ecosystem service values (ESV)

Changes in the total ecosystem service values

The total ESV of the study area presented in Table 7 was USD 29.73 × 10^6 in 1984. After 35 years, the total ESV had decreased to 20.84 × 10^6 (Table 7). This suggested that a total of USD 8.9 × 10^6 ESV was lost due to LULC changes from 1984 to 2019 period (Table 8). The loss of wetlands and water body were taking the majority share to the reduction of total ESV across the study periods (Table 8). As presented in Table 8, wetland and water body ESV loss has contributed to 63.9% and 24.2% of the total loss of ESV in the study area. The ESV of cultivated land and vegetation has also been reduced, whereas grazing land ESV showed small positive changes over the study period.

Effects of land use/land cover changes on individual ecosystem service values

The impacts of LULC changes on the individual ecosystem services are presented in Table 9. All evaluated 18 ecosystem services showed an overall reduction in the ESV with varying degrees between 1984 and 2019 (Table 9). Six ecosystem services such as water supply, food production, waste treatment, local climate regulation, and habitat contributed to the loss of more than 82% of the total ESV. In monetary terms, the loss of ESV from these six ecosystem services was estimated at over USD 7.31 × 10^6 (82.12%) during the investigation period. Water regulation and waste treatment account for 50% (USD 4.46 × 10^6) of the total ESV loss mainly due to losses of wetlands including water bodies.

In 1984, the ecosystem services including water regulation (USD 7.4 × 10^6), waste treatment (USD 5.72 × 10^6), food production (USD 3.15 × 10^6), habitat/refugia (USD 3.03 × 10^6), and water supply (USD 2.64 × 10^6) were the principal (75%) contributors to the total ESV (Table 9). These five ecosystem services have still dominantly contributed to the total ESV of 2019 despite significant reduction compared to 35 years ago. In a broader category, the greatest contributors to the loss of ESV for 35 years in decreasing order are regulating services, provisioning services, supporting services, and cultural services (Table 9).

Ecosystem service sensitivity analyses

Changes in the total ESV and the corresponding CS through the adjustment of 50% increase or decrease in the VC of each land cover type are summarized in Table 10. The 50% up and down adjustment of the total ESV coefficient values for four of the six land categories resulted in < 20% (range= 0.09–0.18) change in total ESV. This indicates that changes in ecosystem service coefficient values for the analysis have relatively little effect in the total ESV. By

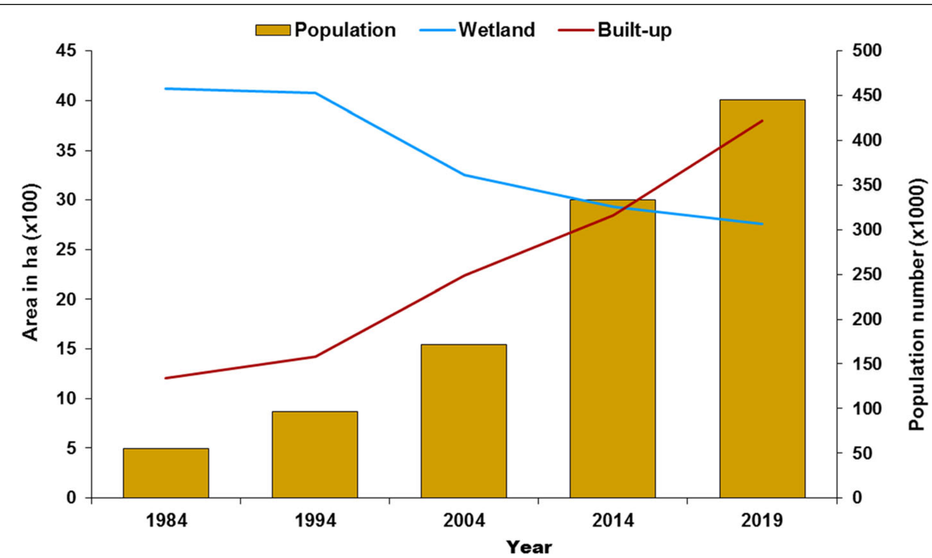

Fig. 4 Wetland shrinkage versus population growth and urban expansion over time in the study area (1984–2019). Source (Ethiopian Central Statistics Agency 1984, 1994, 2007, and 2014, 2019 projected data)

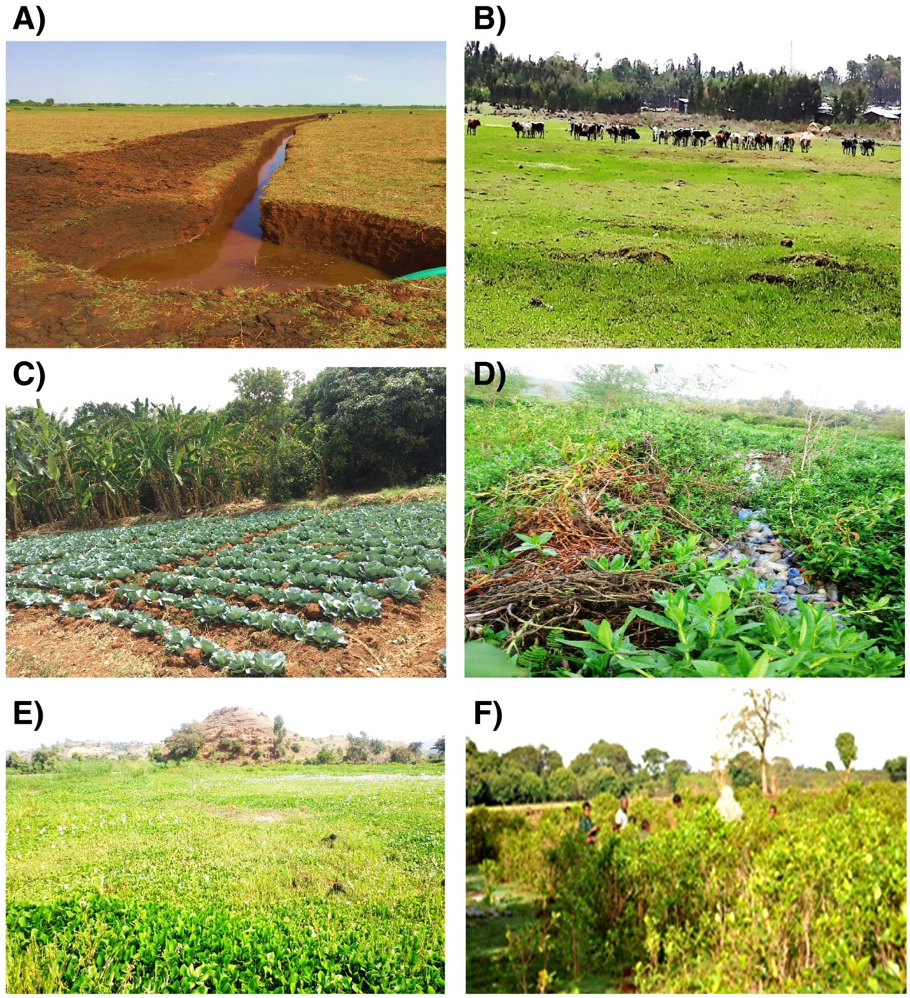

Fig. 5 Photographs showing anthropogenic activities affecting wetland ecosystem in urban and peri-urban areas of Bahir Dar City. **a** Water withdrawal from the wetland for irrigation. **b** Eucalyptus plantation and illegal settlement. **c** vegetables cultivation. **d** pollutants discharging into the wetland. **e** an invasion of water hyacinth on the Blue Nile riverbank, including nearby wetlands. **f** *Khat* cultivation

contrast, CS for wetland was relatively high (≥0.531 in all years), which implies that its VC should be computed more carefully than those of the other land cover types. When the VC for wetlands were adjusted by 50%, the estimated ESV of the study area fluctuated from ±31% to ±29%, while the variation in the VC of other land-cover types resulted in only ± 9% change in ESV. Grazing land was characterized by less than 2% change in ESV in response to a 50% increase or decrease in VC. Generally, the sensitivity

Table 7 The effects of land use/land cover (LULC) changes on the total ecosystem service values (ESV in USD ×10^6) of Bahir Dar City

LULC categories	1984		1994		2004		2014		2019	
	ESV	%	ESV	%	ESV	%	ESV	%	ESV	%
Cultivated land	2.74	9.22	2.78	10.10	2.58	10.01	2.57	10.89	2.45	11.74
Built-up area	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grazing land	0.37	1.25	0.59	2.12	0.46	1.80	0.61	2.60	0.83	4.00
Vegetation	4.35	14.64	3.42	12.36	4.65	18.05	4.00	16.85	3.12	14.98
Water body	5.00	16.68	3.73	13.50	4.40	17.08	4.09	17.35	2.84	13.62
Wetland	17.30	58.20	17.15	62.00	13.68	53.06	12.33	52.32	11.60	55.66
Total	**29.73**		**27.67**		**25.77**		**23.57**		**20.84**	

Table 8 Changes in ecosystem service values (ESVin USD $\times 10^6$) for each land use/land cover (LULC) category of Bahir Dar City

LULC categories	1984–1994		1994–2004		2004–2014		2014–2019		1984–2019	
	USD in millions	change in %	USD in millions	change in %	US D in millions	change in %	USD in millions	change in %	USD in millions	change in %
Cultivated land	0.04	1.91	− 0.20	− 10.53	− 0.01	− 0.46	− 0.12	− 4.35	− 0.29	− 3.25
Built-up area	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grazing land	0.22	10.53	− 0.13	− 6.84	0.15	6.91	0.22	7.97	0.46	5.16
Vegetation	− 0.93	− 44.50	1.23	64.74	− 0.65	− 29.95	− 0.88	− 31.88	− 1.23	− 13.79
Water body	− 1.27	− 60.77	0.67	35.26	− 0.31	− 14.29	− 1.25	− 45.29	− 2.16	− 24.22
Wetland	− 0.15	− 7.18	− 3.47	− 182.63	− 1.35	− 62.21	− 0.73	− 26.45	− 5.70	− 63.90
Total	**− 2.09**		**− 1.90**		**− 2.17**		**− 2.76**		**− 8.92**	

Table 9 The impacts of land use/land cover changes on the individual ecosystem service values (ESV) of Bahir Dar City between 1984 and 2019

SN	Ecosystem services	ESV across periods (USD in millions)					Overall change
		$ESV_{f\ 1984}$	**$ESV_{f\ 1994}$**	**$ESV_{f\ 2004}$**	**$ESV_{f\ 2014}$**	**$ESV_{f\ 2019}$**	**1984–2019**
1	**Provisioning services**						
	Water supply	2.64	2.38	2.29	2.17	1.87	− 0.76
	Food production	3.15	3.14	2.88	2.78	2.62	− 0.53
	Raw Material	1.04	0.99	0.89	0.79	0.71	− 0.33
	Genetic Resources	0.37	0.33	0.34	0.30	0.26	− 0.11
	Medicinal resources	0.14	0.13	0.11	0.10	0.09	− 0.04
	Sub-total	**7.34**	**6.97**	**6.51**	**6.14**	**5.55**	**− 1.77**
2	**Regulating services**						
	Water regulation	7.40	6.54	6.18	5.66	4.64	− 2.76
	Waste treatment	5.72	5.55	4.77	4.33	4.01	− 1.71
	Erosion control	1.38	1.17	1.41	1.23	1.03	− 0.35
	Climate regulation	1.84	1.62	1.73	1.51	1.28	− 0.56
	Biological control	0.32	0.34	0.31	0.32	0.31	− 0.01
	Gas regulation	0.35	0.34	0.29	0.27	0.25	− 0.10
	Disturbance regulation	0.02	0.02	0.02	0.02	0.02	− 0.01
	Sub-total	**17.03**	**15.58**	**14.71**	**13.34**	**11.54**	**− 5.5**
3	**Supporting Services**						
	Nutrient cycling	1.27	1.11	1.25	1.10	0.94	− 0.33
	Pollination	0.18	0.18	0.17	0.17	0.15	− 0.03
	Soil formation	0.24	0.23	0.20	0.18	0.17	− 0.08
	Habitat/refugia	3.03	2.98	2.41	2.17	2.03	− 0.99
	Sub-total	**4.72**	**4.5**	**4.03**	**3.62**	**3.29**	**− 1.43**
4	**Cultural services**						
	Recreation	0.38	0.36	0.31	0.28	0.25	− 0.13
	Cultural	0.23	0.23	0.19	0.17	0.16	− 0.08
	Sub-total	**0.61**	**0.59**	**0.5**	**0.45**	**0.41**	**− 0.21**
	Total	**29.71**	**27.65**	**25.75**	**23.54**	**20.80**	**− 8.90**

Table 10 Percentage change of the total estimated ecosystem service values and sensitivity coefficient (*CS*) after a 50% adjustment of value coefficients (VC) for each land use/land cover type in the Bahir Dar City (1984–2019)

Change in value coefficients	1984		1994		2004		2014		2019	
	±%	CS	±%	CS	±%	CS	±%	CS	±%	CS
Cultivated land VC ±50%	4.61	0.09	5.03	0.10	4.92	0.11	5.44	0.12	5.87	0.10
Grazing land VC ±50%	0.63	0.01	1.06	0.18	0.89	0.03	1.30	0.04	1.99	0.02
Vegetation VC ±50%	7.32	0.15	6.18	0.18	9.03	0.17	8.42	0.15	7.49	0.18
Water body VC ±50%	8.34	0.17	8.75	0.17	8.54	0.17	8.18	0.14	6.81	0.17
Wetland VC ±50%	29.10	0.58	30.98	0.53	26.53	0.52	25.67	0.56	27.83	0.53

analysis suggests that the overall estimated ESV for the study area is likely relatively reliable despite uncertainties in the VC among land-cover types.

Discussion

Driving forces of LULC changes

Evidence from remote sensing image analysis showed a continuous decline of wetland areas including water bodies in the past 35 years (1984–2019) in the study area. The pronounced expansion of the built-up area to the peripheral areas of the same study area was also reported by Fitawok et al. (2020). Nevertheless, the findings of Fitawok et al. (2020) did not clearly show the extent of wetland conversions to urban areas due to the problem created during LULC classification. These authors grouped wetlands with other land cover categories (forests, pastures and water bodies). Similarly, Degife et al. (2019) reported the shrinkage of 6.4% lake area and 42.7% wetland coverage over the period of 45 years. The loss of wetland areas because of urban expansion was also reported by other studies (Zhao et al. 2004; Zorrilla-Miras et al. 2014; Gaglio et al. 2016; Belayneh et al. 2020; Rojas et al. 2019; Hailu et al. 2020). Expansion of built-up area was the main driving force for their transformation by draining, infilling and increasing the impervious areas. This has also made the ecosystems more fragmented and disconnected and thus exacerbated their ecological vulnerability (Mao et al. 2018; Huang et al. 2019). It was observed that the built-up area has been expanded since Bahir Dar City has become the capital of Amhara National Regional State. According to CSA (1994, 2007), the total number of housing units in Bahir Dar City increased from 19,808 in 1994 to 45,501 in 2007. Based on the data obtained from office of the city municipal administration, 63,820 housing units have been constructed from 2007 to 2019 of which nearly 25, 000 were constructed illegally. The rapid population growth of the city is accountable for the built-up area expansion. The trend of the city population growth presented in Fig. 4 showed the rapid increase of population from 1984 to 2020 due to rural-urban and urban-urban migration. According to housing and population census (CSA 1984, 1994, 2007) and population projection, the total population of Bahir Dar City increased from 54,800 in 1984 to 472,063 in 2020. In other words, the city's population has increased by 761% which is equivalent to 11,591 people/year in the past 36 years. Similar trends were reported in other studies (Hurni et al. 2005; Gebrelibanos and Assen 2015; Gashaw et al. 2017; Hussien et al. 2018; Berihun et al. 2019; Degife et al. 2019; Desta and Fetene 2020; Hailu et al. 2020).

The building of infrastructures, social services, and different market centers in line with residential houses have also contributed to the shrinkage of wetlands, cultivated land, water body, vegetation, and grazing land. The findings of the study by Gashu and Gebre-Egziabher (2018) revealed that the area covered by roads, urban parks, roundabouts, public squares and plaza, business building, industrial parks, medians, and sport fields had expanded by 11% from 1975 to 2015 while the growth of the residential area was 10%. Several studies have showed the conversion of wetlands and other LULC (farmland, forest, grassland, shrubland, and woodland) into built-up areas because of rapid growth of urbanization (e.g., Zhao et al. 2004; Anteneh et al. 2018; Degife et al. 2019; Hailu et al. 2020). Lee et al. (2006) demonstrated that rapid urbanization at the expense of wetland ecosystems posed ecological threats such as the changes in hydrological and sedimentation regimes, and the dynamics of nutrients and pollutants. Consequently, the ecological services provided by urban wetlands have been compromised (Ehrenfeld 2000; Lee et al. 2006).

Despite the declining trend of the cultivated land due to built-up areas expansion, farming practices have also contributed to the loss of wetlands in the peri-urban areas of Bahir Dar City. Since *khat* is a more valuable crop per unit area than cereal crop, smallholder farmers of the peri-urban areas have shifted cereal crop production into *khat* plantation (Berihun et al. 2019). The study conducted by Worku (2018) revealed that *khat* (*Catha edulis*) plantation had been expanded by 76% from 2001 to 2016 at expense of cereal crop farmlands in the peri-urban areas of Bahir Dar City. The plantation of *khat* has mostly taken place in the peripheries and within wetlands. *Khat* farms are irrigated by water diverted from the wetlands thereby resulting in extensive wetland drainage. This result is consistent with the findings of McCauley et al. (2015), which reported that the surface areas of wetlands used for irrigation agriculture were drained 197% more than those wetlands with no agricultural irrigation.

The illegal encroachment of farmland into the wetlands exacerbated their shrinkage in the peri-urban areas of the study area. During discussions, the participants reported that large area of the wetlands were converted to cultivated lands illegally. The decline of farmland holding per household and the increasing of landless young people caused illegal encroachment of wetlands. The local government officials have also been allocating wetlands for landless young households. This is in agreement with the research findings of Getenet and Tefera (2017) and Enyew et al. (2020). Getenet and Tefera (2017) reported that farmers with legally owned land in the wetland's peripheries cultivated wetlands illegally. The size of illegally cultivated wetland parts ranged from 0.5 to 4 ha per farmer. The council of kebele administrations has intentionally ignored wetland encroachment believing that it could solve the shortage of farmland (Getenet and Tefera 2017). The effect of the growing number of the landless people in line with unemployment on LULC was also reported in southwestern Ethiopia (Hailu et al. 2020).

Changes in ecosystem service values

Our analysis indicated that the total ESV of the study area has decreased by USD 8.9×10^6 from 1984 to 2019. The loss (USD 26.12×10^6) was even worse considering global valuation coefficients from Costanza et al. (2014). This estimation is nearly three times higher than the adopted local value coefficients. A marked decline in the total ESV was primarily associated with the reduction in the ESV of wetland, vegetation, and water body. Wetland loss represents the majority of the total decline in the ecosystem services values in the study area because it has a high value coefficient. This is in agreement with the findings of Msofe et al. (2020), who found that wetland conversion accounted for the highest share of the total ESV reduction in the Kilombero Valley Floodplain (Tanzania). Likewise, Zhao et al. (2004) reported the decrease of total ESV from USD 316.77 to 120.40 million per year in Dongtan (China) between 1990 and 2000, largely due to a 71% loss of wetlands. Similar reductions of total ESV were also reported in various Ethiopian landscapes. For instance, the conversion of forests, woodland, shrubland, and bushland had contributed to the lion share for the loss of ecological service values in the Munessa-Shashemene watershed (Kindu et al. 2016, 2018), Chillimo forest (Tolessa et al. 2017), and Abaya-Chamo basin (Woldeyohannes et al. 2020). Contrary to our finding, a study conducted in Nigeria showed a slight increase in total ESV despite a significant decrease in forest cover (Arowolo et al. 2018). Among other reasons, the difference in the valuation coefficients used could be the cause of this situation.

The change in LULC progressively diminished the total ESV of the land during the study periods. The trend of ESV reduction is quite similar although it has a higher value than reported in the prior studies (Kindu et al. 2016; Tolessa et al. 2017; Gashaw et al. 2018). This could be related to the use of different LULC categories that determine the selection of global valuation coefficients. In our classification, wetland and water biomes, among others that had higher coefficients of value, were taken into consideration.

Impacts of LULC changes on the individual ecosystem service value

Changes in LULC have resulted in a continuous decline of almost all individual ecosystem services during the study periods. This decline is mainly explained by the reduction in wetland coverage, which in turn leads to loss of ecosystem services essential to water regulation, waste treatment, and habitats for maintenance of biodiversity. The significant reduction of these important ecological services over 35 years could affect flood tolerance and waste assimilation potentials of Bahir Dar City, making it more susceptible to flood and contamination. Various studies have confirmed the adverse effect of LULC change on several ecosystem services. For instance, a decrease in vegetation cover (forests, woodland/shrub/bushland) has led to the decline of many individual ecosystem service values in other parts of Ethiopia (Kindu et al. 2016; Tolessa et al. 2017; Gashaw et al. 2018; Woldeyohannes et al. 2020). Likewise, urban and agricultural pressures on other land resources have brought the reductions of several ecosystem services in China (Zhao et al. 2004; Liang et al. 2017; Jiang et al. 2019), Puget Sound-USA (Zank et al. 2016), and Nigeria (Arowolo et al. 2018). The changes in LULC in Bahir Dar and the peri-urban area have brought significant impacts both on the individual and total ecosystem service values. This suggested the need for intervention to maintain wetlands for stormwater management, water supply, water treatment, and recreation roles (McInnes 2013).

Payment for Ecosystem Services (PES) or incentives for ecosystem services (IES) can be seen as an alternative conservation strategy to address the loss of ecosystem services associated with urbanization (Jiangyi et al. 2020). Implementation of PES would be successfully carried out if the intervention areas of PES are identified through ecosystem-based spatial planning and strategic environment assessment (Dhyani et al. 2018; Ferreira et al. 2019). Additionally, creating green infrastructure in the urban and peri-urban areas, restoration of degraded wetlands with native plants and promotion of environmental education could help maintain the functioning of ecosystem service flows (Ethiopian Wildlife and Natural History Society (EWNHS) 2018; Douglas 2018; du Toit et al. 2018).

Limitation of the study

Despite providing important information, this study has some limitations. Its major limitation stems from the difficulty of classifying wetland, vegetation, and built-up areas. Our LULC data are generated using 30-m Landsat images with acceptable precision and a Kappa coefficient. Classifying LULC using 30-m Landsat images likely leads to classification errors. Identifying wetlands from other LULC types is difficult because wetlands are made up of a variety of entities that can potentially be blended with vegetation, grazing land, and cultivated land. Built-up areas may also be mixed with black soil and waterbodies. Separating natural forests from permanent crops is another challenge confronting us during satellite image classification. Under this circumstance, the loss of ecosystem service values may be underestimated or overestimated as a result of LULC dynamics. Besides, the images could not be classified in detail due to the limited resolution of remote sensing images (Arowolo et al. 2018). Thus, we suggest the use of satellite imagery with higher spatial resolution.

Conclusions

This study evaluated the impacts of LULC changes on the urban wetland ecosystem services in Bahir Dar City over 35 years (1984–2019). The findings displayed severe decline (−1618 ha) of wetlands and water bodies, largely because of built-up area and cultivated land expansion. The changes in the ESVs during the study periods indicated that LULC dynamics driven primarily by urban growth adversely affected the ecosystem services provided by wetlands and other land-covers. Our results have shown a substantial reduction of ESVs in the urban and peri-urban areas of Bahir Dar City. The total ESV which was estimated at USD 29.73 × 10^6 in 1984 had declined to USD 20.84 × 10^6 in 2019. This indicates that approximately USD 8.9 × 10^6 ESV had lost over 35 years. This was connected with the decrease in the ESV of wetland, water body, and vegetation. Moreover, LULC changes resulted in a loss of individual ecosystem services that were essential to water regulation, waste treatment, and habitats for the maintenance of biodiversity. The significant reduction of these important ecological services could affect flood tolerance and waste assimilation potentials of Bahir Dar City, making it more susceptible to flooding and contamination. In general, the results confirmed the existence of a conflict between the sustainable delivery of ecosystem services and urban expansion. In particular, policy-makers and urban planners should develop land-use planning that help to reconcile urban development and wetland conservation.

Abbreviations

CSA: Central Statistical Authority; CS: Coefficient of sensitivity; DEM: Digital elevation model; LULC: Land-use/land-cover; ESV: Ecosystem service values; MEA: Millennium ecosystem assessment; TEEB: The economics of ecosystems and biodiversity; PES: Payment for ecosystem services; IES: Incentives for ecosystem services

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Authors' contributions

WWA designed the study and collected data accordingly. He analyzed the satellite imagery, interpreted the results, and prepared the manuscript. *BGE* contributed in the interpretation of the research findings and literature review. He also edited, commented, and improved the English language of the final manuscript. *AW* edited and commented the manuscript. Finally, all authors read and endorsed the final manuscript for publication.

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All data are included in the manuscript.

Declarations

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Not applicable.

Consent for publication

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Competing interests

The authors declare that they have no competing interests.

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