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Research article

# Assessment of the linkages between ecosystem service provision and land use/land cover change in Fincha watershed, North-Western Ethiopia

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ABSTRACT

Fincha watershed is characterized by the presence of large scale government development projects, such as hydroelectric dam and sugarcane plantation. Within this watershed, land use/land cover (LULC) changes and its linkages with ecosystem services were analyzed for a period of more than three decades (1987–2019). The study first assessed LULC dynamics using ArcGIS software with a standard method. After data on LULC change was obtained, the study used a globally developed values coefficients to estimate the Ecosystem Service Values (ESVs) of the study watershed. The findings revealed that; cultivated land, water body, settlement and sugar cane plantation increased at a rate of 579.8 ha/yr, 199.7 ha/yr, 141.2 ha/yr and 137.1 ha/yr, respectively, whereas wetland, forest land and bare land reduced by 600 ha/y, 328.7 ha/yr and 60.3 ha/yr, respectively, for the study period (1987–2019) considered in the watershed. The increase in water body and sugar cane plantation is mainly attributed to large scale government development projects, while the increase in settlement and cultivated land is the result of small scale farming in the area. Both subsistence farming practices and large scale government projects compete on forest land and wetland. This has resulted in the decrease of the total NCV (Natural Capital Value) by 13.2%. The total ecosystem service values were dominated by cultivated land, which contributed 42.9% of the values in 2019. Elasticity of ESV change in relation to LULC showed the dominance of cultivated land in the overall values of the natural capital. To optimize the values of natural capital at the watershed, making synergies and tradeoffs between land uses is vital by all concerned stakeholders involved in modification of the land uses.

## 1. Introduction

Ecosystem service valuation (ESVs) has received a growing concern from various stakeholders due to the recognition of the benefits obtained from diversity of ecosystems for human well-being and the potential impacts of human activities on the benefits received (Costanza et al., 1997, 2014, 2017; Gómez-Baggethun et al., 2010; de Groot et al., 2012; Tolessa et al., 2017a, b, 2018; Gashaw et al., 2018; Zhang et al., 2019). Many of the ecosystem services are available in different amounts over time and space. In addition, different ecosystems provide diverse levels and amounts of ecosystem services due to the inherent potential of the ecosystems themselves, external factors affecting the productive potential of ecosystems or a combination of both factors (Song and Deng 2017; Schild et al., 2018; Sannigrahi et al., 2019; Arki et al., 2020). Hence, the need to incorporate potential capacity of natural capital to development planning is becoming top agenda of nation states (Kubiszewski et al., 2017). It is also imperative to take into account the tradeoffs between the services aspired from ecosystems as different ecosystem services are not generally optimized at the same time from ecosystems (Jacobs et al., 2015; Duarte et al., 2016; Ellis et al., 2019). For example, provisioning services and regulating services are not equally obtained from ecosystems as the two are competing ends. According to Wang et al. (2019) ecosystem service tradeoffs could emerge from two mechanisms. These are; from the intrinsic trade-offs which reflect the fact that the delivery of multiple Ecosystem Service (ES) depend on the same ecosystem process and management-induced trade-offs, whereby focusing on one ES often leads to the decrease of other ESs. Ecosystems are also constrained with their natural capacity to provide the services aspired at equal amounts. To this end, it has been more than twenty years, since the first paper published on the study of the potential capacity of ecosystems to provide the required level of services, which includes provisioning, supporting, regulating and cultural services (Braat and de Groot 2012; Costanza et al., 2017).

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Attempts to quantify ecosystem service values generally followed two methods (Costanza et al. 1997, 2014; Daily et al., 2009; Schmidt et al., 2016). The first method involves the use of a benefit transfer to assess the changes in ESVs on spatial and temporal scales (Costanza et al. 1997, 2014; Zhao et al., 2004; de Groot et al., 2012; Schmidt et al., 2016). This method is based on the use of globally developed data sets for different biomes. One of the criticisms of using the benefit transfer approach to ESV is, that it does not take into account local level variation, which is inherent characteristics of ecosystems (Nelson et al., 2009; Gómez-Baggethun et al., 2010; Baveye et al., 2013; Schmidt et al., 2016; Horlings et al., 2020). The second method is based on the use of InVEST model, which describes changes in ecosystem services either in economic or biophysical terms (Nelson et al., 2009; Sánchez-Canales et al., 2012; Vigerstol and Aukema 2011; Duarte et al., 2016; Cerretelli et al., 2018; Sahle et al., 2019). The biophysical models of InVEST calculate the relative contribution of different parts of the landscape for the provision of services. But, at local level the use of a biophysical approach is constrained by data availability. Each one of the methods had their own limitations (Song and Deng 2017; Tusznio et al., 2020).

Hence, the use of benefit transfer method, which uses globally developed values coefficients for different biomes can help for rapid assessment of the status of ecosystems in providing the necessary service and informing decision makers about appropriate policy formulation for effective, efficient and defensible natural resource management. Despite the shortcomings, it is widely used in data scarce areas for assessing the status of natural capital values. In this paper a benefit transfer method developed by Costanza et al. (2014) is used to quantify the ecosystem service values in response to land use/land cover (LULC) dynamics over spatial and temporal scale. In addition, attempts to value ecosystem services has been conducted with the two methods in different parts of the world specifically in developed nations and some of the emerging countries in the world with few emphasis in developing countries (Acharya et al., 2019). Hence, the current study attempts to address local level knowledge gap in terms of the status of natural capital expressed in monetary values and add new insights in to existing literature by providing the scope of changes in ESVs in response to LULC dynamics.

Ethiopia is facing unprecedented land degradation problems due to LULC changes, which emanate from a number of proximate and underlying causes (Nyssen et al., 2009; Mengistu et al., 2012; Lanckriet et al., 2015; Tolessa et al., 2019; Yesuph and Dagnew 2019). These LULC change has affected ecosystem service provision over spatial and temporal scales in Ethiopia (Kindu et al., 2016, 2018; Gashaw et al., 2018; Tolessa et al., 2017a, b, 2018; Muleta and Biru 2019; Woldeyohannes et al., 2020) and elsewhere in the World (Samal et al., 2017; Borsuk et al., 2019). Among LULC changes, which altered ecosystem services include the construction of dams for hydroelectric power generation by diverting rivers and establishing large scale sugarcane plantation for production of sugar (Tefera and Stroosnijder 2007; Tefera and Sterk 2008). Despite the substantial benefits derived from dams, however, there are social, environmental, economic and integration problems caused by construction of dams. Among these include, some people are relocated against their will, haphazard land use changes occurred, and soil erosion and reservoir sedimentation increased (Tefera and Stroosnijder 2007). Ethiopia is currently investing huge amount of financial resources to construct dams in an attempt to generate electric power for local consumption and exporting to neighboring countries (FDRE 2011).

Furthermore, the Ethiopian Climate Resilient Green Economy (CRGE) policy document focus on green economy, which takes in to account the natural resources potential of the country to harness energy from water resources, solar, wind and geothermal energy. It further stipulates that reforestation of degraded sites will enhance adaptation to climate change for sustainable development (FDRE 2011). In addition, the available natural resource potential capacity especially water for irrigation and fertile land in the lowlands prompted the country to invest in agro-processing industries such as sugarcane production. To this end, hydro-electric power generation and irrigation projects were established to harness the available natural resource potential in Fincha watershed (Tefera and Sterk 2008). Despite this potential capacity of the watershed for power generation and irrigation for sugarcane plantation, the environmental costs of these projects in terms of ecosystem services were not explored. Hence, this particular research aimed to estimate the ecosystem service values of the watershed in response to changes in LULC dynamics within the watershed in light of the existing large scale government development projects and local level modification of the natural environment by small scale farmers for the study area and period.

## 2. Materials and methods

### 2.1. Study site

Fincha watershed is located in the North-Western parts of Ethiopia. It drains to the Blue Nile River, which is one of the major sources of water for irrigation and hydroelectric power generation in the downstream countries of Sudan and Egypt. Ethiopia is also currently constructing the great renaissance dam at a distance of 40km bordering Sudan (Tesfa 2013; Alrajoula et al., 2016). Geographically, the study site lies between 9°15′15″ - 9°49′40″ N and 36°45′00″- 37°53′00″E (Figure 1). The current study watershed has an area of 238,736.97 ha and covers parts of the four districts namely, Jimma Geneti, Horro, Abbay Chomen, and Guduru. Elevation in the watershed is 2200–3100 masl and 80% of the land surface is a wide rolling plateau (Tefera and Sterk 2008, 2010).

Climatic condition of the watershed is characterized by tropical highland monsoon with an annual rainfall ranging from 960 mm to 1,835 mm with peaks during June to August. The mean monthly minimum and maximum temperatures of the area vary from 6 to 16 °C and from 19.5 to 31.5 °C respectively (Ayana and Kositsakulchai 2012; Dibaba et al., 2020). The soils in Fincha watershed are made of alluvial and colluvial materials from the surrounding escarpments (Ethiopian Wildlife and Natural History Society and Wetlands International 2018). The dominant soils in the watershed have a texture of clay, clay loam and loam. Soil bulk densities range from 1.1Mgm−3 for clay, to 1.3Mgm−3 for loam and clay loam. Soils are deep (>150 cm) on flat lands, but on steep slopes (>30%) soil depths are shallow (<25 cm) (Terefa and Sterk 2010).

The largest portion of the watershed area is under intensive cultivation and with wetlands on the plains. Population density was 98 people/km$^2$ in 2003. State ownership of land persisted since the 1975 land reform. Land redistribution by the state was used as a means of providing land for landless people. The last land redistribution was done in 1975, when all farm households were given a piece of land (Tefera and Sterk 2010). Fincha watershed is rich in fish resources and wildlife. The current potential of Fincha dam for fishing was estimated to be 1700 mt/yr, and this is one of the potential provisioning services, which contribute to the livelihoods of communities around the dam (Breuil 1995). The economy of the inhabitants is mainly based on farming, which involves crop-livestock production systems. Cattle rearing are practiced for draught power, food, soil fertility enhancement and cash income. Natural pasture is a major source of feed for livestock, but crop residues are used to supplement the feed during the dry season (Tefera and Sterk 2010; Tessema and Simane 2019, 2020). Major crops grown are maize (*Zea mays*), beans (*Vicia faba*), Niger seed (*Guizotia abyssinica*), tef (*Eragrostis tef*), barley (*Hordeum vulgare*) and wheat (*Triticum species*).

Due to the high water potential of the watershed and its associated environmental factors, the government of Ethiopia has long been interested to establish dams to generate hydroelectric power and sugar factory within the watershed. Fincha dam was commissioned in 1973, with the purpose of hydroelectric power production. Although not originally planned for, the dam have also become useful to regulate the high flood season and supply water for the downstream irrigated land, as well as supplying water for downstream towns and villages after it generates electricity. Fincha provides water for some 15, 000 ha of irrigable land to the downstream areas (Nile Basin Initiative Regional Power Trade Project 2008). Fincha sugar factory started production in 1998, with sugar

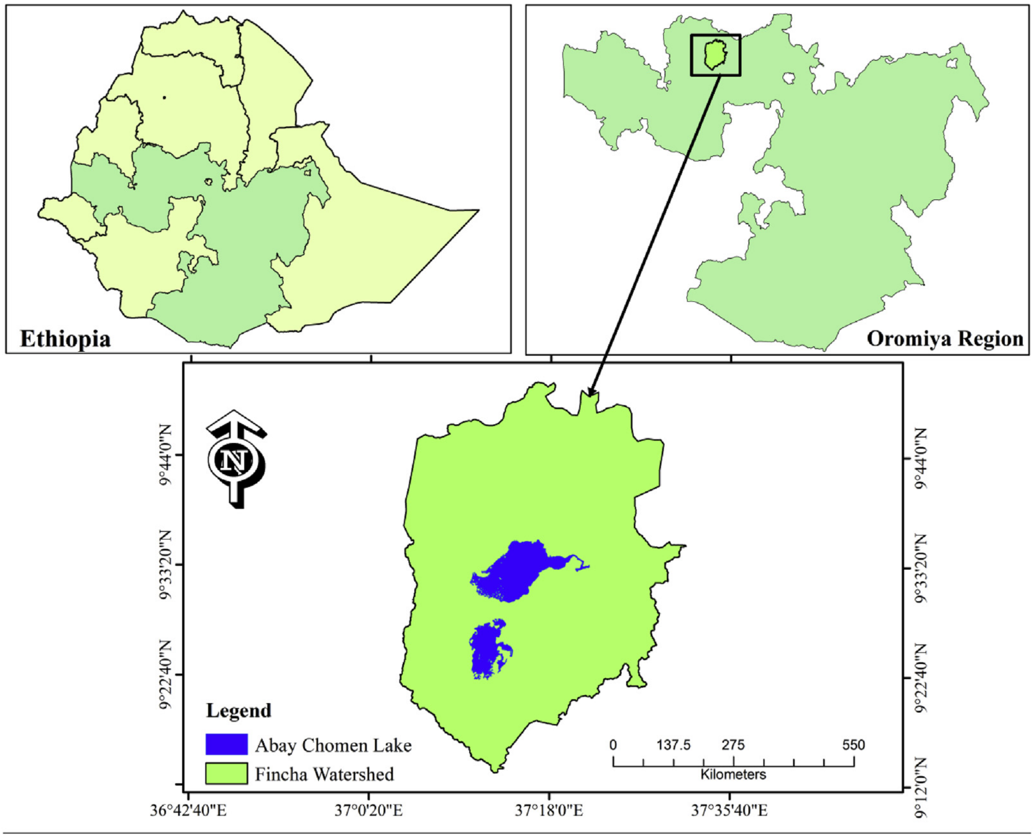

**Figure 1.** Map of the study watershed.

cane plantation near the factory and the factory is also producing ethanol for energy purposes (Ethiopian Sugar Corporation 2018). Extensive wetlands on the upper slopes recharge the river and regulate the hydrology of the basin. Numerous rivers and wetlands in the watershed serve as important buffers to regulate flows and moderate climate change (Ethiopian Wildlife and Natural History Society and Wetlands International 2018).

### 2.2. Land use/land cover dataset

Multi-temporal Landsat imagery of the two study years (Landsat-5 TM 1987 and Landsat-8 OLI–TIRS 2015) were obtained from the United States Geological Survey (USGS) (http://earthexplorer.usgs.gov). The images were retrieved during dry season when spectral differences between the various land cover types are greatest, and cloud contamination is minimal, with less than 10% cloud cover. Details of the image characteristics are tabulated below (Table 1). During pre-processing stage, geometric and radiometric calibration were conducted (Jensen, 2015).

Supervised classification was employed using the maximum likelihood classification (MLC) algorithm while the unsupervised classification was also employed to classify LULC classes (Mengistu et al., 2012; Gashaw et al., 2017; Cerretelli et al., 2018). The classification and post-interpretation phase involved the preparation of LULC maps from the satellite images. The map was classified based on pixel values and therefore it was a raster data (Eastman 2012). Using those classified maps, LULC transformations were performed in the ArcGIS 10.3 platform.

Accuracy assessment methods were used for determining the precision of the classification. Several measures of accuracy assessment such as producer accuracy, user accuracy, overall accuracy and kappa coefficient were performed on supervised classification method (Congalton 1991; Enderle and Weih 2005; Eastman 2012). The supervised classification was based upon 202 training areas identified from reference data and then applied to the imagery using the maximum likelihood classification algorithm. The unsupervised classification used an Iterative Self-Organizing Data Analysis Techniques (ISODATA) algorithm to classify the imagery into classes, which then were identified from reference data. The overall classification accuracy was 89.6% with over all kappa statistics to be 0.83. This has met the minimum standard required for the use of the output for further analysis (Congalton 1991).

In addition, in order to calculate the percentage change in LULC changes between periods, we employed the following equation (Eq.1):

$$\Delta \boldsymbol{A} = \frac{\boldsymbol{A}_{t2} - \boldsymbol{A}_{t1}}{\boldsymbol{A}_{t1}} \times \mathbf{100} \tag{1}$$

where, $\Delta A(\%)$ refers to the change in the percentage of land use between periods, $A_{t2}$ is the area of the land use at the year$t2$ and $A_{t1}$ is the area of the land use at year$t1$.

**Table 1.** Description of imaginary data used for land cover change study in Fincha watershed.

| Imagery date | Imagery type | Resolution | Path and raw | Source |
|---|---|---|---|---|
| 02/07/1987 | Landsat TM | 30 * 30 m | 169/54 | USGS |
| 01/26/2019 | Landsat OLS | 30 * 30 m | 169/54 | USGS |

**Table 2.** Land use/land cover types in Fincha watershed.

| Land use/land cover classes | Description |
|---|---|
| Cultivated land | Land under cultivation of crops |
| Forest land | Land dominated by trees (>5 m in height), with canopy cover greater than 80% |
| Settlement | Urban and rural settlements in the study area |
| Wetland | Areas that are water logged, swampy during the rainy season, and dry during the dry season, perennial marshy areas |
| Water body | Lakes/rivers, stream, Pond |
| Sugarcane plantation | Areas that covered with sugarcane (grass) uses for sugar production |
| Bare land | Areas with no vegetation, which occur in rangelands including gullies and exposed rocks |

We have also calculated the rate of change of LULC changes between years to estimate the spatial changes in land uses with the equation (Eq.2):

$$\Delta \boldsymbol{R} = \frac{\boldsymbol{Y} - \boldsymbol{x}}{\boldsymbol{t}} \tag{2}$$

where $\Delta R$(ha/yr) is the rate of change in land use per year, $Y$ is the recent area of the land use and $x$ is the area of the previous land use and $t$ refers to the time interval between the study periods considered for analysis.

Based on the analysis of LULC classes the following land use types were identified (Table 2).

### 2.3. Estimation of ecosystem service values

LULC change results were used as an input along with the ecosystem service value coefficients developed by Costanza et al. (2014). These value coefficients can be applied in a wider climatic zones, particularly in data scarce regions of the World (Yi et al., 2017). LULC categories and equivalent biomes along with their value coefficients are depicted in Table 3.

The most representative biome was used as a proxy for each LULC category including: (1) Crop land for Cultivated land, (2) Tropical forest for Forest land, (3) Urban for Settlement, (4) Desert for Bare land, (5) Lakes/Rivers for Water body, (6) Swamps/Floodplains for Wet land and (7) Crop land for Sugar cane plantation. Each one of the proxies used is not exact matches, but are relatively good in estimating the values for each land use identified. Crop land can loosely be used to represent cultivated land of our land use, because the purposes of both are used for crop production, where it can serve as a source of provisioning services especially food for the growing population. Similarly, in the watershed forest land is home to a number of plant and animal species. So, the proxy used can represent the current land use identified in the study area. Furthermore, settlement in our study area is not clustered and it is interspersed within other land uses providing organic material to the nearby cultivated land and hence is in a better condition than urban area.

**Table 3.** LULC categories, corresponding equivalent biomes and ESV coefficients.

| LULC category | Equivalent biome | Total ecosystem service value coefficient (2011 USD $ha^{-1}$ $yr^{-1}$) |
|---|---|---|
| Cultivated land | Crop land | 5567 |
| Forest land | Tropical forests | 5382 |
| Settlement | Urban | 6661 |
| Wetland | Swamps/Floodplains | 25681 |
| Water body | Lakes/Rivers | 12512 |
| Sugar cane plantation | Crop land | 5567 |
| Bare land | Desert | 0 |

Data obtained from Constanza et al. (2014).

**Table 4.** Land uses and the corresponding individual Ecosystem service values (USD$million/ha/yr).

| Individual Ecosystem services | Land uses | | | | | | |
|---|---|---|---|---|---|---|---|
| | Cultivated land | Forest land | Settlement | Wetland | Water body | Sugarcane plantation | Bare land |
| Gas regulation | | 12 | | | | | 0 |
| Climate regulation | 411 | 2044 | 905 | 488 | | 411 | 0 |
| Disturbance regulation | | 66 | | 2986 | | | 0 |
| Water regulation | | 8 | 16 | 5606 | 7514 | | 0 |
| Water supply | 400 | 27 | | 408 | 1808 | 400 | 0 |
| Erosion control | 107 | 337 | | 2607 | | 107 | 0 |
| Soil formation | 532 | 14 | | | | 532 | 0 |
| Nutrient cycling | | 3 | | 1713 | | | 0 |
| Waste treatment | 397 | 120 | | 3015 | 918 | 397 | 0 |
| Pollination | 22 | 30 | | | | 22 | 0 |
| Biological control | 33 | 11 | | 948 | | 33 | 0 |
| Habitat/Refugia | | 39 | | 2455 | | | 0 |
| Food production | 2323 | 200 | | 614 | 106 | 2323 | 0 |
| Raw material | 219 | 84 | | 539 | | 219 | 0 |
| Genetic resources | 1024 | 1517 | | 99 | | 1042 | 0 |
| Recreation | 82 | 867 | 5740 | 2211 | 2166 | 82 | 0 |
| Cultural | | 2 | | 1992 | | | 0 |

Data obtained from Constanza et al. (2014).

**Table 5.** Major groups of ecosystem services and LULC types.

| Ecosystem services | | Cultivated land | Forest land | Settlement | Wetland | Water body | Sugarcane plantation | Bare land |
|---|---|---|---|---|---|---|---|---|
| Groups | Individual | | | | | | | |
| **Provisioning** | Water supply | 400 | 27 | | 408 | 1808 | 400 | 0 |
| | Food production | 2323 | 200 | | 614 | 106 | 2323 | 0 |
| | Raw material | 219 | 84 | | 539 | | 219 | 0 |
| | Genetic resources | 1042 | 1517 | | 99 | | 1042 | 0 |
| | **Total** | **3984** | **1828** | | **1660** | **1914** | **3984** | **0** |
| **Regulating** | Gas regulation | | 12 | | | | | 0 |
| | Climate regulation | 411 | 2044 | 905 | 488 | | 411 | 0 |
| | Disturbance regulation | | 66 | | 2986 | | | 0 |
| | Water regulation | | 8 | 16 | 5606 | 7514 | | 0 |
| | Erosion control | 107 | 337 | | 2607 | | 107 | 0 |
| | Waste treatment | 397 | 120 | | 3015 | 918 | 397 | 0 |
| | Biological control | 33 | 11 | | 948 | | 33 | 0 |
| | **Total** | **948** | **2598** | **921** | **15650** | **8432** | **948** | **0** |
| **Supporting** | Soil formation | 532 | 14 | | | | 532 | 0 |
| | Nutrient cycling | | 3 | | 1713 | | | 0 |
| | Pollination | 22 | 30 | | | | 22 | 0 |
| | Habitat/Refugia | | 39 | | 2455 | | | 0 |
| | **Total** | **554** | **86** | | **4168** | | **554** | **0** |
| **Cultural** | Recreation | 82 | 867 | 5740 | 2211 | 2166 | 82 | 0 |
| | Cultural | | 2 | | 1992 | | | 0 |
| | **Total** | **82** | **869** | **5740** | **4203** | **2166** | **82** | **0** |

But, similar to urban land uses, settlement in the rural area generate heat, which alter the temperature condition around, result in impervious surfaces, which affect infiltration and alter the natural ecosystem function. Wetland in our study watershed is equivalent to swamps/floodplains in terms of their function, which is providing water to the nearby land surfaces. Water body in the watershed is a dam for hydroelectric power generation.

In addition, the 17 individual ecosystem services developed by Costanza et al. (2014) for biomes were taken for the identified land uses (Table 4). The individual ecosystem services were further categorized in to four major classes such as provisioning, regulating, supporting and cultural services to see if there are any changes in the categories than individual ecosystem service values (Table 5). The values indicated in Table 5 are the summation of individual ecosystem services for each ecosystem service category, and these values are used to asses any changes in the services values over spatial and temporal scales.

Based on the above values set and the proxies used for each identified LULC classes, the following equations (Eqs. (3), (4), and (5)) were used to determine the total ESVs, individual and percentage change in ESVs between the years (Gaglio et al., 2017; Tolessa et al., 2018).

$$\mathrm{VC_i} = \sum (V_{ij} * A_i) \tag{3}$$

$$\mathrm{V_f} = \sum (A_i * VC_{fj}) \tag{4}$$

$$Percent\ of\ VC\ change = \left(\frac{VC_{recent\ year} - VC_{previous\ year}}{VC_{total}}\right)*100 \tag{5}$$

After we obtained the total VC (Value coefficient), the average VC of the land (US\$ $ha^{-1}$ $yr^{-1}$) in our study watershed was also estimated for the previous years (i.e. 1987 and 2019) following the formula established in Eqs. (6) and (7).

$$VC_{ha} = V_{Ct}/W_a \tag{6}$$

where, $\mathrm{VC_{ha}}$ is the average VC of the land (US\$ $ha^{-1}yr^{-1}$) during a specific year, $\mathrm{V_t}$ is the total VC in that year, and $\mathrm{W_a}$ is the total area of the watershed in ha.

$$NCV = \sum_{i=1}^{M} VC_i \tag{7}$$

where NCV is the total natural capital value (US\$ year-1), Vij is ES value (US\$2007 ha-1 year-1) for the j ecosystem service in the i LULC class, Ai is the area coverage (ha) of i LULC class. M and N are the maximum number of observed LULC classes and ESs, respectively.

**Table 6.** Land use/land cover changes of the study watershed (1987–2019).

| LULC classes | Absolute area coverage (ha) | | Cover change between periods (%) | Rate of change (ha) |
|---|---|---|---|---|
| | 1987 | 2019 | 1987–2019 | 1987–2019 |
| Cultivated Land | 125578 | 144131 | 14.8 | +579 |
| Forest Land | 30143 | 19625.3 | -34.9 | -328.7 |
| Settlement | 14249.91 | 18766.9 | 31.7 | +141.2 |
| Wet Land | 41103.3 | 21894 | -46.7 | -600.2 |
| Water Body | 13199.1 | 19396.1 | 46.9 | +199.7 |
| Sugarcane Plantation | 1287.36 | 5675.36 | 340.9 | +137.1 |
| Bare Land | 11176.3 | 9248.3 | -17.3 | -60.3 |
| Total | 236736.97 | 236736.97 | | |

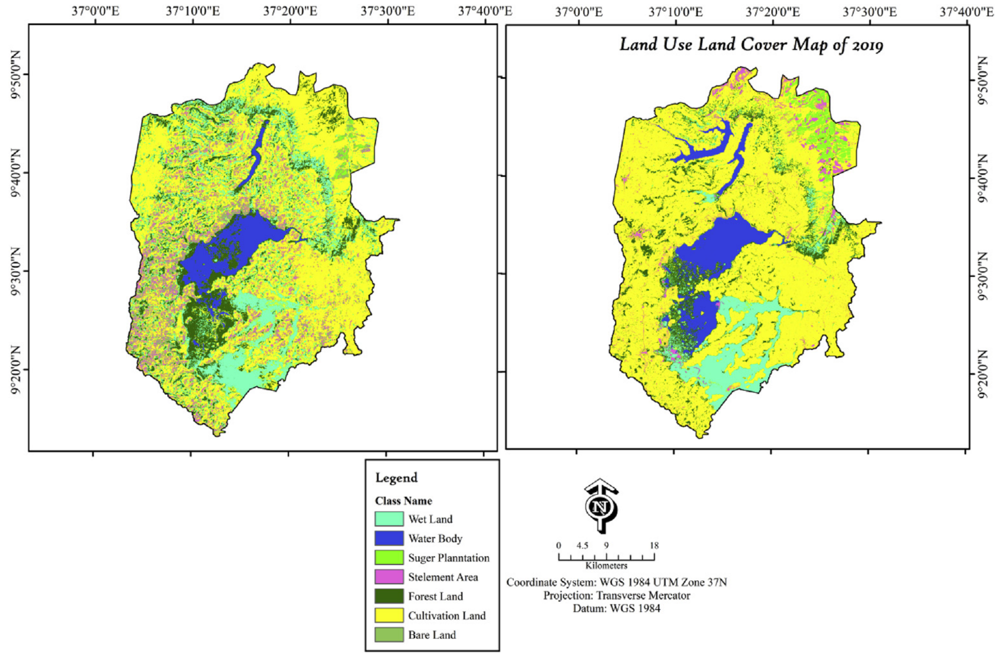

**Figure 2.** LULC change of Fincha watershed (1987–2019).

### 2.4. Elasticity of ESV change in relation to LULC

Elasticity describes how one variable changes in relation to changes in another. In this context elasticity of ESV change was used to measure percentage change in ESV in response to modifications in LULC of the study watershed for a given period of time. To this end, elasticity of ESV was performed to assess changes in NCV of Fincha watershed. The VC (Eqs. (3) and (4)) of a specific LULC class was adjusted by ±50 % keeping the VC constant for the rest of LULC classes (Gaglio et al., 2017). The coefficient of sensitivity (CS) was calculated following the methods used by Mansfield (1985) and Kreuter et al. (2001) after simplification of the method by Aschonitis et al. (2016).

In this particular paper elasticity can be calculated with the following equation (Eq. 8):

$$CS_{t,i} = \frac{VC_{t,i} {}^{*} A_{t,i}}{NCV_t} \tag{8}$$

where, NCV is the total natural capital value (US\$ year-1) of all ESs from all LULC classes at t year (US\$ year-1), $VC_t$, i is the total value of ESs provided by the i LULC class at t year (US\$ year-1) and $A_t$, i is the area coverage (ha) of the i LULC class at t year.

Hence, in this study, Elasticity of ESV change values are used to rank the importance of each LULC class than the assessment of the robustness of our analysis (Gaglio et al., 2017).

## 3. Results

### 3.1. Land use/land cover change

Cultivated land, settlement, water body and sugarcane plantation increased by 14.8%, 31.7%, 46.9% and 340.9%, respectively over the study period. On the other hand, a decrease in forest land, wet land and bare land was observed for the period 1987–2019 with 34.9%, 46.7% and 17.3%, respectively (Table 6). From the changes within the period, we found that the conversion between each land uses are not uniform, that is, wet land converted to other land uses at a higher rate of change (600.2 ha/yr), followed by forest land (328.7 ha/yr), whereas, the lowest value was recorded for bare land (60.3 ha/yr). On the other hand, the rate of gain was highest for cultivated land with a value of 579.8 ha/yr indicating the dominant land use in the area (Table 6).

In addition, the highest reduction was recorded for wetland with 600.2 ha/yr followed by forest land (328.7 ha/yr), which can be attributed to both the inundation of water, which was diverted to these land uses by hydroelectric project in the watershed on one hand, and the conversion of wetland by small scale farmers to grow crops (Table 6). Moreover, the rate of change in land uses across the study period and watershed showed the highest area gain for cultivated land in the period 1987–2019. This highest gain is followed by water body. When we analyze the rate of change in land uses for the study interval (1987–2019), there existed a nonlinear conversion of one type of land use to another due to a number of associated socioeconomic, demographic, political and policy changes. Of these land uses, cultivated land showed an increase in area of 579.8 ha/yr (Table 6; Figure 2).

Figures 3, 4, and 5 shows the different land use types identified. From this picture it can be seen, that wet land and forest land are being occupied by settlement, cultivated land and water body. The level of human activities within the watershed in general and on sloppy areas in particular resulted in the modification of landscapes, where this inevitably cause soil erosion down the hill and subsequently deposited in the dam, which is becoming a major problems in Ethiopia because, when the land is exposed to human activities such as cultivation, grazing and settlement, soil erosion will certainly occur (Figures 3, 4, and 5).

### 3.2. Changes in the total ecosystem service values of the watershed

The overall ecosystem service values of the study watershed for the year 1987 was, USD\$ 2154.1 million and this values was reduced to USD\$1869.6 million in 2019. The total ESVs for the study period (1987–2019) was reduced by USD\$ 284.5 million at an annual change rate of -13.2% (Figure 6 and Table 7). The highest value of ESVs for the year 1987 was USD\$ 1055.6 million for wetland followed by cultivated land, which was USD\$ 669.1 million. But, in 2019 cultivated land overtook other land uses and the estimated ESVs was USD\$ 802.4 million (Figure 6). Similarly, sugarcane plantation had the lowest ESVs of USD\$ 7.2 million, because the size of land covered by this land use type was small and the total ESVs assigned are also relatively low (Table 3 &

**Figure 3.** Mosaic of land uses including forest, settlement and wetland under hilly mountain.

Figure 6). Bare land was assigned with the global value coefficient of zero as this type of land use has no significance in enhancing the value of natural capital. In general, within the study watershed, ESVs declined for the study period. These reductions in the total and individual ESVs could further hamper power generation due to siltation and reduce irrigation water for sugarcane plantation.

### *3.3. Change in individual and grouped ecosystem services*

Within the individual ecosystem services, the lowest value was recorded for gas regulation for the two periods of 1987 and 2019. It was also reduced by 0.006% for the period of 1987–2019 (Table 7). The highest ecosystem service value for Fincha watershed was USD$ 330.1 million and USD$ 367.4 million in the year 1987 and 2019, respectively and this value was for water regulation and food production. Food production increased by 1.9%, while water regulation reduced by 2.9% within 1987–2019. Erosion control reduced from USD$ 130.9 million to USD$ 79.7 million, mainly due to the reduction of forest land and wetland. Pollination increased by 0.01%, which is associated with the increase in cultivated land and sugarcane plantation, that are sources of food for pollinating animals. Due to the presence of water body in Fincha watershed, there exist a potential for tourism and hence, the recreational values are indicator of the availability of this service which needs to be used on sustainable basis. Although, fishing is very much localized to the area and is not widely practiced, it is found to be the untapped potential, when it comes to recreational values and food production.

**Figure 4.** Water body formed through dam construction to generate hydroelectric power.

**Figure 5.** Wetland formed as a result of the dam construction.

Provisioning ecosystem service was found to be the highest for cultivated land for 1987 and 2019, which was USD$ 500.3 million and USD$ 574.2 million, with an increase in USD$73.9 million between the periods (1987–2019). This increment in the provisioning service was associated with the larger area of land covered by cultivated land use and the highest ecosystem service value assigned (Table 8). Regulating, supporting and cultural services are the highest for both years (1987 &2019) for wetland than any of the land uses despite the decrease of these services by 46.7%. Other land uses, such as, forest land, water body and sugar cane plantation provided an intermediate level of provisioning, regulating, supporting and cultural services, whereas settlement as a land use type had the highest cultural services in 2019, but with no provisioning and supporting services (Table 8). In terms of ecosystem service provision, cultivated land is the dominant cover type, but as each one of the land uses have their own peculiarities and characteristics to provide each service, it is important to maintain each one of them by interspersing within the landscape, so that the overall flow of services can be maintained in the long term.

### *3.4. Elasticity of ESV change in relation to LULC*

The sensitivity analysis and the CS calculation for each LULC type, was performed for 1987 and 2019 (Figure 7), which provided information about the contribution of LULC types in ESs assessment. The analysis showed the importance of cultivated land, forest land and water body in the total NCV. CS values increased from 0.39 to 0.62 for cultivated land and 0.102 to 0.252 for water body. A reduction in CS values for forest land (0.23–0.11) and wetland (0.202–0.066) was observed (Figure 7).

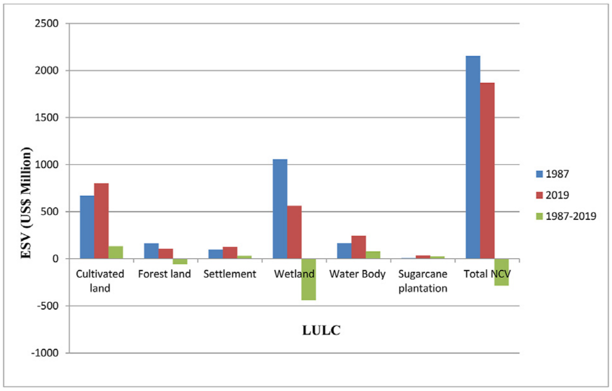

**Figure 6.** Total ecosystem service values estimated for each land use and land cover category and changes from 1987 to 2019 (this value is based on 2011USD$ million/ha/yr).

**Table 7.** Individual ESVs for Fincha watershed (1987–2019) in Millions USD$/ha/yr.

| Individual ESVs | $ESV_{f\ 1987\ (Millions\ USD\$/yr)}$ | $ESV_{f\ 2019\ (Millions\ USD\$/yr)}$ | $ESV_{f\ 1987\text{-}2019}$ | |
|---|---|---|---|---|
| | | | Change ($_{\text{(Millions USD\$/yr)}}$ | CCf (%) |
| Gas regulation | 0.36 | 0.24 | -0.12 | -0.01 |
| Climate regulation | 146.7 | 129.4 | -17.3 | -0.01 |
| Disturbance regulation | 124.7 | 66.7 | -1.2 | -0.07 |
| Water regulation | 330.1 | 268.9 | -61.2 | -2.9 |
| Water supply | 92.2 | 104.5 | 12.3 | 0.58 |
| Erosion control | 130.9 | 79.7 | -51.2 | -2.4 |
| Soil formation | 67.9 | 79.9 | 12 | 0.56 |
| Nutrient cycling | 70.5 | 37.6 | -32.9 | -1.54 |
| Waste treatment | 190 | 145.6 | -44.4 | -2.1 |
| Pollination | 3.7 | 3.9 | 0.2 | 0.01 |
| Biological control | 43.5 | 25.9 | -17.6 | -0.01 |
| Habitat/Refugia | 102.1 | 54.5 | -47.6 | -2.2 |
| Food production | 327.4 | 367.4 | 40 | 1.9 |
| Raw material | 52.5 | 46.3 | -6.2 | -0.3 |
| Genetic resources | 181.98 | 188 | 6.02 | 0.3 |
| Recreation | 237.8 | 227.4 | -10.4 | -0.5 |
| Cultural | 81.9 | 43.7 | -38.2 | -1.8 |
| Total (NCV) | 2154.1 | 1869.6 | -284.5 | -13.2 |

Due to the continuous loss of forest land and wet land, their effect on the overall NCV was also reduced, while cultivated land and water body seems to be the most important LULC type with a progressive increase of its effect on the final NCV. A significant increase in the effects of settlement was also observed, but of lower magnitude. Sugarcane plantation present small effects on the final NCV values, but expected to increase given the policy direction of the government to promote and expand the sector of agro-processing industries within the next couple of years.

## 4. Discussion

### 4.1. Land use/land cover change

In our study watershed, the increase in cultivated land and settlement are attributed to the high level of intervention by small holder subsistence farmers for increasing production to feed the increased human population, whereas the increase in water body and sugar cane plantation is the result of large scale project activities carried out in the form of generating hydroelectric power from the diverted water and sugar cane plantation to increase the supply of sugar for domestic consumption and export. Our results corroborate other findings within the watershed (Tefera and Sterk 2008; Ayana and Kositsakulchai 2012; van Vliet et al., 2017; Dibaba et al., 2020) and other regions in Ethiopia (Mekonnen et al., 2018; Angessa et al., 2019). In addition, in the growth and transformation plan of Ethiopia (GTP I & II), it has been indicated that agriculture should be enhanced to produce more high value crops for export and hydroelectric power generating dams shall be constructed to satisfy the energy demand of the households and industries within the planned period of 2010–2020 (National planning Commission 2016).

Similarly, forest resources are not only shrinking in size at local level but also at country, regional and global level with varying degrees of reduction under different governance regimes (Getahun et al., 2013; Keenan et al., 2015; Young et al., 2020). For example, forests in East-Southern Africa reduced by 1795.96 ha/yr between 1990-2015 (Keenan et al., 2015; Sloan and Sayer 2015) and the mean rate of change in natural forest area for 2000–2010 in Ethiopia was -169 kha/yr (Keenan et al., 2015). Furthermore, projected forest resource area is expected to reduce for the year 2030 at a global level, while local variation depends on policy measures designed by governments (Turner et al., 2007; d'Annunzio et al., 2015). Hence, the reduction in forest land and wetland is a global phenomenon reported in different parts of the World (Yi et al., 2017; Karki et al., 2018; Dibaba et al., 2020).

The reduction in ecologically important land uses identified, such as, wet lands and forest land in the area is signaling a reduction in the

**Table 8.** Major ecosystem services for the year 1987–2019 (Millions USD$/ha/yr).

| Year | Groups of Ecosystem services | Cultivated land | Forest land | Settlement | Wetland | Water body | Sugarcane plantation | Bare land |
|---|---|---|---|---|---|---|---|---|
| **1987** | Provisioning | 500.3 | 55.1 | | 68.2 | 25.3 | 5.1 | 0 |
| | Regulating | 119 | 78.3 | 13.1 | 643.3 | 111.3 | 1.2 | 0 |
| | Supporting | 69.6 | 2.6 | | 171.3 | | 0.71 | 0 |
| | Cultural | 10.3 | 26.2 | 81.8 | 172.8 | 28.6 | 0.12 | 0 |
| **2019** | Provisioning | 574.2 | 35.9 | | 36.3 | 37.1 | 22 | 0 |
| | Regulating | 136.6 | 50.98 | 17.3 | 342.6 | 163.5 | 5.4 | 0 |
| | Supporting | 79.8 | 1.7 | | 91.3 | | 3.1 | 0 |
| | Cultural | 11.8 | 17.1 | 107.7 | 92 | 42 | 0.47 | 0 |
| **1987–2019** | Provisioning | +73.9 | -19.2 | - | -31.9 | +11.8 | +16.9 | 0 |
| | Regulating | +17.6 | -27.32 | +4.2 | -300.7 | +52.2 | +4.2 | 0 |
| | Supporting | +10.2 | -0.9 | - | -80 | - | +2.39 | 0 |
| | Cultural | +1.5 | -9.1 | +25.9 | -80.8 | +13.4 | +0.35 | 0 |

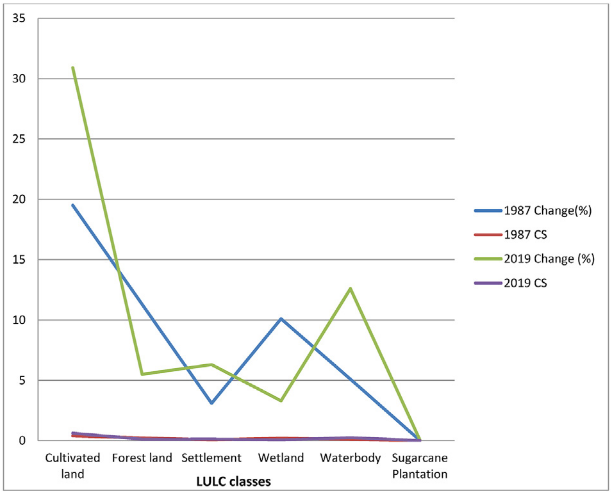

**Figure 7.** Change in total NCV (%) and sensitivity coefficient (CS) after adjusting ESs values by ±50 % in for the years 1987–2019.

capacity of land uses to maintain soil fertility and to reduce sediment deposition, which ultimately affects hydroelectric power generation and irrigation water for large scale projects like sugar production. Sedimentation of dams, irrigation canals and reduction of wet land area is affecting the long term capacity of the watershed to provide the required services (Tefera and Stroosnijder 2007; Devi et al., 2008; Tefera and Sterk 2010; Sica et al., 2016; Ricaurte et al., 2017; Legese et al., 2018; Kaura et al., 2019; Åhlén et al., 2020). The dam was mainly for hydropower production, but has caused major land use changes in the watershed by inundating swamps, grazing land, cropland and forest land. The reduction in bare land in the study period resulted from three major reasons. These are conversion in to settlement, cultivated land and water body in many ways due to the scarcity of land for production purposes, which was depicted in other studies conducted within the study watershed (Tefera & Sterk 2008, 2010).

### 4.2. Changes in the total ecosystem service values of the natural capital

The total values of ecosystem services decreased by 13.2% for the study watershed and period. This was mainly due to the progressive increase in human dominated land uses, particularly cultivated land, settlement and sugarcane plantation, which is attributed to the interest of the government in development activities and small scale farming practices, which compete for the available land uses. Similar studies in Ethiopia (Tolessa et al., 2018; Kindu et al., 2016), China (Zhao et al., 2004; Song and Deng 2017; Wang et al., 2018), Italy (Gaglio et al., 2017) and the World (Costanza et al., 2014; Kubiszewski et al., 2017; Sannigrahi et al., 2020) found progressive decline in the total ecosystem services values. For each year considered, the highest ecosystem service value was recorded for wetland and cultivated land as compared to other land uses. This highest ecosystem service can be attributed to the values assigned for wetland due to its importance in the services rendered and size of the land occupied by cultivated land respectively.

The progressive increases in settlement could be the result of shift in other land uses, particularly wetland and forest land to cultivated land, whereby the abandoned cultivated land could be further shifted to settlement. Hence, given that new houses are built over time implies an increase in population, which further triggers competition of land uses for different purposes as supported by different studies across the globe (van Vliet et al., 2017). In terms of the loss of ecosystem service values by each land use, wetland lost 41.6%, which is significantly higher. In different parts of the world, for example, China, Zhao et al. (2004) reported 71% loss of wetlands/tidal flat, which was attributed to the loss of total ecosystem services and a decline in ecosystem service of wetlands recorded in Europe (Gómez-Baggethun et al., 2019). The tradeoffs in ecosystem services values at the watershed level should be reduced by integrating other land uses, such as forests and wetlands within the landscape.

### 4.3. Changes in the individual and grouped ecosystem service values

Water regulation and food production are the dominant ecosystem services recorded for 1987 and 2019 due to the increase in cultivated land and water body, but other service values are found to be low. This is an indicator of the trends in the dominance of some land uses by others, which could result in homogenization of the watershed that will potentially impact individual service provision. The reduction in certain natural environments, such as forest land and wetland could further significantly affect vital ecosystem services, including gas regulation, climate regulation, disturbance regulation and waste treatment (Ninan and Kontoleon 2016; Kubiszewski et al., 2017; Woldeyohannes et al., 2020). Furthermore, the loss in forest land and wetland resulted in the reduction of erosion control from USD$ 130.9 million to USD$79.7 million in our study watershed. In the long term, this could affect the dam constructed for power generation, water supply, recreation and food production. Many dams were affected from siltation due to upland deforestation and extensive cultivation (Kaura et al., 2019).

In addition, the increase in provisioning services at the expense of other services, especially regulating services cannot be sustainable, unless the existing modification of land uses are halted within the watershed, which hamper the future flow of these important ecosystem services, that is, regulating and supporting services. These findings are consistent with other studies elsewhere (Huq et al., 2019; Luo et al., 2020). Hence, the current optimal provisioning services cannot continue without the protection of regulating and supporting services. So, while managing land uses, it is important to take in to account the tradeoffs and synergies of individual and grouped ecosystem services to enhance sustainability of production (Johnson et al., 2012; Jacobs et al., 2015; Tomscha and Gergel 2016; Mengist et al., 2020). The synergies between supporting and regulating services enhance provisioning services and hence combining mosaics of lands uses such as forests, wetland, settlement, water body and cultivated land within the watershed is vital. The tradeoffs between provisioning and regulating services should take in to account sustainable production for all stakeholders at the watershed level.

### 4.4. Elasticity of ESV change in relation to LULC

From the analysis of elasticity of ecosystem service value changes, we found that within the study period considered cultivated land dominated the watershed with the highest value of 0.39 and 0.62 for 1987 and 2019 respectively (Figure 5). This implies that, the share of cultivated land use in terms of providing ecosystem services is significant followed by forest land and wetland. Similar findings showed the importance of human influenced land uses in dominating the total value of the natural capital in Italy (Gaglio et al., 2017).

### 4.5. Limitation of the study

Our study is limited with locally available value coefficients, which better reflect the overall values of the natural capital and hence the uses of globally available coefficients are constrained by not taking in to account local specific physical, climatic and edaphic factors. In addition, the validity of ES monetary values is also still debatable, because some argue that valuation of ecosystems is either impossible or unwise, that we cannot place a value on such ‘intangibles’ as human life, environmental aesthetics, or long-term ecological benefits (Constanza et al., 1997). Monetary values should not be interpreted as real market values directly applied for payment of ESs schemes or compensation actions. Their use aims to support future governance and to raise awareness about the importance and the magnitude of loss of natural capital.

## 5. Conclusions

Fincha watershed is characterized by the presence of potential hydroelectric generation and sugarcane plantation, and hence attracted the interest of the Ethiopian government as one of the most important development corridor. The current study investigated the impacts of human activities on the values of the natural capital. The watershed was dominated by the increase in cultivated land with the increase in this land use at a rate 579.8 ha/yr and a reduction in wetland at a rate of 600.2 ha/yr for the study period. Other land uses changed with varying degrees between the two land uses depending on the decision of the stakeholders involved in the process of conversion of land uses. We found that due to extensive government projects and small scale farming practices, the total values of the natural capital decreased by USD$ 284.5 million/yr over three decades. In terms of the individual ecosystem services, food production dominated other services with an increase by 1.9%, whereas water regulation reduced by 2.9%, as a result of the conversions of important landscape components particularly wetland and forest land. Our sensitivity analysis has also shown cultivated land dominated the watershed and hence influenced the overall ecosystem services values. Hence, we recommend an appropriate land management practices that takes in to account an optimal level provision of individual ecosystem services for sustainable development within the watershed.

## 6. Significance of the study

This study can be used for public awareness and decision making processes at the watershed level for sustainable development. It also paves the way for future research efforts at the country level and a consolidation of robust value coefficients for better understanding of the potential values of natural capital in the country.

## Declarations

### *Author contribution statement*

Terefe Tolessa; Moges Kidane; Alemu Bezie: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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### *Data availability statement*

Data will be made available on request.

### *Declaration of interests statement*

The authors declare no conflict of interest.

### *Additional information*

No additional information is available for this paper.

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