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Research article

Integrated assessment and mapping of provisioning services for sustainable management of natural resources, the case of Lake Hawassa Basin, Ethiopia

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A R T I C L E I N F O

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A B S T R A C T

Lake Hawassa Basin (LHB)-the study area is known for its rich and diverse aquatic and terrestrial natural resource base. However, the prevailing environmental and social problems, such as land degradation, deforestation, pollution, resource exploitation, etc. impacted the existing provisioning services (PS), and the effect becomes remarkable unless sound management is in place. The study aimed at the assessment and mapping of PS to suggest development options for decision-makers. The study employed various methods including primary and secondary data collection, including existing Land Use Land Cover (LULC), desk review, stakeholder consultations, site visits, expert judgment matrix, and ArcGIS v10.1. The study results include 6 PS identified and prioritized from the existing 14 PS, mapping of the spatial pattern of the selected 6 PS at the basin scale, and alternative development options recommended for the decision-making process conducted by decision-makers and development partners to ensure efficient management of ecosystem services in LHB. The importance of this study, as well as the simplicity and user-friendly nature of the methods and approach adopted, enables interested parties to replicate while conducting similar studies in different places within the country or globally. The intervention of adopting this study approach helps also to avoid or minimize the aforesaid biophysical and socioeconomic environmental problems and ensure development activities planned or implemented in the respective study area are environmentally friendly, and socially acceptable, through sustainable management of natural resources. In this regard, decision-makers and development partners shall provide adequate consideration for this study approach and the result of demonstrating basin scale spatial variability of PS. This plays a vital role in the sustainable management of natural resources as well as provisioning services existing in the study area to benefit the community members, ensure human well-being, and secure the livelihood of the people residing within or around the Lake Hawassa Basin.

1. Introduction

An ecosystem is a dynamic complex of plant, animal, and microorganism communities and the non-living environment interacting as a functional unit [1]. Ecosystem services (ES) are the contributions of ecosystem structure and function - in combination with other inputs - to human well-being. The community benefits from different ecosystem services existing in the study area - Lake Hawassa

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Basin (LHB). This includes Provisioning Services (PS) such as food, water, wood/timber, fiber, etc. [1–4]. This article aimed at conducting an integrated assessment and mapping of PS at basin scale in the study area. Several PS maps at the basin scale are important to assess spatial trade-offs among existing PS, and synergies among multiple ES, as well as to prioritize areas that will allow alignment of multiple natural resources conservation goals [5–10].

Ref. [11] stated that biophysical conditions and human-induced spatial changes in Land Use Land Cover (LULC) and climate change determine the capacity of an ecosystem to provide provisioning services. The concept of ecosystem services assessment approach plays a key role in the maintenance and restoration of basin ecosystems and contributes to the implementation of sustainable management practices to improve the use and importance of natural resources and ecosystem services. This benefits the local people residing in the Lake Hawassa Basin [12], as it is rich in various natural resources, including different habitats with biotic and abiotic features to provide PS [13]. However, the prevailing limiting factors, such as deforestation, land degradation, erratic rainfall, low moisture availability, point and non-point sources pollution, limited knowledge of integrated ecosystem services assessment approach, etc. exhibited in the study area impacted the capacity of these ecosystems to provide PS [13,14].

To address the aforesaid problems and improve the capacity of ecosystems to provide PS, the application of an integrated ecosystem services assessment approach as stipulated in the Millennium Ecosystem Assessment [1] and mapping of provisioning services at a basin scale is the best tool to ensure sustainable development practices as well as securing the livelihood of community members residing within the study area and beyond. Mapping of the spatial patterns of provisioning services at the basin scale is used to indicate the specific locations of existing provisioning services, explain the relevance of each PS to the community members, and initiate discussions among decision-makers and development partners regarding the use and importance of this approach. Hence, these substantiate the need to exert additional efforts for the timely intervention of basin-scale ecosystem service assessment and mapping study to generate alternative development options for decision-makers and development partners [15].

2. Materials and methods

2.1. Description of the study area

Lake Hawassa Basin (LHB) is found in the central northeast part of Rift Valley Lake Basin (RVLB), which is 273 km away from Addis Ababa, the capital city of Ethiopia. LHB covers a total catchment area of l436 km^2 and is centering Lake Hawassa and Hawassa Town, stretching between latitude 6° 48′ 45^2 to 7° 49′ 54^2 N and longitude 38° 16′ 34″ to 38° 43′ 26^2 E, which with 7% of lake coverage, 71% and 21% of the basin area shared in the Sidama and Oromia Regional States, respectively (Fig. 1) [16].

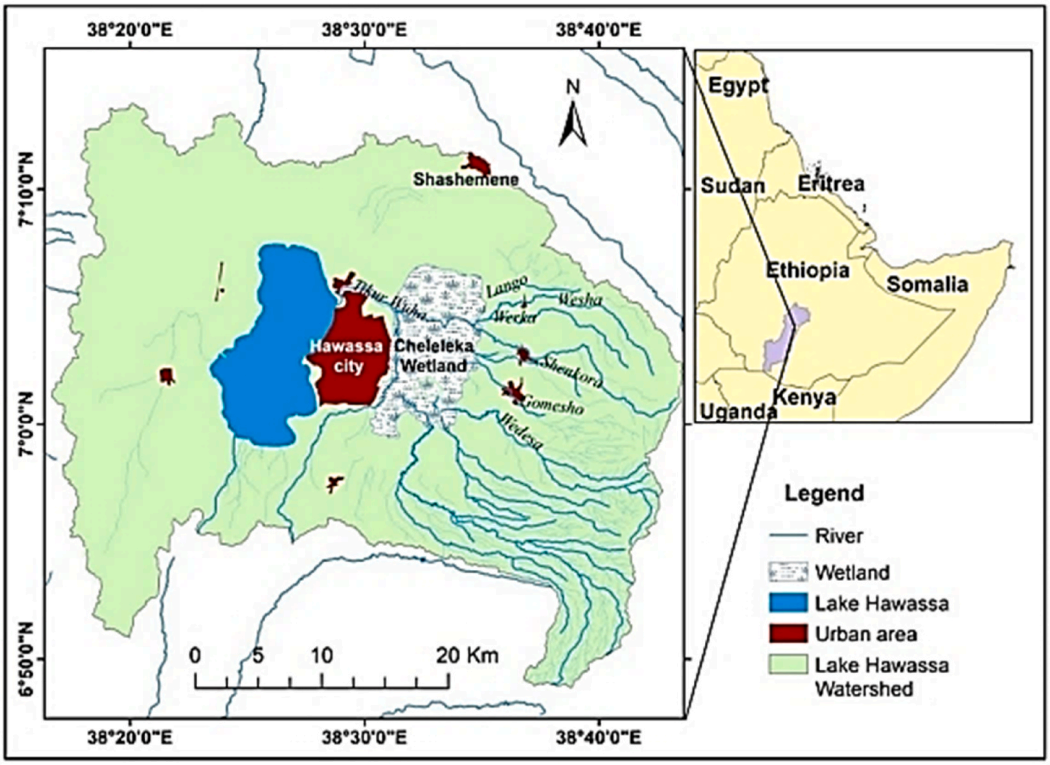

Fig. 1. Location map of Lake Hawassa Basin.
Sources: Extracted from MoWE, 2007.

Lake Hawassa is characterized by closed shallow with no surface water outlet, except the subsurface outflow and evapotranspiration.

The topography of the study area is flat to gently undulate but bounded by steep escarpments, with varied slopes which are 56% of the area is flat to gentle (0–8%), 33% moderately sloping (8–30%), and 5% steep to very steep (>30%). The altitude ranges from 1680 m at Lake Hawassa to 2700 m on the Eastern escarpment of the study area [17]. As per the local agroclimatic classification, the study area is predominantly categorized as a Tepid, humid, sub-humid mountain, rift valley, and lake, cool to a humid agroecological zone. The mean annual rainfall at Hawassa town is about 943.4 mm (range from 693 to 1227 mm) but shows some inter-annual variability without a significant trend. The mean monthly temperature at Hawassa varies from 18.6 °C in November to 21 °C in March. The trend analysis of the mean annual temperature shows an increasing trend, at a rate of about 0.05 °C per year. This is due to climatic changes experienced in the region over the recent years due to increased deforestation, and the situation is expected to get worse with the anticipated change in the global climate in the years to come [18].

2.2. *Conceptual framework (millennium ecosystem assessment (MEA)*

This article uses the conceptual framework of the Millennium Ecosystem Assessment [1]. It explains the dynamic interaction that exists between the ecosystems with their components, which will affect human well-being due to the direct and indirect shifting of human conditions that drive the changes in ecosystem nature and its function (Annex 1). At the same time, social, economic, and cultural factors related to ecosystems alter the human condition, and many natural forces influence the capacity of ecosystems to provide PS [1]. An important feature of the ecosystem service approach arises from the inherent interdisciplinary demand, which emphasizes the characterization of Lake Hawassa Basin goods and services and basic ecological principles considered during the study period. In addition, the socioeconomic aspects that determine environmental evaluations and decision-making processes are also another important factor that requires deep comprehension and valuation of ecosystem services for the successful implementation of this approach [19].

The study methodology adopted the Millennium Ecosystem Assessment Approach [1] which is based on the linkages between the two pillars i.e., Ecosystem services and Human well-being (Annex 2). The strength of these linkages between ecosystem service classes and components of human well-being are commonly encountered indications of the extent to which the possibility of socioeconomic factors intervenes in the linkage. This linkage has a tremendous effect on the existing provisioning services that help to define the demand-supply chain of the system within the study area (Annex 3) [1,20].

2.3. *Methods*

The study used various methods and tools to identify and map the potential PS of the study area. The main methodologies and approaches are discussed in the following sections (Fig. 2). Cognizant of the importance of this study for sustainable management of natural resources, as well as the nature of methodology used for this study, which is simple and user-friendly, it is believed that any interested parties could apply easily for similar studies in the country as well as across the globe to ensure human well-being and sustainable implementation of development projects in the respective study area, mainly at the basin or watershed level. Apart from this, the prevailing limited knowledge of this integrated ecosystem service assessment approach, particularly the absence of similar studies using this approach in the country is one of the challenges that the author, during this study faced. Hence, authors couldn't compare the results of this study with any similar papers conducted using this method in the country. In this regard, it is worth concluding that this study is peculiar in the country, which has vital importance for the swift identification of spatial patterns of PS at the basin level that contributes to sound decision-making during the planning of watershed development projects.

2.3.1. *Data collection*

An integrated ecosystem services approach minimizes the need for complex and costly data collection and analysis. The importance of having valid information is mandatory to identify the conditions and trends of PS in the study area. During the study period, both primary and secondary data, as well as experts' and stakeholders' opinions were collected at national, regional, and local levels and used [21]. The main primary and secondary data including LULC, household population, climate, hydrology, soil, slope, vegetation, etc. were collected from various institutions, such as the Ministry of Water and Energy (MoWE), other government and non-government organizations, universities, fishery associations, etc. Stakeholder consultations, site visits at specific locations, and reviews of various study papers and working documents obtained from the above-mentioned institutions are the main methodologies employed during data collection.

2.3.2. *Stakeholder consultations*

The study used the snowball sampling method to identify relevant stakeholders and avoid missing key informants who are pertinent to the consultation process [22]. During the study period, 80 stakeholders were identified from diverse community groups, including farmers, fishermen, tourists, academicians, officials, and experts, and consulted. The main objectives of consultations are to collect information from each stakeholder regarding their perception and indigenous knowledge of the importance and value of PS, to inform them about the integrated assessment of the PS approach, which considers the ecological, social, and economic factors, and to seek their willingness to fully participate in prioritizing and selection of existed provision services in the study area. During consultation, a brief training was also provided to them on how to apply the checklist and Expert Judgment Matrix in the course prioritization and selection of the top six relevant PS from the recorded fourteen Lake Hawassa Basin's (LHB's) provisioning services and in defining the

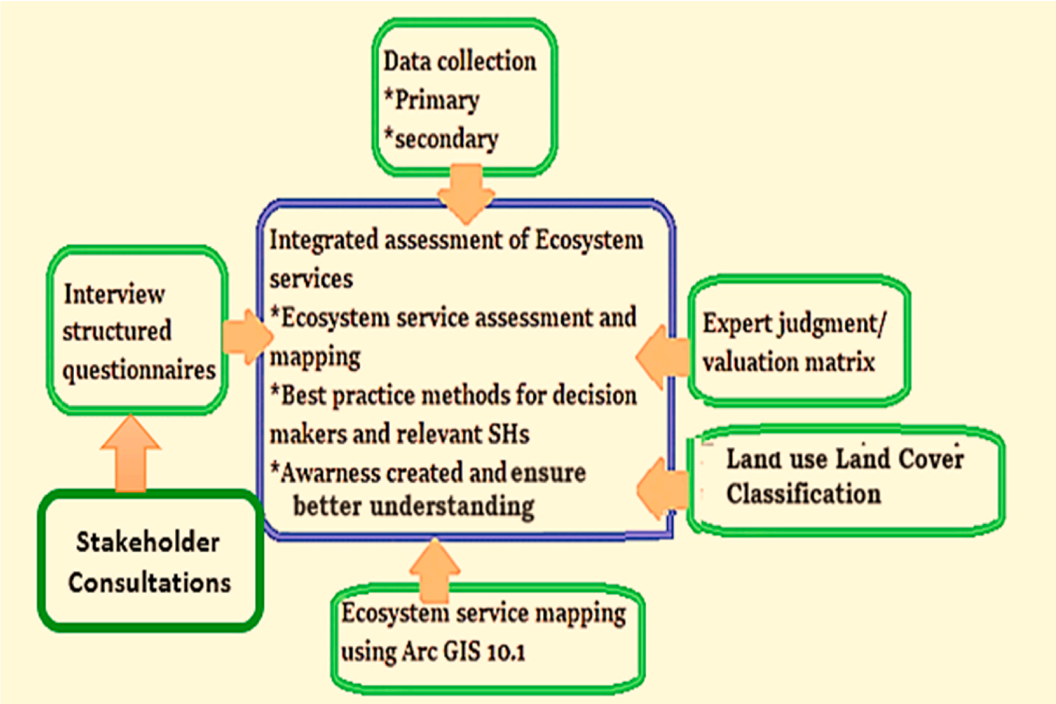

Fig. 2. Typical methodological framework.

Table 1
Lake Hawassa Basin land use land cover classification.

No.	LULC	Code
1	Intensively cultivated smallholder farm	ICSHF
2	Intensively cultivated mechanized farm	ICMF
3	Dense forest	DF
4	Plantation forest	PF
5	Grassland	GL
6	Lake	L
7	Marshland	ML
8	Shrubland	SL
9	Urban/Settlements	U/S
10	Woodland	WL

Source: MoWE, 2007

associated benefits as well as demand-supply chain of the system, based on their understanding and previous experiences with each PS [23–25].

2.3.3. Land use land cover classification

Different ecosystems in LHB have several functions based on their structures and processes. The LULC maps coupled with information on the capacity of each LULC unit to provide provisioning services are used as a tool for decision-makers to identify each ecosystem's potential, possible conflicts, and limits of ecosystems in environmental management [26].

In this study, the identification, and classification of LULC units played a pertinent role in the assessment and mapping of the spatial patterns of selected and relevant provisioning services. The identification exercise of each landscape unit was mainly based on the output of the direct field survey as well as information obtained from reviewed previous study documents, maps, and other supportive information obtained from MoWE, regional bureaus, universities, and other institutions. To determine the existing potential of LHB's provisioning services, this study used 10 Land Use Land Cover (LULC) units classified under the 2007 Rift Valley Lake Basin (RVLB) master plan study [18] (Table 1).

2.3.4. Expert judgment matrix (EJM)

Expert Judgment Matrix (EJM) also called Ecosystem Potential Matrix (ESPM) is one of the most popular ecosystem services (ES) assessment techniques for prioritizing and selecting important provisioning services and for mapping practices (Table 2). This matrix model is technically simple and quickly provides information regarding the prioritized and selected six PS[1] as input for mapping exercises. It also facilitates the involvement of 80 consulted stakeholders. The study adopted a procedure to evaluate spatial differences in prioritized provisioning services based on the analysis of the existing landscape data and the respective capacity of each LULC unit to provide these services [2,20,26,27].

Based on the conceptual framework adapted from Ref. [27], the study used the 2007 LULC data to assess, identify, and illustrate the capacity of each landscape to provide provisioning services which ultimately determines the existing potential capacities of the LHB ecosystems. The selection and prioritization of the existing 14 PS[2] were conducted through consultation and provision of brief training to 80 stakeholders, before starting the selection and prioritization process. The consulted stakeholders used a consecutive numeric value of 1–14 to assign their preference among the 14 PS. Based on their knowledge and preference, number 1 was given to the most important and relevant PS in the study area and number 14 was assigned to the least significant PS. In between the two extremes, based on their knowledge and preference for the value and importance of each PS, they provided the respective value for the remaining 12 PS (Table 3).

The study used the output of stakeholders' exercise of prioritization and selection of preferred PS to evaluate the spatial patterns of selected 6 PS along with the corresponding capacity of each LULC unit through analysis of existing landscape data [26,27]. Once prioritization and selection were completed, to reflect the existing conditions of the prioritized provisioning services, the same stakeholders placed the value for each PS in the blank expert judgment matrix across the corresponding LULC unit. The y-axis of the matrix is designated for 10 LULC types and the x-axis is assigned for 6 prioritized provisioning services as depicted in Table 2. At the intersections, the capacity of each LULC to provide the respective provisioning service was assessed and presented on a 0–5 scale, with each scale value assigned as 0 = no relevant capacity, 1 = very low relevant capacity, 2 = low relevant capacity, 3 = medium relevant capacity, 4 = high relevant capacity and 5 = very high relevant capacity (Table 4).

2.3.5. Mapping using Arc GIS 10.1

Mapping was used to demonstrate the spatial patterns of prioritized provisioning services at the Basin scale as well as to identify the prevailing problems, especially in synergy and tradeoffs among different ecosystem services and between ecosystem services and biodiversity. It also plays a key role in communication to initiate discussions and create awareness among relevant stakeholders, decision-makers, and various development partners on the importance and value of provisioning services, as well as help to indicate the specific locations of valued provisioning services within the LHB. In addition, mapping practice is an important tool to identify and demonstrate the potential capacity of each LULC unit and to understand the status of spatial differences of six prioritized PS at the basin scale [26]. The LULC data is used to map the selected and prioritized 6 provisioning services following the mean value of each PS obtained from the result of the expert judgment matrix. All the required data for mapping including shapefiles were obtained from MoWE. The LULC maps were produced by extracting information from these shapefiles.

Prior to commencing the mapping practices of selected provisioning services, the corresponding relevant indicators were taken into account as input for analysis and mapping [28] (Table 5). The combination of selected 6 PS and the associated indicators was considered to collect information about each PS and also used for further assessment and indication of the spatial distribution of each PS within LHB [23]. The different background colors were employed for mapping to indicate the status of each LULC unit capacity in providing the respective provisioning services. The spatial patterns of each PS generated from the respective LULC class were presented at the basin scale map with varied colors attached to the 0–5 scale value of each LULC unit capacity to provide PS. The different colors assigned to each 0–5 scale value include red color to zero (0) which denotes no relevant capacity and the deep green color assigned to the maximum value of five (5) representing a very high relevant capacity (Table 4). The LULC and PS spatial pattern maps were plotted using ArcGIS v10.1 to illustrate detailed information on the status and potential of Lake Hawassa Basin's ecosystems to provide PS. In addition, the plotted map is relevant to facilitate the identification and assessment of the spatial variation of existing annual potential provisioning services in the study area. The detailed results of the study are discussed in the below result section.

3. Results

This section focuses on six provisioning services (*Crop, Fish, Livestock, Freshwater, Fuelwood, Fodder, and grazing for Livestock*) that were prioritized and selected by the consulted 80 stakeholders drawn from farmers/local community members, fishermen, tourists (local and foreigner), officials and experts from government offices (Regional Agricultural and Water Development Bureaus), scientists from universities, experts and officials from non-government organizations, based on their knowledge and preference on the value and spatial variations of six PS depicted using basin-scale maps.

[1] Crop, fish, livestock, freshwater, fuelwood, fodder and grazing for livestock.

[2] Crop, fish, livestock, freshwater, fuelwood, fodder, grazing for livestock, biomass energy, fiber, timber, aquaculture, wild food, biochemical, medicine mineral resources abiotic energy sources.

Table 2
Typical expert judgment matrix (EJM)/ecosystem potential matrix (ESPM).

No	Land Use Land Cover (LULC)	Provisioning Service						
		Food-Crop	Food-Fish	Food-Livestock	Freshwater	Fuelwood	Fodder, Grazing for livestock	Sum
1	Intensively Cultivated Smallholder farm							
2	Intensively Cultivated Mechanized farm							
3	Dense Forest							
4	Plantation Forest							
5	Grassland							
6	Lake							
7	Marshland							
8	Shrubland							
9	Settlement/Urban							
10	Woodland							

Source: Burkhard et al.2009

Table 3
Lists of Prioritized Provisioning Services
Source: Burkhard et al.2009

Provisioning Services	Rank
Crop	1
Fish	2
Livestock	3
Freshwater	4
Fuelwood	5
Fodder, Grazing for livestock	6
Biomass energy	7
Fiber	8
Timber	9
aquaculture	10
wild food	11
Biochemical, Medicine	12
Mineral resources	13
Abiotic energy sources	14

Table 4
Expert judgment matrix assessment scale (0–5)
Source: Burkhard et al.2009

0	**No relevant capacity**
1	**Very low relevant capacity**
2	**Low relevant capacity**
3	**Medium-high relevant capacity**
4	**High relevant capacity**
5	**Very high relevant capacity**

Table 5
Proposed indicators to represent provisioning services.

No.	Provisioning service	Definition	Potential indicators
1	Crops	Cultivation of edible plants and harvest of these plants on agricultural fields and gardens which are used for human nutrition.	Harvested crops (t/ha*a, kJ/ha*a) Net primary production. (t C/ha*a, kJ/ha*a) Yield (D/ha*a)
2	Biomass for energy	Plants used for energy conversion (e.g., sugar cane, maize)	Harvested plants (t/ha*a, kJ/ha*a) Net primary production (t C/ha*a, kJ/ha*a) Yield (D/ha*a
3	Fodder[a]	Cultivation and harvest of fodder for domestic animals	Fodder plant harvest (t/ha, kJ/ha*a) Net primary production (t C/ha*a, kJ/ha*a) Yield (D/ha*a) Area used for harvesting fodder (ha)
4	Livestock (domestic)	Production and utilization of domestic animals for nutrition and use of related products (e.g., dairy, wool).	Number of animals (n/ha*a, kJ/ha*a) Respective animal products (t/ha*a) Animal production (t C/ha*a, kJ/ha*a) Yield (D/ha*a)
5	Fibre	Cultivation and harvest of natural fibre (e.g., cotton, jute sisal, silk, cellulose) for, e.g., cloths, fabric, paper.	Harvested fibre in t/ha*a kJ/ha*a Yield (D/ha*a)
6	Timber	Wood used for construction purposes.	Harvested wood in (solid) m3*a, volume*a Net primary production (t C/ha*a, kJ/ha*a) Yield (D/ha*a)
7	Wood fuel	Wood used for energy conversion and/or heat production	Harvested wood fuel (m3/ha*a) Net primary production (t C/ha*a, kJ/ha*a) Yield (D/ha*a)
8	Fish, seafood, and edible algae	Catch of seafood/algae for food, fish meal and fish oil.	Caught fish/seafood/algae in (t/ha*a, kJ/ha*a) Animal production (t C/ha*a, kJ/ha*a) Yield (D/ha*a)
9	Aquaculture	Harvest of seafood/algae from marine and terrestrial aquaculture farms.	Harvest of seafood/algae in (t/ha*a, kJ/ha*a) Animal production (t C/ha*a, kJ/ha*a) Yield (D/ha*a)
10	Wild food, semi-domestic livestock, and ornamental resources	Harvest of berries, mushrooms, (edible) plants, hunted wild animals, fish catch from recreational fishing, semi-domestic animal husbandry and collection of natural ornaments (e.g., seashells, leaves and twigs for ornamental or religious purposes).	Amount of respective items collected, number of wild species used for nutrition (kg/ha*a, kJ/ha*a) Catch of fish/shots of wild animals (kg/ha*a) Harvested plant biomass (t C/ha*a) Yield (D/ha*a)
11	Biochemicals and medicine	Natural products used as biochemicals, medicine and/or cosmetics.	Amount or number of products used for medicine/biochemical (kg/ha*a, n/ha*a) Net primary production (t C/ha*a, kJ/ha*a) Yield (D/ha*a)
12	Freshwater	Used freshwater (e.g. for drinking, domestic use, industrial use, irrigation).	Withdrawal of freshwater (l/ha*a, m3/ha*a)
13	Mineral resources[b]	Minerals excavated close from surface or above surface (e.g. sand for construction, lignite, gold)	Excavated minerals (t/ha*a)
14	Abiotic energy sources[b]	Sources used for energy conversion (e.g. solar power, wind power, water power and geothermic power)	Converted energy (kWh/ha) Produced electricity (kWh/ha)

[a] Potential double-counting when fodder is used for feeding on the same farm.
[b] These services are often not acknowledged as ecosystem services (cp. Haines-Young and Potschin, 2010b); but they can be of high importance for policy decisions, land use management strategies and scenarios on local and regional scales.
Source: Kandziora et al., 2012

3.1. Mapping of land use and land cover (LULC)

The LHB's LULCs which are the basis for mapping to present the spatial patterns of the selected and prioritized 6 PS, were further elaborated with a Pie chart (Annex 4) and LULC map (Fig. 3). Both the LULC map and Pi chart showed that among the 10 LULCs, intensively cultivated smallholder farm covers more than half of the study area which accounts for 60.2%. The intensive cultivation of perennial crops, such as Enset, Sugar Cane, and Coffee mainly covered the eastern hills of the basin, whereas intensive cultivation of cereals dominated the western and southern parts of the Basin. The remaining 39.8% of the basin is covered by other LULC units, such as Grassland (9.5%), Shrubland (7.8%), Lake (6.5%), Marshland (5.1%), Urban/Settlements (3.1%), intensively cultivated mechanized farm (2.5%), Woodland (2.3%), dense forest (2%) and plantation forest (0.9%). The 2% dense forest is situated mainly in the eastern part of the basin around Wendo Genet and Wendo Koshe hills (Table 6 and Fig. 3).

These LULC data infer that the study area is covered by varied ecosystems with different degrees of capacity to provide provisioning services, to benefit community members residing within the study area and the surroundings. Given the majority of the LULC class with 60.2% coverage is of an Intensively Cultivated Smallholder farm, the area has the potential of food from crop provisioning service, which by large supports community members in the supply of food to secure their livelihood (Annex 4, Fig. 3). Thus, for planning

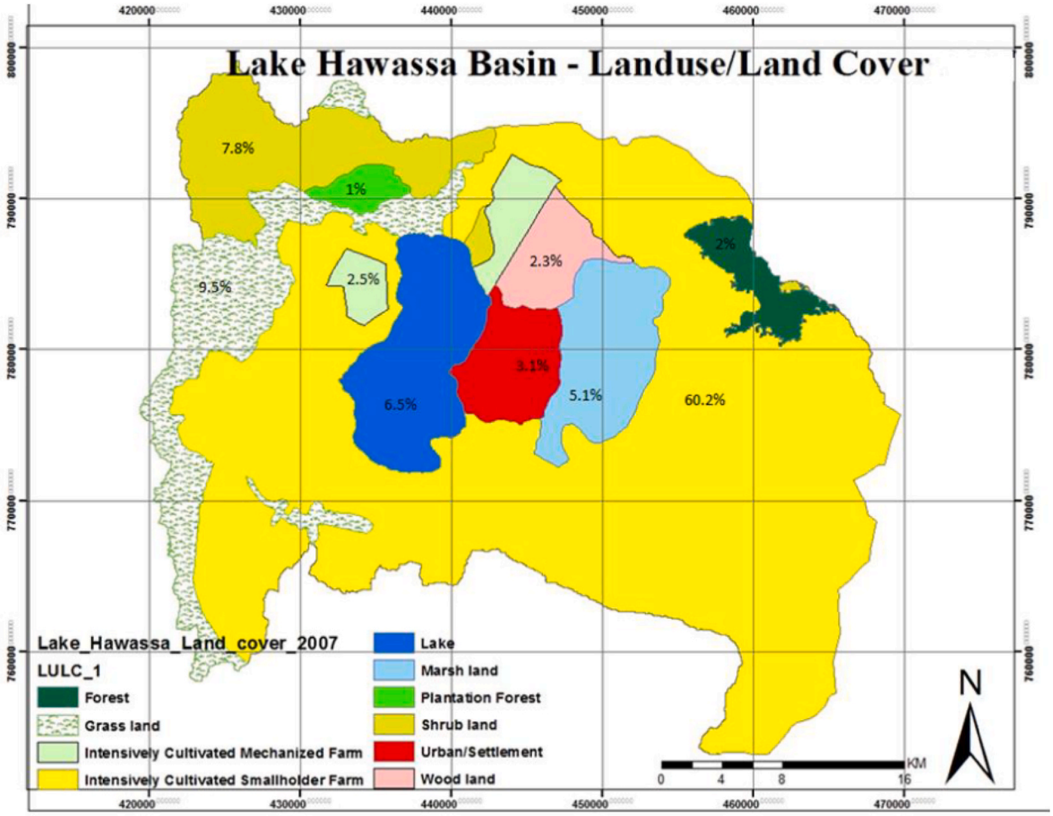

Fig. 3. Land use land cover_2007.
Source: own: Extracted from MoWE, 2007.

Table 6
Lake Hawassa basin LULC (2007)
Source: MoWE, 2007

NO	LULC	Area (KM^2) 2007	%
1	Intensively Cultivated Smallholder Farm	862.3	60.2
2	Intensively Cultivated Mechanized Farm	35.3	2.5
3	Plantation Forest	12.9	0.9
4	Grassland	136.6	9.5
5	Woodland	33.3	2.3
6	Shrub land	111.5	7.8
7	Urban/Settlement	44.9	3.1
8	Marshland	72.9	5.1
9	Forest	29.1	2.0
10	Lake	93.5	6.5
Total		**1432.3**	**100.0**

Table 7
Provisioning services Mean value of LHB Ecosystem Service Potential matrix.

No	Land Use Land Cover (LULC)	Food-Crop	Food-Fish	Food-Livestock	Freshwater	Fuelwood	Fodder, Grazing for livestock
1	Intensively Cultivated Smallholder farm	5	0	3	0	2	4
2	Intensively Cultivated Mechanized farm	5	0	3	0	2	3
3	Dense Forest	3	0	2	3	5	4
4	Plantation Forest	2	0	2	2	5	3
5	Grassland	0	0	5	2	1	5
6	Lake	0	5	1	5	0	0
7	Marshland	0	2	3	4	2	4
8	Shrubland	1	0	2	2	3	3
9	Settlement/Urban	0	0	2	3	1	1
10	Woodland	1	0	2	2	4	3

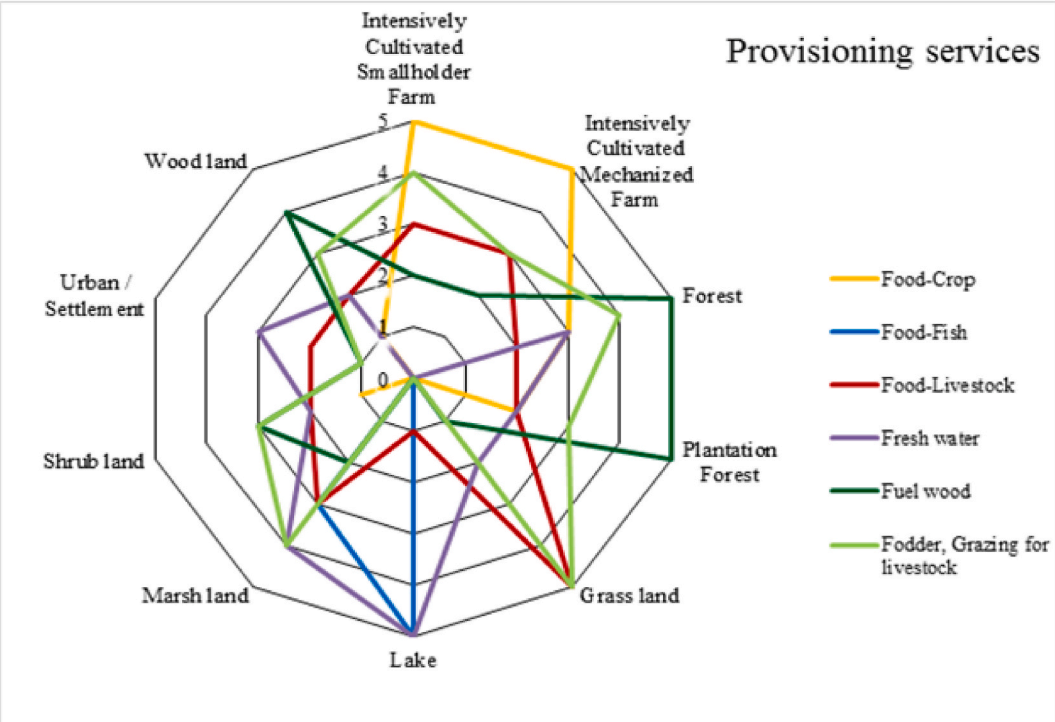

Fig. 4. Radar diagrams of 0–5 assessment scale for the mean value of annual potentials PS.

purposes, this information plays a key role directing the focus of future development planning on enhanced crop farming in locations of the study area with high potential capacity of crop provisioning services to improve the prevailing backward farming practices through proper planning and implementation of improved farming practices. The mean result of each six prioritized provisioning services *(Crop, Fish, Livestock, Freshwater, Fuelwood, Fodder, and grazing for livestock*), as stipulated in the expert judgment matrix (Table 7) have obtained varied mean values across the 10 LULCs, and thus the Capacity of each LULC, as well as the importance of these PS to the community and other stakeholders, also become differentiated.

The major reason for this difference in PS value is due to the prevailing anthropogenic activities in the area that affect the capacity of each LULC unit to provide provisioning services. As depicted in the radar diagram for the mean value of annual potentials PS (Fig. 4), among the different ecosystems, those recorded the value of *5- very high relevant capacity* for the respective provisioning services include dense forests and plantation forests – fuelwood PS, intensively cultivated smallholder and mechanized farms - food-crop PS, Lake-food-fish, and grassland ecosystems-food-livestock PS which reflect their capacity to provide the corresponding provisioning services. Marshland recorded *4-high relevant capacity*-fodder, grazing for livestock, and freshwater PS, whereas urban/settlement and shrubland ecosystems are less contributors to the area's provisioning services, which they recorded a mean value for relevant capacity to provide PS ranges 0–3 (Fig. 4 and Table 7).

3.2. Spatial patterns of provisioning services

As stated above, the various maps were plotted for the spatial patterns of six selected provisioning services *(Food-Crop, Food-Fish, Food-Livestock, Freshwater, Fuelwood, Fodder, and grazing for livestock),* and presented in this section to demonstrate the feature of each PS interaction with the respective ecosystem of the study area.

Provisioning Services- Food Crop: This provisioning service derived from the various ecosystems at various scales is depicted in Fig. 5 below. Among the ten LULC classes, intensively cultivated smallholder and mechanized farms recorded *(5) very high relevant capacity,* forest ecosystem *(3) medium relevant capacity*, and the value for Lake and grassland ecosystems indicated *(0) no relevant capacity* to provide this service. Considering the vast area covered by the LULC of intensively cultivated smallholder farms, the contribution of the LHB ecosystems to provide Food Crop services to the community is paramount to support and improve their economic activities. Thus, to enhance and ensure this potential for the benefit of the community, planning, and implementation of an intervention in the development of modern crop farming practices, mainly in areas where this ecosystem with high relevant capacity record to provide crop-food PS existed will be feasible and most relevant.

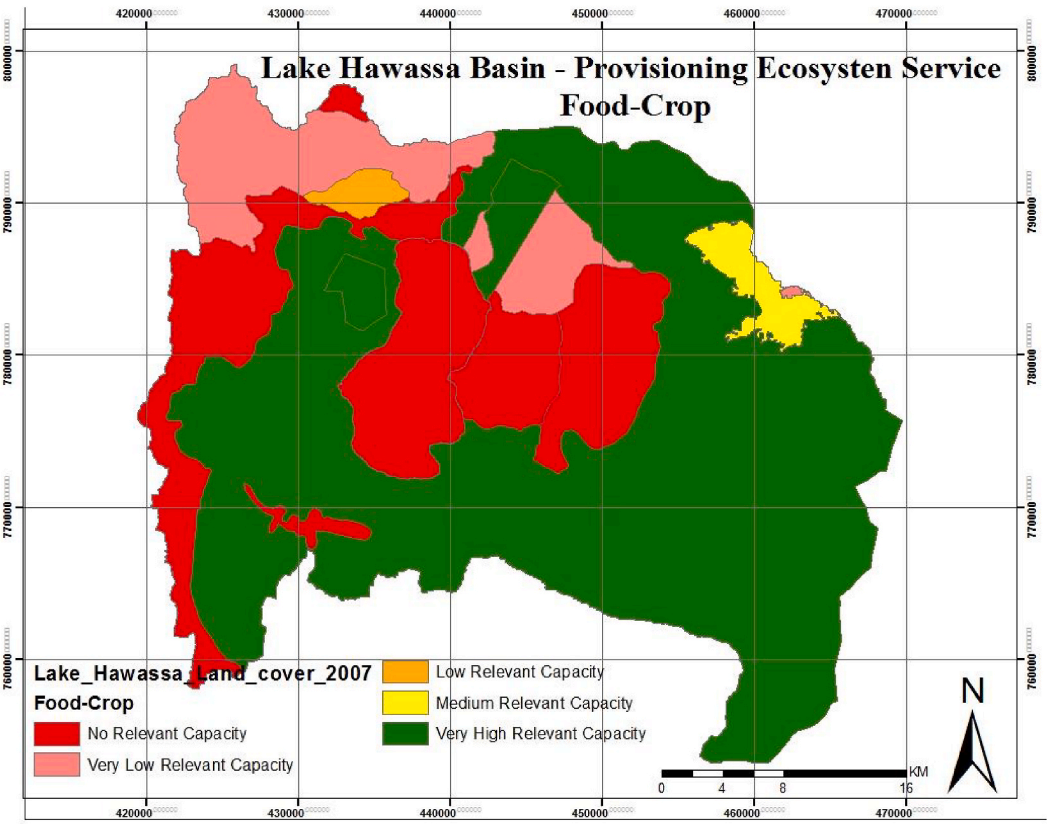

Fig. 5. Spatial distribution of Lake Hawassa basin annual potential of provisioning ESS- Food_Crop.

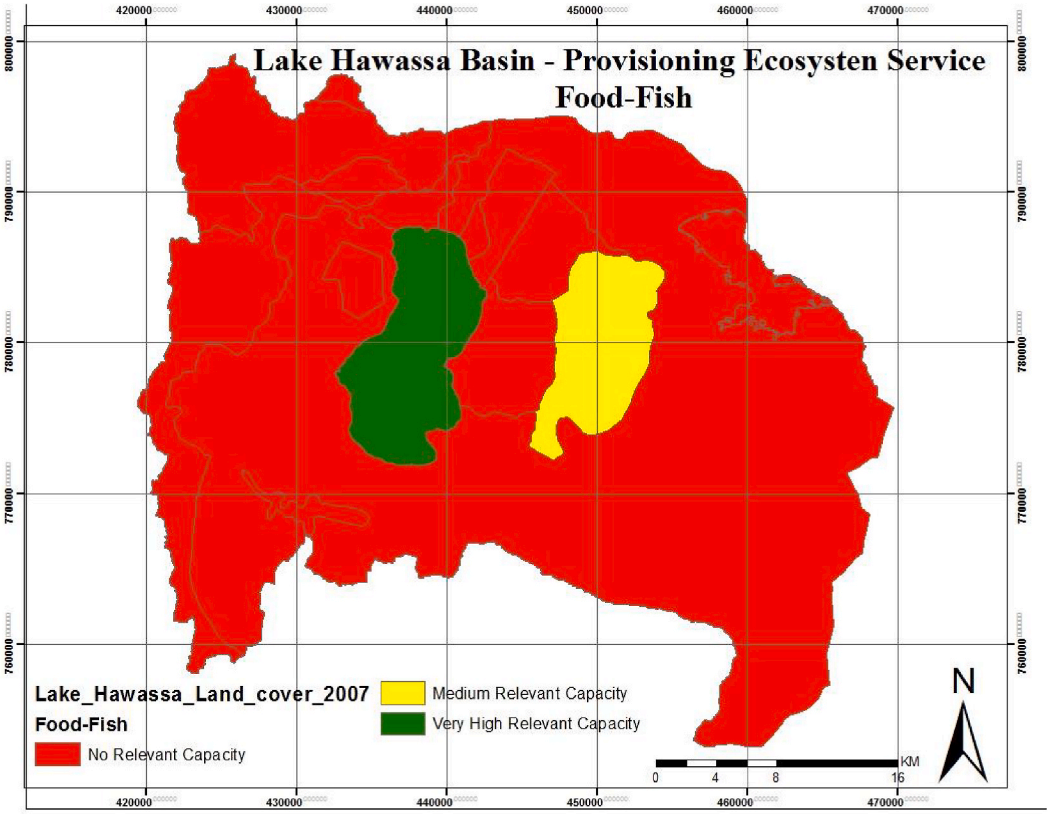

Fig. 6. Spatial distribution of Lake Hawassa basin annual potential of provisioning ESS- Food-Fish.

Provisioning Services - Food-Fish: The result of annual potential food from Fish in LHB indicated that only the Lake and the marshland ecosystems recorded *(5) very high and (3) medium relevant capacities* respectively (Fig. 6). Unlike this, the other LULC classes exhibited *0 = no relevant capacity*. This result informs the decision makers and other development partners during the planning and prioritization of the development agenda in LHB to give attention to fishery projects, as well as the associated businesses, such as small trade, shops, cafeterias, selling fresh and cooked fish, etc. contribute to the enhancement of economic activities in the study area and beyond. The Lake Hawassa ecosystem by its nature and function has a potential capacity to provide fish resources, which the study also confirmed.

***Provisioning Services – Food- Livestock*:** As depicted in the below map (Fig. 7), the spatial variation of provisioning services within the basin ecosystems, food - livestock PS are dominant in the western parts of the study area where grassland with (5) high relevant capacity existed. This information on the potential PS generated from the grassland ecosystem initiated the community and other businessmen to engage in livestock husbandry to enhance their economic activities and benefited them as an alternative food source in the LHB. Among the remaining 9 LULC units, 5 of them recorded *(2) low relevant capacity*, 3 LULC units exhibited *(3) medium relevant capacity,* and finally, the lake recorded the value of *(1) very low capacity*.

Provisioning Services - Freshwater: For any development project related to water resources, the result helps to select the appropriate location of ecosystems within the Lake Hawassa Basin. The result showed the spatial patterns of freshwater annual potential capacity supplied by the different LULC classes in the study area. This includes, the Lake ecosystem scored *(5)-very high relevant capacity*, followed by the marshland ecosystem with *(4)- high relevant capacity.* The Dense Forest and Settlement/Urban LULCs recorded *(3) medium relevant capacity* record and the rest of the LULC classes recorded as *(2) Low relevant capacity and (0) no relevant capacity* to provide this service (Fig. 8).

***Provisioning Services - Food- Fuelwood*:** The Lake Hawassa Basin ecosystem has also the potential to provide fuelwood services. Fig. 9 depicts the spatial variation of fuelwood PS in the Basin. The dense forest in the eastern highland parts of the basin and plantation forest ecosystems have scored a value of *(5)-very high relevant capacities*, woodland, and shrubland valued as *(4)- high and (3)- medium relevant capacities,* respectively. The area covered by smallholder and mechanized farm-intensive cultivation LULCs has recorded the value of *(2) low relevant capacity, where are Settlement/urban and grassland LULCs with (1) very low relevant capacity* and the Lake with *(o) no relevant capacity* to provide fuelwood services. This information benefits development practitioners to come up with sound planning for the various development programs including forest conservation and protection, habitat and biodiversity conservation, afforestation, plantation program, etc. aligned with each ecosystem potential to ensure sustainable management of natural resources in the LHB.

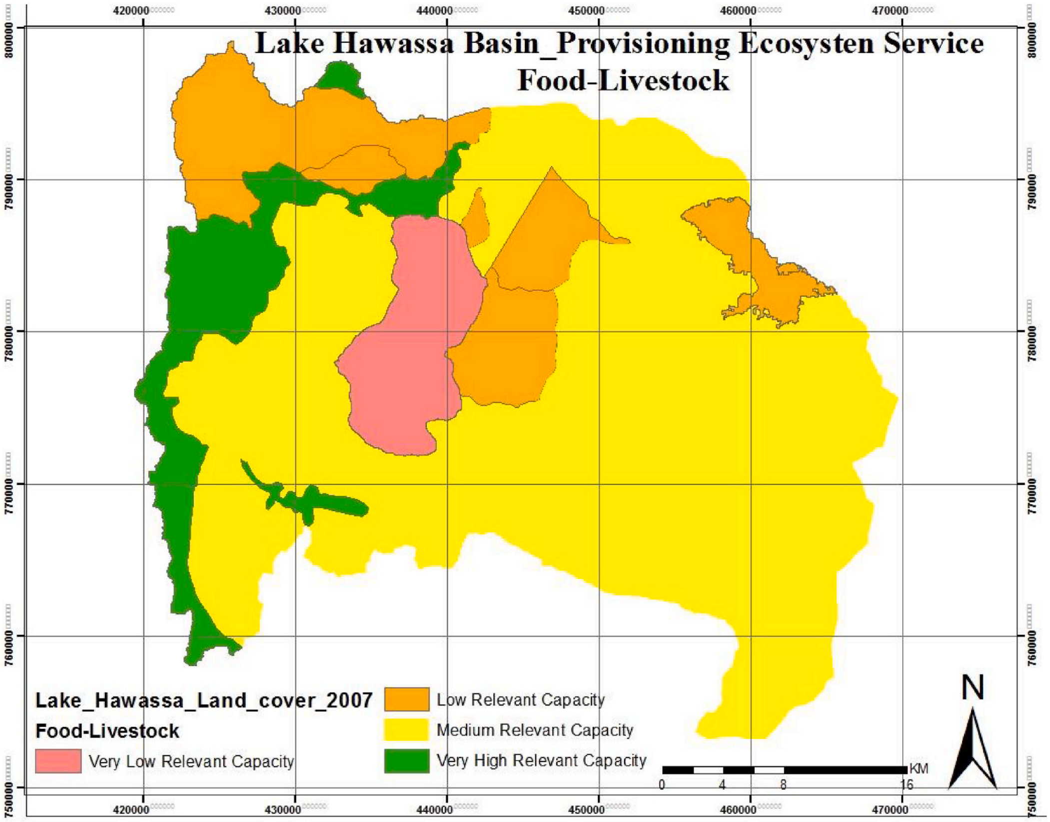

Fig. 7. Spatial distribution of LHB annual potential of provisioning ESS_Food_Livestock.

Provisioning Services – Fodder, Grazing for Livestock: Fig. 10 below shows the map that demonstrates the spatial patterns of Fodder, Grazing for Livestock PS in the basin, and thus the Lake and urban ecosystems scored *(0) no relevant capacity and (1) very low relevant capacities, respectively*. Conversely, grassland has the potential to provide this service with a value of *(5) very high relevant capacity*, followed by intensive cultivation of smallholder, marshland, and dense forest ecosystems with *(4) high relevant capacities,* which also cover the larger parts of the basin, as compared to the other LULC classes. The remaining LULCs recorded *(3) medium relevant capacity.*

4. Discussion and conclusion

The annual potential of provisioning services is determined by the presence of natural resources, including biodiversity which depend on the function and structure of various ecosystems in the Lake Hawassa Basin. As presented in the above result section, the study generated relevant information on the capacity of different study area ecosystems and demonstrated a spatial pattern of the prioritized six PS. This information serves as a source of knowledge on maintaining ecosystem services and human welfare. In addition, the result of the study also suggests alternative development options to benefit the local community as well as other stakeholders, including decision-makers and development partners during the planning and implementation of natural resources conservation and management in the study area [29,30].

The primary purpose of this study is to provide information on the spatial pattern of PS at the basin scale and suggest alternative options relevant to the decision-making process for the planning and implementation of watershed management projects in the area. The study presented the spatial variability of each PS, which resulted from the structure and function of existing ecosystems as well as the respective supply capacity of LULCs. The overall assessment results and illustration of the relevant capacities of each LULC to provide six PSs assist stakeholders and other interested parties in the nation or across the globe to have adequate knowledge of the linkage between landscape type and spatial distribution of PS. This ultimately helps all parties to apply the approach and methodologies employed in this study for similar study in the nation or beyond as well as to benefit from the result of the study for any future watershed management plan and activities in the study area. Such information derived from the study simplifies the planning exercise of the area to determine the right applicable decision for development projects, mainly those development projects or programs related to forests, fishery, water resources, crop production, etc.

Considering this, the ecosystem with a record of high value to provide food crop PS requires stakeholders to focus on crop production of various types, mainly sorghum and maize as produced commonly in the locality, and benefit the community members by

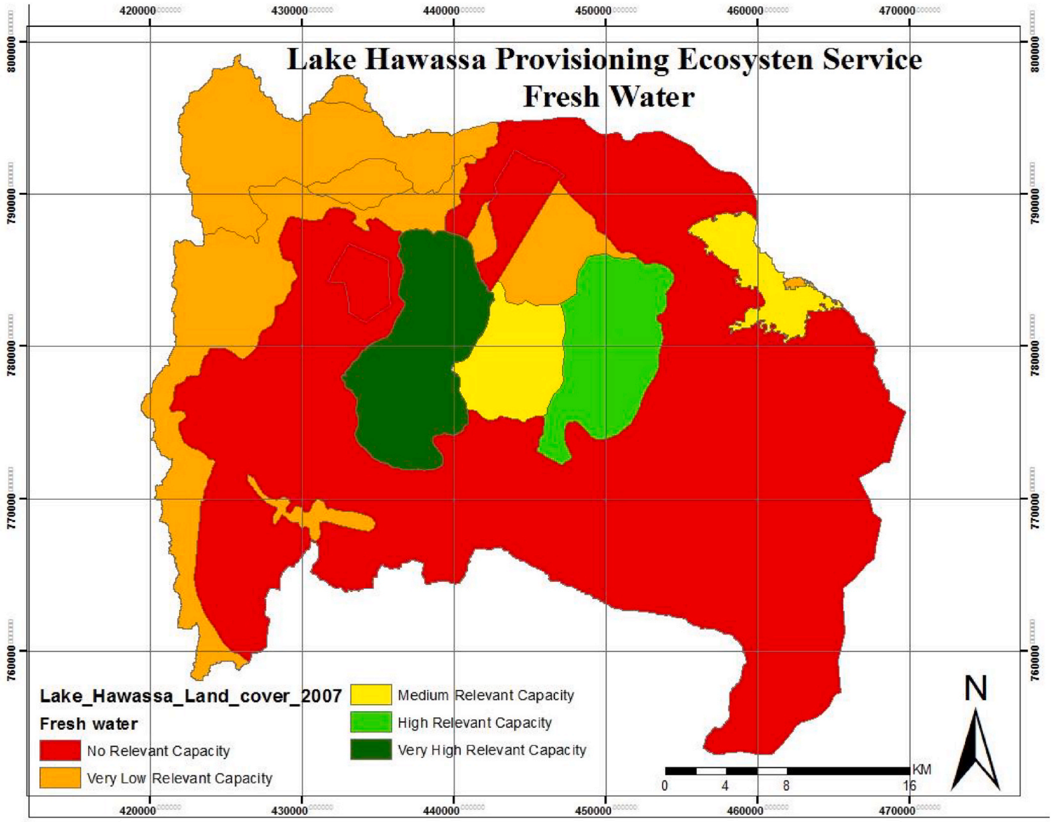

Fig. 8. Spatial distribution of LHB annual potential of PS_Fresh water.

ensuring food self-sufficiency and securing their livelihood. Similarly, the study informs, that the spatial variability of PS is reflected in the demand-supply activities between the ecosystem and the human beings. Among all the identified and prioritized services, fresh water supply, fish, production of livestock, and fuel wood were found to be the most important and dependent ecosystem services for most of the primary stakeholders, mainly the community living around them [31].

In this study, different ecosystem services were considered important by different consulted local stakeholder groups, involving different social interests [32]. This occurred in terms of their perception of the value and importance of PS while participating in prioritizing and selecting six ecosystem services voluntarily and filling the expert judgment matrix that was finally used for mapping practices. The differences between stakeholders' perceptions and knowledge regarding ecosystem services are mainly related to their importance for human needs. Certain previous studies concluded that the inclusion of different stakeholder groups, particularly the local community, and other stakeholders, is required in ecosystem service assessment and prioritization exercises, as they have varied levels of connections to the landscape and knowledge [33,34]. The participation of stakeholders has key value in terms of the basin scale mapping to describe and demonstrate spatial patterns based on the perceptions of consulted and participated stakeholders on existing ecosystem services in the area. Their special interest is contributing to differences in ecosystem services maps produced using their local knowledge as it derives from their exercise in filling the expert judgment matrix.

The involvement of local stakeholders with different levels of influence in the decision-making process would serve to empower stakeholders [35] and generate a collective plan for development planning [36]. The full participation and involvement of relevant stakeholders to take part in the study help them to become familiar with the process of the ecosystem service assessment approach that promotes knowledge sharing and collective action [32]. This practice and understanding of the ecosystems' capacity to provide PS has not only focused on enhancing sustainable management practices [37,38], but also on improving the level of knowledge for designing those multifunctional ecosystems to ensure the delivery of PS [39].

According to the findings of the study, the LULCs with a very high and high relevant capacity of the provisioning services fresh-water entail in the planning and implementation exercise of development projects associated with water resources to be cost-effective, socially acceptable, economically feasible, and ensure the sustainability of the project. Likewise, information regarding the specific location of the basin with LULC units with high relevant capacity value record of Provisioning Services – Food- Livestock and Fodder, grazing for livestock, also provides additional information for planning purposes that the community members and other stakeholders to be engaged in forage production, fattening, and cattle rearing development projects which contribute to boost their economic return and increase their annual revenue.

Overall, this study helps to avoid and minimize environmental and socioeconomic problems by safeguarding or abating land

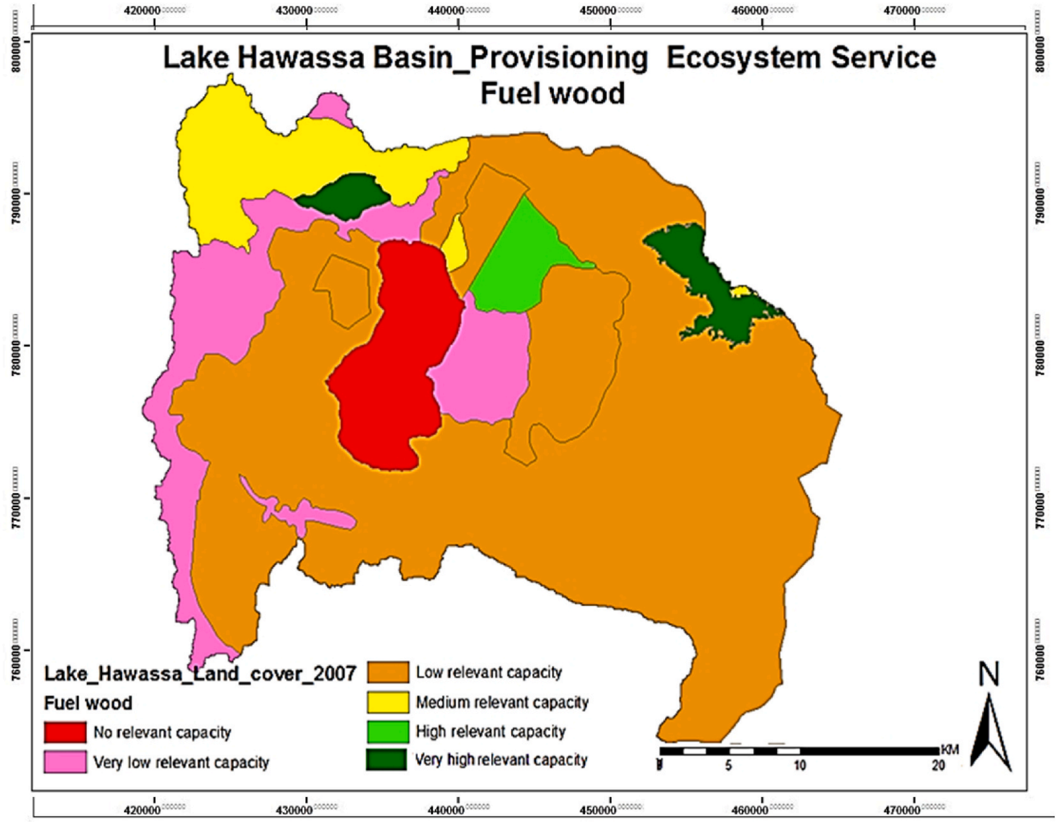

Fig. 9. Spatial distribution of annual potential of provisioning service_ Fuel wood.

degradation, deforestation, pollution, resource exploitation, etc., and ensures all development activities planned or implemented in the study area are environmentally friendly, socially acceptable, economically feasible through sustainable management of natural resources.

In conclusion, the study shows that each LULC class determines the relevant capacity to provide PS. This is linked with the existing natural resources in the LHB and thus such information will be an asset for the development plan and activities in the area. The result of this study following the assessment and mapping of provisioning services is used as a source of information to be integrated into the national sectoral policies to benefit the existing and future planning and management of any development activities within the Lake Hawassa Basin. In this regard, it is possible to infer that the use of integrated assessment of PS has paramount importance for planning and implementation of individual projects in the study area through collecting, collating, and archiving vigorous, reliable, and comparable data, including LULC and existing PS [1]. Therefore, appropriate consideration of the study methodology and wise use of the result will play a key role and be relevant for the sustainable management of natural resources in the study area.

In addition, the study results together demonstrate that ecosystem services mapping is a highlighting tool "for grasping the socio-cultural realities of communities, regions, landscapes and ecosystems" [40,41] and, make evident the need for including different stakeholder groups in the ecosystem service assessment and mapping to capture the diversity of knowledge sources, human-environment relations, and value systems. However, given the simplicity and user-friendliness that could be adopted by any interested parties as well as the limited output, to further qualify and gain much-advanced output, as a next step it is recommended to conduct a similar study with additional methodological input of modeling and valuation of prioritized PS.

5. Limitation

The limitation of the study includes a lack of adequate similar studies in the study area that precluded comparison of the study to published data; a limited number of stakeholders participated in the study, inadequate facilities of shapefiles specific to the study area; and limited awareness of integrated ecosystem service assessment approach.

Ethics approval and consent to participate

Stakeholders' verbal consent was obtained prior to commencing the study.

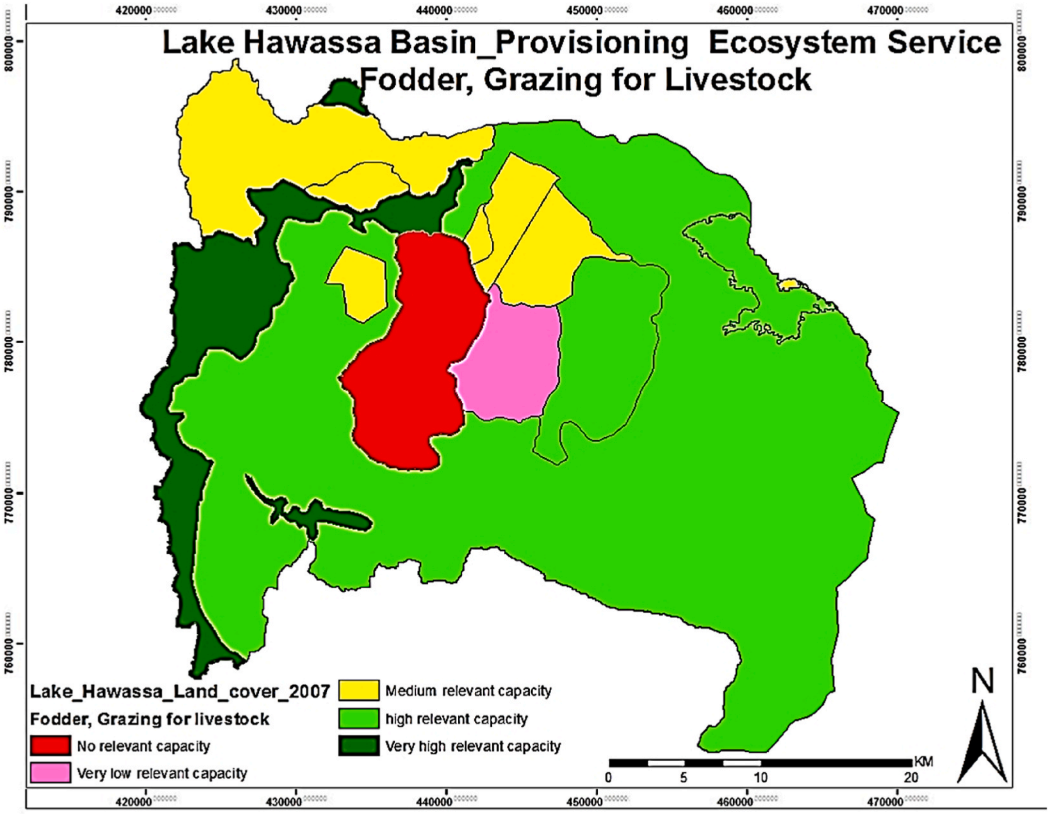

Fig. 10. Spatial distribution of annual potential of provisioning service_ Fodder, Grazing for livestock.

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Additional information

Additional information is included in the supplementary material.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Bedilu Amare Reta: Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Teshome Soromessa:** Writing – review & editing, Validation, Supervision, Project administration, Investigation, Conceptualization.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e24847.

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