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# Review of forest ecosystem services evaluation studies in East Africa

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The East African region hosts diverse forest ecosystems, such as woodlands, highland forests, and coastal mangrove forests. These ecosystems are crucial for biodiversity and support various plant and animal species. They provide essential resources, benefiting livelihoods directly and indirectly. Examining regional and global variations in forest ecosystem valuation, especially regarding livelihood benefits, is crucial for sustainable resource management aligned with forest-based climate solutions. The aim of this review is to assess how regional contextual factors and global trends impact the valuation of ecosystem services (ES) in East Africa, with two main objectives (1) to identify the most evaluated ES in East Africa and (2) to identify the preferred ES valuation methods and approaches applied in East Africa. Data from the Web of Science/Clarivate platform was used in the systematic review process using the Reporting standard for Systematic Evidence Syntheses to retrieve and analyse 222 articles. The ES were categorized using the Millennium Ecosystem Assessment framework and the Common International Classification of Ecosystem Services in order to create a review database. Provisioning services i.e., wood biomass and food production were the most assessed at 55%, followed by 30% regulating services i.e., carbon storage, 8.6% support services i.e., habitat and 6.4% cultural services i.e., ecotourism which reflected communities' direct reliance on forest resources. The preferred direct ES valuation techniques included market price at 14.9% for assessing provisioning services and travel cost methods at 10.4% for cultural services. Amongst the indirect ES valuation techniques, remote sensing at 14.7% were preferred as they proved efficient for large and remote tropical forest areas. Participatory methods such as interviews at 11.8% were also preferred because they offer holistic perspectives on community priorities. This review provides spatial context on the regional priorities of ES valuation which is vital for safeguarding natural resources for future generations.

KEYWORDS

**ecosystem services, valuation methods, forest ecosystem benefits, livelihoods, biodiversity, community benefits, East Africa**

# 1 Introduction

Forest ecosystems are primary habitats for a wide range of species (Isbell et al., 2011) and the abundance of biodiversity provides the flow of ecosystem services (ES), offering multiple benefits for human wellbeing (Sangha et al., 2023; Sharpe et al., 2023). Forest ecosystems are important because they form the baseline for achieving sustainable circular economies as global commitments are being made towards transitioning to carbon neutrality, bioeconomy, and green energy (Baker et al., 2010; Manoj et al., 2024). Moreover, forests contribute towards alleviating climate change by regulating the levels of atmospheric carbon and Green House Gases (GHG) (Jhariya et al., 2024). They also perform mitigation by developing resilient habitats which minimize risks associated with the effects of climate change such as global warming, floods, and low agricultural productivity (Locatelli, 2016; Chapman et al., 2022). The interactions of the living and non-living components of forests as a functional unit allows ecosystems to have dynamic responses to a mix of temporal and spatial disturbances (Calderon-Aguilera et al., 2012), influencing both their structure and function. Ecological variations are also significant when factors such as intensity, magnitude, and frequency of either anthropogenic or natural disturbances are considered (Osewe et al., 2022). Biological diversity is interlinked with ecosystem vitality and health (Manoj et al., 2022). Loss of biodiversity and changes in heterogeneity directly influence the ability of an ecosystem to provide and supply essential services and can affect the long-term capacity of natural systems in adapting and responding to global pressures (Butchart et al., 2010; Nyongesa et al., 2023). Therefore, changes in genetic diversity can affect the ability of an ecosystem to provide essential ecological, economic, and social benefits services needed by society (Roger et al., 2012; Coates et al., 2018).

Three landmark studies on ES have given a comprehensive framework to enable practitioners to categorize and understand with more clarity the various aspects involving ES. They are the Millennium Ecosystem Assessment (MEA), Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) and the Economics of Ecosystems and Biodiversity study (TEEB) (Tisdell, 2014; Reid and Mooney, 2016). Research articles on ES widely accept the classification by the MEA which puts forward four categories: (1) Provisioning services i.e., fibre, food, freshwater, genetic resources and wood, (2) Regulatory services i.e., pollination, water purification, climate regulation and water regulation, (3) Supporting services i.e., nutrient cycling, primary production and soil formation, (4) Cultural services i.e., spiritual, religious, ecotourism, inspirational, aesthetic and cultural heritage benefits (Mooney et al., 2004).

Resource scarcity and environmental awareness have been the major drivers towards understanding the contribution of ES to societies, considering the global concern of climate change (Calderon-Aguilera et al., 2012) and the response to other pressures (Xepapadeas, 2011; Rizos et al., 2019). Concerns over the depletion of natural capital and loss of ES after the industrialization era have become more pronounced resulting in a common understanding of ecosystem benefits of the use and non-use values of nature (Boehnert, 2016). The interdisciplinary intersection between research areas of forest ecology and classical economics has enabled better understanding of natural capital and recognized contribution of ES to the overall economic structure of societies which were previously undervalued. For instance, Costanza et al. (2014) through the quantitative global assessment report on ES estimated the value of natural capital to be significantly higher than the global gross domestic product (GDP).

Different studies on ecosystem valuation have elicited both criticism and support through the varied responses concerning estimates of natural capital being significantly higher than global GDP as reported by Costanza et al. (2014). Across many scholarly articles on ES there's ambiguity in the definition of reference terms i.e., the definition of ecosystem processes and ecosystem functions, the differences in providing benefits and biophysical relationship that exists between nature and human beings regardless of the benefits (Hooper et al., 2012). These differences, including those related to the used terminology, have limited comparative understanding of asset flows in ecosystem studies and its relation to the end user benefits (Notte et al., 2017). However, the common understanding that daily livelihoods depend on the goods and services provided by nature emphasizes the importance of protecting ecosystems (Chettri et al., 2021; Fan et al., 2022).

Forest ecosystem valuation give quantitative evidence of the ES provided by forests using certain conceptual and methodological frameworks (Mukherjee et al., 2014; Whitham et al., 2015), that estimate the economic value of market and non-market environmental goods and the economic value of various ES which is essential in achieving sustainable forest management. This knowledge of natural capital forms the foundation of sustainable forest programs by prioritizing policies geared for green economies through innovative economic expansion based on natural resources (Wackernagel and Rees, 1997; Engelbrecht, 2009). 13 out of 17 United Nations Sustainable Development Goals are directly or indirectly reliant on the condition of natural resources (Baumgartner, 2019). Therefore, decisions about the sustainable management of natural capital are supported by the valuation of forest ES, which has led to more innovative approaches towards reduction of anthropogenic pressures on forests and climate change (Boehnert, 2016).

Globally, recognition of critical interdependencies between sustainable resource management, socio-economic development and forest conservation plays a key role when establishing approaches for assessing forest ES. Effective methods of ES valuation encapsulate the multifunctionality of forest ecosystems such as ecological, social, and economic parameters to provide information about trade-offs (Börner et al., 2009; Kindu et al., 2022). The existing mechanisms include subsidy schemes that use economic incentives towards resource management practices that ensure continuous provision of quality ES (Börner et al., 2009) i.e., Payment for Ecosystem services (PES) schemes. They are voluntary with a clearly defined ES being traded or bought on the conditionality that the provider safeguards continuous provision of ecosystem services. Long-term sustainability of PES schemes with regards to Carbon as the ES traded, has proven to be more successful when more buyers of the ES like the local governments are included (Osewe et al., 2023a). Moreover, land property rights and tenure, as well as cash transaction types have shown inequities when Carbon is traded in a PES scheme (Kolinjivadi et al., 2023).

In Africa, tropical forest ecosystems are important natural resources because of their immense contribution to livelihoods through direct and indirect ES (Tranquilli et al., 2014). Tropical forest in Sub-Sahara, Central and West Africa cover large areas which act as carbon pools (Fischer et al., 2015)and significantly contribute towards environmental quality and climate stability through carbon sequestration (Adetoye et al., 2018).Studies on African (Keenan et al., 2015; Corbeels et al., 2020) forest ecosystems have shown loss in forested areas often resulted from human-induced pressures such as over exploitation of forest resources, deforestation, increased demand for wood energy and land use change (Müller and Mburu, 2009; Tompkins et al., 2015). The assessment of dry Afromontane Forest ecosystem in Northern Ethiopia (Solomon et al., 2019) using benefit transfer methods revealed a decrease in ecosystem services, which was attributed to the conversion of forest land to arable lands and fuel wood extraction by adjacent communities.

Economic valuation approaches for non-use values like the case study of East Mau Forest in Kenya (Langat et al., 2018), has shown the critical role of forest ecosystems in climate regulation by quantifying the amount of carbon sequestered, which accounted for 80% of the total economic value. Similarly, the valuation of Kakamega National Forest Reserve estimated the total economic value to be over US$ 70 million per year through the supporting and regulatory services (Mutoko et al., 2015). In Tanzania, the valuation was conducted using consumption surveys and choice modelling for non-use values versus market price for use-values. This led to the development of an effective PES model for the wetland area of Kilombero Valley (Mombo et al., 2014), which reduced the rate of deforestation and degradation of catchment forest. The assessment of non-use values (Jensen, 2009) gives insight on the economic potential of forest ecosystems and informs approaches for developing appropriate valuation tools (Sourokou et al., 2023; McIntosh and Zhang, 2024).

Previous studies on forest ES within East Africa revealed that conservation priorities of forest adjacent communities were linked with ES that support subsistence use of resources, because of their direct dependence on forest products such as wood, water, food, and other raw materials to meet basic household needs (Swallow et al., 2009; Anley et al., 2022; Osewe et al., 2023b). Additionally, forest fragmentation and cover loss especially at the edge layers were linked to expansion of agricultural fields in forested areas (Osewe et al., 2022). Similar studies (Heubach et al., 2011; Jamouli and Allali, 2020; Wale et al., 2022; Chama et al., 2023; Charnley, 2023) have also established that ES are beneficial to the communities and perceived priorities influence their attitudes towards utility of forest resources (Apsalyamova et al., 2015). Further, the review by Jamouli and Allali (2020) on economic valuation of ES in Africa established that between the year 2005 and 2020 more than 50% of ecosystem valuation studies in Africa were done in Southern Africa and East Africa (Quijas and Balvanera, 2013).

Our review study builds on the previous findings by detailing the regional variations on ES and the valuation methods. The aim of this review is to assess how regional contextual factors and global trends impact the valuation of ecosystem services (ES) in East Africa, with two main objectives (1) to identify the most evaluated ES in East Africa and (2) to identity the preferred ES valuation methods and approaches applied in East Africa. Data was collected through a meta-analysis of indexed journals in the Web of Science/Clarivate platform and the analysis aimed at providing ground for future ES relates research in the East Africa (i.e. Kenya, Uganda, Tanzania and Ethiopia) regional context, by (a) identifying the ES that have been subject to evaluation, (b) identifying the preferred ES valuation methods and approaches applied in connection with the targeted ES and (c) identifying ES valuation related research gaps that should be addressed in the future for a better understanding of the relationship between forest ecosystems and human communities.

## 2 Methodological frame

### 2.1 Study area

The study area consists of four East African countries i.e., Kenya, Uganda, Tanzania, and Ethiopia. The region has a wide range of forest ecosystems such as tropical rainforest, dryland forest, savannah woodlands, afro-alpine habitat, coastal forest, montane forest, and mangrove forest (Tekalign et al., 2018). These forest ecosystems provide a wide range of goods and services that support livelihoods of the local communities, as detailed in Table 1. Forest management approaches across the region have slight variations but stress on: (a) conservation effort to balance socio-economic and ecological need, (b) sustainable practices and (c) involvement of local communities (Wangai et al., 2016). In Kenya majority of the forest is managed by Kenya Forest Service (Ototo and Vlosky, 2018), in Uganda by National Forest Authority (Obua et al., 2010), in Tanzania by the Forest and Bee keeping Division (Mgaya, 2021), and in Ethiopia by different entities including the Ethiopian Environment and Forest Institute (Kassa et al., 2022). The region experiences an array of climates due to varying geographical location and topography. In Kenya, the western region experiences tropical climate, with consistent rain throughout the year while the north and northeastern region experience hot and dry climate. Uganda has tropical climate with two rainy seasons and short dry seasons. In Tanzania the coastal region has topical climate with high humidity with two rainy seasons, and Ethiopia experience mostly tropical monsoon climate with two rainy seasons (Wangai et al., 2016).

In Kenya, the total forest area is estimated at 4.3 million ha (Ototo and Vlosky, 2018), which comprises of two forest types i.e., natural and plantation forest: natural forest consisting of montane forest, western rainforest, coastal forest, and dryland forest, while plantation forest consists of both exotic and indigenous trees meant for production purposes. The main issues affecting the forestry sector include population pressure, increased demand for agricultural land, and demand for wood products to supply the deficit of industrial raw materials. Forest types in Uganda include dryland, montane, swamp,

TABLE 1 Summary of ecosystem service categories assessed in East Africa.

| Categories of ecosystem services assessed. Using MEA framework and CICES structure | | Frequency count of ecosystem services assessment per country | | | | Total number in East Africa | Share (%) |
|---|---|---|---|---|---|---|---|
| | | Kenya | Uganda | Tanzania | Ethiopia | | |
| **Provisioning services** | Wood fuel | 5 | 1 | 7 | 4 | 17 | *7%* |
| | Fresh water supply | 11 | 4 | 13 | 9 | 37 | *15%* |
| | Food production | 13 | 8 | 9 | 28 | 58 | *23%* |
| | Genetic resources/ biodiversity | 13 | 5 | 5 | 19 | 42 | *17%* |
| | Biomass | 18 | 3 | 13 | 35 | 69 | *28%* |
| | Raw materials | 6 | 1 | 3 | 6 | 16 | *6%* |
| | Timber | 5 | 1 | 1 | 3 | 10 | *4%* |
| | **Total assessment per country** | **71** | **23** | **51** | **104** | **249** | **100%** |
| **Regulating services** | Water regulation | 7 | 4 | 12 | 9 | 32 | *24%* |
| | Climate regulation | 7 | 1 | 6 | 9 | 23 | *17%* |
| | Soil erosion control | 3 | 1 | 2 | 7 | 13 | *9%* |
| | Biological control | 1 | – | 2 | 2 | 5 | *4%* |
| | Carbon storage | 10 | 3 | 7 | 12 | 32 | *24%* |
| | Pest and disease control | 1 | – | – | 1 | 2 | *1%* |
| | Pollination | 4 | – | 1 | 3 | 8 | *6%* |
| | Atmospheric compositions | – | – | 1 | 1 | 2 | *1%* |
| | Waste removal/ treatment | 1 | – | 1 | 2 | 4 | *3%* |
| | Coastal protection | 8 | – | 7 | – | 15 | *11%* |
| | **Total assessment per country** | **42** | **9** | **39** | **46** | **136** | **100%** |
| **Supporting services** | Habitat/refuge | 10 | 1 | 3 | 4 | 18 | *62%* |
| | Nutrient cycling | 1 | – | 2 | 3 | 6 | *21%* |
| | Soil formation | 2 | – | 1 | 2 | 5 | *17%* |
| | **Total assessment per country** | **13** | **1** | **6** | **9** | **29** | **100%** |
| **Cultural services** | Ecotourism/ tourism | 11 | 1 | 3 | 2 | 17 | *44%* |
| | Spiritual | 1 | – | | 4 | 5 | *13%* |

*(Continued)*

TABLE 1 Continued

| Categories of ecosystem services assessed. Using MEA framework and CICES structure | | Frequency count of ecosystem services assessment per country | | | | Total number in East Africa | Share (%) |
|---|---|---|---|---|---|---|---|
| | | Kenya | Uganda | Tanzania | Ethiopia | | |
| | Recreational | 4 | – | 1 | 4 | 9 | *23%* |
| | Cultural | 1 | 2 | | 5 | 8 | *20%* |
| | **Total assessment per country** | **17** | **3** | **4** | **15** | **39** | **100%** |

savanna woodlands, and tropical rainforest totalling to about 3.6 million ha (Masiga et al., 2012). The main issues in the forestry sector are inadequacies in implementation of forest plans, legislation and policy, technical constraints, and inadequate financing of forest resource management. In Tanzania the main forest types include montane, miombo woodlands (Næsset et al., 2020), coastal mangrove, and tropical rainforest with a total area coverage of 35.2 million ha (Ntiyakunze and Stage, 2022), while the main challenges of the sector are forest degradation and deforestation, limited access to alternative source of energy, and poor forest governance. In Ethiopia the main forest types are Afromontane Forest (Kassun et al., 2024), dry Afromontane Forest, riparian forest, dry deciduous forest, and savanna woodlands forest. Total forest area is estimated at 13.6 million ha (Kassun et al., 2024) and the main challenges include population pressure on forest, land tenure issues, and inadequate financing (Kimengsi et al., 2022; Tebkew and Atinkut, 2022).

## 2.2 Data collection

Data search on evaluated forest ES categories and valuation methods was conducted on the Web of Knowledge/Clarivate database platform (https://www.webofscience.com) accessed in March 2023 (Yeung, 2023). The search function used key words "forest ecosystem services" to retrieve articles on relevant studies published from 2007 to 2023. A systematic review process was conducted using the Reporting standards for Systematic Evidence Syntheses [ROSES] (Haddaway et al., 2018) in three main phases: (1) search from database using key words, (2) screening process using established parameters, and (3) critical analysis of selected articles (Figure 1). Retrieved papers having key words in their abstracts or titles were restricted to display case studies from Kenya, Tanzania, Uganda, and Ethiopia. The exclusion parameters at the screening stage considered the availability of articles at full text and relevancy by checking titles, abstracts, and introduction sections. Articles with only the authors from region of interest or institutional affiliations without a case study from the study area were also excluded during the second phase. To determine suitability of the articles, further examination of the methodology and discussion sections was done at the critical analysis stage. The data was extracted from suitable articles and used to create a database for analysis of categories of ES assessed, methods and approaches of ecosystem valuation.

## 2.3 Classification of ES and valuation methods for analysis

We selected a total of 222 articles suitable for review i.e., 98 from Ethiopia, 82 from Kenya, 22 from Tanzania, and 20 from Uganda. Data were extracted from the 222 articles that satisfied ROSES criteria for analysis as shown in Figure 1. The ES were categorised using the MEA framework and the Common International Classification of Ecosystem Services [CICES] (Roy and Potschin, 2018). For CICES, the ES had a five-level structure as a reference: Section (e.g., Provisioning services), Division (e.g., biomass), Group (e.g., plants), Class (e.g., cultivated plants) and Class type (e.g., cereals). For the MEA framework (Grima et al., 2023) ES were classified as follows: (1) Provisioning services i.e., fibre, food, freshwater, genetic resources, and wood, (2) Regulatory services i.e., pollination, water purification, climate regulation and water regulation, (3) Supporting services i.e., nutrient cycling, primary production, and soil formation, (4) Cultural services i.e., spiritual, religious, ecotourism, inspirational, aesthetic, and cultural heritage benefits. The valuation methods and approaches (Markanday et al., 2024) were categorised using the following classification: (1) direct valuation methods i.e., revealed preference and stated preference and (2) indirect valuation approaches i.e., participatory approaches, modelling, and mapping as detailed in Figure 2 (Martin and Mazzotta, 2018; Acharya et al., 2019). We first made quantitative research which included count for every country on how many times different ES categories were assessed, and count on how many times a certain method for ES valuation was used. Secondly, we made a qualitative analysis on the results of the studies and presented the results of the analysis.

Numeric values resulted by counting the number of ES valuations/methods identified in the analysed papers and by classifying them as indicated above.

# 3 Results and discussions

## 3.1 Categories of ES that were subject to valuation

More than half of the articles analysed in this review assessed provisioning services as detailed in Figure 3. The ease at which provisioning ES are quantifiable and measurable prioritizes its assessment across most studies, when compared to other ES

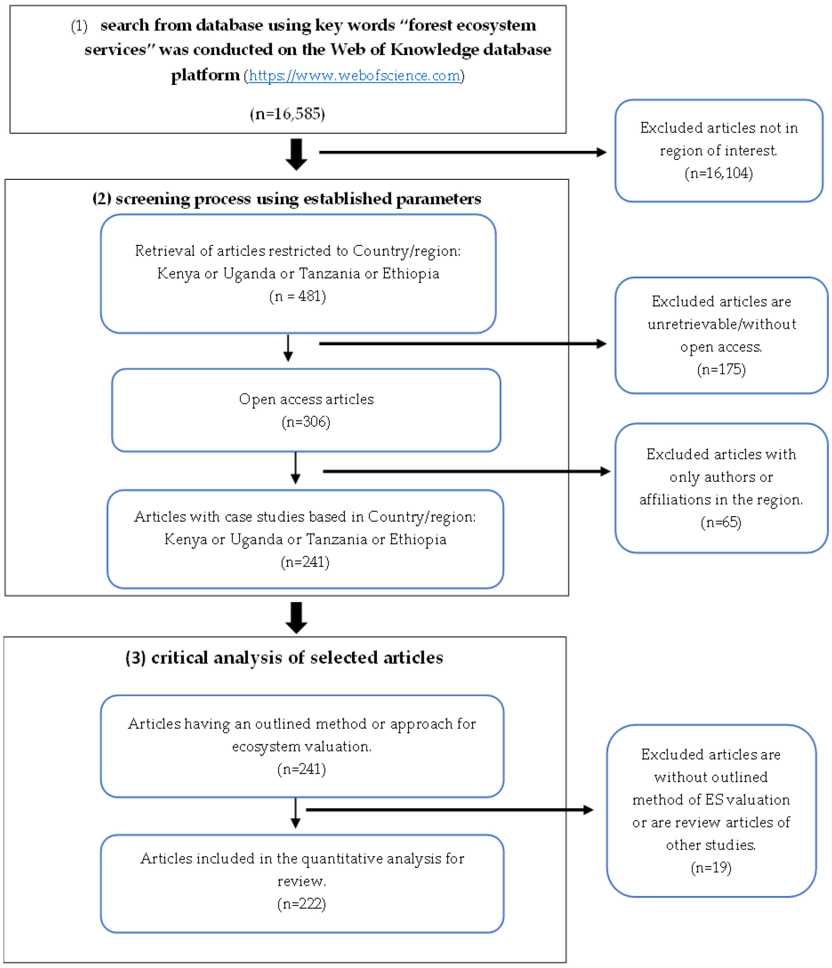


FIGURE 1
Conceptual framework using ROSES systematic review adapted from (Haddaway et al., 2018) systematic flowchart diagrams.

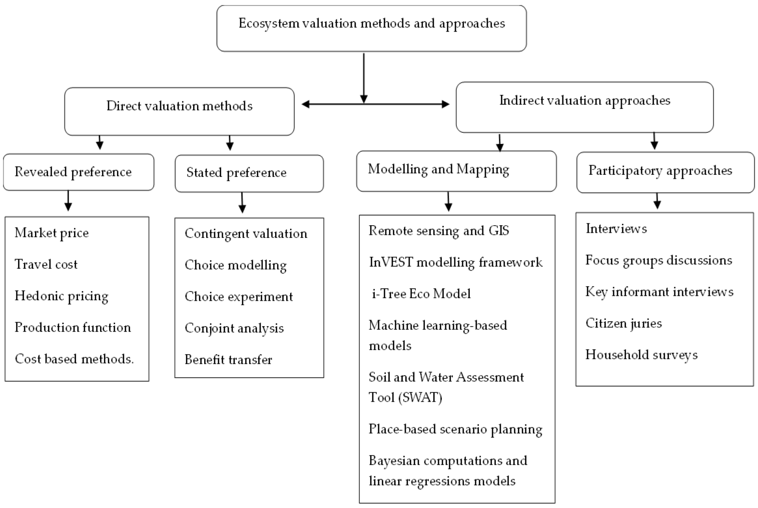


FIGURE 2
Classification model used for identifying ES valuation methods and approaches adapted from Acharya et al. (2019).

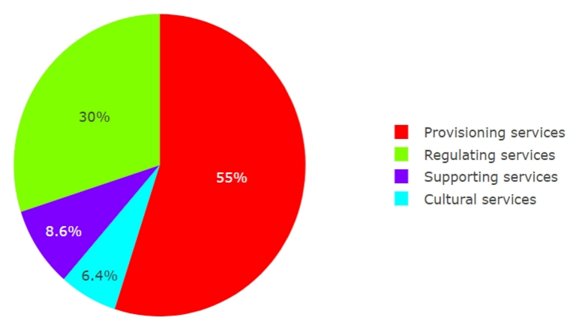


FIGURE 3
Detailing share of the ecosystem categories evaluated in East Africa.

categories as they are easily associated with tangible and marketable goods or services (Ajwang' Ondiek et al., 2016; Strauch et al., 2016). Impacts of changes in provision ES were more immediate and visible compared to other ES categories (Tamire et al., 2023).

The reliance on provisioning ES by forest adjacent communities in Africa (Egoh et al., 2012), Southeast Asia and South America has been cited as a major cause of ecosystem valuation studies prioritizing this category of ES for assessment (Quijas and Balvanera, 2013). For instance, the valuation of provisioning ES in India linked socio economic factors of households near the tropical dry forest of Vindhyan highlands to their income portfolios and established the significance of provisioning services to their livelihoods (Sharma et al., 2023). Similarly (Wangai et al., 2016), in a review of ES in Africa established that there were more studies focusing on provisioning services such as wood for fuel, a significant number of studies addressed regulating services such as carbon sequestration while fewer studies addressed supporting and cultural services in the context of the communities as opposed to singling out one of the commonly studied services like ecotourism (Samal and Dash, 2023). In contrast, the valuation studies in Europe (Fitter et al., 2010) revealed that ES without the ability to provide goods for conventional markets are usually undervalued, provisioning services such as biodiversity were only valued based on their ability to create marketable goods, while regulating services such as pollination were undervalued despite their linkage to marketable goods from agricultural production (Food Agriculture Organisation (FAO), 2016).

### 3.1.1 Provisioning services

East Africa heavily relies on agriculture and forests for food and to support informal livelihoods (Salami et al., 2010). The region's fertile soils, diverse climates, and suitable growing conditions support a wide range of crops, including staple foods like maize, sorghum, millet, and beans (Tittonell et al., 2010; Kansiime et al., 2018). Agriculture is a significant contributor to the economy and employment in East Africa, with millions of people involved in farming and related activities. Assessing food production helps understand the availability, accessibility, and sustainability of the region's food supply facing challenges like climate variability, market demands, policy restrictions etc (Midega et al., 2015). These challenges affect the wellbeing and livelihoods of the locals and exacerbates forest dependency, especially on provisioning ES. This comparative review revealed that all categories of provisioning ES were assessed in different studies, as shown in Table 1, with varying contribution to forest fringe community's livelihood and use.

In Kenya, 42% of the respondents in Mt Marsabit identified provisioning service like wood fuel and fodder for livestock as the most frequently used amongst other ES (Ouko et al., 2018). According to the respondents, anthropogenic activities like deforestation reduced supply of the provisioning ES to local forest communities. The research findings recommended long term engagement with the local community to initiate social learning processes that improve forest management practices. Similarly, in Uganda (Mawa et al., 2022) about 50% of the Budogo respondents identified wood fuel and raw materials like thatch material as the most frequently used for both subsistence and commercial purposes (Masiga et al., 2012). Mawa et al. (2022) revealed that participants in forest conservation groups had increased income derived from forest stands after two decades of management from USD 281 to USD 359. This was attributed to the allocation of agricultural use sections in forest plantation to participants who planted trees and gained income from the harvest. Another contributing factor was the involvement of participants in PES schemes in the region that promoted farm planting of trees with cash transactions for participating in the PES scheme (Aganyira et al., 2020). Further, the findings recommended that community involvement in forest management would significantly enhance the forest adjacent livelihoods and promote sustainable non-farm economic models with higher returns (Call et al., 2017).

In Rufiji (Tanzania) the respondents identified 67% of the provisional ES as the most important amongst other ES due to their direct market value and ease of accessibility (Nyangoko et al., 2022). Some of the prioritized provisioning ES include poles for building, wood fuel for cooking, and honey used as additive in tea. According to Nyangoko et al. (2022) some other provisioning services were identified but ranked lowly like traditional medicines, which were used in the past before the presence of health care centres offering modern medicines. In contrast to the findings in Mt Marsabit (Kenya), respondents in Rufiji identified fodder as an important provisional ES, but lowly ranked due to inland grazing (i.e., grasses and shrubs). In Ethiopia's Munessa-Shashemene forest (Furo et al., 2022), the provisioning ES identified as important included wood fuel, honey, construction poles and non-timber forest products that support household income. This overdependence on the forest resulted in forest degradation and deforestation (Duguma et al., 2019). Further, Girma et al. (2022) indicated that wood fuel contributed more to household income compared to other provisioning ES identified by the respondents, mainly attributed to the use of wood fuel in alcohol production within the study area. The policy recommendations of the study were to incentivize and subsidize strategies that increase agricultural income for the studied local communities (Abebaw et al., 2012).

### 3.1.2 Regulating services

Regulating services occurred as either final or intermediate benefit, and often supporting the delivery of other service categories (Kumar et al., 2010). In most of the economic valuation of ES, high consideration was given to services with a consumptive or productive function (Kieslich and Salles, 2021). Our findings revealed that water regulation, carbon storage and climate regulation had the highest percentage share in terms of assessments amongst the other regulating services (Table 1). These results reflect the general interest to assess deforestation rates and establish sustainable forest management within tropical forest ecosystems in developing countries (Rahman et al., 2017), because of their ability to sequester and store carbon, improve water quality and quantity, regulate floods and climate (Logsdon and Chaubey, 2013; Gould et al., 2024). Interest for regulating ES varies according to the spatial scale. For instance, in Kenya the implementation of a PES mechanism with the aim of equitable payment for watershed in reference to water quality as ES ensured up stream farmers managed their lands to control soil erosion, conservation of riparian lands by reforestation, reduce use of ago-chemicals, and use of grass strips to retain soil (Nyongesa et al., 2016). This improved the water quality downstream, and participants of the PES mechanism reported an improvement in soil fertility and increased crop productivity (Haile et al., 2019).

East Africa is the preferred destination for most of the carbon sequestration PES in Africa (Jindal et al., 2008; Lee et al., 2016). For instance, in Kibale (Uganda) (Cavanagh and Benjaminsen, 2014) the carbon sequestration PES has led to 1.2 million tons of carbon sequestered since inception (Omeja et al., 2011). The project totals about 6,500 ha of restored natural forest and has directly created 140 permanent jobs. Some of the PES schemes indirectly promoted regulation ES which was not the focus of the PES schemes. For instance, the PES scheme in Kenya (Khalifa et al., 2021) with the aim of incentivizing local communities to be involved in forest management by using commercial insects, led to increased abundance of pollinating bees which benefited the horticultural famers.

In Tanzania, Nyangoko et al. (2022) assessed ES in Rufiji Delta and established that 53% of the respondents identified three regulating ES that improved their well-being i.e., sediment trappings, coastal protection, and climate regulation. Further, Ntibona et al. (2022), revealed that respondent's insight on the value of mangrove forest protecting their villages coincided with coastal flooding due to overflow of River Rufiji. The respondents also identified rain formation as a contribution of mangrove forest, which provided suitable conditions for agricultural activities (Njana, 2020). Sediment trappings had the lowest score from rankings of the regulating ES, and this was attributed to its intangible value, which made it difficult to identify and rank. In Ethiopia, Mekuria et al. (2018) determined that changes in regulating ES occurred in communal grazing lands after the establishment of enclosures. The study revealed that all the enclosures displayed a higher ES than communal lands. Over a 30-year period, 246 Mg ha -1 of carbon was sequestered while the total soil nitrogen increased by 7.9 Mg ha -1. The net ES value of the enclosures was 28% more than alternative wheat production. This highlighted how enclosures were a better competitive alternative land use than communal lands (Mekuria et al., 2018; Kleinschroth et al., 2021).

### 3.1.3 Supporting services

The valuation of supporting ES was limited due to a lack of consensus in the definition of terms when the intermediate benefits were assessed (Khan, 2020). In this review, supporting services were the least assessed category at 6.42%. Moreover, only three services resulted from this meta-analysis of ES valuation i.e., habitat at 62%, nutrient cycling at 21% and soil formation at 17% (Table 1). Similarly, a study on the global perspective of ecosystem classification by Notte et al. (2017) established that some studies opted to exclude the economic valuation of support services because of the difficulty in finding a valuation technique which distinguishes between intermediate services and final benefits (Boerema et al., 2017). Further, some services such as soil formation often require a much longer time frame for proper assessment, while others, like nutrient cycling, must be evaluated while considering underlying ecological systems which pose a potential for duplicity in evaluation (Khan, 2020; Kadykalo et al., 2021; Ingram et al., 2023).

Provision of ES is dependent on the state and maintenance of habitats which form the grounds for most biological interactions between organisms (Rajpar, 2018). For instance, the ecosystem accounting study in Uganda by UNEP revealed that protected wildlife habitats prevented loss of natural ecosystem benefits and had a higher diversity index compared to degraded habitats (King and Obst, 2017). Similarly, the mangrove ecosystems along the coast of Kenya and Tanzania have also been credited for harbouring different species of crabs, which recycle nutrients by feeding on detritus that provide a food source for other marine species (Theuerkauff et al., 2018; Kimeli et al., 2021; Naidoo, 2023). In Ethiopia (Fashing et al., 2022), the isolated Afromontane regions exhibited higher levels of biodiversity and ecosystem services compared to the explored sections in the lowlands which consequently exhibited lower quality of ecosystem services (Mengist et al., 2022). Therefore, the quality of support ES which often stems from high species diversity relies on habitat status (Durán et al., 2020).

### 3.1.4 Cultural services

East Africa is one of the leading tourist destinations in the African continent, with a diverse portfolio ranging from clear sandy beaches, wildlife safaris and cultural tourism (Okello and Novelli, 2014; Gogo and Masaki, 2022). This review established that ecotourism ranked highest at 44% amongst all the other cultural services i.e., recreational at 23%, cultural practices at 20% and spiritual services at 13%. Results in Table 1 shows that nearly half of the ecotourism assessments were done in Kenya. Reports by the Kenya Tourism Board indicate that the country had over 2 million visitors pre-COVID-19 and 1.5 million of them were non-resident who primarily visited for holiday and ecotourism purposes, which directly contributed over USD 5 billion to the country's GDP (Tourism Research Institute (TRI), 2023). Moreover, the tourism performance increased by 70.45% post -COVID-19 which registered a growth of 83% according to the annual report by Tourism Research Institute (Ministry of Tourism, 2022; Tourism Research Institute (TRI), 2023).

In terms of cultural tourism, both Kenya and Tanzania have the Maasai tribe who live in the border-region and are nomadic between the Maasai-Mara National Reserve and Serengeti National Park (Snyder and Sulle, 2011; Brinks, 2016). The unique cultural niche offered by the Maasai is their preservation of indigenous way of life i.e., beliefs system, arts, food, and customs (Ngaruiya, 2015; Oduor, 2020). Uganda has remnants of the Baganda Kingdom and Kabaka palaces, which offer a perspective on the indigenous cultural practices of the Baganda people (Kasfir, 2020). However, there is still heavy reliance on wildlife-based tourism since Uganda is landlocked and prioritizes marketing its national parks since touristic earnings from them account for approximately 9% of the national GDP (Ayorekire et al., 2019). Similarly, Tanzania's tourism sector contributes about 10.7% to the national GDP (Kweka et al., 2003).

Ethiopia exhibited a diverse portfolio of cultural services: studies frequently assessed the spiritual and recreational sites such as the churches of Lalibela, the site of true Holy Cross of Christ, Ethiopian Tewahedo Orthodox churches (Gessese et al., 2021) and Tiya stones (Karbo, 2013). Moreover, the county has a religious history as amongst the oldest to accept Christianity and Islam (Aerts et al., 2016). However, the country's tourism sector underperforms (Ali, 2016) when compared to countries like Tanzania and Kenya, resulting from touristic preference towards game drives and beaches as well as low marketing campaign to attract tourist from the relevant authorities (Norton, 1996; O'Halloran, 2016).

## 3.2 Methods and approaches of ES valuation in East Africa

Both the direct valuation methods and indirect approaches (Markanday et al., 2024) were applied in the studies reviewed, and the valuation methods depended on the ES identified and prioritized in each of the East African countries as detailed in Table 2. Amongst the direct ES valuation methods used, the market price approach under revealed preference category and contingent valuation method (CMV) under the stated preference category were preferred (Stenger et al., 2009; Acharya et al., 2019). For the indirect ES valuation approaches, interviews were preferred under the category of participatory approaches. Further, a variety of modelling and mapping approaches were used for ES assessment with Geographic Information Systems (GIS), Light Detection and Ranging (LiDAR) having more preference.

### 3.2.1 Direct valuation methods

The production function approach under revealed preference category was used to assess supporting ES primarily associated with agricultural production i.e., soil fertility, nutrient cycling, and soil organic matter (Bekunda et al., 2005). Regionally, the African Development Bank (Salami et al., 2010) reported agriculture as one of the main economic activities in the East African region, primarily done by small holder farmers who occupied farmlands adjacent to forest ecosystems (Gelgo et al., 2023; Birkhofer et al., 2024). Further, the International Food Policy Research Institute affirms that agriculture contributes an average of 30% to the GDP of Kenya, Tanzania, Uganda, and Madagascar (Waithaka et al., 2013; Tambo et al., 2023). In Kenya, the land degradation surveillance network established indicators of productivity in Sasumua catchment and its capacity to deliver ES to the local farmers (Kyei, 2017). Similarly, sample plots in Usambara Mountains (Tanzania) determined the productivity of farms using soil organic carbon as an indicator. The studies enabled the improvement of crop productivity to small holder farmers (Winowiecki et al., 2016).

The rural communities in this review demonstrated overwhelming dependence on provisioning ES products such as wood fuel and raw materials (Miller et al., 2021). In Uganda, assessment on forest stock and household fuel choice established that the likelihood using biofuel significantly increased for households in rural areas near large forest stocks (Gebru and Elofsson, 2023). For wood and raw products, market price approaches determined demand and supply of wood fuels and the priority areas of wood energy use in Eastern Africa i.e., Rwanda, Kenya, Tanzania, Uganda, Egypt, Burundi, and DR Congo (Sulaiman et al., 2017). The study established a nexus between the use of wood fuels under the prevailing socioeconomic conditions within the region and suggested effective points of intervention (Drigo, 2005). Similarly, market price approaches were used to assess regulatory ES of two different catchment areas in Kenya (Elgeyo and Nyambane), and their estimated value was over USD 480 million (Eregae et al., 2022).

For cultural ES, the ecotourism and recreational value of Maasai Mara National Park in Kenya was estimated to be over US$ 70 million (Mulwa et al., 2018) per year, using the individual travel cost methods derived from modelling the visitor data logs and entrance fees (Márquez et al., 2023). Abdeta (2022) used a contingent valuation method (CVM) to assess household willingness to pay (WTP) for the conservation of spiritual and recreational values of forest sites in Ethiopia (Ramdas and Mohamed, 2014). The findings indicated that demographic and socio-economic factors influenced perceived ES benefits and highlighted the need for public participation to improve management of forest resources. Similarly, stated preference methods such as CVM were used estimate the WTP for the cultural ES in Wof-Washa Forest in Ethiopia (Getachew, 2018).

### 3.2.2 Indirect valuation methods

The global demand for accurate, verifiable, and cost-efficient forest inventory data, especially for the vast and unexplored tropical ecosystems in Africa, South America and Southeast Asia led to the adoption of the recent advancements in forest management i.e., use of satellites, drones, LiDAR, and GIS (Mitchell and Schaab, 2008; Tang and Shao, 2015; Li et al., 2019). This assisted to bridge conventional ecosystem management methods with remote sensing and GIS applications (Baban and Niţă, 2022; Diallo et al., 2024) in forest ecosystem valuation. Different studies (Breugel et al., 2011; Rodríguez-Veiga et al., 2017; Vorster et al., 2020) indicate a demand for accurate forest biomass data because of its significance in the estimation of carbon (Araujo Barbosa et al., 2015). Remote sensing techniques and GIS application were primarily used for the valuation of provisioning ES (Araujo Barbosa et al., 2015; Negese, 2024). In Eastern Africa, regulatory ES i.e., climate and weather

TABLE 2 Summary of methods and approaches of ecosystem valuation in East Africa.

| Methods/Approaches used in ecosystem valuation | Frequency count of methods used in case studies per country | | | | Total number in East Africa | Share (%) |
|---|---|---|---|---|---|---|
| | Kenya | Uganda | Tanzania | Ethiopia | | |
| Benefit transfer method | 1 | – | 2 | 5 | 8 | *2.3%* |
| Remote sensing, GIS, and LiDAR | 11 | 3 | 7 | 30 | 51 | *14.7%* |
| Interviews | 6 | 6 | 13 | 16 | 41 | *11.8%* |
| Focus group discussions | 7 | 4 | 10 | 17 | 38 | *10.9%* |
| Household surveys | 10 | 8 | 5 | 11 | 34 | *9.8%* |
| Travel cost method | 16 | 4 | 7 | 9 | 36 | *10.4%* |
| Sentinel pest experiment | 1 | – | – | – | 1 | *0.3%* |
| Conjoint analysis | 8 | – | 2 | 11 | 21 | *6.1%* |
| InVEST modelling framework | 2 | – | – | 3 | 5 | *1.4%* |
| Market price approach | 14 | 9 | 11 | 18 | 52 | *14.9%* |
| Contingent Valuation Method (CMV) | 5 | – | 3 | 7 | 15 | *4.3%* |
| i-Tree Eco Model | – | – | 1 | 1 | 2 | *0.6%* |
| CA-Markovian prediction model | – | 1 | – | – | 1 | *0.3%* |
| Production function approach | 2 | – | 1 | 1 | 4 | *1.1%* |
| Hedonic pricing | 3 | – | 2 | 4 | 9 | *2.6%* |
| Choice modelling | – | 1 | 1 | – | 2 | *0.6%* |
| SEBAL model, utilizing Monteith's framework for ecological production. | – | – | 1 | – | 1 | *0.3%* |
| Soil and Water Assessment Tool (SWAT) | 1 | – | 1 | 1 | 3 | *0.9%* |
| Place-based scenario planning | 1 | – | – | 1 | 2 | *0.6%* |
| Bayesian computations and linear regressions | 3 | – | 4 | 9 | 16 | *4.6%* |
| Machine learning-based models | 1 | 1 | – | – | 2 | *0.6%* |
| Land Degradation Surveillance Framework (LDSF) | 1 | 1 | – | 1 | 3 | *0.9%* |
| **Total number of assessment methods** | | | | | **347** | **100%** |

variability too, were assessed to determine effect on agricultural output using remote sensed data from the period 1961 to 2016 (Luc et al., 2021).

The valuation of the provisioning ES in Central Ethiopia, Biratu et al. (2022) highly relied on spatial data derived from remote sensing techniques to get an estimate of the total ecosystem valuation for the timeframe 1986–2021. Similarly, remote-sensing and GIS approaches provided crucial data on water supply, which was used in the quantification of livelihood dependency of communities along the Omo River in Turkana Basin at the boarder of Kenya and Ethiopia (Kleinschroth et al., 2021). The data were crucial for the assessment of changes in ES benefits along River Omo Basin (Yigezu et al., 2018; Anose et al., 2021) and its implications on the culture of nomadic people in that region. The rise of interest in biomass and carbon storage estimates were incentivized by mechanisms such as REDD+ and carbon credit systems for developing countries (Scharlemann et al., 2010; Parrotta et al., 2012; Thangata and Hildebrand, 2012). For instance, USD 100 billion was pledged in the Africa Climate Summit towards climate adaptation on the continent (African Union (AU), 2023). In contrast, the priorities of the European countries towards quantification carbon are to reduce GHG emissions and reduce dependence on fossil fuels (Siddi, 2020; Allam et al., 2022). Further, the European Green Deal (Vela Almeida et al., 2023; Popielak et al., 2024) centres on assisting EU countries to become carbon neutral (European Union (EU), 2021).

The participatory approaches identified in this review (Langan et al., 2018; Ketema et al., 2021; Daw et al., 2023) i.e., interviews, focus groups discussions, and household surveys gave an overall perspective on the value attributed to the regulating ES. In the context of ES valuation, it was particularly important when assessing WTP for non-market ES i.e., temperature and coastal protection (Comte et al., 2016). In Kenya, interviews with open-ended questionnaires were the preferred method to assess and quantify the full value of ES benefits to livelihood of forest adjacent communities in Maasai Mau (Koech et al., 2009). Similarly, a series of household surveys and interviews in Uganda (Bush et al., 2005) were used to estimate the value of tropical high forest in protected areas to the livelihoods of communities surrounding them and determine contribution of the non-market ecosystem services to the GDP. This approach recognised the values communities hold, their priority towards ecosystem services and offered a more informed perspective for decision makers (Mawa et al., 2023).

For cultural ES, participatory approaches such as interviews, focus group discussions and household surveys (Waruingi et al., 2021; Masselus and Fiala, 2024) highlight the effectiveness of non-monetary approaches in evaluating perception of non-market values of ES such as culture and recreational benefits (Zeppel, 2007; Márquez et al., 2023). In Kenya, Wangai et al. (2017) used household surveys to determine cultural ES indicators of well-being within the peri-urban areas of Nairobi and to develop suitable ES response models. Similarly, Mwakaje et al. (2013) used data from key informants and focus group discussions to assess the perceived cultural ES benefits from respondents living in Northern Tanzania on the value associated with living near the Serengeti National Park (Zeng et al., 2023).

In many cases, ES valuation required a combination of different methods. For instance, cultural ES exhibited a diverse portfolio of services and perceived values amongst the 4 countries assessed, the variations necessitated application of two different techniques for valuation i.e., ecotourism evaluated using travel cost method in Kenya, Tanzania and Uganda, while spiritual values evaluated using participatory approaches in Ethiopia (Okello and Novelli, 2014). Moreover, this review has shed light on inequities inherent in carbon trading within PES schemes, in the payment for watershed with reference to water quality and the appreciation of genetic resources. Practitioners are better equipped to navigate the multifaceted challenges present in PES by incorporating integrated valuation methods that work towards implementing more equitable and sustainable PES mechanisms addressing various environmental and socio-economic concerns effectively. Our findings demonstrate how different regions prioritize ES benefits and inform further studies on temporal and contextual shifts in ES valuations. Moreover, the findings illustrate effective strategies for practitioners conducting ES valuation at country level and regional level.

## 4 Conclusions

Despite the fact that this study was limited to Kenya, Uganda, Tanzania and Ethiopia within the East African region and the data was exclusively obtained from open access indexed journals in the ISI Web of science platform, our analysis revealed a series of conclusions that are useful for further ES valuation research.

Provisioning services were the most assessed ES category amongst all the 4 countries. Their direct linkage to livelihoods necessitated relevance and priority in valuation because changes and impacts were more immediate and visible compared to other categories. Another contributing factor was the linkage between perceived benefits from tangible goods and motivation of communities to understand aspects of availability in quantity for ES goods like food, raw materials, and water. ES categories like regulating services were mainly linked to the rising interest in carbon sequestration and storage. The least evaluated ES was the supporting services, which were often intermediate and indistinguishable from final ES benefits. This indicated a gap in methodologies tailored specifically for evaluating supporting ES, highlighting the need for adaptable valuation techniques that can accommodate varying temporal and ecological complexities.

In the context of ES benefiting communities, provisioning ES were assessed using market price approaches in all the 4 countries and production function approaches only in Kenya, Tanzania and Ethiopia because of the direct reliance on tangible ES goods i.e., wood, cultivated plants and raw materials. Remote sensing and GIS applications in forestry were the most preferred method in Kenya and Ethiopia for modelling and mapping because of the available technological know-how, factors of cost and time efficiency in assessment of often large and remote tropical forest ecosystems. Participatory approaches such as interviews, household surveys and focus groups were extensively used in all the 4 countries which gave a perspective on the utility priorities that communities attach to the various ES. This reiterates the long-term benefits of community involvement in improving quality ES.

## Author contributions

EOO: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. BP: Formal analysis, Methodology, Supervision, Validation, Writing – review & editing. HV: Data curation, Methodology, Validation, Writing – review & editing. IO: Visualization, Writing – review & editing. IVA: Funding acquisition, Project administration, Resources, Supervision, Validation, Writing – review & editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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