Land use/land cover dynamics, trade-offs and implications on tropical inland shallow lakes’ ecosystems’ management: Case of Lake Malombe, Malawi

Rodgers Makwinja a,b, Seyoum Mengistou b, Emmanuel Kaunda c and Tena Alamirew d

* African Center of Excellence for Water Management, College of Natural and Computational Science, Addis Ababa University, P.O.Box 1176, Addis Ababa, Ethiopia; Ministry of Forestry and Natural Resources, Department of Fisheries, Senga Bay Fisheries Research Center, P.O.Box 316, Salima, Malawi; African Center of Excellence in Aquaculture and Fisheries (AquAfish), Department of Fisheries Science, Lilongwe University of Agriculture and Natural Resources, P.O.Box 219, Lilongwe, Malawi; Water and Land Resource Centre of Addis Ababa University, P.O. Box 3880, Addis Ababa, Ethiopia

ABSTRACT

Lake Malombe supports various ecosystem services (ESs). However, it is increasingly experiencing human-induced pressure. This study used geospatial, household surveys, focus group discussion, key informant interviews, consultative meetings, and field observation on assessing the Land use/Land cover dynamics (LULCD), its trade-offs, and implications on ESs. The findings demonstrated a decrease in forest land (52,932 ha to 78,983 ha) at the expense of cultivated (52,932 ha to 78,983 ha) and settlements (7054 ha to 17,595 ha). Changes in ecological indicators such as fishery, river flow, soil erosion, turbidity, biodiversity, invasion of alien species, scenic beauty, extinction of some species, frequent flooding, cultural value, and carbon sequestration were significantly (p<0.05) linked to some LULCD classes. The study findings are significant to policymakers, ecosystem managers, the local population, and various stakeholders in understanding conflicting interests and policy priorities to balance the lake ecological restoration and human welfare.

Introduction

Tropical inland shallow lakes’ catchments support diverse ESs such as regulatory, purification, supporting, provisioning, culture, and aesthetic services (Guo et al., 2019; Aneseyee et al., 2020; Makwinja et al., 2021a). Regulatory services are crucial in maintaining a world where people can live and control the adverse effects of floods, disasters, and diseases (Mengist et al., 2020). Terrestrial, marine, and freshwater ecosystems sink anthropogenic carbon emissions, with gross sequestration of 5.6 gigatons of carbon per year (IPBES, 2018). An estimated 4 billion people rely primarily on ecosystem provisioning services (EPSs) as a source of natural medicines (Brockerhoff et al., 2013). More than 2 billion people rely on wood fuel to meet their primary energy needs (Van Der Kroon, et al., 2013). Rural and urban populations in the least developed countries depend on EPSs for their sustenance (Plisnier et al., 2018). In Africa, meeting local food production demands is highly linked to the vast expansion of agricultural lands at the expense of natural forests and grasslands (Ngaruiya, et al., 2017; Roser & Ritchie, 2019; Shehab et al., 2021; Watson et al., 2019). With the rapid population explosion and the ongoing socio-economic activities, landscape alterations in Africa have been expected. Catchment degradation due to the vast expansion of settlements, and agricultural production instigated by high rate (2.3%) of human population growth, progressively ground cover removal, socio-economic development, and climate change has been linked to ESs erosion, particularly in tropical inland shallow lakes (Aneseyee et al., 2020; Davivongs et al., 2012; Ewunet et al., 2021; Gondwe et al., 2019; Nkwanda et al., 2021; NSO, 2018; Seuloali & Beckedahl, 2015). Many researchers such as Lambin and Geist (2006), Sharma et al. (2011), and Makwinja et al. (2014) have also acknowledged that LULCDs affect ES functioning and human livelihoods through a reduction in water supply, reservoir storage capacity, agricultural productivity, and world-ecology. Vallet et al. (2018) also documented that a high rate of land conversion to satisfy the demand for food production has increased pressure on ESs. About 55% of tropical forest in Africa has been lost to agriculture, and this trend is typified in the SADC region’s inland shallow lakes—characterized by rapid population growth (Keohoe et al., 2017).
In Malawi, landscape transformation has become the emergent trend, particularly in inland tropical shallow lakes driven by rapid population growth, climate change, and environmental degradation (Kosamu et al., 2017; Makwinja et al., 2019; Njaya, 2009). Malawi is ranked as one of the countries in the SADC region experiencing forest loss, with estimates show that about 30,000–40,000 hectares of land are lost annually due to increased agricultural activities and excessive wood and charcoal biomass consumption (Ngwira & Watanabe, 2019; Nkwanda et al., 2021). Over 90% of the population predominately depends on farming for their livelihood (Chingala et al., 2017; Kaland-Joshua et al., 2011). The shallow lake catchments are continuously invaded and transformed into agricultural land as the farming activities intensify, even the areas designated as buffer zones with ecological consequences such as habitat alteration, increased landscape degradation, severe soil erosion, heavy loss of ecological functions, and drastic decrease in the lake ecosystem productivity (Jamu et al., 2003; Kafumbata et al., 2014; Makwinja et al., 2021a; Ratner et al., 2012). Climate-related disasters such as prolonged drought and seasonal floods further stress the lake ecosystem, triggering landscape degradation (Likoya, 2019; Makwinja & M’balaka, 2017; Robledo et al., 2012). With a least Human Development Index of 0.4726, Malawi is experiencing unprecedented freshwater ecosystem loss (Pullanikkatil et al., 2018), and future projection indicates the worst (Cacho et al., 2020; GoM, 2016; Lorena, 2018). Currently, acute food shortages have become chronic among the rural population, which is worrisome as far as the local population’s sustenance is concerned (Ellis et al., 2003; FISH, 2015; Froese et al., 2016; MacPherson et al., 2012; Makwinja et al., 2021c; Mueller & Geist, 2016; Njaya, 2007). Lake Malombe provides the best example, with many studies pointing towards increased local population exposure to vulnerability and catastrophic decline in the lake ecosystem productivity (Dulanya et al., 2014; FISH, 2015; Jamu et al., 2011; Kapute, 2018; Makwinja et al., 2021a). The concept of landscape management, associated trade-offs, and implications under the changing catchment, mainly in the inland shallow lakes such as Lake Chilwa, Lake Malombe, Lake Chiuuta, has not been adequately discussed (Mendham et al., 2012). Much of the studies in these lakes have focused on the fishery, ecology, rural livelihoods, stock assessment, co-management, and governance (Dulanya et al., 2014; Hara, 2006; Hara & Njaya, 2016; Makwinja et al., 2021a; Tweddie et al., 2015).

There is generally insufficient data regarding the extent to which the landscape of these lakes has been transformed, their associated trade-offs, and their ESs implications. Therefore, the overall objective of this study is to assess the intensification of landscape transformation in the tropical freshwater shallow lakes’ catchment, the potential trade-offs, and the implications citing Lake Malombe in Southern Malawi as a case study representing scenarios in other inland shallow lakes in Malawi and Africa. Specifically, the study was conducted to answer the following research questions: (i) To what extent has the Lake Malombe landscape been transformed over the past years? (ii) What are the potential trade-offs and opportunity costs associated with such landscape transformation? (iii) What are the potential lake ESs implications linked to such transformation?

Materials and methods

Description of the study area

The study was conducted in Lake Malombe catchment located between 14°21’ to 14°45’ south and 35°10’ to 35°20’ east in southern Malawi (Makwinja et al., 2021b) (Figure 1).

It is connected to the Lake Malawi South East Arm through the 19 km stretch of the Shire River basin-an outlet of Lake Malawi (FISH, 2015). Lake Malombe lies entirely within the Great African Rift Valley complex and is characterized by a series of major and minor faults. It has a high productive catchment dominated by calcimorphic soils, which occur along the rift valley floor. Typical calcimorphic soils include mopanosols, dark grey, sandy-clay soils with low permeability, and alluvial soils, grey to brown (Government of Malawi, 2014). The eastern part of the catchment has a low risk of soil erosion as it is partially protected by the forest reserve and Liwonde National Park. The western part is deforested and is prone to soil erosion. Lake Malombe is fed by water from Lake Malawi via a stretch of the Upper Shire River and shares the same aquatic ecology with Lake Malawi, including a high level of fish biodiversity, genetic plasticity, and endemism (FISH, 2015). Limnologically, Lake Malombe is a shallow, turbid, and nutrient-rich lake with shelving vegetated shores compared to Lake Malawi (Makwinja et al., 2021d). The lake is highly productive because of the water column, which mixes freely, recycling the bottom nutrients. Although the current trend indicates otherwise, the lake once produced 17% (15,00 tons) of Malawi’s total fish biomass landings in the 1980s (Njaya, 2007).
**Data collection process**

Primary data were collected using a combination of participatory and formal procedures. The structured household questionnaire was used to capture various information relevant to the research objective. The household survey questionnaire consisted of three sections: the first section captured direct and indirect ESs. The second section captured the general information about access and use of lake ESs, and the third section asked for detailed information about each ESs’ changes, impact, vulnerability, and coping strategies. The household survey adopted the cluster sampling technique. The three traditional authorities (Chowe, Mponda, Chimwala) were delineated into clusters (the group village headmen). The 30 × 12 clusters model was used as a guiding principle (Makwinja et al., 2021c). A total of twelve clusters was chosen based on their proximity to the lake. In addition, six university graduates coordinated face-to-face interviews at the respondents’ houses or the fish landing sites. The required sample size was calculated using a simple population proportion formula to assume that the study area’s population had unknown proportions and was assumed to be heterogeneous (i.e. 50/50 split).

\[
n_r = P(1 - P) \left( \frac{Z}{E} \right)^2
\]

(1)

Where \( n_r \) = sample size and \( z \) = value from the standard normal distribution reflecting the confidence level (\( z = 1.96 \) for 95% level of confidence) of unknown population proportion (p). The \( p = 0.5 \) value was used (assuming maximum heterogeneity), \( E \) is a margin of error. The margin of error (\( E = 0.0425 \)) was used to calculate a statistically representative sample of 533. Traditional authorities Chowe, Chimwala, and Mponda, had 45, 39, and 16% of the sample size, respectively. The intensive household survey was complemented by twelve focus group discussions (FGDs), direct field observation, consultative meetings, and in-depth key informant interviews. The consultative meetings were conducted with Mangochi District Environmental Office, District Agriculture Development Office, District Forest Office, District Water Office, District Disaster Risk Management Office, District Director of Development and Planning Office, District Fisheries Office, and the Liwonde National Park Office. Following the discussion from the diverse stakeholders, important lake ESs were ranked based on (i) ability to meet the local population’s basic needs and (iii) the likelihood of obtaining enough quality data on the ESs for computation. The Focus group discussion (FGDs) explored a greater depth of ESs dynamics using a community as a unit of analysis. When conducting FGDs, questions were presented as guidelines for discussion using four participatory research tools: resource mapping, institutional analysis, cause-effect analysis, and well-being analysis. The FGDs were conducted along with household surveys and in-depth key informant interviews. To facilitate openness, women and men formed separate groups. Each group had an average of 10 people. The FGDs involved fishers,
crew members, farmers, fish processors, natural resource governance leaders, traders, and traditional leaders in all villages. All groups consisted of residents and migrants of all gender groups, including women, men, and youths.

The FGD was complemented with direct field observation. The rationale behind direct field observation was observing livelihood strategies, socio-economic activities, governance issues, culture, and customs. Direct field observation provided rich data set through an interpretive approach to people’s socio-economic reality and subjective meanings by eliciting and observing what ES is essential to them. The researcher gathered the evidence during the field observation while interpreting the local communities’ interpretations of the ESs. Direct observation in the Lake Malombe catchment was done from September to November 2019. Lake Malombe West is the central hub of fishing activities with a high level of migration and mobility. The upper catchment about 19 km away from Lake Malombe is Mangochi Town. The local communities first misinterpreted the researcher as a trader, and many households came to present their various products derived from the lake ecosystem, such as fish, woven craft, fruits, and birds. After some weeks, the researcher could interact with the communities, and the field observation began. The researcher inquired about the diverse ESs derived from the lake, trade-offs, social networks, governance issues, culture, and customs. This was achieved by walking every morning and evening to various fish landing sites, markets, upland areas, and the lake catchment to observe various economic activities in the study area. The researcher also engaged 30 key informants residing in the lake catchment. The in-depth key informant interviews were conducted after seeking consent from the respondents. The key informants were selected based on their experience of ecosystem dynamics and the duration of residing in the catchment. Preferably those who stayed for more than 50 years were selected. A snowball sampling technique was used in choosing informants, where each informant was used to identify one or two other possible informants through networks. The number of key informants increased after adding each informant until the sample size grew with each subsequent interview and eventually became saturated where no significant new information was gathered. Interviews were chosen for their relevance to the conceptual questions rather than their representativeness.

**Satellite images pre-processing and land use classification**

The Landsat TM images (covering Landsat 5, 7, and 8) of LULC of 1989, 1999, 2009, and 2019 were produced from spectral Landsat imagery with a spatial resolution of 30 m retrieved from the United States Geological Survey Website (USGS, http://glovis.usgs.gov/) using Worldwide Reference System Path 29 and Row 32. Seasonal errors were reduced by selecting the images with similar calendar dates. The four bands (band 2, 3, 4, and 5) combinations were considered for image classification. A minimum of 10–30 band cases per class was used to train and validate pixels from TM imagery. Approximately 200 representative training pixels for all classes were selected based on stratified random sampling for 1989, 1999, 2009, and 2019 images. A separate dataset of approximately 180 points and a ground truth classified image were collected to assess generated prediction maps.

**Landsat image interpretation**

The atmospheric correction was not required for image classification of the same calendar date because it is the same as subtracting a constant from all pixels in a spectral band. The Landsat TM imagery was obtained at Level 1 T and was already geometrically corrected and orthorectified. The Landsat TM imagery was imported into the ENVI 5.4 software. The image georeferencing accuracy was checked with a reference map of the study area accessed from the Malawi Department of Survey. All the input images had the same map and projection data with the same number of layers. After layer stacking, sub-setting was performed to get a portion of a large image file into one smaller file to reduce the image file size, focus the region of interest, and speed up the processing time. The exact number of bands (Band 2, 3, 4, and 5) were used for classification in all cases to minimize the biases caused by different band combinations. The training and validation data during optimization were generated using polygon vectors designed for each land-cover type. Supervised training-based region of interest mapping was used for selecting land cover types, and five classes (Table 1) were determined from 1989, 1999, 2009, and 2019 Landsat imagery.

ArcGIS software version 10.7.1 was used to compute LULC change-traditional matrix using overlay procedure to quantify the area converted from a particular LULC class to another LULC category during the study period. The annual rate of change was determined as shown in the equation below.
Table 1. Description of land-use/land cover categories

| LULC types        | Descriptions                                                                 |
|-------------------|-------------------------------------------------------------------------------|
| Cultivated land   | Agricultural production areas, including areas prepared for cultivation, covered by crops, are practiced subsistence or commercial farming or grazing land during the dry season or rice scheme. Crop production includes maize widely adapted in both highland and lowlands, and it is a staple food, rice, and vegetables dominated in the lowland areas of Lake Malombe, beans, cotton, and groundnuts in the upland. |
| Forestry land      | Areas with tall trees above 20 m or fewer shrubs with no undergrowth. Mangochi district has five gazette forest reserves dominated by miombo woodlands tree species and Palms. The Palm Forest reserve is dominated by *hyphe petersoniana* (gwalangwa) and some valuable tree species such as (mbaawa) *Khaya anthotheca* (Mlombwa), *Pterocarpus angolensis* (Ngwenya), *Adina microcephala*, and (tsanya) *Colophospermum mopane*. Bare rock and coarse fragments. Areas that do not have an artificial cover as a result of human activities. These areas include areas with less than 4% vegetative cover. |
| Bare land/shrubs, grassland | Bare land/shrubs, grassland include areas that do not have an artificial cover as a result of anthropogenic activities, have shrubs and permanent or seasonal grass. |
| Build upland      | These include areas used for settlements, permanent concentration buildings, and human-made structures and activities, ranging from large villages to town scale. |
| Marshes           | This is an area dominated by herboaceous rather than woody plant species. The marshes are typically found at the edges of the lakes and streams, forming a transition between aquatic and terrestrial ecosystems. Grasses, reeds, and rushes mostly dominate them. |
| Water bodies      | Water bodies include permanent lakes, rivers, streams, seasonal or permanent wetland, intermittent pools, perennial marshy and human-made dams. |

\[
r = \left( \frac{1}{t^2 - t^1} \right) \times \ln \left( \frac{S_2}{S_1} \right) \tag{2}
\]

Where \( r \) is the annual rate of change for each class, \( S_1 \) and \( S_2 \) are areas of each LULC class at a time \( t^1 \) and \( t^2 \) respectively.

**Normalized difference vegetation index**

The Normalized Difference Vegetation Index (NDVI) was used to assess the presence of green vegetation and was computed as follows:

\[
NDVI = \frac{NIR - RED}{NIR + RED}
\]

\[
NIR = \text{Near infrared, RED = Redband}
\]

NDVI values ranged from −1 to 1 means the higher the NDVI value, the higher the fraction of green vegetation present in the area. Landsat band 4 (0.8–9.94 mm) measured the reflectance in the NIR region, and Band 3 (0.63–0.69 mm) measured the reflectance in the Red region. However, for Landsat 8, the NIR and Red regions had different wavelength ranges. Therefore, they were computed using bands 4 and 5 for Red and NIR, respectively, which resulted in values ranging from 0–200 and fit within an 8-bit structure. The green color showed the presence of vegetation, and other colors show the absence of green vegetation. These attributes help classify the images.

**Maximum likelihood (ML) classification**

This study used the maximum likelihood classification algorithm for image classification because it considers the class signature’s variances and covariances when assigning each cell to one of the classes represented in the signature file. The algorithm used by the ML tool is based on Baye’s theorem of decision making, where cells in each class sample in the multidimensional space are normally distributed. In this study, a class was characterized by mean vector and covariance matrix. The statistical probability was computed for each class to determine the membership of the cells to the class. Each cell was classified to the class to which it has the highest probability of being a member. The algorithm for computing the likelihood \( D \) of unknown measurement vector \( X \) belongs to one of the known classes, was based on the following Bayesian equation:

\[
D = \ln(a) - 0.5 \ln(|\text{cov}_c|) - 0.5(X - M_c)^T(\text{cov}_c^{-1})(X - M_c) \tag{4}
\]

Where \( D \) = weighted distance (likelihood), \( c \) = a particular class, \( X \) = the vector measurement of the candidate pixel, \( M_c \) = the mean vector of the sample of class \( c \), \( a \) = percent probability that candidate pixel is a member of class \( c \) (defaults to 1.0 or is entered from prior knowledge), \( \text{cov}_c \) = the covariance matrix of the pixels in the sample of class \( c \), \( |\text{cov}_c| \) = determinant of \( \text{cov}_c \) (matrix algebra), \( \ln \) = natural logarithm function, \( T \) = transposition function (matrix algebra).

**Accuracy assessment**

In order to evaluate the performance of the classifiers, the accuracy assessment was carried out using a validation dataset, assuring distribution in a rational pattern so that a specific number of observations were assigned to each category on the classified image. The Kappa accuracy was computed as given below:

\[
k = \frac{N \sum_{i=1}^{r} (x_{c+})(x_{c+})}{N^2 - \sum_{i=1}^{r} (x_{c+})(x_{c+})} \tag{5}
\]
Where \( r \) is the number of rows in the matrix, \( X_{ii} \) is the number of observations in row \( i \) and column \( i \) (the diagonal elements), \( x_{ri} \) and \( x_{ir} \) are marginal totals of row \( r \) and column \( i \) respectively, and \( N \) is the number of observations. The overall accuracy measured the proportion of the assessed area classified correctly. The user’s accuracy measured the proportion of pixels classified as belonging to a class that genuinely classified as belonging to that class. The user’s and producer’s accuracy measurements are related to commission and omission errors.

**Statistical analysis**

Qualitative data were decoded, translated into English, and analyzed using content analysis for related themes. The analysis involved coding in generating initial themes among the codes and reviewing and naming the themes. The identification of related themes was based on the historical pattern within the data. On the other hand, Geospatial LULC Landsat satellite data were analyzed using GIS and remote sensing approaches. ArcGIS version 10.7.1 and ENVil 5.4 software were used. The mixed-effects linear regression model was used to explain the extent to which LULC classes influence ESs in the study area. Quantitative data were analyzed using descriptive and inferential statistics. STATA version 15 was used in the data analysis.

**Results and discussion**

**The accuracy assessment and LULC classes**

The overall producer’s accuracy assessment for 2019 was 89.36 with 85.01 for the forest, 89.93 for marshes, 90.05 for cultivated land, 93.93 for shrubs/grass/bare land, and 82.15 for waterbody (Table 2). Table 2 further shows that the user’s accuracy, which is the percentage of correctly classified data, was 99.86% for forest, 82.69% built up, 80.54% marshes, 81.09% cultivated land, 99.85% shrubs/Grass/bare land, and 84.35% water body. Thus, the overall accuracy assessment was 89.36%, with a Kappa coefficient of 0.87. Pontius (2000) suggested that the Kappa coefficient of smaller than 0.4 indicates poor, 0.4 to 0.7 indicates good, and greater than 0.75 indicates excellent. This study’s Kappa coefficient was 0.87, suggesting that the classification map strongly agreed to the ground reference data since it falls within excellent ranges for all the LULC classes. Six major LULC classes were identified using field data and Landsat images from 1989, 1999, 2009, and 2019. The classified LULC classes were Shrubs/Grass/Bare land, built up, cultivated land, waterbody, forest, and marshes (Table 3).

Like other lake ecosystems in Malawi, Africa, and the globe, most of the local population living in the catchment depends on farming activities (Schuyt, 2005). Figure 2a and b show that about 75.5% of the respondents own a farm for agricultural activities, and cereal crops such as maize are ranked the highest.

| Table 2. Accuracy assessment of classified image |
|------------------------------------------------|
| ![Table 2](image) |

| Table 3. Absolute area coverage |
|--------------------------------|
| ![Table 3](image) |
Figure 2. Main source of food (a), food products from lake ES (b).
Note: Rodgers Makwinja captured photo (a) while Mr Chisesa captured photo (b) during our exploratory survey in October, 2019 in Western Lake Malomb.

Figure 3. Land use/land cover classes.

Figure 4. Lake malombe catch (Makwinja, et al., 2021c), lake depth, and area fluctuations.
Table 3 and Figure 3 show that the land-use class for cultivation has increased significantly. The cultivation includes upland areas, flood plain, and wetlands, predominately cultivated for rainfed and irrigated agriculture (Government of Malawi, 2014). The results agree with the findings of Swallow et al. (2009), Nakawuka et al. (2018), Zebire et al. (2019), BaHonfoga (2018), Kanyika-Mbewe et al. (2020), and Mensah et al. (2020), and Aneseyee et al., 2020) in East, South and West Africa, and Makwinja, et al., (2021b) in Malawi.

The study further shows that land under cultivation increased from 52,932 ha to 78,983 ha from 1989 to 2019. In Ethiopia, Hailu et al. (2020) also reported a tremendous increase in cultivated land from 1973 to 2019. The increase in cultivated land was done at the expense of forest land, which can be attributed to the spike of small-scale farming as the lake fishery and waterbody declining (Figure 4a and b) (Hailu et al., 2020; Powlson et al., 2011; Yaro, 2013). Evidence in Figure 4a shows that the total annual fish catch slightly fluctuated positively from 1976 to 1984 and registered a peak within 1988 to 1990s and then declined sharply from 1990 to 2000 with the lowest recorded from 2000 to 2004 and later slightly fluctuated positively from 2005 to 2016. Figure 4a further shows that fishing effort declined as the fisherfolks temporarily or permanently abandoned fishing during low catches and increased pressure on the landscape due to increased demand for cultivated land at the expense of forest. Many studies in Malawi and Sub-Saharan Africa also reported increased cultivated land at the expense of forest land, biodiversity, fishery, and waterbody (Jamu et al., 2011; Wasige et al., 2013; du Toit et al., 2018; Munthali et al., 2020). In Malawi, Palamuleni et al. (2011) reported an 18% increase in agricultural land in the Upper Shire river catchment from 1989 to 2002. Jamu et al. (2003), on the other hand, reported increasing deforestation in the Likangala River of Lake Chilwa catchment, Southern Malawi. In Zimbabwe, particularly the Buzi sub-catchment, Chemura et al. (2020) also reported a similar trend. In the Ndembera watershed, Tanzania, Hyandye et al. (2018) reported increasing agricultural land and evergreen forests by nearly 10% and 7%, respectively, from 2013 to 2020. Bare land/shrubs, grassland has also been transformed into other land-use types. Figure 3 shows that the lake catchment and lowland areas are characterized by dense cultivation, densely populated, and treeless dominated by shrub and grassland. The area under study was found that the bare/shrub/grassland increased from 1989 to 2019, which aligns with the findings of Daniel (2008), Tolessa et al. (2017), and Siraj et al. (2018). The increase in bare/shrub/grassland is attributed to the high rate of forest reserve conversion into bare land (plate 1a) as the demand for charcoal production and agricultural activities increases. Plate 1b shows that wetland is converted into a cultivated while forest into bareland /shrubs/ grassland.

Charcoal production is one of the income generation activities for the Lake Malombe local population. This study found that in 2019, the hilly part of Lake Malombe catchment remained bare, with increased gullies developing each rainy season as trees are continuously harvested. As a result, the waterbody size decreased from 33,300 ha in 1989 to 30,483 in 2019 (Table 3). Arnhold et al. (2014) explained that mountainous farmland cultivation at the expense of forest land triggers severe soil erosion. The rate of soil loss in Lake Malombe catchment though not yet estimated, could be more than 29 t/ha/year estimated at the national level (Mzuza et al., 2019). One of the most outstanding phenomena of this present findings is that human activities are strongly linked to the current status of the lake ES dynamics which agree to the recent work by Dulanya et al.

Plate 1. Conversion of forest land for charcoal and agriculture (a), wetland converted into agriculture (b) Note: Photo (a) is extracted from the 2014 Mangochi District Environmental Outlook Report (Government of Malawi, 2014) while Rodgers Makwinja captured photos (b) during the field survey conducted in August 2019 in the Eastern Lake Malombe
(2014), who evidenced that Lake Malombe has been experiencing accelerated eutrophication in the recent past 100 years. Magadza (2010) also had similar findings in Lake Kariba and Zambezi River Valley. The main reason for decreased waterbody in Figure 4b is the prolonged drought, siltation, and rainfall decline as temperatures in the catchment increase (Likoya, 2019; Ngongondo et al., 2020; Power, 2010).

**Trade-offs between ecosystem services**

Lake Malombe provides multiple ecosystem services to both local and global communities. These diverse ESs generates potential trade-offs (Farley, 2012; De Groot et al., 2010; Kremen, 2005; Langner et al., 2017; Martinez-Harms et al., 2015). Figure 3 shows that the local population is continuously modifying the Lake Malombe landscape for unsustainable settlements. Such enormous socio-economic development has put more pressure on the lake landscape, making it more vulnerable to extreme climate events and natural hazards such as floods, drought, and long-term effects of ES degradation. An attempt was made to bring some significant ESs provided by Lake Malombe to the local and global communities’ attention to raise awareness. This was achieved by introducing a set of ecological indicators that do not directly measure ESs but demonstrate the lake’s ecological status in response to landscape dynamics. Biodiversity loss was selected as an indicator because it is associated with greater resource use efficiency within the lake ecosystem and forms a significant component of its socio-ecological system (Geist, 2011). Loss of biodiversity can compromise the livelihood of the local population, future conditions of the lake, species composition, and food-web diversity (Schallenberg et al., 2013). Loss of biodiversity is further linked to cultural value and carbon sequestration changes, and these too were selected as indicators. Lake fishery was selected as a significant ESs indicator because it represents harvestable food and is a significant resource for the Lake Malombe population. For example, Lake Malombe is best known for the mass depletion of fish biomass in Africa (Jamu et al., 2011). This mass depletion exposed the local population to risks and vulnerability, forcing them to devise unsustainable strategies to deal with the fisheries resource scarcity (Makwinja et al., 2021c), negatively impacting the lake ecosystem functions (Makwinja et al., 2021e). The loss of macrophytes from Lake Malombe 1960s caused a sudden regime shift from clear-water to turbid states (Dulanya et al., 2014). Turbidity is linked to human pressure due to increased demand for cultivated land and settlements as the fishery collapses—hence in this study, it was selected as an indicator. Invasion of alien species is a critical anthropogenic activity affecting the ESs, with freshwater considered ecosystems the most impacted by species invasions. In this study, the invasion of alien species was selected because it is linked to other forms of environmental degradation instigated by human activities. Extinction of some species is linked to change in habitats and over-exploitation instigated by increased human population (Pelletier & Coltman, 2018) and hence was selected as an ecological indicator. The indicators mentioned above were introduced into the mixed-effect regression model.

**Table 4. Mixed-effects regression model for built-up land-use class**

| ES indicators          | β      | Std. Err | t      | p>|z| | (95% conf. Interval) |
|------------------------|--------|----------|--------|--------|---------------------|
| Fishery                | −1.55  | 0.39     | 4.19   | 0.000**| 0.24 7.22           |
| River flow             | 7.01   | 0.65     | 5.27   | 0.045  | 0.20 4.26           |
| Soil erosion           | 0.34   | 0.00     | 4.78   | 0.014  | 0.29 0.40           |
| Turbidity              | −7.01  | 0.04     | 2.57   | 0.000**| 0.29 0.40           |
| Biodiversity loss      | −2.02  | 0.10     | 3.16   | 0.020  | −0.51 5.50          |
| Invasion of alien species | 8.00  | 0.00     | 0.73   | 0.132  | −2.50 4.60          |
| Scenic beauty          | 5.02   | 0.04     | 0.82   | 0.050  | 0.85 1.20           |
| Extinction of some species | −0.06 | 0.69   | 3.51   | 0.000  | 0.04 5.50           |
| Frequent flooding      | −0.03  | 0.08     | −0.75  | 0.124  | −0.18 2.72          |
| Cultural value         | 0.12   | 0.31     | 3.20   | 0.054  | 0.09 9.45           |
| Carbon sequestration   | 0.15   | 0.09     | 0.34   | 0.061  | 0.15 5.43           |

*Note: CPUE means catch per unit effort which in this context indicates the fish species abundance in the lake.*

Table 4 shows that land degradation in the Lake Malombe catchment is highly linked to socio-economic development. The model demonstrates a significant (p < 0.05) trade-off between the built-up areas and fishery, turbidity, biodiversity loss, and extinction of some species. Increased built-up land use areas in the lake catchment are done at the expense of biodiversity, some EPS such as fishery, supporting and regulatory services such as water purification and carbon sequestration). Aquatic plants such as **Pennisetum purpureum schumach**, **Phragmites mauritianu**, **Typha latifolia**, and **Cyperus papyrus** play a significant role in climate regulation through carbon sequestration (Kayranli et al., 2010; Were et al., 2021), water quality purification through the removal of heavy metals (Bernardini et al., 2016; Ceschin et al., 2021; Parzych et al., 2016), fecal pathogens removal (Kipasika et al., 2016), nutrients regulation, habitat provision (Bornette & Pujialon, 2011) and food regulation (Rooney et al., 2013; Scheffer et al., 2003; Wang et al., 2019). Aquatic plants such as **Typha domingensis**, **Terminalia sericea**, **Azadirachta indica** found in
Lake Malombe’s shoreline, and wetlands are medicinal plants.

Log likelihood = -257.013, Wald Chi squared = 213.02, Prob > Chi squared = 0.000, ns indicates not significant while ** and * indicate significance at 0.01 and 0.05 probability level of Confidence

They culturally provide services to local communities and cure diseases such as bilharzia, pneumonia, diarrhoea, antiseptic wounds, and Malaria (Pullanikkatil et al., 2018). However, these dominant aquatic plants are increasingly exploited and used for constructing temporary shelters, local tea rooms, and woven curios. The findings agree with Zohary and Ostrovsky (2011), who noted that the weakening of keystone species, loss of biodiversity, and increased internal nutrient loading are linked to increased socio-economic activities such as land use transformation for settlements. Hou et al. (2020) noted that major socio-economic events such as the vast expansion of built-up areas strongly impacted flood risk mitigation capacity and water quality in Yangtze Plain freshwater lakes. Similar trade-offs are reported by Asadollahi et al. (2018) in Iran, Lake Chilwa basin, in Malawi (Mvula & Haller, 2009; Pullanikkatil et al., 2013), and Lake Chad (Zieba et al., 2017).

Lake Malombe fishery, for a very long period, supported the livelihoods of thousands of local populations from different parts of the catchment (Pinnegar et al., 2016). However, the fishery has faced a series of combined threats, including over-exploitation, pollution, and invasive species (Walker, 2012). Jul-Larsen et al. (2003) reported a severe decline of *Copadichromis spp* (*Viginalis kajose*) from 937 metric tons in 1991 to 412 tons/year in 2001. Dulanya et al. (2014) also noted that Lake Malombe had experienced a catastrophic decline in fish stocks. Researchers such as Makwinja et al. (2014) and Xu et al. (2020) pointed out that the decline in fish production is highly linked to the fishery’s over-dependence. Similar findings have been reported in inland lakes and wetlands in Malawi and tropical regions (Kafumbata et al., 2014; Kosamu et al., 2017; Nagoli et al., 2017; Njiru et al., 2010). The mixed-effect regression results in Table 5 demonstrated a significant (p < 0.05) negative relationship between the fishery and cultivated land—class, suggesting that the collapse of the fishery in Figure 2a opened new alternative livelihood opportunities beyond fishing (FISH, 2015). Farming in the Lake Malombe flood plain is one of the most prominent activities that has witnessed a substantial expansion over the past years (Figure 3). As the water body area shrinks (Figure 3), the flood plain areas have become attractive for farming throughout the year (Aneseyee et al., 2020; Vehrs & Heller, 2017). The agricultural yield derived from cultivating these emerging landscapes is high, and this has been a pull factor for immigration into the catchment leading to rapid population explosion and decreased landholding capacity. However, EPSs such as cropping are done at the expense of cultural and aesthetic values, biodiversity, some valuable endemic animal and plant species, the capacity of the lake catchment to regulate flood, river flow, erosion, and climate. Several researchers, such as Keesstra et al. (2016), have evidenced these trade-offs, who concluded that the rate of species extinction, turbidity, soil erosion, and flooding increased with increasing cultivated land. Kay et al. (2009), Kanyika-Mbewe et al. (2020), and Nkwanda et al. (2021) also reported similar trade-offs.

Table 3 shows that the increase in agricultural activities in the Lake Malombe catchment is done at the expense of forest land and natural wetland vegetation. A similar observation has been made by several authors

| Table 5. Mixed-effects regression model for cultivated land-use class |
|---------------------------------------------------------------|
| ES indicators | Coef. | Std. Err | z | p>|z| | (95% conf. Interval) |
|----------------|-------|----------|---|---|------------------|
| Fishery | -6.43 | 0.70 | 3.30 | 0.021 | -2.63 | 7.22 |
| River flow | 6.69 | 0.32 | 3.46 | 0.031 | -5.34 | 4.74 |
| Soil erosion | 0.017 | 0.074 | 2.20 | 0.024 | -0.128 | 0.16 |
| Turbidity | 2.16 | 0.79 | 2.37 | 0.046 | 3.32 | 7.92 |
| Biodiversity | -4.06 | 0.16 | 2.03 | 0.000 | 31.68 | 45.45 |
| Invasion of alien species | 0.71 | 0.25 | -3.82 | 0.011 | -8.445 | 7.21 |
| Scenic beauty | -8.59 | 0.26 | 5.41 | 0.000** | 7.74 | 9.64 |
| Extinction of some species | 4.23 | 0.70 | -4.24 | 0.000 | -8.34 | -1.42 |
| Frequent flooding | 4.86 | 0.02 | -3.27 | 0.000 | -9.34 | -0.43 |
| Cultural value | 1.10 | 0.10 | 0.03 | 0.21* | 0.05 | 5.43 |
| Carbon sequestration | -3.12 | 0.05 | 4.07 | 0.000** | 0.86 | 8.56 |

Note: Log likelihood = -468.112 Wald Chi squared = 5089.23, Prob > Chi squared = 0.000, ns indicates not significant while ** and * indicate significance at 0.01 and 0.05 probability level of Confidence

| Table 6. Mixed-effects regression model for forest land-use class |
|---------------------------------------------------------------|
| ES indicators | β | St. Err | z | p>|z| | (95% conf. Interval) |
|----------------|---|----------|---|---|------------------|
| Fishery | 9.12 | 0.31 | 0.181 | 0.061** | 194.20 | 430.02 |
| River flow | 9.60 | 0.29 | 13.20 | 0.000** | -8.13 | 0.001 |
| Soil erosion | 3.83 | 0.54 | -16.62 | 0.000** | -8.06 | 3.47 |
| Turbidity | -4.23 | 0.14 | -14.02 | 0.044* | -0.752 | -0.001 |
| Biodiversity loss | 5.16 | 0.69 | 8.16 | 0.000** | -1.08 | 0.060 |
| Invasion of alien species | 6.41 | 0.35 | -0.150 | 0.118** | -1.80 | 6.340 |
| Scenic beauty | 2.23 | 0.59 | -0.111 | 0.031* | -5.916 | 5.077 |
| Extinction of some species | -6.44 | 0.95 | -92.20 | 0.000** | -1.041 | 3.600 |
| Frequent flooding | -2.20 | 0.94 | 97.55 | 0.000** | -9.181 | 0.909 |
| Cultural value | 6.38 | 0.89 | -0.06 | 0.232* | -6.023 | -1.430 |
| Carbon sequestration | 6.20 | 0.53 | -5.20 | 0.000** | -1.110 | 1.026 |

Note: CPUE means catch per unit effort which in this context indicates the fish species abundance in the lake,
such as Allan, 2004), Schuett (2005), Palamuleni et al. (2011), and Kafumbata et al. (2014) in Malawi, Dibaba et al. (2020) in Ethiopia, Uwimana et al. (2018) in Southern Rwanda, Sibanda and Ahmed (2021) in Zimbabwe, and Thonfeld et al. (2020) in Tanzania. Figure 3 shows that forest land has been cleared out from 1989 to 2019, leading to loss of terrestrial and aquatic biodiversity, diminishing supporting, regulatory, cultural, and aesthetic services. Table 6 shows that forest land-use class had a significant (p < 0.05) positive regression coefficient with river flow, biodiversity, scenic beauty, and carbon sequestration. Conversely, soil erosion, turbidity, extinction of some species, and frequent flooding had a significant (p < 0.05) negative regression coefficient.

**Log likelihood = -65.278, prob >chi square = 0.000, Wald Chi square = 416.06, ns indicates not significant while ** and * indicate significance at 0.01 and 0.05 probability level of Confidence**

During FGDs, it was pointed out that the rate at which terrestrial and aquatic fauna are displaced has increased as forest land decreases (Government of Malawi, 2014). Díaz et al. (2009) also emphasized the link between climate regulation through carbon sequestration and the stability or increase in vegetation over a long time. The increased farming is done at the expense of forest land, shrubs, mangroves, marshes, and vegetation. Loss of forest land has a severe negative ESs impact. The findings agree with the 2018 IPBES report, which indicates that agricultural expansion alongside rapid population growth and increased food consumption has come at the expense of forests, wetlands, and grasslands, compromise climate regulation, supporting, cultural and aesthetic ecosystem service values. In Malawi, Njaya et al. (2011), Nagoli and Chiwona-Karlton (2017) also observed in the Lake Chilwa Basin.

On the other hand, Jogo and Hassan (2010) suggested that diversifying livelihoods from agriculture while improving economic well-being can enhance the conservation of the tropical freshwater shallow lakes ESs. Climate regulation is essential for both global and local communities. However, it is not a key priority among the local population and cannot be traded off with EPSs such as cropping, fuelwood, and charcoal production. The integrity of the forest ecosystem in Lake Malombe catchment can be achieved through the introduction of several schemes, including compensation of local forest managers for ESs provided to a broader community—an initiative which is done in Costa Rica also known as payment ecosystem services (Chadzon, 2008; Morse et al., 2009). The benefits of this initiative will also boost other ESs such as water regulation, pollination, habitat provisioning, and biodiversity conservation. Turpie et al. (2008) also highlighted that concentration effort should be on ESs such as water supply, carbon sequestration as umbrella services to achieve a range of conservation goals. Sachedina and Nelson (2012) also supported this approach and acknowledged that it could solve global environmental challenges.

The increase cultivated at the expense of forest coupled with climate change impact is done at the expense of water bodies. Figure 3 shows that the water bodies in the catchment have been shrinking over the years due to severe land degradation. During the key informant interviews, the following anecdote was expressed. “Some important rivers such as Mikongo, Lusalumwe, Namingundi, Nangapoche, Msuka, Lutende, Unga, Lugola, Litisa, Lilole, Liwesa, Nanyumbu, Msinje, Mpilipili, Luchimwa, Lipinda, Mchokloa, Namasawi, Luwelele, Ngapani, Namangandwe, Masongola, Mandimba, Nyenyezi, Lingamasa, Masanje, Sangadzi, Nansenga, Mpale,

Plate 2: Msinje river dried up (a), a sand bar extending to the shoreline as Lake Malombe shrinks (b). Note: Rodgers Makwinja captured photos (a and b) during the field survey conducted in October 2019 in Lake Malombe
Mtamankhokwe, Namingundi, Koche, Nakundu, Thema and Kabudira drain into Lake Malombe, Lake Malawi and Shire river have recently dried up". Said the BVC chairperson at Khande Beach, October 2019. Plate 2a and b confirmed that the rivers have dried out, and lake volume has considerably declined.

The findings agree with Hecky et al. (2003), Kosamu et al. (2012), Makwinja et al. (2017), Pullanikkatil et al. (2018), and Ngongondo et al. (2020) in Lake Malawi, Elephant Marsh wetland, and Lake Chilwa. Furthermore, Table 7 shows that the regression coefficient for the fishery, turbidity, frequent flooding, and biodiversity displayed a positive regression coefficient and was significant at the 0.05 level of confidence, suggesting that a decrease in water bodies could result in a decrease in fishery and biodiversity (Gownaris et al., 2016; Ng’onga et al., 2019; Wang et al., 2019).

However, turbidity is also reduced and increases with increased water bodies due to erosion (Wantzen & Mol, 2013; Xu et al., 2020). Frequent flooding is also reduced due to prolonged drought in the study area. However, under extreme rainfall, the intensity of flooding events increases (Government of Malawi, 2014). The findings align with Bond et al. (2008), who acknowledged the loss of habitats due to the shrinking of water bodies under the severe drought. Nkwanda et al. (2021) also noted the strong relationship between water quality degradation and aerial coverage of the water bodies in the Lilongwe River catchment. The scenario depicted in Lake Malombe also applies to other African tropical inland freshwater shallow lakes (Elka & Laekemariam, 2020).

For example, in Malawi, Nagoli et al. (2017) reported that Lake Chilwa in Southern Malawi experienced severe water recession due to prolonged dry spells and frequent drought leading to the disruption of ESs. In Ethiopia, Lake Hiromasa disappeared from 1989 to 2005, resulting in the loss of aquatic biodiversity (Yilma, 2010). In Kenya, Lake Naivasha, an official ‘Ramsar Site’—30,000 ha, turned into a shallow mud pool during the 2009 drought resulting in a decline in the aquatic ecosystem (Ogola et al., 2012). Once the most significant freshwater Lake, Lake Chad shrunk dramatically in the last 40 years (Pham-Duc et al., 2020).

### Conclusion

Lake Malombe ESs support both local and global communities. Changes in the landscape have benefited a few individuals and cause chronic constraints to the majority sharing the common pool resources. This study demonstrates how the landscape dynamics changes instigated by human and climatic-induced factors shape Lake Malombe socio-ecological system. The study further demonstrates that the local population will continue to depend on EPs for their sustenance, and increasing demand will shrink other essential ESs making the local population more vulnerable and trapped in the vicious cycle of poverty. The study findings are of practical importance to policymakers, the local population, and various stakeholders in understanding competing interests and policy priorities to balance ecosystem management and human welfare. Engaging diverse stakeholders is required to reduce the risks of competing interests and sectoral policies conflict. The discussion in this study further highlights future research gaps. There is a need to understand how the local population embraces an effective governance system to achieve sustainable integrated freshwater ecosystem management.

### PUBLIC INTEREST STATEMENT

The urgent need to conserve various inland tropical freshwater shallow lakes is one of the global challenges ecologists and policymakers face. However, a management policy can cause unprecedented consequences if done without ample evidence. Therefore, an informed decision is necessary to reduce unexpected trade-offs between human demand and the need to safeguard multiple freshwater ecosystem services. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) initiated the need to link scientific evidence and management policies. Against this background, the researcher tried to assess Lake Malombe LULCDs, trade-offs, and potential implications on the ESs to provide appropriate policy recommendations in formulating and implementing Freshwater Ecosystem Management approach to fisheries in Malawian and global freshwater lakes.
Acknowledgements

The authors wish to thank the FAO-FiRM project, Mangochi Office, Malawi, for administrative support during the data collection.

Funding

This work was supported by African Center of Excellence (ACEWM) for Water Management through the World Bank African Center of Excellence (ACEII) project grant [GSR/9316/11]

Notes on contributors

Rodgers Makwinja holds a Bachelor of Science Degree in Aquaculture and Fisheries Science from University of Malawi, First Master of Science Degree (Fisheries Science) from Mzuzu University and Second Master of Science Degree (Water Resources and Supply Management) from the University of Malawi. He is a graduate research associate at Addis Ababa University, Addis Ababa, Ethiopia with a particular interest in marine and freshwater ecosystems. His research in the Great African Rift Valley complex focuses on natural resource economics (i.e. Integrated Valuation of Ecosystem Services and Tradeoffs, ecosystem sustainability framework, restoration, socio-ecological system dynamics, biodiversity, habitat integrity, landscape dynamics, trophic cascade, fish population trends, and modeling.

Prof Seyoum Mengistou has been a Director of Zoological Natural Museum, Editor in Chief of the Ethiopian Journal of Biological Sciences, Member of Society International of Limnology and Founding member of Ethiopian Fisheries and Aquatic Association (EFASA).

Prof Emmuel Kaunda is the Vice-Chancellor of Lilongwe University of Agriculture and Natural Resources, and Director of African Center of Excellence in Aquaculture and Fisheries (AquaFish). He received his PhD from Rhodes University where he got the esteemed "Best PhD. Seminar Award". In 2013, he received 3rd Prize of the IMPRESSA by RUFORUM as the best scientist in Africa. He is a co-founder of African Fisheries Experts Network and also a coordinator of the African Union Aquaculture Working Group and Coordinator of the NEPAD Fish Node of the Southern Africa Network on Biosciences (SANBio).

Dr Tena Alamirew is an academic researcher with 25 years experience- lecturing numerous courses and supervising undergraduate and graduate students. He has been involved in the design and effective implementation of several national and international collaborative research programs that support graduate students. He demonstrated his leadership attributes while serving as the academic research Vice of Haramaya University. He is a founding director of Ethiopian Institute of Water Resources and serve as the Deputy Director of Water and Land Resource Center and heads the research division.

ORCID

Rodgers Makwinja http://orcid.org/0000-0002-0818-4727
Tena Alamirew http://orcid.org/0000-0001-7491-4401

Declaring conflict of interest

The authors of this paper declare that there is no conflict of interest.

Source funds

The African Centre of Excellence for Water Management (ACEWM) provided financial support for this study under the World Bank’s African Centres of Excellence (ACE II) Project, Grant number GSR/9316/11.

Data availability

All data generated during this study are available upon request from the corresponding author.

References

Allan, J. (2004). Influence of land use and landscape setting on the ecological status of rivers. *Limnetica*, 23(3–4), 187–197. www.personal.umich.edu

Aneyee, A., Elias, E., Soromessa, T., & Feyisa, G. (2020). Land use/land cover change effect on soil erosion and sediment delivery in the Winike watershed, Omo Gibe Basin, Ethiopia. *Science of the Total Environment*, 728, 138776. https://doi.org/10.1016/j.scitotenv.2020.138776

Arnhold, S., Lindner, S., Lee, B., Martin, E., Kettering, J., Nguyen, T.,...Huwe, B. (2014). Conventional and organic farming: Soil erosion and conservation potential for row crop cultivation. *Geoderma*, 219–220(2014), 89-105,https://doi.org/10.1016/j.geoderma.2013.12.023

Asadolahi, Z., Salmanmahiny, A., Sakieh, Y., Mirkarimi, S., Baral, H., & Azimi, M. (2018). Dynamic trade-off analysis of multiple ecosystem services under land-use change scenarios: Towards putting ecosystem services into planning in Iran. *Ecological Complexity*, 36(2018), 250–260. https://doi.org/10.1016/j.ecocom.2019.09.003

BaHonfoga, B. (2018). Diagnosing soil degradation and fertilizer use relationship for sustainable cotton production in Benin. *Cogent Environmental Science*, 4:1,1422366, 1-24 https://doi.org/10.1080/23311843.2017.1422366

Bernardini, A., Salvatori, E., Guerrini, V., Fusaro, L., Canepari, S., & Manes, F. (2016). Effects of high Zn and Pb concentrations on Phragmites australis (Cav.) Trin. Ex. Steudel: Photosynthetic performance and metal accumulation capacity under controlled conditions. *International
Journal of Phytoremediation, 18(1), 16–24. https://doi.org/10.1080/15226514.2015.1058327

Bond, N., Lake, P., & Arthington, A. (2008). The impacts of drought on freshwater ecosystems: An Australian perspective. Hydrobiologia, 600(1), 3–16. https://doi.org/10.1007/s10750-008-9326-z

Bornette, G., & Pujalson, S. (2011). Response of aquatic plants to abiotic factors: A review. Aquatic Sciences, 73(2011), 1–14. https://doi.org/10.1007/s00027-010-0162-7

Brockerhoff, E., Jactel, H., Parrotta, J., & Ferraz, S. (2013). Role of eucalypt and other planted forests in biodiversity conservation and the provision of biodiversity-related ecosystem services. Forest Ecology and Management, 301(2013), 43–50. https://doi.org/10.1016/j.foreco.2012.09.018

Cacho, O., Moss, J., Thornton, P., Herrero, M., Henderson, B., Bodirsky, B., … Lipper, L. (2020). The value of climate-resilient seeds for smallholder adaptation in sub-Saharan Africa. Climatic Change, 162(2020), 1213–1229. https://doi.org/10.1007/s10584-020-02817-z

Ceschin, S., Bellini, A., & Scalici, M. (2021). Aquatic plants and ecotoxicological assessment in freshwater ecosystems: A review. Environ Sci Pollut Res, 28(2021), 4975–4988. https://doi.org/10.1134/S11350620214963-3

Chadzón, R. (2008). Beyond deforestation: Restoring forests and ecosystem services on degraded lands. Science, 320 (2008), 1458–1460. https://doi.org/10.1126/science.1155365

Chemura, A., Rwasoka, D., Mutanga, O., Dube, T., & Mushore, T. (2020). The impact of land-use/land cover changes on water balance of the heterogeneous Buzi sub-catchment, Zimbabwe. Remote Sensing Applications: Society and Environment, 18, 100292. https://doi.org/10.1016/j.rse.2020.100292

Chingala, G., Mapiye, C., Raffrenato, E., Hoffman, L., & Dzama, K. (2017). Determinants of smallholder farmers perceptions of the impact of climate change on beef production in Malawi. Climatic Change, 142(1–2), 129–141. https://doi.org/10.1007/s10584-017-1924-1

Daniel, A. (2008). Remote Sensing and GIS-based Land Use and Land Cover Change Detection in the Upper Djo River Catchment, Silte Zone, Southern Ethiopia (MSc Thesis). Addis Ababa: Addis Ababa University.

Davivongs, V., Yokohari, M., & Hara, Y. (2012). Neglected canals: Deterioration of indigenous irrigation system by urbanization in the West Peri-Urban area of Bangkok. Water, 4(2012), 12–27. https://doi.org/10.3390/w4010012

de Groot, R., Alkemade, R., Braat, L., Hein, L., & Willemsen, L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management, and decision making. Ecological Complexity, 7(3), 260–272. https://doi.org/10.1016/j.ecocom.2009.10.006

Díaz, S., Hector, A., & Wardle, D. (2009). Biodiversity in forest carbon sequestration initiatives: Not just a side benefit. Current Opinion in Environmental Sustainability, 1(1), 55–60. https://doi.org/10.1016/j.cosust.2009.08.001

Dibaba, W., Demissie, T., & Miegel, K. (2020). Drivers and implications of land use/land cover dynamics in finchaa catchment, Northwestern Ethiopia. Land, 9(4), 113. https://doi.org/10.3390/land9040113

du Toit, M., Cilliers, S., Dallimer, M., Goddard, M., Guenat, S., & Cornelius, S. (2018). Urban green infrastructure and ecosystem services in sub-Saharan Africa. Landscape and Urban Planning, 180(2018), 249–261. https://doi.org/10.1016/j.landurbplan.2018.06.001

Dulanya, Z., Croudace, I., Reed, J., & Trauth, M. (2014). Palaeolimnological reconstruction of recent environmental change in Lake Malombe (S. Malawi) using multiple proxies. Water SA, 40(4), 11–18. https://doi.org/10.4314/wsa.v40i4.17

Elka, E., & Laekemarian, F. (2020). Effects of organic nutrient sources and NPS fertilizer on the agronomic and economic performance of haricot bean (Phaseolus vulgaris L.) in Southern Ethiopia. Applied and Environmental Soil Science, 2020, 1–9. https://doi.org/10.1155/2020/885355

Ellis, F., Kutengule, M., & Nyasulu, A. (2003). Livelihoods and rural poverty reduction in malawi. World Development, 31(9), 00111–6. 1495–1510, https://doi.org/10.1016/S0305-750X(03)

Ewunetu, A., Simane, B., Teferi, E., & Zaitchik, B. (2021). Land cover change in the blue Nile river headwaters: farmers’ perceptions, pressures, and satellite-based mapping. Land, 10(1), 68. https://doi.org/10.3390/land10010068

Farley, J. (2012). Ecosystem services: The economics debate. Ecosystem Services, 1(2012), 40–49. https://doi.org/10.1016/j.ecoser.2012.07.002

FISH. (2015). Environmental threats and opportunities assessment (ETOA) of four major lakes in malawi.

Froese, R., Walters, C., Pauly, D., Winker, H., Weyl, O., Demirel, N., … Holt, S. (2016). A critique of the balanced harvesting approach to fishing. ICES Journal of Marine Science, 73(6), 1640–1650. https://doi.org/10.1093/icesjms/fsv122

Geist, J. (2011). Integrative freshwater ecology and biodiversity conservation. Ecological Indicators, 11(6), 1507–1516. https://doi.org/10.1016/j.ecoind.2011.04.002

GoM. (2016). National climate change management policy. Government of Malawi.

Gondwe, M., Cho, M., Chirwa, P., & Geldenhuyw, C. (2019). Land use land cover change and the comparative impact of co-management and government-management on the forest cover in Malawi (1999–2018). Journal of Land Use Science, 14(4–6), 281–305. https://doi.org/10.1080/1747423X.2019.1706654

Government of Malawi. (2014). Mangochi district state of environment and outlook. Mangochi District Council.

Gownaris, N., Pikitch, E., Allier, J., Kaufman, L., Kolding, J., Lwiza, K., … Rountos, K. (2016). Fisheries and water level fluctuations in the world’s largest desert lake. Estuaries and Coasts, 10(1), 1-16. https://doi.org/10.1002/eco.1769

Guo, Y., Peng, C., Zhu, Q., Wang, M., Pend, S., & He, H. (2019). Modeling the impacts of climate and land-use changes on soil erosion: Model applications, limitations, and future challenges. J.Environ. Manag, 259,109403, https://doi.org/10.1016/j.jenvman.2019.109403

Hailu, A., Mammo, S., & Kidane, M. (2020). Dynamics of land use, land cover change trend and its drivers in Jimma Geneti District, Western Ethiopia. Land Use Policy, 99, 105011. https://doi.org/10.1016/j.landusepol.2020.105011

Hara, M. (2006). ‘Restoring the chambo in Southern Malawi: Learning from the past or re-inventing the wheel? Aquatic
Ecosystem Health & Management, 9(4), (4)419–432. https://doi.org/10.1080/1463498060103335

Hara, M., & Njaya, F. (2016). Between a rock and a hard place: The need for and challenges to implementation of rights-based fisheries management in small-scale fisheries of southern Lake Malawi. Fisheries Research, 174(2016), 10–18. https://doi.org/10.1016/j.fishres.2015.08.005

Hecky, R., Bootsmas, H., & Kindon, M. (2003). Impact of land use on sediment and nutrient yields lake Malawi/Nyasa (Africa Lake Malawi/Nyasa (Africa). 139. Great Lakes Res, 29(Suppl. 2), 139–158. https://doi.org/10.1016/S0380-1330(03)70544-9

Hou, X., Feng, L., Tang, J., Song, X., Liu, J., Zhang, Y., … Bryan, B. (2020). Anthropogenic transformation of Yangtze Plain freshwater lakes: Patterns, drivers and impacts. Remote Sensing of Environment, 248, 111998. https://doi.org/10.1016/j.rse.2020.111998

Hyandye, C., Worqul, A., Martz, L., & Muzzuka, A. (2018). The impact of future climate and land use/cover change on water resources in the Ndembera watershed and their mitigation and adaptation strategies. Environmental System Research, 7(7), 2018. https://doi.org/10.1186/s40068-018-0110-4

IPBES. (2018). The regional assessment report on biodiversity and ecosystem services for Africa.

Jamau, D., Banda, M., Njaya, F., & Hecky, R. (2011). Challenges to sustainable management of the lakes of Malawi. Journal of Great Lakes Research, 31(1), 3-14. https://doi.org/10.1016/j.jglr.2010.11.017

Jamau, D., Chimphamba, J., & Brummett, R. (2003). Land use and cover changes in the Likangala catchment of the Lake Chilwa basin, Malawi: Implications for managing a tropical wetland. African Journal of Aquatic Science, 28(2), 123–135. https://doi.org/10.2989/16085910309505777

Jogo, W., & Hassan, R. (2010). Balancing the use of wetlands for economic well-being and ecological security: The case of the Limpopo wetland in southern Africa. Ecological Economics, 69(7), 1569–1579. https://doi.org/10.1016/j.ecolecon.2010.02.021

Jul-Larsen, E., Kolding, J., Overå, R., Nielsen, J., & Zwieter, P. (2003). Management, co-management, or no management? Major dilemmas in southern African freshwater fisheries. 1. Synthesis report. FAO Fisheries Technical Paper. No. 426/1.

Kafumbata, D., Jamu, D., & Chiotha, S. (2014). Riparian ecosystem resilience and livelihood strategies under test: Lessons from Lake Chilwa and Malawi in other lakes in Africa. Phil Trans R Soc B. 369(1639), 20130052. https://doi.org/10.1098/rstb.2013.0052

Kaland-Joshua, M., Nsongondo, C., Chipeta, L., & Mpembeka, F. (2011). Integrating indigenous knowledge with conventional science: Enhancing localized climate and weather forecasts in Nessa, Mulanje, Malawi. Physics and Chemistry of the Earth, Parts A/B/C, 36(14–15), 996–1003. https://doi.org/10.1016/j.pce.2011.08.001

Kanyika-Mbewe, C., Thole, B., Makwinja, R., & Kaonga, C. (2020). Monitoring of carbaryl and cypermethrin concentrations in water and soil in Southern Malawi. Environmental Monitoring and Assessment, 192(595), 2020. https://doi.org/10.1007/s10661-020-08557-y

Kapute, F. (2018). The role of the Liwonde National Park in conserving fish species diversity in the upper Shire River, Malawi. Aquatic Ecosystem Health & Management, 21(2). 132-138,https://doi.org/10.1080/14634988.2018.1457389

Kay, P., Edwards, A., & Foulger, M. (2009). A review of the efficacy of contemporary agricultural stewardship measures for ameliorating water pollution problems of key concern to the UK water industry. Agricultural Systems, 99(2–3), 67–75. https://doi.org/10.1016/j.agsy.2008.10.006

Kayranli, B., Scholz, M., Mustafa, A., & Hedmark, A. (2010). Carbon storage and fluxes within freshwater wetlands: A critical review. Wetlands, 30(2010), 111–124. https://doi.org/10.1007/s11273-009-0003-4

Keesstra, S., Bouma, J., Wallinga, J., Tittonell, P., Smith, P., Cerdà, A., … Fresco, L. (2016). The significance of soils and soil science towards the realization of the United Nations Sustainable Development Goals. Soil, 2(2016), 111–128. https://doi.org/10.5194/soil-2–111–2016

Kehoe, L., Romero-Muñoz, A., Polainia, E., Ester, L., Krefl, H., & Kuenmerle, T. (2017). Biodiversity at risk under future cropland expansion and intensification. Nature Ecology & Evolution, 1(2017), 1129-1135. https://doi.org/10.1038/s41559-017-0234-3

Kipasika, H., Buza, J., Smith, W., & Njau, K. (2016). Removal capacity of faecal pathogens from wastewater by four wetland vegetation: Typha latifolia, cyperus papyrus, cyperus alternifolius, and phragmites australis. African Journal of Microbiology Research, 10(19), 654–661. https://doi.org/10.5897/AJMR2016.7931

Kosamu, I., de Groot, W., & Kambewa, P. (2017). Actor-based design of a management system for the elephant marsh fishery in Malawi. citor-Based Design of a Management System for the Elephant Marsh Fishery in Malawi, Society & Natural Resources, 30(3), 299–314. https://doi.org/10.1080/08949120.2016.1209604

Kosamu, I., De Groot, W., Kambewa, P., & De Snoo, G. (2012). Institution and ecosystem-based development potentials of the elephant marsh, Malawi. Sustainability, 4 (12), 3326–3345. https://doi.org/10.3390/su4123326

Kremen, C. (2005). Managing ecosystem services: What do we need to know about their ecology? Ecology Letters, 8(5), 468–479. https://doi.org/10.1111/j.1461-0248.2005.00751.x

Lambin, E., & Geist, H. (2006). Land use and land cover change: Local processes and global impacts. Springer.

Langner, A., Irauscheck, F., Perez, S., Pardos, M., Zlatanov, T., Öhman, K., … Lexer, M. (2017). Value-based ecosystem service trade-offs in multi-objective management in European mountain forests. Ecosystem Services, 26(2017), 245–257. https://doi.org/10.1016/j.ecoser.2017.03.001

Likoya, E. (2019). Change in the Context of Changing Land Use and Cover: Case Study of the Shire River Basin Flood of 2015. MSc Thesis. University of Cape Town.

Lorena, P. (2018). The urban governance of climate change adaptation in least-developed African countries and in small cities: The engagement of local decision-makers in Dar es Salaam, Tanzania, and Karonga, Malawi. Climate and Development, 12(4), 408-419,https://doi.org/10.1080/17575529.2019.1632166

MacPherson, E., Sadalaki, J., Nyongopa, V., Nkhwazi, L., Phiri, M., Chimphonda, A., … Theobald, S. (2012). Exploring the complexity of microfinance and HIV in fishing communities on the shores of Lake Malawi. Review of African Political Economy, 42(145). 414-436,https://doi.org/10.1080/03050244.2015.1064369
Magadza, C. (2010). Environmental state of lake kariba and zambezi river valley: Lessons learned and not learned. *Lakes & Reservoirs: Research and Management, 15*(3), 167–192. https://doi.org/10.1111/j.1440-1770.2010.00438.x

Makwinja, R., Mengistou, S., Kaunda, E., Alemirew, T., Phiri, T. B., Kosamu I. B. M. & Kaonga, C. C. (2021a). Modeling of Lake Malombe annual fish landings and catch per unit effort (CPUE). *Forecasting, 3*(1), 39–55. https://doi.org/10.3390/forecast310004

Makwinja, R., Chapotera, M., Likongwe, P., Banda, J., & Chijere, A. (2014). Location and roles of deep pools in Likangala River during 2012 recession period of Lake Chilwa basin. *International Journal of Ecology, 2014*, 4. Article ID 294683. https://doi.org/10.1155/2014/294683

Makwinja, R., Kaunda, E., Mengistou, S., & Alamirew, T. (2021b). Impact of land use/land cover dynamics on ecosystem service value—a case from Lake Malombe, Southern Malawi. *Environmental Monitoring and Assessment, 193*(8). https://doi.org/10.1007/s10661-021-09241-5

Makwinja, R., Kaunda, E., Mengistou, S., Alemirew, T., Njaya, F., Kosamu, I. B. M. & Kaonga, C. C. (2021c). Lake Malombe fishing communities’ livelihood, vulnerability, and adaptation strategies. *Current Research in Environmental Sustainability, 3*, 100055. https://doi.org/10.1007/j.crsust.2021.100055

Makwinja, R., Kosamu, I. B. M. & Kaonga, C. C. (2019). Determinants and values of willingness to pay for water quality improvement: Insights from Chia Lagoon, Malawi. *Sustainability, 11*(17), 4690. https://doi.org/10.3390/su11174690

Makwinja, R., & M’balaka, M. (2017). Potential impact of climate change on Lake Malawi Chambo (*Oreochromis spp.*) fishery. *Fishery. J Ecosystem Ecography, 6*, 227. doi:10.4172/2157-7625.1000227

Makwinja, R., Mengistou, S., Kaunda, E., & Alamirew, T. (2021d). Spatial distribution of zooplankton in response to ecological dynamics in tropical shallow lake: Insight from Lake Malombe, Malawi. *Journal of Freshwater Ecology, 36*(1), 127–147. https://doi.org/10.1080/02705060.2021.1943019

Makwinja, R., Mengistou, S., Kaunda, E., & Alamirew, T. (2021e). Lake Malombe fish stock fluctuation: Ecosystem and fisherfolks. *Egyptian Journal of Aquatic Research. https://doi.org/10.1016/j.ejar.2021.07.001*

Makwinja, R., Phiri, T., Kosamu, I. B. M. & Kaonga, C. C. (2017). Application of stochastic models in predicting Lake Malawi water levels. *Int. J. Water Res. Environ. Eng, 9*(9), 191–200. https://doi.org/10.5897/IJWREE2017.0740

Martinez-Harms, M., Bryan, B., Balvanera, P., Law, E., Rhodes, J., Possingham, H., & Wilson, K. (2015). Making decisions for managing ecosystem services. *Biological Conservation, 184*(2015), 229–238. https://doi.org/10.1016/j.biocon.2015.01.024

Mendham, E., Curtis, A., & Millar, J. (2012). The natural resource management implications of rural property turnover. *Ecology and Society, 17*(4), 5. http://dx.doi.org/10.5751/ES-05071-170405

Mengist, W., Soromessa, T., & Feyisa, G. (2020). A global view of regulatory ecosystem services: Existed knowledge, trends, and research gaps. *Ecological Processes, 9*(40(2020). https://doi.org/10.1186/s13717-020-00241-w

Mensah, C., Julia, A., Kabo-Bah, A., Švěk, M., Acheampong, D., Kyere-Boateng, R., … Merek, M. (2020). Impact of urban land cover change on the garden city status and land surface temperature of Kumasi. *Cogent Environmental Science, 6*(1), 178773. https://doi.org/10.1080/23311843.2020.1787738

Morse, W., Schedlbauer, J., Sesnie, S., Finegan, B., Harvey, C., Hollenhorst, S., … Wulffhorst, J. (2009). Consequences of environmental service payments for forest retention and recruitment in a Coastal Rican biological corridor. *Ecol Soc, 14*(1), 23. https://doi.org/10.5751/ES-02688-140123

Mueller, M., & Geist, J. (2016). Conceptual guidelines for the implementation of the ecosystem approach in biodiversity monitoring. *Ecosphere, 7*(5), e01305. https://doi.org/10.1002/ecs2.1305

Munthali, M., Mustak, S., Adeola, A., Botai, J., Singh, S., & Davis, N. (2020). Modeling land use and land cover dynamics of Dedza district of Malawi using hybrid cellular automata and markov model. *Remote Sensing Applications: Society and Environment, 17*, 100276. https://doi.org/10.1016/j.rsa.2019.100276

Mvula, P., & Haller, T. (2009). Common pool resource management in Lake Chilwa, Malawi: A wetland under pressure. *Development Southern Africa, 26*(4), 539–553. https://doi.org/10.1080/03768350903181332

Mzuza, M., Zhang, W., Kapute, F., & Wei, X. (2019). The impact of land use and land cover changes on the nkula dam in the middle shire river catchment, Malawi. In A. Pepe & Q. Zhao (Eds.), *Geospatial Analyses of Earth Observation (EO) data* (pp. 9). IntechOpen.

Nagoli, J., & Chiwona-Karltn, L. (2017). Uncovering human social networks in coping with Lake Chilwa recessions in Malawi. *Journal of Environmental Management, 192*(2017), 134–141. https://doi.org/10.1016/j.jenvman.2016.12.049

Nagoli, J., Green, E., Mulwafu, W., & Chiwona-Karltn, L. (2017). Coping with the double crisis: lake chilwa recession and the great depression on chisi island in colonial Malawi, 1930–193. *Human Ecology, 45*(2017), 111–117. https://doi.org/10.1007/s10745-016-9882-1

Nakawuka, P., Langan, S., Schmitter, P., & Barron, J. (2018). A review of trends, constraints, and opportunities of smallholder irrigation in East Africa. *Global Food Security, 17*, 198–212. https://doi.org/10.1016/j.gfs.2017.10.003

Ng’onga, M., Kalaba, F., Mwitwa, J., & Nyimbiri, B. (2019). The interactive effects of rainfall, temperature, and water level on fish yield in Lake Bangweulu fishery, Zambia. *Journal of Thermal Biology, 84*(2019), 45–52. https://doi.org/10.1016/j.jtherbio.2019.06.001

Ngaruiya, C., Hayward, A., Post, L., & Mowafi, H. (2017). Obesity as a form of malnutrition: Over-nutrition on the Uganda “malnutrition” agenda. *The Pan African Medical Journal, 28*, 49. https://doi.org/10.11604/pamj.2017.28.49.11176

Ngwira, S., & Watanabe, T. (2019). An analysis of the causes of deforestation in Malawi: A case of mwazisi. *Land, 8*(3), 48. https://doi.org/10.3390/land8030048
Njaya. (2009). The Lake Chilwa Fishing Household Strategies in Response to Water Level Changes: Migration, Conflicts, and Co-Management, Ph.D. Thesis. University of Western Cape.

Njaya, F. (2007). Governance challenges for the implementation of co-management: Experiences from Malawi. *International Journal of the Commons*, 1(2007), 137–153. https://doi.org/10.18352/ijc.21

Njaya, F., Snyder, K., Jamu, D., Wilson, J., Howard-Williams, C., Allison, E., & Andrew, N. (2011). The natural history and fisheries ecology of Lake Chilwa, southern Malawi. *Journal of Great Lakes Research*, 37(1), 15–25. https://doi.org/10.1016/j.jglr.2010.09.008

Njiru, M., Mkumbo, O., & van der Knaap, M. (2010). Some possible factors leading to decline in fish species in Lake Victoria. *Aquatic Ecosystem Health And*, 13(1), 3–10. https://doi.org/10.1016/S1434-9809(0)356253

Nkwanda, I., Feyisa, G., Zewge, F., & Makwinja, R. (2021). Impact of land-use/land-cover dynamics on water quality in the upper Llongwe river basin, malawi. *International Journal of Energy and Water Resources*, 5(2), 193–204. https://doi.org/10.1007/s42108-021-00125-5

NSO. (2018). 2018 Malawi population and housing census report. Malawi National Statistics Office.

Ogola, P., Davidsdottir, B., & Fridleifsson, I. (2012). Potential contribution of geothermal energy to climate change adaptation: A case study of the arid and semi-arid eastern Baringo lowlands, Kenya. *Renewable and Sustainable Energy Reviews*, 16(6), 4222–4246. https://doi.org/10.1016/j.rser.2012.01.081

Palamuleni, L., Ndomba, P., & Annegarn, H. (2011). Evaluating land cover change and its impact on hydrological regime in upper shire river catchment, malawi. *Regional Environmental Change*, 11(2011), 845–855. https://doi.org/10.1007/s10113-011-0220-2

Parzych, A., Sobisz, Z., & Cymer, M. (2016). Preliminary research of heavy metals content in aquatic plants taken from surface water (northern Poland). *Desalination and Water Treatment*, 57(3), 1451–1461. https://doi.org/10.1080/19443994.2014.1002275

Pelletier, F., & Coltman, D. (2018). Will human influences on evolutionary dynamics in the wild pervade the Anthropocene? *BMC Biology*, 16(1), 7. https://doi.org/10.1186/s12915-017-0476-1

Pham-Duc, B., Sylvestre, F., Papa, F., Frappart, F., Bouchez, C., & Créaux, J. (2020). The Lake Chad hydology under current climate change. *Scientific Reports*, 10 (5498), 2020. https://doi.org/10.1038/s41598-020-62417-w

Pinnegar, J., Engelhard, G., Jones, M., Cheung, W., Peck, M., Rijnsdorp, A., & Brander, K. (2016). Socio-economic impacts-Fisheries. In M. Quante & F. Colijn (Eds.), *North sea region climate change assessment. regional climate studies*. Springer. https://doi.org/10.1007/978-3-319-39745-0_12

Plissnier, P., Nshombo, M., Mgana, H., & Ntakimazi, G. (2018). Monitoring climate change and anthropogenic pressure at Lake Tanganyika. *Journal of Great Lakes Research*, 44(2018), 1194–1208. https://doi.org/10.1016/j.jglr.2018.05.019

Pontius, J. R. (2000). Quantification error versus location error in comparison of categorical maps. *Photogrammetric Engineering and Remote Sensing*, 66(8), 1011–1016.

Power, A. (2010). Ecosystem services and agriculture: Trade-offs and synergies: Review. *Phil. Trans. R. Soc. B*, 365(2010), 2959–2971. https://doi.org/10.1098/rstb.2010.0143

Powlson, D., Gregory, P., Whalley, W., Quinton, J., Hopkins, D., Whitmore, A., . . . Goulding, K. (2011). Soil management in relation to sustainable agriculture and ecosystem services. *Food Policy*, 36(1), S72-S87,https://doi.org/10.1016/j.foodpol.2010.11.025

Pullanikkatil, D., Maneka, B., Phalira, B., Mkanthama, C., & Chiotha, S. (2013). Linkages between population, reproductive health, gender and climate change adaptation in Malawi case study from lake chilwa basin. LEAD SEA Publications.

Pullanikkatil, D., Mograbi, P., Palamuleni, L., Ruhiiga, T., & Shackleton, C. (2018). Unsustainable trade-offs: Provisioning ecosystem services in rapidly changing Likangala River catchment in southern Malawi. *Environment, Development, and Sustainability*. https://doi.org/10.1007/s10668-018-0240-x

Ratner, B., Barman, B., Cohen, P., Mam, K., Nagoli, J., & Allison, E. (2012). Strengthening governance across scales in aquatic agricultural systems. The WorldFish Center.

Robledo, C., Clot, N., Hammill, A., & Riché, B. (2012). The role of forest ecosystems in community-based coping strategies to climate hazards: Three examples from rural areas in Africa. *Forest Policy and Economics*, 24(2012), 20–28. https://doi.org/10.1016/j.forpol.2011.04.006

Rooney, R., Carfi, C., & Bayle, S. (2013). River connectivity affects submerged and floating aquatic vegetation in floodplain wetland. *Wetlands*, 33(6), 1165–1177. https://doi.org/10.1007/s11273-013-0471-4

Roser, M., & Ritchie, H. (2019). *Hunger and Undernourishment*. Published online at Our World In Data.org. https://ourworldindata.org/hunger-and-undernourishment.

Sachedinia, H., & Nelson, F. (2012). The development of payments for ecosystem services as a community-based conservation strategy in East Africa. In J. Ingram, F. DeClerck, & C. Rumbaitis del Rio (Eds.), *Integrating ecology and poverty reduction*. Springer. https://doi.org/10.1007/978-1-4614-0186-5_12

Schallenberg, M., De Winton, M., Verburg, P., Kelly, D., Hamill, K., & Hamilton, D. (2013). Ecosystem services of lakes. In J. Dymond (Ed.), *Ecosystem services in New Zealand-conditions and trends*. Manaaki Whenua Press.

Scheffer, M., Szabo, S., Gragnani, A., Van Ness, E., Rinaldi, S., Kautsky, N., . . . Franken, R. (2003). Floating plant dominance as a stable state. Proceedings of the national academy of sciences of the United States of A. *Proceedings of the National Academy of Sciences of the United States of America*, 100(7), 4040–4045. https://doi.org/10.1073/pnas.0737918100

Schuyt, K. (2005). Economic consequences of wetland degradation for local populations in Africa. *Ecological Economics*, 53 (2), 177–190. https://doi.org/10.1016/j.ecolecon.2004.08.003

Seutloali, K., & Beckedahl, H. (2015). A review of road-related soil erosion: An assessment of causes, evaluation techniques, and available control measures. *Earth Sciences Research Journal*, 19(1), 73–80. http://dx.doi.org/10.15446/esrj.v19n1.43841

Sharma, A., Tiwari, K., & Bhadoria, P. (2011). Effect of land use land cover change on soil erosion potential in an agricultural watershed. *Environmental Monitoring and
Assessment, 173(2011), 789–801. https://doi.org/10.1007/s10661-010-1423-6

Shehab, Z., Jamil, N., Aris, A., & Shafie, N. (2021). Spatial variation impact of landscape patterns and land use on water quality across an urbanized watershed in Bentong, Malaysia. Ecological Indicators, 122, 107254. https://doi.org/10.1016/j.ecolind.2020.107254

SiBanda, S., & Ahmed, F. (2021). Modeling historical and future land use/land cover changes and their impact on wetland area in Shashe sub-catchment, Zimbabwe. Model. Earth Syst. Environ., 7(1), 57–70. https://doi.org/10.1007/s40808-020-00963-y

Siraj, M., Zhang, K., & Mogen, M. (2018). Retrospective analysis of land use land cover dynamics using gis and remote sensing in central highlands of Ethiopia. J.Lands. Ecol, 11(2), 31–52. https://doi.org/10.2478/jlecol-2018-0005

Swallow, B., Sang, J., Nyabenge, M., Bundotch, D., Duraipappah, A., & Yatich, T. (2009). Trade-offs, synergies, and traps among ecosystem services in the Lake Victoria basin of East Africa. Environmental Science & Policy, 12(2009), 504–519. https://doi.org/10.1016/j.envsci.2008.11.003

Thonfeld, F., Steinbach, S., Muro, J., & Kirmi, F. (2020). Long-term land use/land cover change assessment of the Kilombero catchment in Tanzania using random forest classification and robust change vector analysis. Remote Sens., 2020(12). 1057. https://doi.org/10.3390/rs12071057

Tolessa, T., Sembeta, F., & Kidane, M. (2017). The impact of land use/land cover change on ecosystem services in the central highlands of Ethiopia. Ecosyst. Serv., 23(2017), 47–54. https://doi.org/10.1016/j.ecoser.2016.11.010

Turpie, J., Marais, C., & Blignaut, J. (2008). The working for water programme: Evolution of payments for ecosystem services mechanism that addresses both poverty and ecosystem service delivery in South Africa. Ecological Economics, 65(4), 788–798. https://doi.org/10.1016/j.ecolecon.2007.12.024

Tweddle, D., Cowx, I., Peel, R., & Weyl, O. (2015). Challenges in fisheries management in the Zambezi, one of the great rivers of Africa. Fisheries Management and Ecology, 2015(22), 99–111. https://doi.org/10.1111/fme.12107

Uwimana, A., Van Dam, A., Gettel, G., & Irvine, K. (2018). Effects of agricultural land use on sediment and nutrient retention in valley-bottom wetlands of Migaza catchment, southern Rwanda. Journal of Environmental Management, 219(1), 103–114. https://doi.org/10.1016/j.jenvman.2018.04.094

Vallet, A., Locatelli, B., Levrel, H., Wunder, S., Seppelt, R., Scholes, R., & Oszwald, J. (2018). Relationships between ecosystem services: Comparing methods for assessing trade-offs and synergies. Ecological Economics, 150 (2018), 96–106. https://doi.org/10.1016/j.ecolecon.2018.04.002

Van Der Kroon, B., Brouwer, R., & Van Beukering, P. (2013). The energy ladder: Theoretical myth or empirical truth? Results from a meta-analysis. Renewable and Sustainable Energy Reviews, 20(2013), 504–513. https://doi.org/10.1016/j.rser.2012.11.045

Vehrs, H., & Heller, G. (2017). Fauna, fire, and farming: landscape formation over the past 200 years in pastoral east pokot, Kenya. Human Ecology, 45(5), 613–625. https://doi.org/10.1007/s10745-017-9926-1

Walker, L. (2012). The biology of disturbed habitats. Oxford University Press.

Wang, L., Han, Y., Yu, H., Fan, S., & Liu, C. (2019). Submerged vegetation and water quality degeneration from serious flooding in Liangzi Lake, China. Frontiers in Plant Science, 10, 1504. https://doi.org/10.3389/fpls.2019.01504

Wantzen, K., & Mol, J. (2013). Soil erosion from agriculture and mining: A threat to tropical stream ecosystems. Agriculture, 3(4), 660–683. https://doi.org/10.3390/agriculture304066

Wasige, J., Groen, T., Smaling, E., & Jetten, V. (2013). Monitoring basin-scale land cover changes in Kagera Basin of Lake Victoria using ancillary data and remote sensing, International Journal of Applied Earth Observation and Geoinformation, 21(2013), 32–42. https://doi.org/10.1016/j.jag.2012.08.005

Watson, K., Galford, G., Sonter, L., Koh, I., & Ricketts, T. (2019). Effects of human demand on conservation planning for biodiversity and ecosystem services. Conservation Biology, 33(4), 942–952. https://doi.org/10.1111/cobi.13276

Were, D., Kansiime, F., Fetahi, T., & Hein, T. (2021). Carbon dioxide and methane fluxes from a tropical freshwater wetland under natural and rice paddy conditions: Implications for climate change mitigation. Wetlands, 41(5), 52. https://doi.org/10.1007/s11273-021-01451-4

Xu, X., Shrestha, S., Gilmori, H., Gumma, M., Siddiqui, B., & Jain, A. (2020). Dynamics and drivers of land use and land cover changes in Bangladesh. Regional Environmental Change, 20(2), 54. https://doi.org/10.1007/s10113-020-01650-5

Yaro, J. (2013). The perception of and adaptation to climate variability/change in Ghana by small-scale and commercial farmers. Reg Environ Change, 13(6), 1259–1272. https://doi.org/10.1007/s10584-013-0443-5

Yilma, A. (2010). Climate Change & adaptation in Africa//Ethiopia. International Water Management Institute (IWMI)

Zebire, D., Ayele, T., & Ayana, M. (2019). Characterizing soils and the enduring nature of land uses around the Lake Chamo Basin in South-West Ethiopia. Journal of Ecology and Environment, 43(1). https://doi.org/10.1186/s41610-019-0104-9

Zieba, F., Yengoh, G., & Tom, A. (2017). Seasonal migration and settlement around Lake Chad: Strategies for control of resources in an increasingly drying lake. Resources, 6(3), 41. https://doi.org/10.3390/resources6030041

Zohary, T., & Ostrovsky, I. (2011). Ecological impacts of excessive water-level fluctuations in stratified freshwater lakes. Inland Waters, 1(1), 47–59. https://doi.org/10.5268/IW-1.1.406