International Journal on Food, Agriculture, and Natural Resources
Volume 06, Issue 02, Page 80-86
ISSN: 2722-4066
http://www.fanres.org

Original Paper

Impacts of different Land Management practices on Ecosystem Services at Agew Maryam Watershed Wag-Himra zone, Ethiopia

Yalelet Abie[1], Haymanot Lamesgn[1], Yonas Reda[1], Hailu kindie[2]*
1) *Sekota Dryland Agricultural Research Center, P.O. Box 62, Sekota, Ethiopia*
2) *Amhara Region Agricultural Research Institute, P.O. Box 62, Sekota, Ethiopia*
*) *Corresponding Author: yaleletabie@gmail.com*

Received: 14 December 2023; Revised: 13 March 2025; Accepted: 03 June 2025
DOI: *https://doi.org/10.46676/ij-fanres.v6i2.258*

Abstract— **Accelerated soil erosion driven by anthropogenic activities has numerous adverse impacts on ecosystem services mainly affecting forest, rangeland, and agricultural ecosystems. To tackle the problem, substantial resources and efforts were invested in promoting soil and water conservation measures to improve agricultural production and environmental conditions and reduce land degradation. The study aimed to identify the impacts of different land management practices that hold different soil and water conservation measures on the provisions and regulations of ecosystem services. In this study, InVEST model version, 3.12.0 was used for other ecosystem services and to generate the scenario. The data type used for the model digital elevation model (DEM), rainfall erosivity map, soil erodibility map, land use map, watershed boundary, nutrient runoff proxy, and biophysical table were prepared from collected row data with Arc GIS 10.7.1. The total amount of sediment exported to the stream was 14.64t ha-1yr-1. Agew_Maryam watershed total score belongs slight rank. Sediment retention that had ecosystem service had minimized and retained soil from being eroded and transported in the Agew_Maryam watershed where 517.9 t ha-1yr-1 sediment ecosystem service is served and the difference of sediment retention from the bare land. Ecosystem service of nitrogen and phosphorus retention is 0.098 %ha−1 yr−1 and 5.6PPM ha−1 yr−1 of nitrogen and phosphorus retained in the watershed per hectare impacts on avoided treatment costs and or improved water security through access to clean drinking water. The watersheds have considerably avoided export and avoid erosion. That can service retention of sediment and nutrients by cover factors and conservation practices that decrease total suspended solids impacting health and distribution of aquatic populations, in reservoir sedimentation diminishing reservoir performance or increasing sediment control costs impact. Attention should be taken to land management with soil and water conservation practices to deserve better ecosystem service meant for livelihood.**

Keywords— Ecosystem service, Nutrient retention, Sediment retention, and Watershed

I. INTRODUCTION

Accelerated soil erosion driven by anthropogenic activities such as the conversion of natural ecosystems to agroecosystems has numerous adverse impacts on ecosystem services. Erosion adversely affects the productivity of the forest, rangeland, and agricultural ecosystem (Pimentel & Kounang, 1998). Soil degradation has been associated with a lack of adequate consideration of soil ecosystem services (Forouzangohar, et al, 2014). To tackle the soil erosion problem in the Ethiopian Highlands, the government and development agencies have invested substantial resources and efforts in promoting soil and water conservation (SWC) measures to improve agricultural production and environmental conditions to ultimately reduce land degradation (Addis, et al, 2016; Gebrernichael et al., 2005).

Identifying the impacts of SWC measures on ecosystem services is vital to enhancing agricultural production and maintaining the agro-ecosystem. Ecosystem services modeling tools allow the quantification, spatial mapping, and in some cases economic valuation of ecosystem services. The outputs from these tools can provide essential information for land managers and policymakers to evaluate the potential impact of alternative management options (Sharps et al., 2017).

Various national and international research institutions have been conducting studies on the impacts of SWC practices in the northwestern highlands of Ethiopia (Addis et al, 2020; Addis et al, 2015; Addis et al., 2016; Alemayehu et al, 2020; Alemayehu et al 2020; Klik et al., 2018; Klik & Strohmeier, 2015; Melaku et al, 2018). Despite such efforts, no comprehensive assessment has been done on the ecosystem services of SWC measures based on the provisions and regulations of ecosystem services to society. Ecosystem services are commonly defined as the benefits that humans obtain from ecosystem functions (Groot et al, 2002). Meanwhile, identifying the ecosystem services of SWC measures concerning the provisions and regulations of ecosystem functions should be given due attention. Therefore, this study aimed to identify the impacts of different land management practices on the provisions and regulations of ecosystem services. Therefore the objective of this study is to identify the Impacts of different land management practices that hold different soil and water conservation measures on ecosystem services and to determine soil ecosystem services under current land-use scenarios.

II. MATERIALS AND METHODS

A. Study Area Description

The study was conducted at the Agewu-Maryam model watershed in Sekota woreda, Waghimra zone, Amhara region, northern Ethiopia. The study area covers 157.685 ha, which is located at 38^{o} 55‘10‘‘to 38o 56’10” E longitudes to 12^{o} 31’ 40” to 12^{o} 32’30” N latitudes. The elevation of the watershed ranges from 2108 to 2395 m above sea level. Based on an ArcGIS watershed delineation using a 30 m* 30m grid Digital Elevation Model (DEM) produced by SRTM (Shuttle Radar Topography Mission).

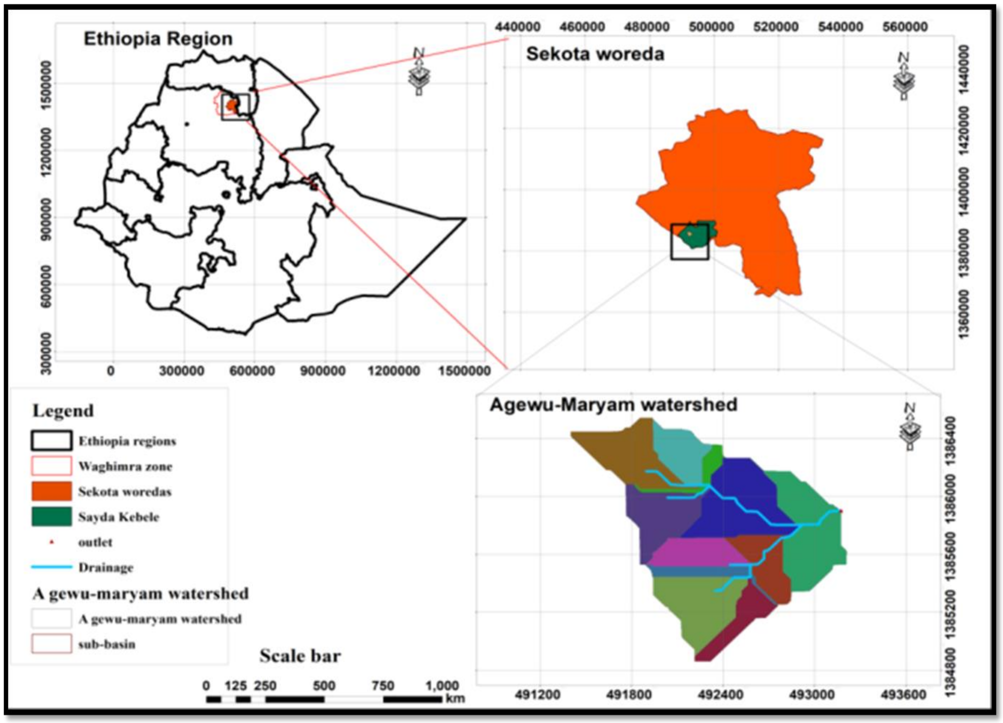

Fig. 1. Map of the study area

The watershed is characterized by highly rugged topography with steep slopes ranging from over 50 % (very steep slope) to less than 5% (gentle slope). According to (FAO-, (1998) the soil type of the Agewu-Maryam watershed was mainly of two types namely Eutric Regosol covering (38.73%) and Eutric Cambsol covering (61.268%). The soil textural class in the Agewu-Maryam watershed is mostly dominated by sandy loams covering 65.9% of the watershed, and the rest is sand clay loam 2.7%, loam 8.6%, and loamy sand 20.4% sand 2.4 %. The land-use type coverage is 63.168% of the total catchment area is covered with cultivated, 23.831% is bushland 8 % is area closure and forest, 1.986% is bare land, and 3.014%. The people of the Agewu-Maryam watershed exercise rain-fed, subsistence-oriented mixed crop-livestock farming. The major crops grown in the area are sorghum, Teff, Wheat, Barley, common bean, and field pea (Yonas, et al, 2024).

B. Model description

In this, study InVEST, model version; 3.12.0 was used for different ecosystem services to generate the scenario. The model selection relies on its simplicity, applicability across the globe, flexible scale, easily available data, relevance to many kinds of decisions, biophysical and economic output, multi-service assessment, and free and open-source as compared to other ecosystem models. Such as artificial intelligence for ecosystem services (ARIES), Co$ting Nature (C$N), Ecosystem Services Toolkit (EST), multi-scale integrated models of ecosystem services (MIMES), and Water World model (WW) (James & Helen, 2018). InVEST is a tool for geographic, economic, and ecological accounting on ES according to specific land use and land cover. This tool aims to inform managers and policymakers about the impacts of alternative resource management choices on the economy, human well-being, and the environment in an integrated way. The software also can evaluate specific ES trade analyses of different LULCs (baseline, current, and future). InVEST helps to map, quantify, and value multiple ecosystem services. In this study Sediment delivery ratio and nutrient delivery ratio were considered in the ecosystem services model.

C. Sediment delivery ratio

The sediment delivery model estimates the soil losses, sediment load delivered to the stream and retained by vegetation, and topographic features on an annual time scale. The sediment delivery module is a spatially explicit model working on the spatial resolution of the input DEM raster. For each pixel cell of the DEM raster, the model first computes the amount of eroded sediment, then the sediment delivery ratio, which is the proportion of soil loss reaching the catchment outlet. The amount of annual soil loss on the pixel is obtained using the Universal Soil Loss Equation (USLE) based on rainfall erosivity, soil erodibility, slope length and gradient, crop management, and support practice factors. Sediment dynamics at the catchment scale are mainly determined by climate, soil properties, topography, and vegetation; and anthropogenic factors such as agricultural activities. Sediment retention was estimated using the universal soil loss equation (USLE), which considers LULC information along with soil properties, rainfall data, and elevation as described in Equation 1.

A = R*K*LS*C*P ....(1)

where R is the rainfall erosivity (MJ/ha/(mm /h)) The R-factor is a multi-annual average index that measures rainfall's kinetic energy and intensity to describe the effect of rainfall on sheet and rill erosion; K (ton/MJ/ha/(mm /h)) is the soil erodibility a soil's susceptibility to erosion by erosive agents (water and wind) factor and the last three factors are dimensionless.

Sediment export (ton/yr) = USLE*SDR ....(2)

Where: SDR is the sediment delivery ratio

The data used for sediment delivery ratio are DEM, LULC, watershed biophysical table, flow accumulation, slope factor, management practice, rainfall erosivity, and soil erodibility

D. Nutrient delivery ratio

The template is used to format your paper and style the text. All margins, column widths, line spaces, and text fonts are prescribed; please do not alter them. You may note peculiarities. For example, the head margin in this template measures proportionately more than is customary. This measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire proceedings, and not as an independent document. Please do not revise any of the current designations. natural nutrient cycle. The data used for nutrient delivery ratio are DEM, LULC, watershed biophysical table, flow accumulation, and nutrient runoff proxy.

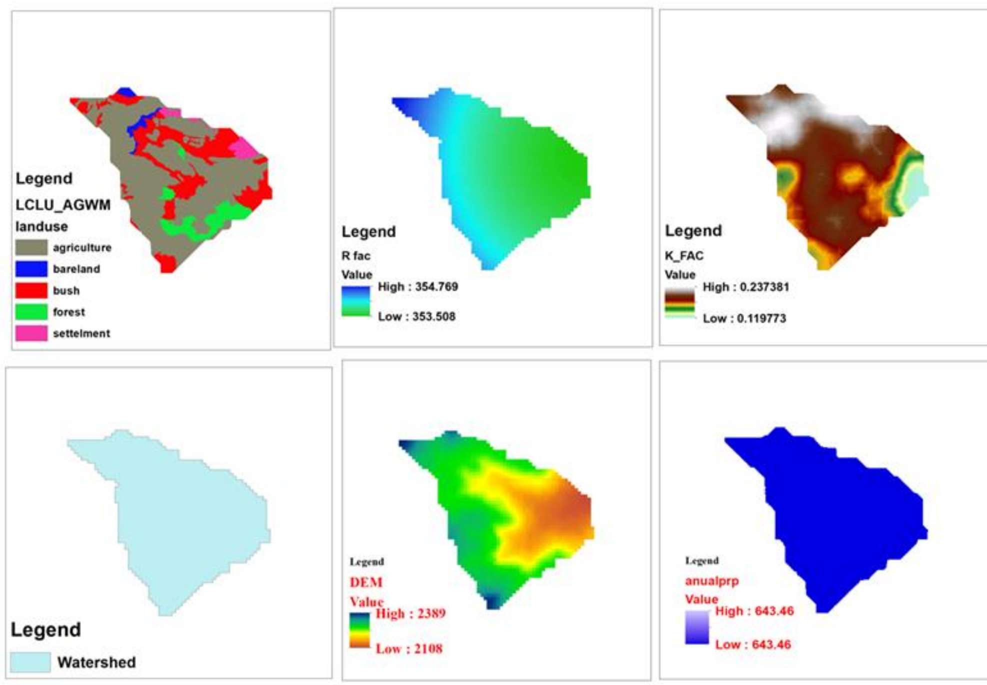

Fig. 2. Materials used for GIS software and InVEST model, Watershed boundary, DEM, Land use land cover, R factor, K factor, precipitation

The land use land cover and other datasets were obtained from various primary and secondary sources and prepared according to the models' requirements some of which are listed in Figure 2. Indicators of selected ecosystem services were quantified and mapped under current land use management scenarios. The ecosystem services map shows the locations of hotspots as well as potential trade-offs in service supply under new land configurations.

E. Total Potential Soil Loss

The sediment export from a given pixel I Ei (units: $tons \cdot ha^{-}1yr^{-1}$), is the amount of sediment eroded from that pixel that reaches the stream. Sediment export is given by:

$Ei = uslei \cdot SDRi$...(3)

III. III.Result and Discussion

A. Sediment delivery ratio

B. Total Potential Soil Loss

The sediment delivery ratio is the proportion of soil loss reaching the catchment outlet. The amount of annual soil loss on the pixel is obtained using the Universal Soil Loss Equation (USLE) based on rainfall erosivity, soil erodibility, slope length gradient, crop management, and support practice factors. Sediment dynamics at the catchment scale are mainly determined by climate, soil properties, topography, and vegetation from this context total potential soil loss per pixel from current land cover calculated from the USLE equation as described in Table 1 and Figure 3 was 14796.2t/watershed, which are 94.2 t/ ha^{-1} yr^{-1}.

TABLE I. INVEST SEDIMENT OUTPUT TABLE

FID	WS ID	Usle Total (T/Ha)	Sediment Export (T/Ha/Yr)	Sediment Depositon	Avoid Export	Avoid Erosion
1	1	94.24	14.64	0.5	123.75	1828
2	2	1724.5	532.6	28.1	28.1	0.05
Difference or Ecosystem service (ES)		1630.26	517.9	27.6	95.6	1827.9

Where WS ID: watershed identity FID: Field identity

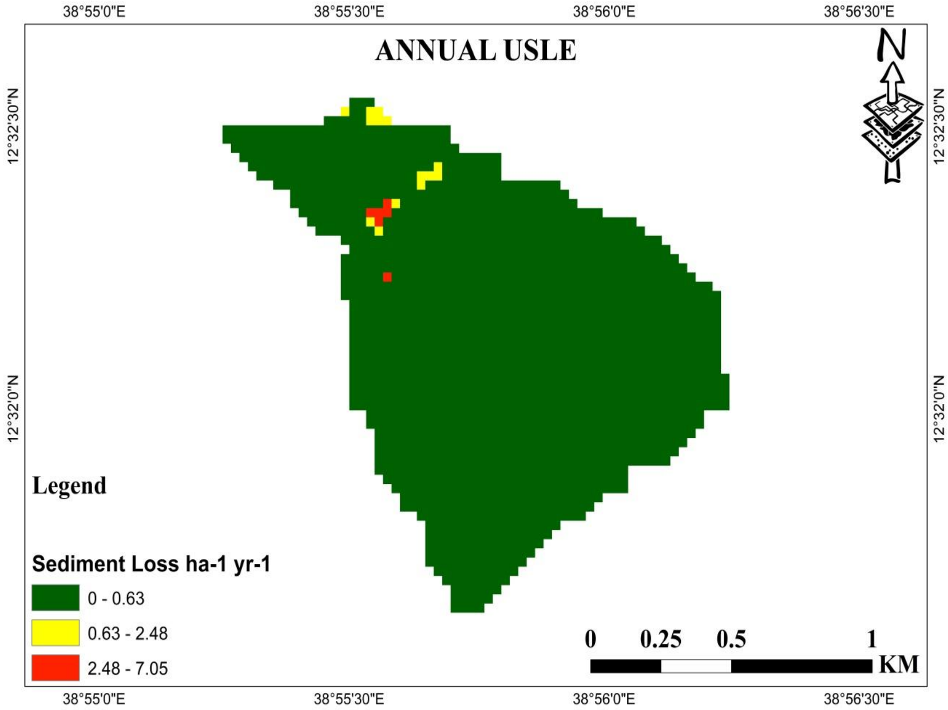

Fig. 3. The total amount of sediment exported

The total amount of sediment exported to the stream per watershed and hectare of Agew Maryam watershed is 2299.4t/ which is 14.64 t $ha^{-1}yr^{-1}$ as mentioned in Table 1 and Figure 3. The result is closely related to the sediment yield of the observed result of Agew_Maryam watershed which is about 14.149 t $ha^{-1}yr^{-1}$. The author stated that the total score was divided into five classes at approximate intervals of 1.5 and assigned numerical ranks from 1 to 5, and each rank was assigned a range of mean soil loss values as follows: score 0–1.5 = 0–5 t $ha^{-1}yr^{-1}$, score 1.5–3.0 = 5–15 t $ha^{-1}yr^{-1}$, score 3.0–4.5 = 15– 30 t $ha^{-1}yr^{-1}$, score 4.5–6 = 30–50 t $ha^{-1}yr^{-1}$, score N6.0 $\geq$ 50 t $ha^{-1}yr^{-1}$ based on this reference Agew_Maryam watershed belongs the range of 15-30 t $ha^{-1}yr^{-1}$. The ranks were also given verbal labels of "very slight," "slight," "moderate," "severe," and "very severe," respectively, and to that of range the watershed sediment export is under the "slight," rank. The rank corresponds well with the judgments of the group of experts for the three field observation stations in the UBNR basin(Haregeweyn et al., 2017). The result was 42 % much better than the earlier finding 2020 of the Agew_Maryam watershed as the author stated that the annual soil loss of the watershed was 25 t $ha^{-1}yr^{-1}$(Gebrehana et.al, 2020) (Chakoro et al, 2022) above the tolerable range of soil loss.

C. *Sediment Deposition /Retention*

The quantitative value of sediment retention of Agew_Maryam watershed is 80.75 t/watershed means 0.514 t $ha^{-1}yr^{-1}$ and for quantitative assessment of the retention service as discussed in Table 2 and illustrated in figure 4. The value of the retention service extracted from Figure 4 is based on the difference between sediment export from bare soil catchment and that of the scenario of interest, for those reason Agew_Maryam watershed retention service is about 81324.88t/watershed is 517.9 t $ha^{-1}yr^{-1}$ sediment ecosystem service is served and the difference of sediment retention from the bare land. Whereas, the baseline sediment retention was about 4331.072t/watershed or 27.586 t $ha^{-1}yr^{-1}$.

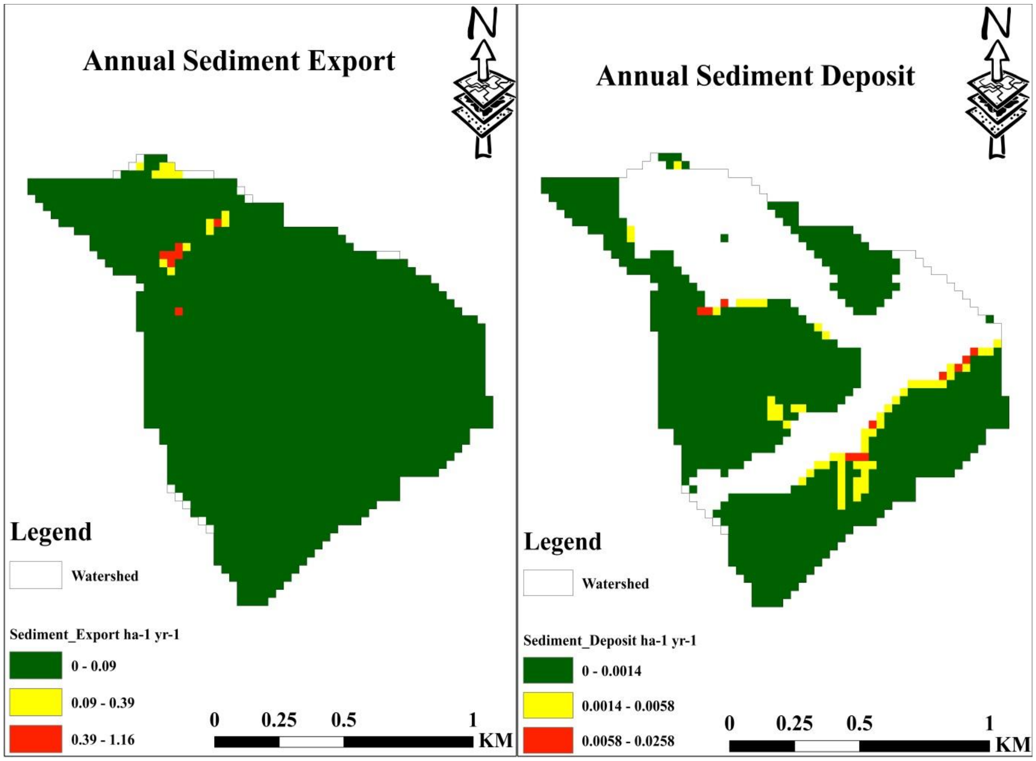

Fig. 4. Annual deposition and export

D. Nutrient delivery ratio

It is to map nutrient sources from watersheds and their transportation to the stream. This spatial information can be used to assess the service of nutrient retention by natural vegetation. The retention service is of particular interest for surface water quality issues and can be valued in economic or social terms, such as avoided treatment costs or improved water security through access to clean drinking water, and the output result of the InVEST model is presented in Table 2.

TABLE II. INVEST NUTRIENT DELIVERY RATIO OUTPUT TABLE

FID	WS ID	N- Surface Load	N -Surface Export	N- Total Export	P -Surface Load	P-Surface Export
1	0	0.113	0.015	0.015	6.4	0.8
2	1	0.071	0.017	0.017	4.18	0.98
Ecosystem		0.04	0.002	0.002	2.25	0.17

Where N: nitrogen p: phosphorus

Observed annual total nitrogen and phosphorus is 1.34%n ha−1 yr−1 or 0.008%n ha−1 yr−1 and 381.74ppm or 2.43 ppm ha−1 yr−1. The NDR model does not directly quantify the amount of nutrients retained on the landscape. However, if you have scenarios that are being compared with current conditions, the nutrient retention service may be estimated by taking the difference in nutrient export between the scenario and current conditions. This quantifies the difference in nutrients reaching a stream, based on the changes in land cover/climate/etc present in the scenario, which provides a way of evaluating impacts to downstream uses such as drinking water.

On this ground the nitrogen and phosphorus retention from the total N and P export is 0.002%N ha−1 yr−1 and 0.17ppm ha−1 yr−1 as described in Table 2, and illustrated in Figure 5 and Figure 6. The other option stated in the user guide suggested that nutrient retention can be calculated per pixel nitrogen and retention services within a single scenario.

The result of ecosystem service of nitrogen and phosphorus retention is 0.098 % ha−1 yr−1 and 5.6ppm ha−1 yr−1 as described in Table 2 and in Figure 5 of nitrogen and phosphorus retained in the watershed per hectare as described in Table 2, map in Figure 5 and Figure 6.

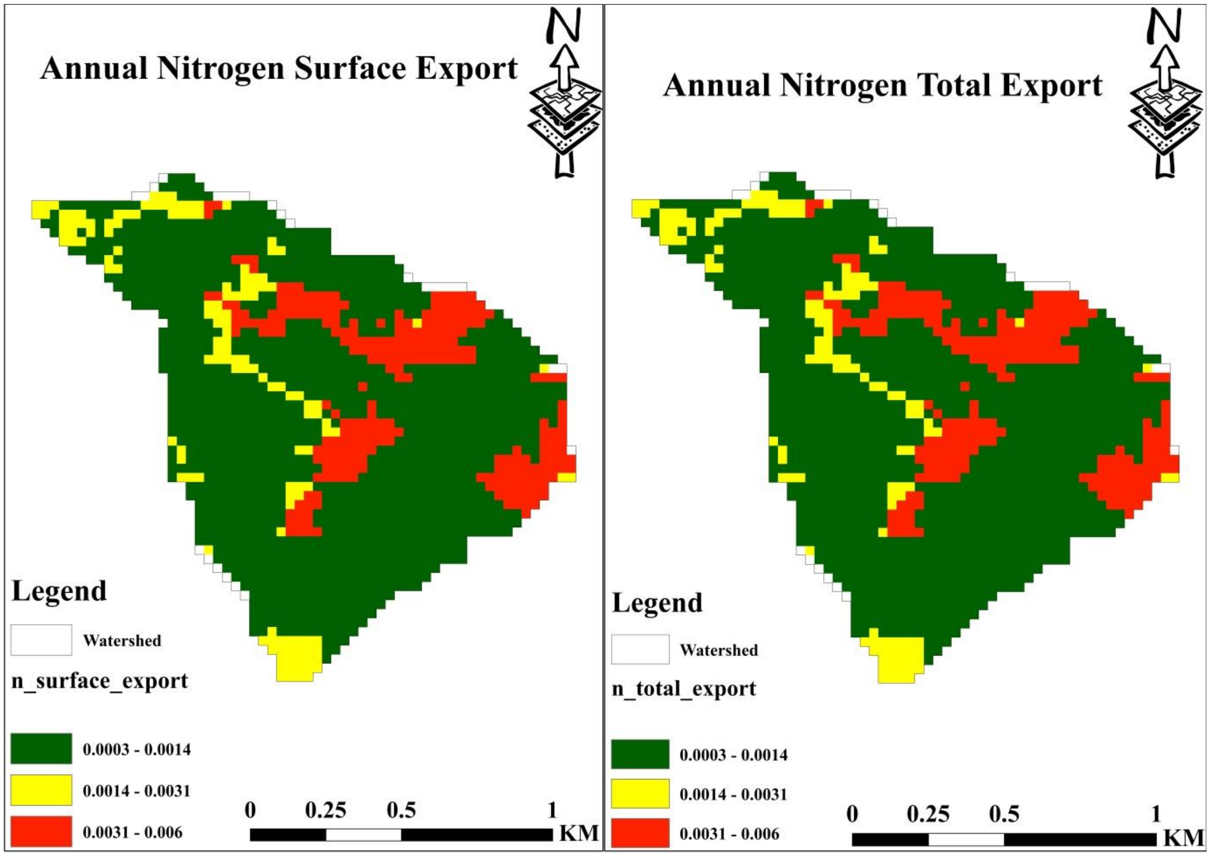

Fig. 5. Map of annual Nitrogen surface and total export %N/ha

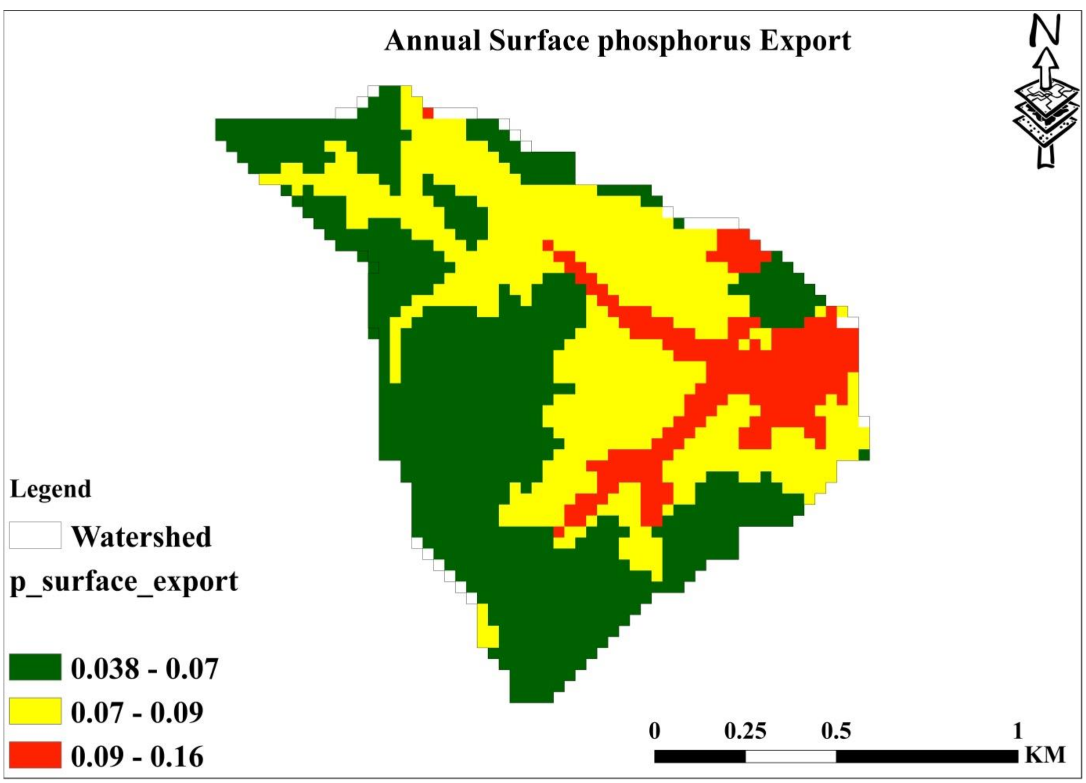

Fig. 6. Map of annual phosphorus surface export PPM/ha

IV. Conclusion and Recommendation

The study was used the InVEST SDR and InVEST NDR models for the soil loss and nutrient export at Agew_Maryam watersheds. The sediment export rates in the Agew_Maryam watershed are generally in 15 to 30 t ha-1yr-1 range because positive factors that hinder to export the eroded runoff. The watersheds have considerably avoided export and erosion that can service retention of sediment and nutrients by different land management and conservation practices that minimize total suspended solids impact, healthy and distribution of aquatic populations, in reservoir sedimentation diminishing reservoir performance or increasing sediment control costs and addition of much fertilizer application. Attention should be taken to land management with soil and water conservation practices to deserve better ecosystem service meant for livelihood.

Using the InVEST model can quantify and spatially map the watershed for ecosystem services of SDR and NDR models held by the land managers, watershed-based development stakeholders, and mega project owners with the addition of calibration for the Nutrient model in the InVEST model.

References

[1] Addis, H. K., Abera, A., & Abebaw, L. (2020). Economic benefits of soil and water conservation measures at the sub-catchment scale in the northern Highlands of Ethiopia. Progress in Physical Geography: Earth and Environment, 44(2), 251-266.

[2] Addis, H. K., Klik, A., & Strohmeier, S. (2015). Spatial variability of selected soil attributes under agricultural land use system in a mountainous watershed, Ethiopia. International Journal of Geosciences, 6(06), 605.

[3] Addis, H. K., Strohmeier, S., Ziadat, F., Melaku, N. D., & Klik, A. (2016). Modeling streamflow and sediment using SWAT in Ethiopian Highlands. International Journal of Agricultural and Biological Engineering, 9(5), 51-66.

[4] Alemayehu, A. A., Getu, L. A., & Addis, H. K. (2020). Impacts of stone bunds on selected soil properties and crop yield in Gumara-Maksegnit watershed Northern Ethiopia. Cogent Food & Agriculture, 6(1), 1785777.

[5] Alemayehu, A. A., Muluneh, A., Moges, A., & Kendie, H. (2020). Estimation of sediment yield and effectiveness of level stone bunds to reduce sediment loss in the Gumara-Maksegnit watershed, Nile Basin, Ethiopia. Journal of Soils and Sediments, 20(10), 3756-3768.

[6] Tamire, Chakoro, Eyasu Elias, and Mekuria Argaw. "Spatiotemporal dynamics of soil loss and sediment export in Upper Bilate River Catchment (UBRC), Central Rift Valley of Ethiopia." Heliyon 8.11 (2022).

[7] Duarte, G. T., Ribeiro, M. C., & Paglia, A. P. (2016). Ecosystem services modeling as a tool for defining priority areas for conservation. PloS one, 11(5), e0154573.

[8] Forouzangohar, M., Crossman, N. D., MacEwan, R. J., Wallace, D. D., & Bennett, L. T. (2014). Ecosystem services in agricultural landscapes: a spatially explicit approach to support sustainable soil management. The Scientific World Journal, 2014.

[9] Girmay, Gebrehana, Awdenegest Moges, and Alemayehu Muluneh. "Estimation of soil loss rate using the USLE model for Agewmariayam Watershed, northern Ethiopia." Agriculture & Food Security 9 (2020): 1-12.

[10] Gebremichael, D., Nyssen, J., Poesen, J., Deckers, J., Haile, M., Govers, G., & Moeyersons, J. (2005). Effectiveness of stone bunds in controlling soil erosion on cropland in the Tigray Highlands, northern Ethiopia. Soil use and management, 21(3), 287-297.

[11] Groot, R. d., Wilson, M. A., & Boumans, R. M. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological economics, 41(3), 393-408.

[12] James, B., & Helen, D. (2018). A guide to selecting ecosystem service models for decision-making: Lessons from sub-Saharan Africa: World Resources Institute.

[13] Klik, A., Schürz, C., Strohmeier, S., Demelash Melaku, N., Ziadat, F., Schwen, A., & Zucca, C. (2018). Impact of stone bunds on temporal and spatial variability of soil physical properties: A field study from northern Ethiopia. Land Degradation & Development, 29(3), 585-595.

[14] Klik, A., & Strohmeier, S. (2015). Monitoring of surface run-off and soil erosion processes Mitigating Land Degradation and Improving Livelihoods (pp. 145-170): Routledge.

[15] Klik, A., Wakolbinger, S., Obereder, E. M., Strohmeier, S., & Melaku, N. D. (2016). Impacts of Stone Bunds on Soil Loss and Surface Runoff: A Case Study from Gumara Maksegnit Watershed, Northern Ethiopia.

[16] Melaku, N. D., Renschler, C. S., Flagler, J., Bayu, W., & Klik, A. (2018). Integrated impact assessment of soil and water conservation structures on runoff and sediment yield through measurements and modeling in the Northern Ethiopian highlands. Catena, 169, 140-150.

[17] Mueller, N. D., Gerber, J. S., Johnston, M., Ray, D. K., Ramankutty, N., & Foley, J. A. (2012). Closing yield gaps through nutrient and water management. Nature, 490(7419), 254-257.

[18] Pimentel, D., & Kounang, N. (1998). Ecology of soil erosion in ecosystems. Ecosystems, 1(5), 416-426.

[19] Sharps, K., Masante, D., Thomas, A., Jackson, B., Redhead, J., May, L., . . . Jones, L. (2017). Comparing strengths and weaknesses of three ecosystem services modeling tools in a diverse UK river catchment. Science of the total environment, 584, 118-130.