Modeling of Sediment Export and Retention Capacity of Land covers in Taguibo Watershed, Butuan City, Philippines using InVEST-SDR

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https://doi.org/10.5109/7323372

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 10, pp.938-942, 2024-10-17. International Exchange and Innovation Conference on Engineering & Sciences
バージョン：

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Modeling of Sediment Export and Retention Capacity of Land covers in Taguibo Watershed, Butuan City, Philippines using InVEST-SDR

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Abstract: *Soil erosion stands as the predominant cause of land degradation on a global scale. This paper presents the utilization of the InVEST-SDR model to quantify the sediment export and retention capacity of Taguibo River based on different land cover types. The Integrated Valuation of Ecosystem Services and Tradeoffs- Sediment Delivery ratio (InVEST-SDR) model was used for quantification and mapping. Data such as Land Use Land Cover (LULC), Digital Elevation Model (DEM), rainfall, soil, and other biophysical parameters were incorporated as primary input data. The results demonstrate that palm cultivation contributes most significantly to sediment export, with 785.87 tons/year, 270.03 tons/year, and 918.58 tons/year in 2011, 2016, and 2021, respectively. Followed by forest, with contributions of 178.9 tons/year, 106.89 tons/year, and 184.84 tons/year in the same years. Emphasizing the crucial role of forests in mitigating soil erosion and maintaining watershed health.*

Keywords: InVEST-SDR, Taguibo watershed, Soil erosion, Sediment Export, Sediment Retention

1. INTRODUCTION

The most common cause of land degradation worldwide is soil erosion, which accounts for around 85% of the amount that affects both agricultural and forest ecosystem. This is due to several reasons, such as environmental changes and human activity, which lower the potential land productivity, and reduce crop yield by 17% [1]. Moreover, soil erosion types like upland surface erosion, soil mass movement, hillslope and gully, stream bank erosion, and bed erosion always lead to sediment accumulation. The climate, particularly the intensity of the rain, the characteristics of the soil, the topography, and the vegetation, all play a major role in determining the extent of land degradation [2].

Watershed management is crucial for the provision of water for domestic, agricultural, and commercial use. The Taguibo Watershed, the primary source of water for the entire city of Butuan, is currently facing a predicament in managing water distribution. This valuable resource is responsible for supporting a significant population of 372,910 residents (according to the 2020 census) in Butuan City and serves the National Irrigation Administration by supplying water to an irrigation dam that covers 761.90 hectares of rice [3]. However, the water distribution has been interrupted in multiple incidents due to the presence of suspended sediments originating from eroded soil. Once in the water system, these sediments can cause blockages and reduce the efficiency of water treatment processes, leading to disruptions in water supply.

Ureta et al. [3] stated that erosion and sediment delivery occur at varying geographical scales. Hence, measuring actual data by manually gathering measurements in the field is challenging and expensive. Since it is difficult to measure soil erosion on a large scale, the adaptation of soil erosion models has been a method to produce estimations. Various models for quantifying ecosystem services have been developed. Most of these models were designed along with geographic information systems (GIS) and remote sensing products, such models also include Integrated Valuation of Ecosystem Services Tradeoffs (InVEST). According to Derakhshan-Babaei et al. [4], InVEST is a model that aims to quantify and map ecosystem services. Thus, this study will utilize the InVEST-SDR model for quantifying sediment export and retention capacity in the Taguibo watershed.

2. MATERIALS AND METHODS

The InVEST-SDR model utilizes specific parameters, such as climate, soil properties, topography, vegetation, and anthropogenic factors to estimate soil loss, sediment export, and retention capacity per land cover type. Table 1 displays the following dataset needed with the corresponding values to run the InVEST-SDR model.

2.1 LULC Generation

This study used a satellite data source with a multispectral sensor to generate LULC in 2011, 2016, and 2021. This Satellite data was Landsat, which was available and was obtained from United States Geological Survey (USGS) Earth Explorer Global. The Landsat data was imported to Google Earth Engine (GEE) as an image collection and then executed pre-processing to correct existing atmospheric and geometric errors in the Landsat imagery. To classify the LULC in GEE, a supervised Support Vector Machine (SVM) classifier was applied.

Table 1. List of required inputs in InVEST-SDR

Input	Data type	Values *(range)*	Sources
Digital Elevation Model (DEM)	Raster file	50.9295 m-1903.37 m	CSU-CReATe (Center for Resource Assessment, Analytics, and Emerging Technologies)
Rainfall erosivity (R)	Raster file	2011: 538.184m — 550.285m 2016: 302.824m — 322.869m 2021: 282.146m — 293.268m	Terra Climate https://www.climatologylab.org
Soil Erodibility (K)	Raster file	Mountain soil: 0.19 Silt loam: 0.34 Butuan loam: 0.04 Camansa clay: 0.05	CSU-CReATe Food Agriculture Organization
LULC map	Raster file	-	USGS Earth Explorer https://earthexplorer.usgs.gov
Watershed	Vector file	-	CSU-CReATe, Food Agriculture Organization
Biophysical table	Non-spatial data matrix	rusle_c: Agricultural land:0.377 Forest: 0.003 Bare soil: 1 Settlement: 0.25 Palm: 0.2 Water: 0 rusle_p: 1 (all LC type)	[5][6]
Default values:			
Borselli k	Integer	2	[7]
Borselli IC_0	Decimal	0.5	[7]
Threshold Flow Accumulation	Integer	1000	[7]
Maximum SDR value	Integer	0.8	[7]
Maximum L value	Integer	122	[7]

This study utilizes secondary sources to aid the processing and implementation of study approaches. These datasets were integrated into the InVEST-SDR workbench. Then, the model computes first the eroded sediment using the revised universal soil loss equation (RUSLE) [8]. To calculate sediment export, for each pixel, the model first computes the amount of annual soil loss from that pixel, then computes the sediment delivery ratio (SDR), which is the proportion of soil loss reaching the stream [7].

Sediment export from a given pixel i E_I (tons/ha/year) is mathematically expressed as:

$$E_i = usle_i \cdot SDR_i \qquad (1)$$

The amount of the annual soil loss per pixel (ton ha−1 ·year−1) is estimated using the Revised Universal Soil Loss Equation (RUSLE) expressed as:

$$usle_i = R_i \cdot K_i \cdot LS_i \cdot C_i \cdot P_i \qquad (2)$$

Where R is rainfall erosivity, K is soil erodibility, LS is the slope length-gradient factor, C is the cover management factor, and P is the support practice factor. These parameters were automatically computed in the InVEST-SDR model processing through raster calculation. The model then produces raster maps, including sediment export and avoided export which was this study focuses on.

Finally, the InVEST model was validated through the comparison of the simulated data and the available observed data which is the Total Suspended Solids (TSS). To convert TSS units to tons/year, TSS was multiplied by water discharge.

2.2 Digital Elevation Model

This dataset is a raster grid of topography acquired from United States Geological Survey (USGS) Earth Explorer Global —DEM data was analyzed to extract information about basin characteristics relevant to sediment transport, including drainage area, elevation, slope steepness, slope length, flow direction, and flow accumulation. This served as a comprehensive and detailed representation of the land surface. This facilitated the researchers in delineating drainage systems, detecting variations in elevation that determine flow routes, and conducting an in-depth analysis of slope complexities that influence the mechanisms of sediment transport within the confines of the basin [9] [10].

2.3 Rainfall Erosivity

Rainfall erosivity map depicts the intensity and duration of rainfall within the specified area. The erosion potential increases with greater intensity and duration of the rainstorm [7]. The rain erosivity factor accounts for the influence of raindrops and the runoff caused by rainfall

[3]. R was obtained from published values for a tedious calculation; and for a given location, it is expressed in MJ mm/ha/h/year [7].

2.4 Soil Erodibility

Soil erodibility, denoted as (K), is a measure that reflects the vulnerability of soil particles to detachment and transport by forces such as rainfall and runoff, this measure is influenced by the biophysical and chemical properties of the soil. The unit of measurement for soil erodibility is (t ha− 1 h MJ−1 ha−1 mm− 1), and it is derived from data on various soil types [11].

3. RESULTS AND DISCUSSION

3.1 Land Use and Land Cover Map

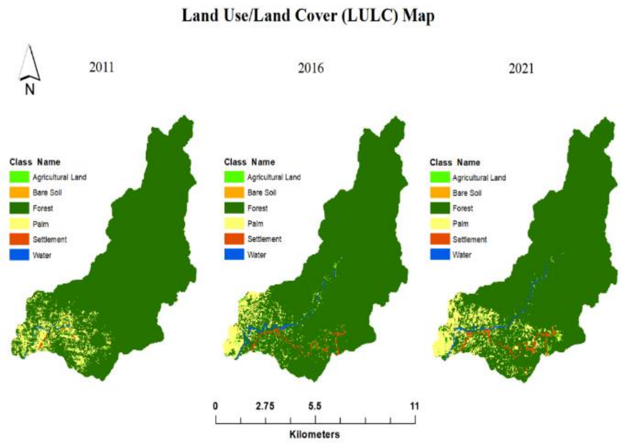
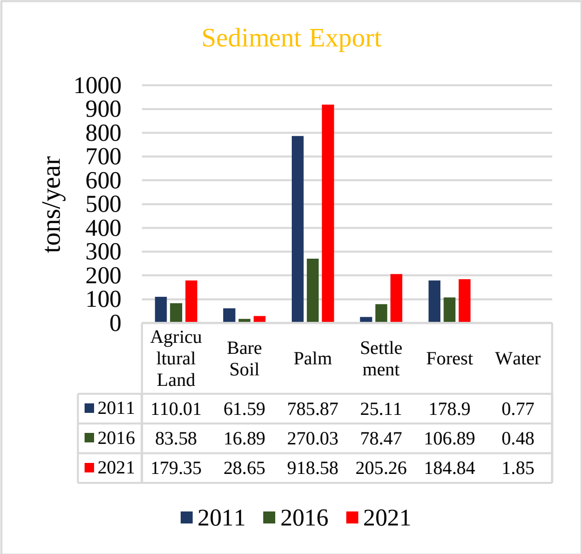


Fig. 1. LULC Change from 2011-2021

As presented in figure 1, it shows the generated map of land use and land cover of Taguibo watershed. The map is classified into six (6) classes: (1) Agricultural Land, (2) Bare Soil, (3) Palm, (4) Settlement, (5) Forest, and (6) Water. It also shows the spatial representation of LULC types from 2011-2021 and as well as the change in land cover over time, with forest having the largest coverage area, while bare soil has the least area coverage. Indicating that the forest coverage area decreases over time, this is due to land cover alterations.

3.2 Sediment Export

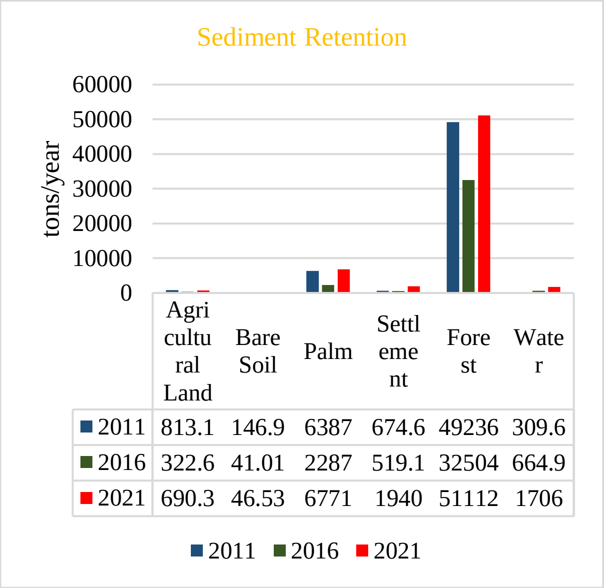


	Agricultural Land	Bare Soil	Palm	Settlement	Forest	Water
🟦 2011	110.01	61.59	785.87	25.11	178.9	0.77
🟩 2016	83.58	16.89	270.03	78.47	106.89	0.48
🟥 2021	179.35	28.65	918.58	205.26	184.84	1.85

Fig. 2. Sediment Export to streams by each land cover.

Figure 2 depicts that palm cultivation is by far the most dominant contributor lulc due to its notable contribution to sediment export. As noted by Satriawan et al. [12], soil erosion within palm plantations has the potential to lead land degradation due to increased erosion, decreased infiltration rates, and soil surface disturbance during land preparation. Followed by forest and agricultural land that consistently contribute sediment within the range of 106.9 tons/year to 184.8 tons/year. Given the extensive forest land coverage within the watershed, this outcome comes as no surprise. In contrast, settlements demonstrate a gradualincrease in sediment contribution over time. Conversely, bare soil experiences a decline from 2011 to 2016, and a slight increase in 2021. Water maintains consistency in sediment export contributions throughout the studied period.

3.3 Sediment Retention



	Agricultural Land	Bare Soil	Palm	Settlement	Forest	Water
🟦 2011	813.1	146.9	6387	674.6	49236	309.6
🟩 2016	322.6	41.01	2287	519.1	32504	664.9
🟥 2021	690.3	46.53	6771	1940	51112	1706

Fig. 3. Sediment Retention by each land cover

Figure 3 shows the sediment retention in various land covers over the years 2011, 2016, and 2021 revealing distinct trends and fluctuations. In forest, sediment retention has a notable decline from 2011 to 2016 but experienced a subsequent increase, surpassing the 2011 level by 2021 which implies that forest has the highest ecosystem provision. Additionally, the majority of vegetated areas – especially forestland – consist of mountain soils, and clay loam soil types which have the ability to retain water and nutrients effectively [3].

Palm sediment retention, on the other hand, displayed a decline from 2011 to 2016, followed by a notable increase in 2021. Among the remaining land covers were agricultural land, settlement, water, and bare soil; sediment retention ranged from 41.01 ton/year to 1939.67 ton/year. Bare soil consistently demonstrated the lowest sediment retention, followed by water, settlement, and agricultural land, which displayed retention within the specified range.

3.4 Model Validation

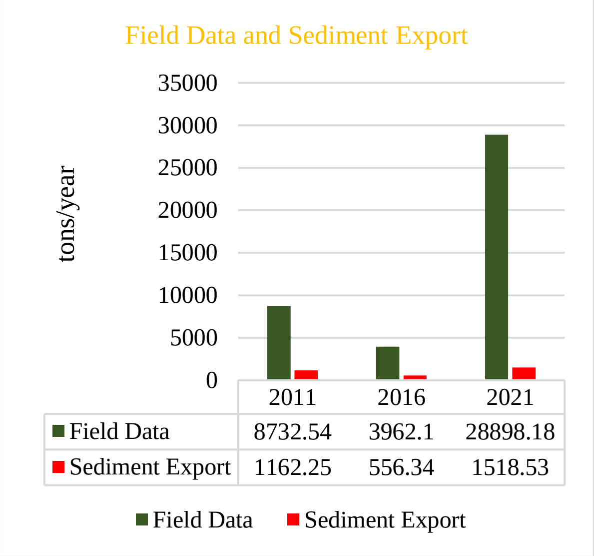


Fig. 4. Sediment Retention to streams by each land cover.

Figure 4 depicts the annual contributions of two datasets: the field-acquired data and the model-simulated data, as presented in Table 8. As observed, sediment export is comparatively less than the field-collected data, which is expected due to the model's limitations, as it only calculates the sheet and rill erosion [13]. The InVEST-SDR model did not account for additional erosion types, such as gully erosion, stream bank erosion, landslide, and tunnel erosion [12].

4. CONCLUSION

Applying InVEST within the Philippine context further creates opportunities for estimating ES such as sediment retention and sediment losses across landscapes. The research highlights the substantial contribution of palm cultivation to sediment export, while forested regions demonstrate the highest sediment retention capacity. Palm cultivation contributes to sediment exports of 785.87 tons/year, 270.03 tons/year, and 918.58 tons/year in 2011, 2016, and 2021, respectively. On the other hand, the forested area exhibits the highest sediment retention capacity, retaining 49235.86 tons/year, 32503.8 tons/year, and 51112.1 tons/year in 2011, 2016, and 2021, respectively.

These findings emphasize the nature of land cover changes and their environmental implications, emphasizing the importance of sustainable land management practices for the conservation of the watershed. The study concludes that addressing soil erosion and sedimentation is critical for maintaining the health of the watershed's ecosystem and ensuring the continued availability of clean water. However, the study acknowledges the limitations of the InVEST-SDR model, which only represents the overland erosion process and neglects other sediment sources in the study area. Future studies are recommended to consider these limitations when applying the InVEST-SDR model to other regions.

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