

Prediction Soil Erosion Using GIS-USLE Under Different Land Uses In West Timor, Indonesia

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Abstract. Transformation of land uses from several semi-arid agroecosystems in Indonesia: forest to settlement, dryland agriculture, and others had affected to soil erosion. This study was conducted to evaluate soil erosion at semi-arid Manikin Baki watershed, West Timor, Indonesia. USLE method was used to predict soil erosion supporting ArcGIS 10.3 software. The results showed that the highest soil erosion occurred at dryland farming (60.22% with total land cover 11% of total areas), while the smallest one went to the forest (0.20% with total land cover 42% of total areas). Another finding that soil erosion at Manikin Baki watershed was dominated by class I (12,251.77 Ha; 64.38% of total areas), while the smallest one was majored for class IV (1.59% of total areas).

Keywords: dryland farming, mixed cropping, forest land, GIS, USLE

1. Introduction

There are numbers of definition for dryland: upland, rainfed agriculture or unirrigated land. In general, dryland has a steep slope, shallow soil depth, and hilly-mountainous areas. Dryland with a steep slope and low soil depth could provide high potential of soil erosion risk and lack of water. Therefore agricultural practices only could be applied once a year [1]. According to geographic and agroclimatic position, East Nusa Tenggara (ENT) Province belongs to dryland in a semi-arid region. In 2015, the Central Bureau of Statistics (BPS) reported total dryland in ENT province was about 3,584,394 Ha (94%), while wetland (paddy field) was 210,774 Ha (6%). Some West Timor soils were prone of erosion risk due to moderate to high erodibility of soil. However, it has to support about 5 million people who recognized as the most top stunting problem (40.3%) nationally. According to climatic type Schmidt-Ferguson, ENT belongs to type D (moderate, vegetation on rainy season), E (semi-arid, vegetation savanna forest), and F (dryland, vegetation savanna forest). Its soils are mostly lack of soil organic matter [2].

Semi-arid Manikin Baki watershed is one area which potential of soil erosion risk located in Kupang regency, West Timor-Indonesia about 19,000 Ha. This area consists of 19 villages where

the basin became a vital source of water and land for rural people, especially at downstream. Any activity at upstream would affect social, cultural, and economics of people at downstream. For instance, lack of groundwater and high run off due to land-use change. Although this region has climate type E (semi-arid), but it still high risk of erosion. Soil erosion was supported by high intensity of rainfall at rainy season (1000-2000 mm yr⁻¹), slope gradient (> 15°), soil depth (< 1m), and less soil conservation practices. Land use changes from forest to cropping land at upstream (Baumata and Oeltua villages), and settlement (housing) were also other reasons [3]. The settlement in this context means house with a little yard (field) for cropping. Since the settlement could also include in soil erosion equation as a socioeconomic factor [4].

One study for global assessment indicated that Southeast Asia is one of the prone areas to soil erosion due to land-use change [5]. There are some reasons for dryland degradation in West Timor-Indonesia: pollution, intensive agriculture, soil erosion, un-suitable land uses, lack of fertile soil and water because of soil compaction, stony soil, and lack of organic matter, as defined by [6]. Type of farming systems had shown to effect on soil nutrients depletion in Ghana and recommended to apply legume crops to reduce soil erosion [7]. Not only land-use changes but also atmospheric CO₂ and climate change had also affected to decreasing of soil organic carbon by soil erosion [8].

Soil erosion had become one of the serious problems not only for the environment but also community [9], [10] because it is related to world food production [9]. About 10 million Ha agricultural lands had loss annually due to erosion, which affects to reduce food production [10] or 75% of fertile soil from soil surface loss due to soil erosion, and resulted in the decreasing of soil depth and soil fertility [9, 10]. Soil diminishing from agricultural land was 10-40 times faster than its formation. Ironically, at the same time when all sectors are focusing on improving crop production, on the other hand, land degradation is also increasing over the world. When population growth is increasing, food production per capita is also decreasing [11], approximately 35% surface soil was prone to soil erosion, and almost one-third of world agricultural land was lost due to erosion [9]. Thus, chosen for soil and water conservation practices become crucial to overcome all the risks on soil erosion (nutrient loss, soil moisture, income, and crop yield), as suggested by [12], agroforestry and vegetative barriers systems and applying proper technology [13].

Eventually, soil erosion is crucial for dryland in a semi-arid region where has limited arable land and high topography but have to supply enough production and quality of foods. Therefore, this study was conducted to estimate soil erosion at a semi-arid watershed in West Timor at various land uses.

2. Materials and Methods

This study was conducted through four steps (field survey, observation, data collection, and data analysis). Field survey and observation were conducted in February 2018 at Manikin Baki watershed to determine land cover and land uses from upstream to downstream areas. Primary and secondary data were also prepared to get more information before establishing fieldwork maps. A land unit map is from overlay soil, slope, and land uses maps, then produced land units (area

samples). Soil and slopping maps used in this study was Kupang regency soil map scale 1:350.000 from Watershed Management Bureau of Benain Noelmina (2012). Land use map was produced from satellite imagery SPOT 6, recorded in 2018 and ground checked.

Data collection was done by collecting all primary data such as slopping, soil depth, soil structure, land uses, and soil conservation practices. Climate data was collected from Geophysics and Meteorology Board of ENT from surrounding stations: Naibonat, Oekabiti, Baun, Naioni, Maulafa and Kelapa Lima stations for 13 years (2004 - 2017). Soil samples were also collected from each field (area samples) at 0-30 cm to analyze soil texture, organic matter, permeability, and soil mass.

Soil erosion could be calculated by numbers of equations (EPM, USLE, Koutsoyiannis and Tarla, RUSLE) [14]. This study used combination GIS/USLE methods [15], [16], [17], A=RKLSCP. Rainfall erosivity (R) uses equation of Bols (1978) in [18] $R = 38,8 + 0,35$ (annual rainfall-mm). Annual rainfall data for last 13 years (2004 - 2017) were collected from BMKG (Geophysics, Climatology and Meteorology Bureau) Kupang regency. Soil erodibility (K) uses Hammer (1978) $K = [2,173M^{1.14}(10^{-4})(12-a)+3,25(b-2)+2,5(c-3)]/100$, where M (soil particle size % silt+% fine sand) x (100-% clay), a (organic matter = % C x 1,724), b (code of soil structure), and c (code of soil permeability). Soils were collected at 0-30 cm depth and analyzed particles size, organic matter, soil structure, and soil permeability at soil laboratory. Factor length and steep slope (LS) were determined based on the steeps (%): 0-8%, 8-15%, 15-25%, 25-45%, > 45% (LS 0.25, 1.20, 4.25, 9.50, 12.0, respectively). The steep slope was observed directly in the field and compared to GIS map. The factor of land cover/vegetative and conservation (CP) was determined based on field observation and used classification by *Ministry of Public Work* (2012) (Table 1).

Table 1. Factor of land cover/vegetation and conservation (CP).

No.	Land cover	Slope classification/ CP			
		0-2%	2-15%	15-40%	>40%
1.	The settlement	0.0500	0.0500	0.0500	0.0500
2.	Irrigated rice field	0.0100	0.0100	0.0100	0.0250
3.	Rainfed rice field	0.0445	0.0625	0.0955	0.1365
4.	Nursery	0.0045	0.0104	0.0199	0.0338
5.	Agro forestry	0.0223	0.0313	0.0478	0.0683
6.	Natural forest	0.0002	0.0005	0.0010	0.0010
7.	Production Forest	0.0010	0.0010	0.0020	0.0020
8.	Shrubs	0.0010	0.0015	0.0020	0.0020
9.	Savanna (grassing)	0.0050	0.0100	0.0020	0.0020
10.	Bare ground	1.0000	1.0000	1.0000	1.0000

Source: Ministry of Public Work, 2012.

Eventually, estimation of soil erosion was determined based on erosion level classification (Director of Land Reforestation and Rehabilitation No.041/Kpts/1998): class I, II, III, IV (< 15, 15-60, 60-180, 180-480, > 480 t ha⁻¹ year⁻¹, respectively).

Land unit is a unit mapping analysis based on similar physical land characteristics. This study produced land unit mapping based on overlay three parameters (slopes, land uses, and soil type) using ArcGIS 10.3. The maps were used for deciding sample locations. There are six types of land uses used in this study (dryland cropping, forest, grassing- shrub, agroforestry, paddy field, and the settlement).

The erosion level was also determined at a unit land level. It resulted that from 141 land units, some of the body water (pond, check dam, and wetland) were ignored. Additionally, for the land that has total area <10 Ha and airport area were also eliminated from picked samples. Finally, it resulted in about 89 land units with total 18,634 Ha to be analyzed. Finally, all of 89 land units were overlaid with rainfall erosivity (three classes using isoerodent) then produced 287 points. All data were analyzed using Microsoft Excel.

3. Results and Discussion

Total soil erosion at Manikin Baki watershed was approximately 41,008 tons for total 18,634 Ha (average 2.20 t ha⁻¹ year⁻¹). The most extensive land areas at Manikin Baki watershed (Figure 1) was forest land (42%; 7,767 Ha), and the smallest was paddy field (6%; 1,067 Ha). Forest land has been occupied almost half of the total land cover (42%), but it has proven to be the lowest soil erosion level (82 t ha⁻¹ year⁻¹) (Figure 2a,b). On the other hand, dryland cropping although only 11% of entire land cover, it had produced the highest soil erosion level (24,79 t ha⁻¹ year⁻¹) or 61% of soil erosion (Figure 2a,b).

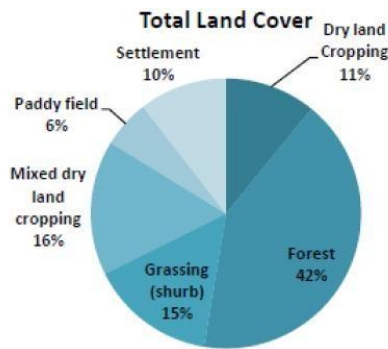


Fig. 1. Composition of total land areas per land uses (%)

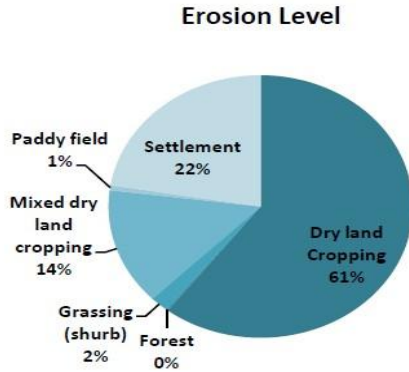


Figure 2a. Proportion soil erosion per land uses ($\text{ton}\cdot\text{h}^{-1}\cdot\text{y}^{-1}$).

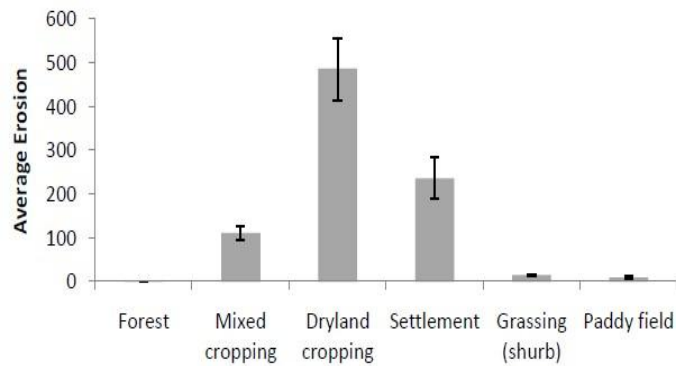


Figure 2b. Mean soil erosion per land uses with SE bars.

The local farming system, as commonly applied by all West Timor people was dryland cropping with dominant crops such as maize, cassava, banana, and beans. They used to apply slash and burn practices annually at forest land and grassing/shrublands towards rainy season (September-October). The main reason for doing that was to clean up all the land even from woody/annual trees as competitor plants and biomasses before planting. Thus, this is prone to soil erosion. Uncover surface soil with rare plants will effect to increase detachment particle soil, transportation, and sedimentation at new places. Conventional practices slash and burn could increase availability P [19], but it had affected on the changes of soil properties (physical, chemical and biological properties) of forest soils, and promoted leaching and erosion [20]. Soil losses due to run off could

reach 45-57 t ha⁻¹ (40-50 times compare to no burnt soil) with total runoff 142-181mm of 1,636 mm total rainfall and nutrients losses (N-265-290 kg.h⁻¹, P-23-28 kg.h⁻¹,K-1380-1710 kg.h⁻¹) [19]. In addition, the burned soil could also reduce infiltration, porosity, sorptivity and hydraulic conductivity [21], changes of soil mineralogy for all fire intensity [22]. Thus, it is indicated that soils with slash and burn practices had impacted land degradation (erosion).

Additionally, relief, land uses, and soil factors were other important factors that affect soil erosion at to semi-arid region. Manikin Baki watershed is mainly covered by hills with steep slope >15%, affect to increase runoff. Land use for settlement also has rare plants comparable to dryland agriculture which support soil erosion, as well as high soil erodibility factor (Table 2.). As found in this study that cropping provided the highest erosion (24,79 t ha⁻¹ year⁻¹) as well to other cultivations, like wheat lands (17.6 t km⁻² yr⁻¹) [23], cereal agriculture [24]. One case study in China, they defined land-use types and erosion level in order cropland > pastureland > woodland > grassland > shrubland [25], as well as in Turkey in which cropland > grassland > recreation > plantation and > forest [17] these comparable to our results cropping > settlement > mixed cropping (agroforestry) > shrub > paddy field > forest. This showed that human-induced transformation of land uses impacted to soil erosion nearly 60% [26].

Meanwhile, forest land has shown to have the lowest soil erosion compared to other land uses. Forest at semi-arid especially surrounding the watershed was dominated by woody trees like jati (*Tectona grandis*), mahoni (*Swietenia macrophila*), gamalin (*Gmelina arborea*), kabesak (*Acacia leucophaloea*), johar (*Senna siamea*), and sengon (*Paraseriantes falcataria*). Those type of plants have depth roots system, full crop header (shoot system), stratification shoot system, and producing high biomass that could add organic matter, improve soil structure and soil permeability. Thus, forest land has a lower soil erosion risk at a semi-arid watershed. Besides, grassing (shrub) and paddy field was also provided more moderate erosion due to the surface covering intensity.

Table 2. Statistic Description, mean of A=(RKLSCP).

Land uses	n	R	K	LS	CP	A (t.ha ⁻¹ .y ⁻¹)	SD	SE
Forest	60	604	0,76	3	0,001	1	1	0
Mixed cropping	53	602	0,81	3	0,080	111	116	16
Dryland cropping	51	608	0,84	3	0,388	486	507	71
Settlement	39	603	0,83	2	0,200	236	294	47
Grassing (shurb)	57	606	0,77	3	0,010	14	5	1
Paddy field	27	616	0,89	2	0,010	9	10	2
Total	287							

n (sample size); R (rainfall erosivity); K (soil erodibility); LS (length & slope); CP (vegetation & conservation); A (actual erosion); SD (standard deviation); SE (standard error).

Ultimately, refer to Director of Land Reforestation and Rehabilitation No.041/Kpts/1998 about classification of soil erosion, class I was the widest soil erosion in terms of land cover

(64.38%) with the lowest amount of soil erosion (1.1%), while Class V with high risk of soil erosion was only 1.59% of total land cover (Table 3).

Table 3. Classification of soil erosion at Manikin Baki Watershed.

No.	Soil Erosion (t.h ⁻¹ .y ⁻¹)	Classes of soil erosion	Amount of soil erosion (t.h ⁻¹ .y ⁻¹)	Percentage (%) of soil erosion	Land areas (Ha)	Percentage (%) of soil erosion
1.	< 15	I	456.39	1.10	12251.77	64.38
2.	15-60	II	2477.77	6.01	4286.07	22.52
3.	60-180	III	3637.55	8.83	1253.75	6.59
4.	180-480	IV	7747.20	18.81	935.93	4.92
5.	>480	V	26850.05	65.21	302.89	1.59

Soil erosion at class IV (heavy) and V (very heavy) depend on soil depth. Even though, those classes placed only 7% but still need to think seriously for the loss of soil at the land 1,239 Ha, especially those areas are part of catchment areas (Figure 3). This number would increase over a period of time if there were no conservation technology practices. Thus, it will affect to the decreasing of clean water at downstream areas which are the capital city of ENT (Kupang) and several villages in Kupang regency. Regarding this problem, as suggested by [12], strong commitment from the government by providing regulation, infrastructure, and service will encourage local farmers to apply a sustainable land management system.

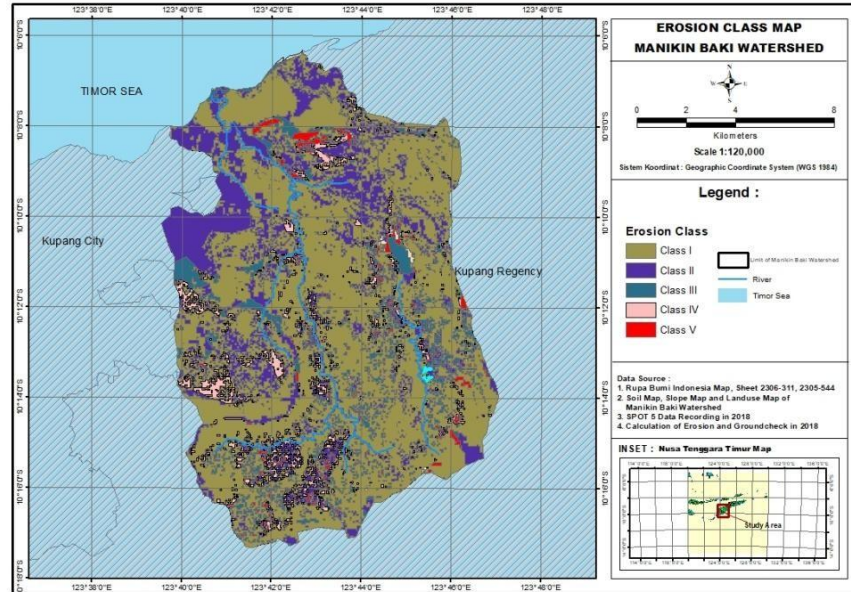


Fig. 3. Map of erosion class at Manikin Baki Watershed.

4. Conclusions

Soil erosion had been affected to some land uses at Manikin Baki watershed West Timor. The highest soil erosion occurred at dryland cropping (61%), followed by settlement (22%), dryland mixed cropping (14%), and the lowest one was forest land (0.20%). Dryland cropping induced more erosion, probably due to conventional practices of slash and burn for land clearing and its land cover. Although most of the land in Manikin Baki watershed was still at class I-III (1,7791.59 km²), area of 1,239.8 km² (class IV-V) could not be ignored; otherwise, this number will increase. Conservation technology should have been done for reducing erosion level, especially in lower soil depth and high soil erodibility. Further study on determining the dominant factor each land uses need to be accomplished. Thus, local government and farmers will be able to do appropriate soil, and water conservation technology based on the land uses.

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