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Determination of Farm Level Soil Erosion Using the Revised Universal Loss Equation (RUSLE)

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Abstract

The authors present this investigation concerning estimate of soil loss at a corn farm. Soil erosion is an enormous concern particularly in sloping agricultural lands. Heavy siltation of any river system after a heavy rain event upstream is indicative of soil erosion. However, it is difficult to convince farmers of the urgency to initiate soil erosion control measures at the individual farm level without providing estimates of soil loss. The objectives of this study were a) to generate terrain or digital elevation models (DEMs); and b) to estimate the extent of soil erosion in a representative corn-producing farm using the Revised Universal Soil Loss Equation (RUSLE). DEMs were generated by extracting data from Google Earth (GE), and conducting a topographic profiling using dual frequency survey-grade Global Positioning System (GPS) receivers on a representative corn-growing farm in Claveria, Misamis Oriental, Philippines. The annual amount of soil erosion estimated by the RUSLE for the modeled corn farm was 16 mTha-1 (4.08 cm) using GE DEM. On the other hand, the use of GPS-derived DEM had about 340% higher estimated soil loss at 55 mTha-1 (12.85 cm). The GE elevation was higher than GPS in 22% of the land area while 77% of the study land area had GPS elevation higher than GE. The soil erosion figures obtained in the study serve as an objective starting point in exploring ways and means to mitigate the loss of soil which is an agricultural resource of vital importance, thereby contributing to agricultural sustainability and productivity.

Keywords: soil erosion, digital elevation model, GPS, GE, RUSLE

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1. Introduction

The presence of an ideal soil structure for plant growth and development is ultimately dependent on soil aggregation, since soil moisture and nutrient retention depend on it. Soil aggregates bring together all the components of soil texture (i.e., sand, silt and clay), as well as organic matter. These different components are held together by different mechanisms (Hillel, 1998). For example, organic matter provides positive charges at the edges of its molecular structure, attracting negative charge from clay particles. Clay, on the other hand, attracts cations from fertilizer materials, keeping them within the root zone for ease of access to plant roots (Po *et al*., 2010). Outright soil particle removal through erosive forces disrupts these bonding mechanisms, leading to nutrient removal from the root zone as it moves either vertically down through the soil profile, or as run-off on the surface, making it unavailable to growing plants. One of the major sources of this disruption is erosive rain. To a farmer, soil erosion has real direct negative consequences on his ability to maintain a sustainable and resilient farming economic activity. With the movement of nutrients out of the immediate root zones of his crop, his productivity will be negatively impacted.

Everyone engaged in farming, especially those on sloping areas, is aware that soil erosion due to the erosive nature of rain coupled by susceptible terrain, occurs even in totally vegetated areas. Estimating the amount of soil that leaves the farm adds a dimension to the mental calculus a farmer takes into consideration when posed with the question of how sustainable and resilient his farming system is, and the extent to which he is willing to go to achieve it. A look at the literatures shows different levels of soil erosion from negligible to 255 $mTha^{-1}yr^{-1}$ (Gashaw *et al*., 2018; Toubal *et al*., 2018) at the watershed level. In croplands, it can even be as high as 400 $mTha^{-1}yr^{-1}$ (Asio *et al*., 2009). At that rate, it is akin to removing a sack of soil 40kg in weight every year from each square meter of a farm. Without intervention, the once fertile lands will eventually become unproductive. Schmitt (2007) estimated that about 416,000 ha of Negros Island's (Philippines) productive land in 1960 (i.e., 36% of the base productive land) will be rendered unproductive by 2050 due to soil erosion. The amount of soil loss reported by Delgado and Canters (2012) for a watershed in Claveria, about three kilometers to the southeast of the area covered by this present study, was about 12 $mTha^{-1}yr^{-1}$. Schmitt (2007) also argued for the appropriateness of using the RUSLE over other erosion prediction models, especially in data-challenged locations like the Philippines, due to its minimal data requirements. The DEM used in Schmitt's study as topographic input to the

RUSLE had a cell size of 90m x 90m land area dimension. At the 90m x 90m dimension, important micro-topographic features of a farm are lost, as most farms in the study area were equal to, or less than the cell size. In the Delgado and Canters (2012) study, DEM was derived by digitizing 20m contour intervals from a 1:50,000 paper map. However, this was not applicable to this present study, since the maximum elevation difference in the study field was lower than 20m. Hoffmann and Winde (2010) used elevation data derived from GE to produce a high-resolution DEM for wetland research, but the number of points they generated per hectare was less than 2. On a specific farm basis, determining how much is the contribution of the unique set of topographic and climatic patterns of a farm to soil erosion is difficult to pinpoint. At best, data from experimental plots are the ones quoted, which cannot be directly translated into real farm situations. Analyzing soil erosion at the watershed level, as most, if not all studies on erosion are conducted, has value in quantifying the amount of erosion. However, the proponents of the present study utilized a set of methodologies that is flexible enough for implementation at the level of a farmer's field.

It is the hypothesis of this study that when presented with the right information on the extent or quantified amount of soil erosion occurring within his own field, a farmer will eventually start adopting ways and means to protect his soil to ensure sustainability and resiliency. The objectives of the study were: a) to generate DEM from GE and a survey-grade, dual frequency GPS receiver; and b) to estimate the extent of soil erosion in a representative corn-producing farm using RUSLE. It is not within the scope of this study to identify the specific erosion management and control measures that a farmer can adopt.

2. Methodology

2.1 Study Site

The study area is in Barangay Gumaod, in the municipality of Claveria, Misamis Oriental in the Philippines, at false northing and easting of 479861m and 956662m (Philippines Reference System of 1992; PRS92), respectively (Figure 1). The location (~2 hectares) was representative of sloping areas grown with corn in Claveria and elsewhere. The soil type was classified as Jasaan Clay. No soil sample was obtained from the area to test

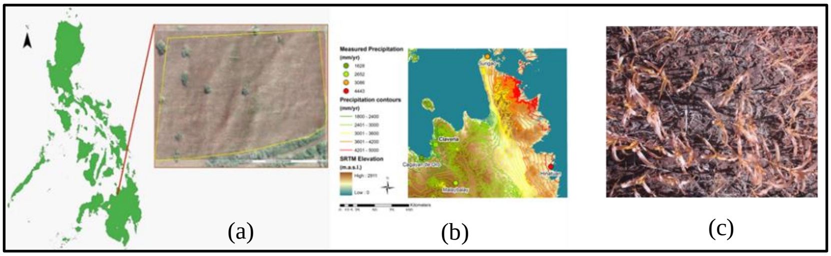

Figure 1. a) Location of the erosion study in Gumaod, Claveria, Misamis Oriental, Philippines with aerial imagery taken from GE, b) graphics showing precipitation point and interpolated surface in Northern Mindanao, Philippines, c) and top view of a section of the corn field taken 2 meters above the ground by a modified near-infrared Canon camera

for the nutritional status and organic matter. However, data compiled by the authors from the Regional Soils Laboratory of the Department of Agriculture Field Unit 10 showed that Claveria has an average soil organic matter (SOM) of 3.31%. Ground elevation points for this study were taken using Global Positioning System (GPS) receivers when the corn was more than 30 days after planting. No meteorological station was available in the area. Magcale-Macandog *et al.* (2010) estimated the average yearly rainfall as 2197 mmyear^{-1} for the municipality of Claveria, but no reference was provided on which agro-meteorological station it was taken from. Delgado and Canters (2012) reported nearly double that rainfall amount (4,000 mmyear^{-1}) at the 220-550 m above sea level locations in Claveria. The present study was conducted at 464 to 481 m elevation. Hijmans *et al.* (2005) generated a world-wide interpolated precipitation surface of the world at a 1 km ground horizontal resolution utilizing data from 20,590 recording stations. Based on the afore-mentioned precipitation surface, the present study area had an estimated annual normal rainfall of 2197 mmyear^{-1}.

2.2 GPS Ground Elevation Data Collection

Four survey-grade GPS receivers were used to conduct post-kinematic survey. The units consisted of Trimble 4000 SSE and Trimble 4000 SSI GPS units (Trimble, Sunnyvale, CA., USA). The survey collected three-dimensional (3-D) data consisting of latitude, longitude and elevation using the World Geodetic System of 1984 (WGS84) projection, logging at 5-second intervals. To simulate the tractor movement over the study area, the distance between transects followed by the study was approximated at 1.8m. Prior to the conduct of the survey, a temporary base station was established to facilitate the efficient conduct of the survey. The geographic coordinate of a temporary base location was determined by placing one of the GPS receivers at the survey monument (MSE3190) established by the Land

Management Bureau of the Department of Environment and Natural Resources, located approximately 2.5 km from the study location (Figure 2), within the Hinaplanan Elementary School.

Figure 2. GE aerial imagery showing study site location and the Philippine Reference System of 1992 (PRS92) GPS reference survey monument located inside the Hinaplanan Elementary School, Claveria, Misamis Oriental.

MSE3190 is a 3rd order survey monument of the PRS92. At the same time the unit at MSE3190 was logging at 5 second intervals, another unit was placed at the identified temporary base station and logging at the same rate. The set-up was left to collect positional data for three hours. The collected data were processed using Trimble Geomatic Office (TGO) v1.6 software. During the day of the topographic survey, one of the GPS receivers was placed on the exact location of the temporary base station, and kinematic survey proceeded (Figure 3). After the entire two hectares were covered by the survey, generating 2234 individual locational points (Figure 4a), the TGO software was used to correct the collected data for positional error, this time using the coordinates of the temporary base station as reference point. The baseline corrected points were exported to shapefiles and processed using ArcGIS 9.2 (ESRI, Redlands, CA, USA) software. Exploratory analyses were also conducted using Quantum GIS 1.80 software.

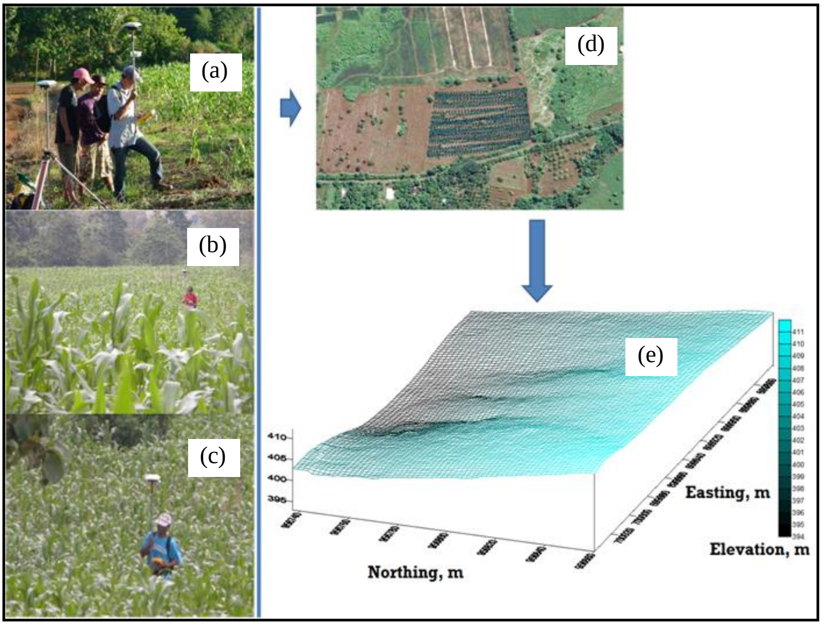

Figure 3. Three-dimensional geographic data collection showing Trimble Global Positioning System receivers (4000SSE/SSI) base and rover set-up (A); topographic survey of the corn production area with two personnel traversing the field at 1.8m width interval (equivalent to a mid-size tractor width; [B/C]); plotted topographic points taken by the GPS units (D); and interpolated surface derived from the topographic points (E) (Po and Sabines, 2013).

2.3 Elevation Points from GE

The study area was identified from GE 7.1 (Mountain View, CA, USA) aerial and satellite imagery. After pinpointing the location, a grid was created using QGIS through its research tool module spaced at 5m. The resulting shapefile of the grid was exported as a keyhole markup language file (kml) and opened in GE. The add path utility of GE was activated and at each intersection of the grid file that was within the study area, a vertex was created by clicking on the touchpad of the dual core computer running on Windows Vista used in the processing (Sony Vaio Computer with Intel Core Duo T7300 2.0GHz CPU). A total of 823 vertices were created (Figure 4b). The resulting pathway was saved as a kml and used as an input into a 3D Route Builder 1.3.9 software (HybridDSP GeoTools; Rijswijk, Netherlands). The 3D builder served as an interface with GE to supplement the two-dimensional latitude-longitude data generated through the path utility with elevation data, making the resulting output file 3-dimensional and appropriate to use for the creation of a DEM. Once the GE data was updated with elevation information, it was imported into ArcGIS/Quantum GIS for appropriate processing into a DEM.

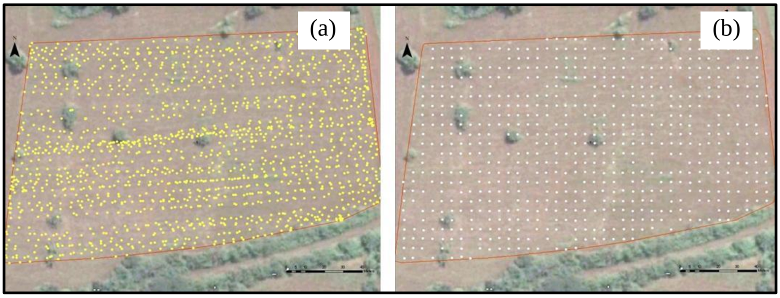

Figure 4. Three-dimensional geographic data collected using GPS (a) and GE (b) with points spaced at 1.8m and 5m, respectively at the erosion study site located in Barangay Gumaod, municipality of Claveria, Misamis Oriental, Philippines.

2.4 RUSLE Processing

The RUSLE quantifies net rill and sheet erosion occurring in an area. Net erosion is determined as the product of six factors, namely rainfall erosivity (R), soil erodibility (K), slope length (L), slope steepness (S), cover management (C), and erosion control (P). Under a Geographic Information System-driven analysis, L and S are combined into LS factor. RUSLE integrates the various conditions of the six factors in a year to come up with the amount of erosion.

2.5 Rainfall Erosivity and Runoff Factor (R)

R factor represents the component that causes the sheet and rill erosion process (Renard *et al.* 1991). Mathematically, it is expressed as:

$$R = \frac{1}{n}\sum_{j=1}^{n}\left[\sum_{k=1}^{m}(E)_k\,(I_{30})_k\right]_j \quad (1)$$

where:

E = Total storm kinetic energy
I_{30} = Maximum 30-minute rainfall intensity
n = Number of years to determine the average
m = Number of storms in each year (Renard and Freimund 1994)

However, due to scarcity of data, the model developed by El-Swaify *et al.* (1987) which is appropriate for tropical climate was used instead, to determine the *R* factor. The model is described as:

$$R = 38.5 + 0.35P \tag{2}$$

where:

P = Annual precipitation in millimeters (Merritt *et al.*, 2005)
R = Factor in $mTha^{-1}yr^{-1}$

This model has been applied in the Philippines as reflected in the works of Blanco and Nadaoka (2006), and Adornado *et al.* (2009) in Laguna Lake and Quezon Province, respectively.

2.6 K Soil Erodibility Factor (K)

K is soil loss per unit R. It represents the effect of soil properties and soil profile characteristics on soil loss (Romkens *et al.* 1997). Since the soil type in the study area was clay with organic matter at approximately 3.31%, a value of 0.16 was assumed in the calculations, based on the work of David (1988) as shown in Table 1. David (1988) derived the *K* numerical values for a number of Philippine soils based on the empirical equation developed by Wischmeier and Mannering (1969).

Table 1. Soil erodibility of clay soil (David, 1998)

OM (%)	Sand (%)	Silt (%)	Clay (%)	K
4.9	17	27	56	0.13
3.0	15	29	56	0.16
1.2	16	30	54	0.26

2.7 Slope Length and Steepness Factor (LS)

LS factor accounts for the influence of topography to soil erosion (McCool *et al.*, 1997). It considers slope gradient and slope length or the horizontal distance from the beginning of overland flow, to a point where deposition starts, or surface runoff becomes concentrated. Several studies proposed improvement to the calculation of the LS factor. For complex terrains, the model proposed by Mitasova *et al.* (1996) is the widely used technique. This method replaces the traditional computation of slope length with an upslope contributing area to integrate the impact of flow convergence as proposed by

Moore and Burch (1986), Desmet and Govers (1996) and Mitasova *et al.* (1996). Mathematically, this is expressed as:

$$LS = (m+1)\left[\frac{A}{a_0}\right]^m \left[\frac{\sin b}{b_0}\right]^n \quad (3)$$

where:

A = Upslope contributing area per unit contour width
b = Slope
a_0 = 22.1 m
b_0 = 0.09
m and n = Parameters equal to 0.4-0.6 and 1-1.3 (Mitsova *et al.*, 1996; 2000).

Adornado *et al.* (2009) and Blanco and Nadaoka (2006) employed this method in estimating the LS factor for the watersheds in Quezon province and Laguna lake, respectively. In this study, m is assumed as 0.4 and n is taken as 1.3, as suggested by Moore and Burch (1986) and Engel (1999). Mitasova *et al.* (2000) also had a similar recommendation for parameter values, specifically when both sheet and concentrated flow types are present.

2.8 Data Preparation and Analysis

2.8.1 R, K, C, and P

The study area defined by the cadastral boundary was digitized and rasterized. The area within the lot boundary was given a value of 1. The *K* (0.16), C (0.4) and P (1.0) factors were multiplied to the rasterized study area using the Spatial Analyst extension of ArcGIS. In calculating for *R*, the average annual P (2197 mm/year^{-1}) was multiplied to the rasterized study area and substituted to equation 2. Table 2 shows the formula implemented in Raster Calculator.

Table 2. Map formula used for estimating annual potential soil loss

RUSLE Factor	Formula
Rainfall and Runoff	R = 38.5 + 0.35*P Where P = SA x 2,197 mm/yr SA = Study Area
Soil Erodibility	K = SA x 0.16
Topographic	LS = (1.4)*((F*cs/22.13)**0.4)*((sin(S*3.14/180)/0.0896)**1.3) Where F = Flow accumulation S = Slope in degrees Cs = cell size, 1m
Crop Cover	C = SA x 0.4
Conservation Practice	P = SA x 0.4
Soil Loss	SL = 0.1*R*K*LS*C*P*SA

2.8.2 LS

To calculate for LS using equation 3, a flow accumulation grid representing the upslope contributing area and slope grid were generated. Both the data were derived from the DEM of the study area. DEM was generated using the procedure developed by Hutchinson (1988), which is a thin plate spline technique (Wahba, 1990) using an iterative finite difference interpolation method. This method was designed to generate hydrologically-correct DEM, thus applicable for this study. The elevation points were used as input for the interpolation.

The flow accumulation grid was generated using the technique by Jenson and Dominique (1988). The method calculates the number of cells that drains into a cell. It requires flow direction grid as input which serves as basis for the calculation. The flow direction was derived using the hydrologically-correct DEM of the study area. The LS factor grid was calculated based on the map formula described in Mitasova *et al.* (2000), as shown in Table 2.

2.8.3 Annual Potential Soil Loss (SL)

To determine the annual potential soil loss per cell, the grids of each RUSLE factors were multiplied together with the grid of the study area as indicated in Table 2. A conversion factor of 0.1 (conversion factor from 10,000 $m^2 1000kg^{-1}$) was also introduced to arrive at a soil loss unit of “kilograms per square meter” instead of tons per hectare. The result was presented in continuous surface by applying image stretching using the minimum-maximum method.

2.8.4 Soil Vulnerability

The annual potential soil loss was categorized into 6 classes representing degrees of vulnerability using the classification system used by Adornado *et al.* (2009), but annual soil loss was modified to kgm^{-2} (Table 3). The land area [A, in m^2] and its proportion [P, in %] to the total area were determined using equations 4 and 5.

$$A = \text{Number of Pixels x cell size} \tag{4}$$

$$P = (\text{A/Total Area}) \text{ x } 100 \tag{5}$$

Table 3. Soil vulnerability

Class	Description	Annual Soil Loss in tons/hectare	Annual Soil Loss in kg/m^2
1	None to Slight	0-5	0 - 0.5
2	Moderate	5-15	>0.5 – 1.5
3	High	15-50	>1.5 – 5.0
4	Very High	50-150	>5.0 - 15
5	Severe	150-300	>15 - 30
6	Very Severe	>300	>30

3. Results and Discussion

3.1 Interpolation Method

The use of the thin plate spline to generate the DEM was tested for its adequacy in representing the actual values of the collected points by removing 20% of the data points from both GE and GPS as validation points. The observed root mean square error (RMSE) was 0.188 and 0.092 for GE and GPS, respectively.

3.2 Topographic Profile

Visual comparison of the GE and GPS DEMs would indicate there is less detail present in the GE DEM compared to the GPS DEM (Figure 5). This result is not unexpected, as GE's DEM is based on the Shuttle Radar Topography Mission (NASA, 2013) with a grid size of 90m by 90m. If raw SRTM cells were used in the analysis, not much detail can be shown as the entire 2-hectare area would be mostly composed of two cells. Archived of satellite imageries in GE indicated the most recent year with data was 2016 covering the dates of August 11, March 15 and January 20. Of the three dates, only January 20 had an image of the bare ground (Figure 1), since the other two dates either had cloud cover or vegetation cover. Figure 1 clearly showed undulations that were reflected in the GPS DEM, but not in the GE DEM. This was a significant distinction between the two sources of DEMs that will have a bearing on excess precipitation surface flow, and ultimately soil erosion. Any intervention designed to slow down water movement and the associated soil erosion will have to take into account topographic complexity.

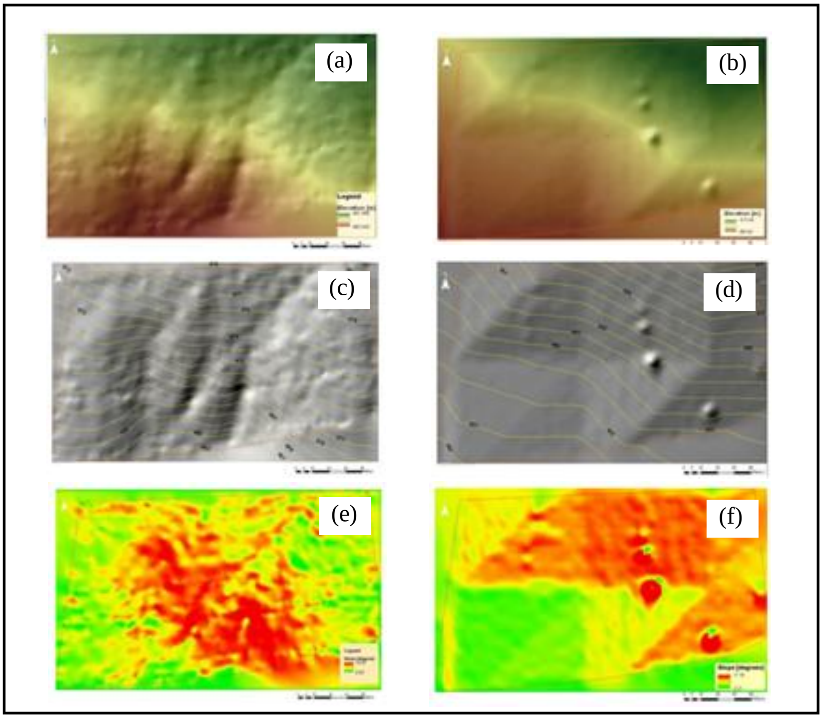

Figure 5. (DEM), contour, and slope of the corn growing area erosion study location in Gumaod, Claveria, Misamis Oriental, Philippines derived from GPS (a, c, e) and GE (b, d, f), respectively

3.3 Annual Potential Soil Loss

Table 4 shows the estimated annual potential soil loss across different erosion classes showing similar numerical trends for GE and GPS. In both methodologies, areas with very high erosion occurred in more than 59% of the farm, followed by the high erosion incidence class (>19%). However, only moderate correlation was observed between GE and GPS erosion figures (*r*=0.63). Spatially, a high proportion of the study field showed higher elevation using data from the GPS compared to the GE (Figure 6).

Table 4. Annual potential soil loss using GE and GPS derived DEMs

Class	Description	Annual Soil Loss (kg/m^2)	GE		GPS	
			Area (m^2)	%	Area (m^2)	%
1	None to Slight	0 - 0.5	530	2.60	1,007	4.90
2	Moderate	>0.5 - 1.5	488	2.40	64	0.30
3	High	>1.5 - 5.0	5,791	28.40	3,906	19.00
4	Very High	>5.0 - 15	13,027	63.50	12,112	59.00
5	Severe	>15 - 30	598	2.90	2,761	13.50
6	Very Severe	>30	81	0.40	665	3.20
		Total	20,515	100.00	20,515	100.00

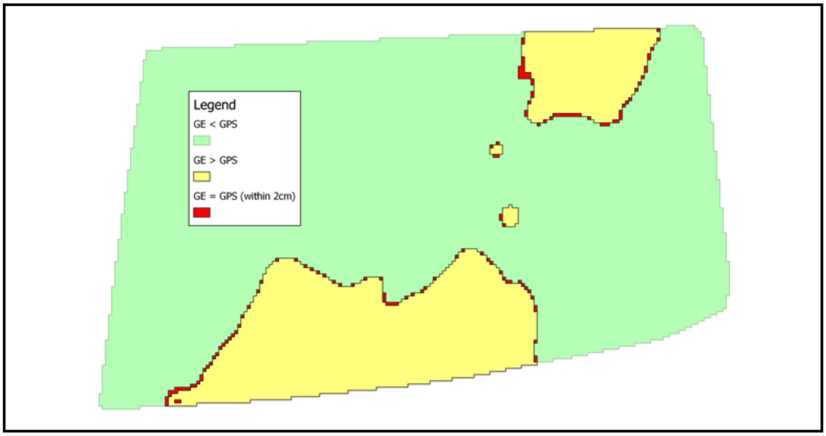

Figure 6. Over-determined (GE > GPS; 22% of land area) and under-determined (GE < GPS; 77% of land area) elevation sections of the erosion study area located in Gumaod, municipality of Claveria, Misamis Oriental, Philippines

Figures 5a and 5b show distinct ridge locations in the GPS compared to the GE surface. These are the distinct continuous yellow lines in Figure 7, and the dark green continuous lines in Figure 8. These ridges move runoff to either side of its topographic surface. The GE surface demonstrated more generalized straight line ridges which could be an artifact of the underlying SRTM DEM previously explained. On the ridge itself, runoff is low, but as soil and water move downslope (sheet erosion) in a rain event, it picks up momentum and starts creating rills which are concentrated channels of increased erosion.

The annual amount of erosion estimated by the RUSLE for the modeled corn farm was 16 $mTha^{-1}$ using GE DEM. On the other hand, use of GPS-derived DEM had about 340% higher estimated soil loss at 55 $mTha^{-1}$. The computed soil erosion figures were lower than those reported by Asio *et al.* (2009; 400 $mTha^{-1}yr^{-1}$), Gashaw *et al.* (2018; 237$mTha^{-1}yr^{-1}$) and Toubal *et al.* (2018; 255 $mTha^{-1}yr^{-1}$). The present study erosion figures are 133% (GE) and 458% (GPS) higher than the figure (12 $mTha^{-1}yr^{-1}$) reported by Delgado and Canters (2012) from a nearby watershed area No soil physical properties measurements were collected in this present study, but assuming a 1.3Mgm^{-3} bulk density for clay soil, the estimated depth of soil lost in a year can be as high 12.86 cm and 4.05 cm for GPS and GE, respectively (Figure 9).

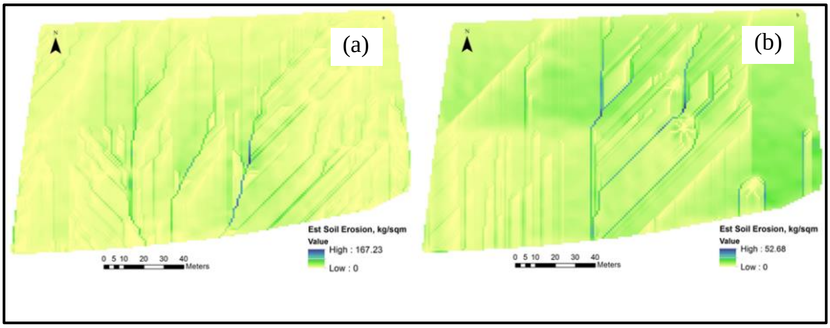

Figure 7. RUSLE computed annual soil loss estimates based on GPS (a) and GE (b) with yellow to dark blue color gradient representing lowest to highest annual potential soil loss in kgm^{-2}.

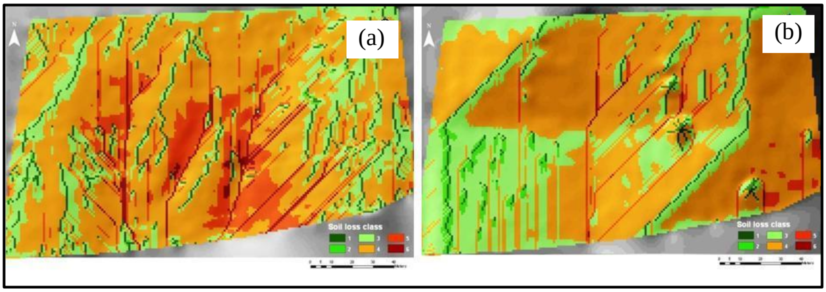

Figure 8. Net sheet and rill erosion severity computed through RUSLE using GPS (a) and GE (b) data with green to red color gradient representing slight to very severe erosion class.

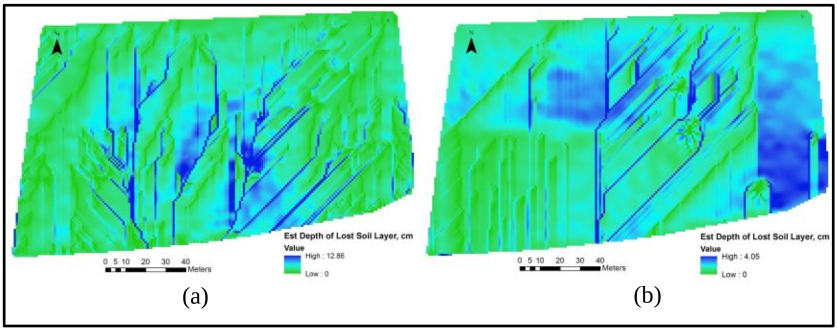

Figure 9. Annual estimated depth of soil loss (cm) at an assumed $1.3 Mgm^{-3}$ bulk density for GPS (a) and GE (b) based net rill and sheet erosions computed through RUSLE.

4. Conclusion and Recommendation

This study successfully generated two digital elevation models based on data collected using dual frequency, survey-grade GPS receivers and digitized elevation points from GE. Quality check conducted on the DEM using validation points yielded a very small amount of root mean square error, although the GE DEM had twice the level observed compared to the GPS DEM. The amount of estimated soil erosion differed between the two data sources, but both were higher than the erosion estimates from another study conducted at a nearby watershed. The methodology used in this investigation can serve as a model to estimate soil loss applied to other crop systems. No other parameters except those required by RUSLE were considered by the study. For future studies, use of other soil erosion models (i.e. EPIC and WEPP models) can provide more insight into the erosion problem. There was no ground verification done on the actual soil being eroded from the area, although an in-depth study of this component is recommended. Hence, the figures reported here will have to be taken with caution. The important contribution of this research is the ability to quantify, with some caveats, the soil erosion level at the farm level. Therefore, any farmer who is interested in pursuing continued sustainability of his production field can be provided with specific data using the framework presented in this study. Although not explored in this presentation, RUSLE has the capacity to accommodate in its soil erosion computation the impact of management intervention.

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