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Spatio-Temporal Estimation of Soil Erosion Using the Revised Universal Soil Loss Equation Model in Pantabangan-Carranglan Watershed, Philippines

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ABSTRACT

Soil erosion is both the cause and effect of land degradation. Land use/land cover conversion that changes the inherent landscape structure of watersheds leads to soil loss increase. Pantabangan-Carranglan Watershed (PCW) as a major source of irrigation, electricity, biodiversity, livelihood, and other ecosystem services, thus, it is imperative to spatially and temporally estimate the soil erosion within its boundary to assist and guide decision-makers in planning conservation and management of the watershed. Using the Revised Universal Soil Loss Equation (RUSLE) model, remotely sensed data, soil analysis, and geographical information system, the soil erosion rate in PCW was estimated. Results showed that there is increasing soil erosion in PCW over time. In 2010 soil erosion rate was estimated to be 134 tons·ha^{-1}·yr^{-1} which increased to 141 tons·ha^{-1}·yr^{-1} and 154 tons·ha^{-1}·yr^{-1} in 2015 and 2020, respectively. Considering the average soil erosion rate and land cover types in PCW, annual crop and open/barren land cover types have the highest average soil erosion rate through time with moderate and catastrophic erosion levels, respectively.

Keywords: soil erosion, watershed, land cover, RUSLE model, GIS.

INTRODUCTION

Land degradation is a result of land intensification and conversion that starts with human interventions resulting in changes in the inherent land cover. The inherent land degradation that occurs in a certain landscape is exacerbated by land use/land cover changes that destroy the ability of the land to resist and regenerate from natural factors of land degradation. The system of recovery becomes slower than the degradation process which causes the need for conservation practices.

Soil erosion is the removal of surface soil in accelerated form with the action of water, wind, tillage, ice, and gravity (FAO and ITPS, 2015; GaSWCC, 2000). These accelerated losses of topsoil are considered as "the greatest challenge for sustainable soil management" by the Food and Agriculture Organization of the United Nations.

Soil erosion as a global concern post different major problems in different ecosystems. In a watershed scenario, the deposition of sediments in the reservoir decreases the loading capacity of a watershed. Pantabangan-Carranglan Watershed (PCW) is located in the province of Nueva Ecija and some of its ridges are within Nueva Vizcaya and Aurora provinces. PCW is considered by the government as a critical watershed as it generates electric supply and serves as a reservoir for irrigation in the near provinces (Pulhin et al., 2006). The ecosystem services that the Pantabangan-Carranglan Watershed provides are not limited to electric generation and irrigation, but it also serves as a habitat for various organisms, provides flood control services, and performs socio-economic functions.

In a watershed, it is critical to conduct land conservation practices as well as formulate the policies that can control and mitigate soil erosion. In the formulation of such, understanding the soil erosion process is essential. The use of the well-known Revised Universal Soil Loss Equation (RUSLE) model, remotely sensed data, and geographic information system spatial and temporal estimates of soil erosion within the watershed were provided. Specifically, this study aimed to (1) determine the average soil erosion rate of PCW in 2010, 2015, and 2020 using a raster calculator, (2) analyze the impact of land use/land cover changes over time on soil erosion in Pantabangan-Carranglan Watershed, and (3) locate the areas in the watershed where massive soil erosion is occurring,

MATERIALS AND METHODS

Study area

Pantabangan-Carranglan Watershed, based on the 1999 land use map as cited by Saplaco et al. (2001), has a total area of 97, 318 ha and 4,023 ha of which is a water reservoir. It lies between 15.7333° to 17.46667° latitude and 120.6° to 122° longitude. The watershed is located within the proximity of different municipalities within the three provinces in Central Luzon: the municipalities of Sta Fe, Aritao, Alfonso Catañeda, and Dupax del Sur in the province of Nueva Vizcaya, the municipality of Maria Aurora in the province of Aurora, and municipalities of Bongabon, Llanera, Pantabangan and Carranglan in the province Nueva Ecija (Saplaco et al., 2001).

Situated in Pantanbangan-Carranglan Watershed is the Pantabangan Lake, which serves as a water reservoir that supplies water to the connected Pampanga River for agricultural lands within the near provinces. Also, the Pantabangan Dam is located in the watershed; it generates 100,000 kilowatts of hydroelectric power that supply electricity in the region (National Power Corporation, 1997).

The delineation of the Pantabangan-Carranglan Watershed was done using Digital Elevation Model Shuttle Radar Topography Mission (SRTM) 1 Arc Second through watershed delineation in ArcGIS Pro software.

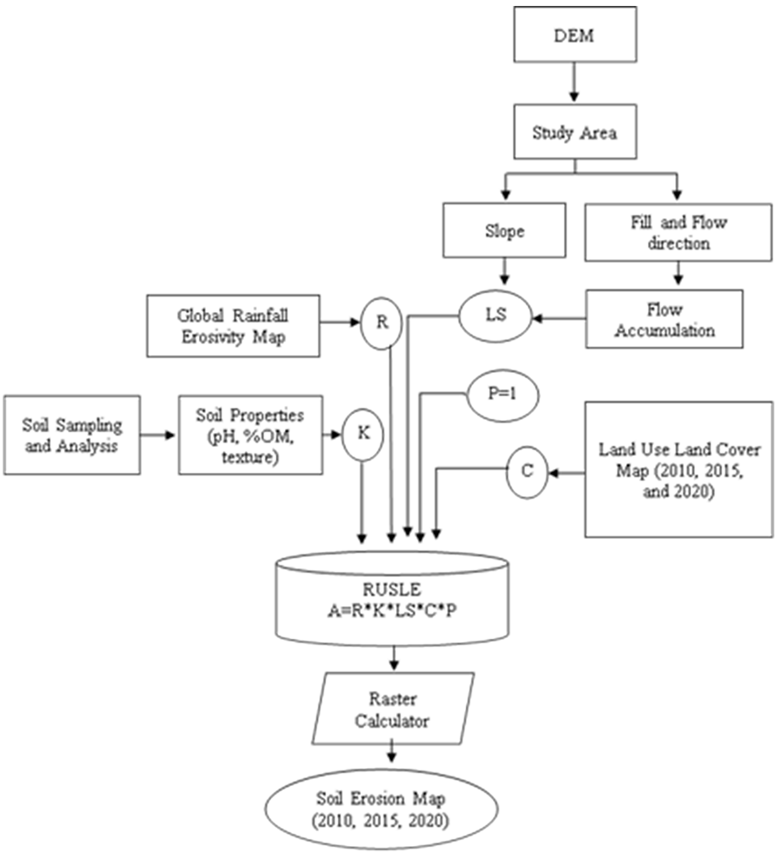

Figure 1. Flowchart of methodology of the study

RUSLE Model

The flowchart of the methodology of the study is illustrated in Figure 1. The Revised Universal Soil Loss Equation (RUSLE) was used in estimation of soil loss ($t \cdot ha^{-1} \cdot year^{-1}$). In determining the soil loss of the study area, the equation below with five factors was considered (Wischmeier and Smith, 1958):

$$A = R \times K \times LS \times C \times P \qquad (1)$$

where: symbol "A" represents the resulting soil loss ($t \cdot ha^{-1} \cdot year^{-1}$) and computed by multiplying the five factors: the ability of rainfall to cause erosion or rainfall erosivity (R), ability of soil to resists erosion or soil erodibility (K), steepness and length of slope (LS), conservation practices employed (P), as well as the land use and land cover present (C). Each factor has rasterized layer while P is represented by 1. The six factors were input in raster calculator to produce soil erosion map.

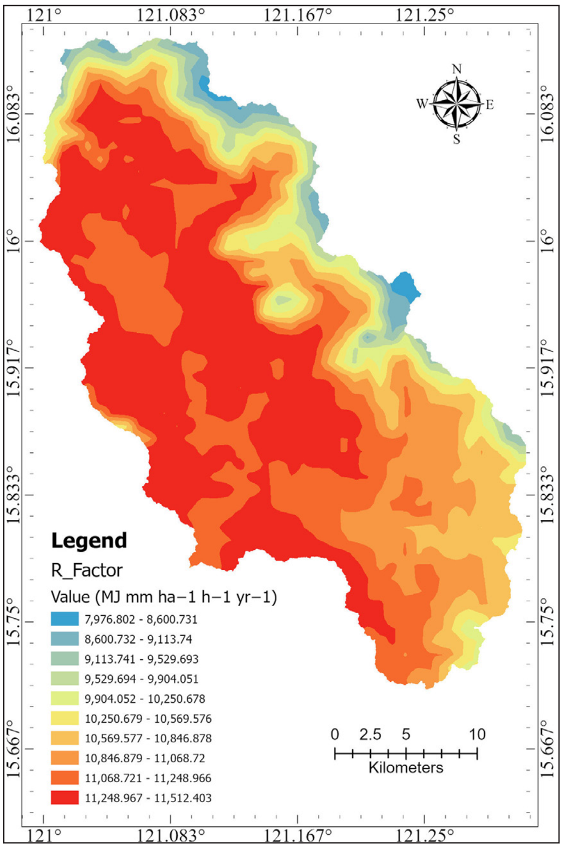

Figure 2. Rainfall erosivity (R) factor map of PCW

Rainfall erosivity factor (R)

In this research, rainfall erosivity map produced by Panagos et al. (2017) was used. The global rainfall erosivity map that was used is produced using collected rainfall data with high-temporal resolution, erosivity factor (R) calculation from different rainfall station, normalization of calculated R-factor with different time steps (1 min to 60 min), and spatial interpolation of point values of R-factor (Panagos et al., 2017). In accordance with predicted vs. measured R-factor according to Panagos et al. (2017) the produced map has R-squared of 0.811 compared to Naipal et al., Nachtergaele et al. (2010), and Yang et al. with R-squared of 0.155, 0.385, and 0.207, respectively.

The delineated PCW boundary was used to clip the Global R map. Results show that the R-Factor in PCW ranges from 7,976.802 $MJ \cdot mm\ (ha \cdot h \cdot yr)^{-1}$ to 11,512.403 $MJ \cdot mm\ (ha \cdot h \cdot yr)^{-1}$. The northeast part of PCW is within the range of lower rainfall erosivity compared to southwest part with higher range of rainfall erosivity, as shown in the Figure 2.

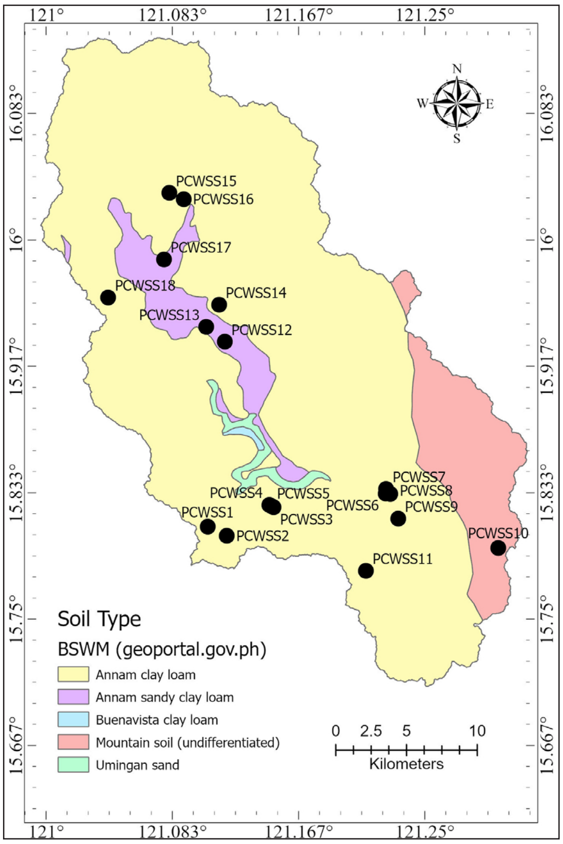

Figure 3. Soil sampling sites within the different soil types of PCW

Soil erodibility factor (K)

In determining the soil erodibility factor, soil samples within the boundary of PCW were collected. Using the soil type map produced by

BSWM downloaded through geoportal.gov.ph number of soil samples were determined. Using a very extensive survey, one sample point was collected per 5.000 ha of watershed. As shown in Figure 3, three soil samples were collected on Annam Sandy Clay Loam, 1 for undifferentiated mountain soil and 14 for Annam Clay Loam with a total of 18 soil samples. In each sample point, about 3 kg of soil samples were collected within the depth of 0–30 cm. These soil samples were properly labeled and sealed and prepared for laboratory analysis. Location were soil sample collected were geotagged for interpolation of K-factor using ArcGIS Pro software. In determining the K-factor of PCW equation by David (1988) was used. It was based on the equation produced by Wlschmeier and Mannering (1969).

$$K = \begin{bmatrix} (0.043 \times pH) + \left(\frac{0.62}{OM}\right) + \\ + (0.0082 \times S) - (0.0062 \times C) \end{bmatrix} \times Si \quad (2)$$

where: pH – pH of the soil, *OM* – organic matter in percent, *S* – sand content in percent, *C* – clay ratio – %clay/(%sand+%silt), Si – silt content = %silt/100.

The required data for the computation of K was determined using different laboratory methods as shown in Table 1. Laboratory analyses were conducted at Department of Soil Science, Central Luzon State University for soil pH and textural distribution following their laboratory protocol, and percent organic matter were analyzed in Analytical Service Laboratory of Division of Soil Science, University of the Philippines Los Baños also following their protocol. Using the calculated K-value it was input on sample points and interpolated using ArcGIS Pro to produce K-factor map. Inverse distance weighting (IDW) with power of 2 was used in the interpolation. Soil erodibility map of PCW as shown in Figure 4 has the lowest k-value of 0.215 tons ha·h $(\text{ha·MJ·mm})^{-1}$ and highest k-value of 1.214 tons·ha·h $(\text{ha·MJ·mm})^{-1}$

Table 1. Soil properties and their method of analysis

Soil property	Method of analysis
Soil pH	pH meter (soil to KCl system 1:5 m/v)
Soil textural distribution	Hydrometer method
Percent organic matter	Walkley-black method

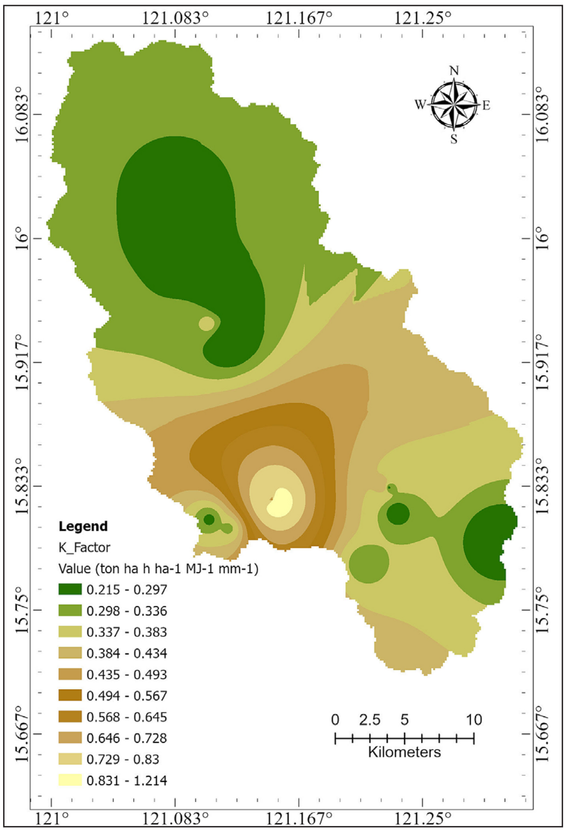

Figure 4. Soil erodibility (K) factor map of PCW

Slope length (L) and steepness (S) factor

The LS factor or topographic factor is represented by the standard ratio of steepness of the slope and the length of the slope. For the LS factor of the study area, it was computed using equation number 3 which is proposed by Moore and Burch (1986) and used by Desmet and Govers (1996), and Mitasova et al. (1996).

$$LS = (m+1)\left[\frac{A}{a_o}\right]^m \left[\frac{sinb}{b_o}\right]^n \quad (3)$$

where: *A* – upslope contributing area per unit contour width, b – degree slope, a_0 – 22.1 m, b_0 – 0.09, *m* and *n* – parameters equal to 0.4 and 1.3 (Mitsova et al., 1996; 2000).

This equation was also used in estimating the LS factor in the watershed of Quezon province (Adornado and Yoshida, 2010) and Laguna Lake (Blanco and Nadaoka, 2006). This equation requires flow accumulation and slope degree map that were generated in ArcGIS Pro using the Digital Elevation Model. The flow accumulation map is shown in Figure 5 and slope degree map is shown in Figure 6.The LS factor was calculated using raster calculator function in ArcGIS based on the Equation 3 by (Moore and Burch, 1986).

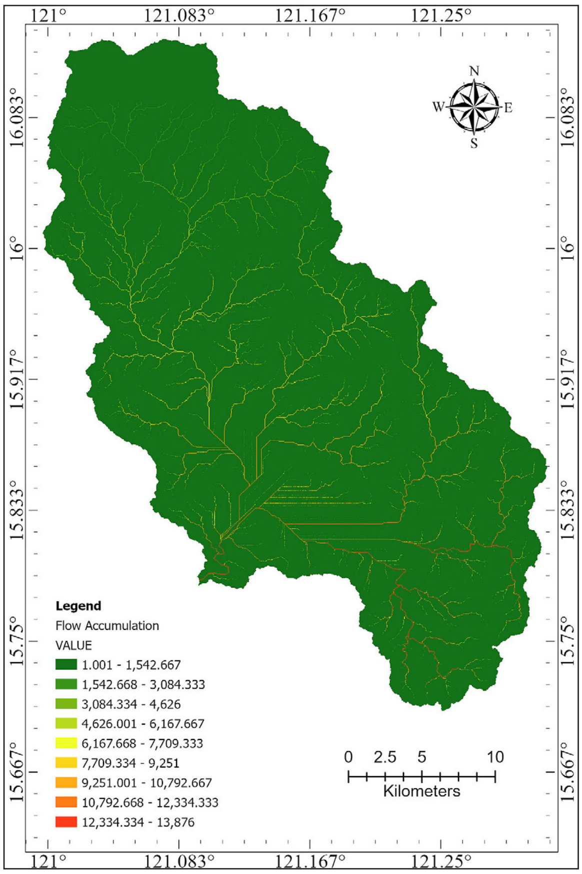

Figure 5. Flow accumulation map of PCW

The calculated LS-factor of PCW as shown in Figure 7 was ranging from 0–48.331. The LS-factor has a mean of 0.1589 and a standard deviation of 0.8739. Figure 7 shows concentrated yellow to red patches which pertains to high LS value around the Pantabangan lake and water channels going to the lake.

Cover and management factor (C)

The land use/land cover (LULC) factor or cover and management factor are firstly compared by Wischmeier and Smith (1978) value over a "clean-tilled continuous fallow soil". The land cover map of 2010, 2015 and 2020 produced by National Mapping and Resource Information Authority available at geoportal.ph were used (Fig. 8). Land cover categories are assigned with C values based on the Table 2. The used C values are estimated by David, (1988). These values are commonly used by different researchers in estimation of soil erosion. It was used by Aguilos et al. (2021) and Dapin and Ella, (2023) in estimation of soil erosion in Maasin Watershed Forest Reserve, Iloilo, Philippines and Watersheds Bukidnon, Philippines, respectively. The

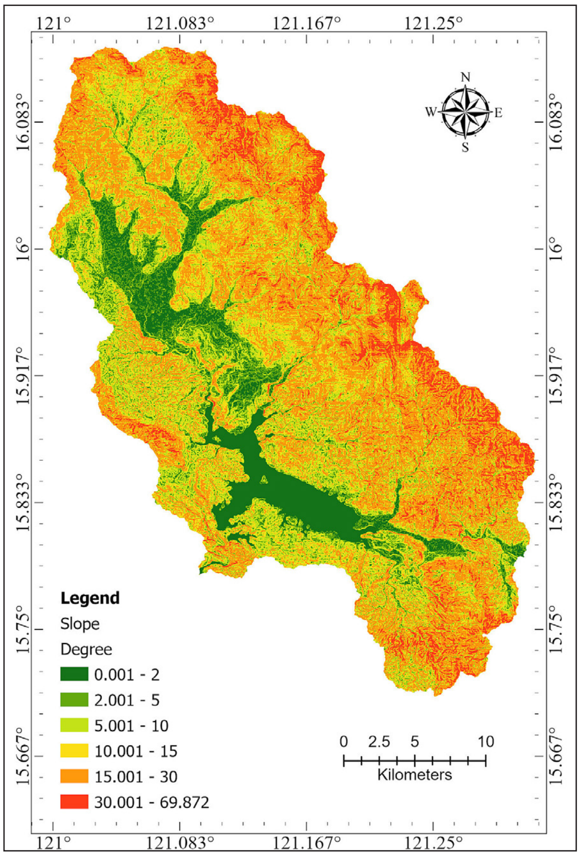

Figure 6. Slope (degree) map of PCW

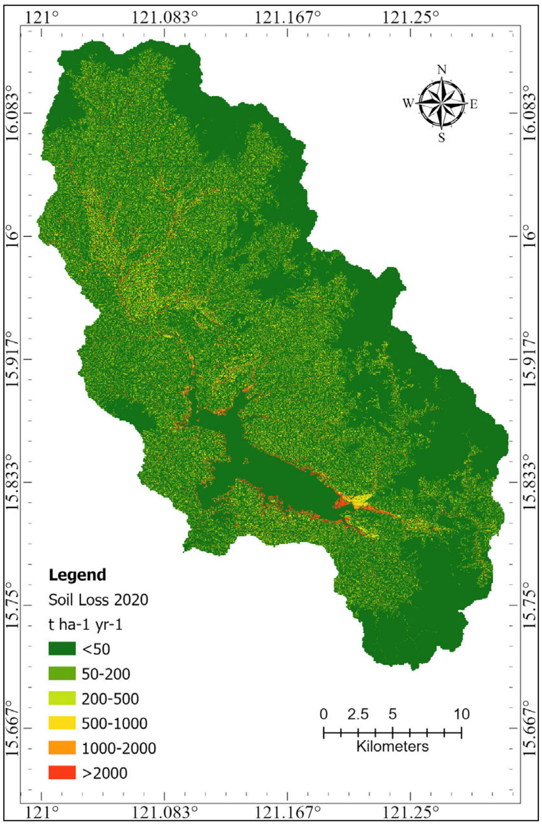

Figure 7. Slope length (L) and steepness (S) factor map of PCW

C values calculated by David, (1988) were also applied in farm level estimation of soil erosion by (Po et al., 2018). Hernandez et al. (2012) also applied the C values by David, (1988) in estimation of soil erosion caused by changing land use Pagsanjan–Lumban catchment located at Laguna de Bay, Philippines. In estimating the soil erosion risk of the Marinduque province Salvacion, (2022) also used the C values from David (1988).

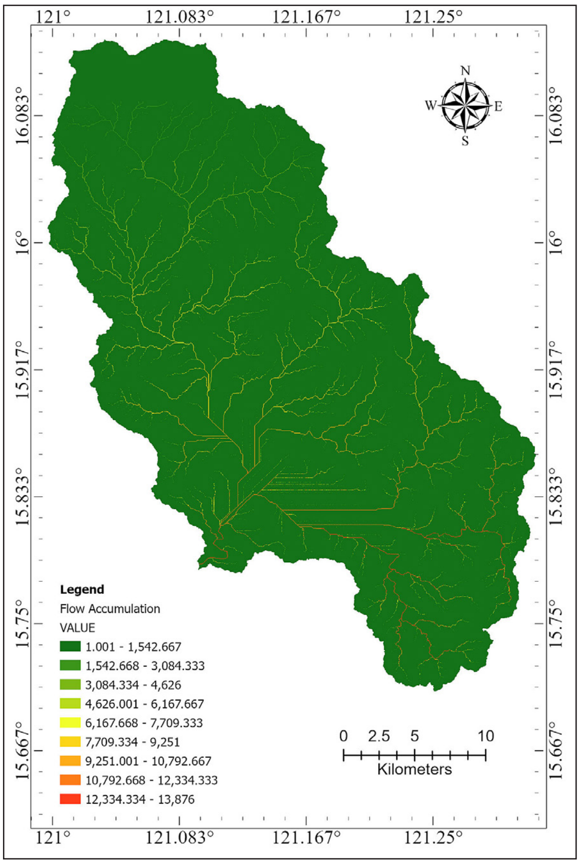

Figure 8. Cover and management factor map of PCW in (a) 2010, (b) 2015, and (c) 2020

Conservation support practice factor (P)

The conservation support practice factor was set to value of 1 because of the lack of data regarding conservation practices in the area. Reforestation of area is continuously practiced within the PCW by National Irrigation Administration (NIA), but there is lack of data regarding conservation practices such as terracing, contouring, strip cropping, minimum tillage practices and mulching. Assumptions of using a P value of 1 were also used by Aguilos et al. (2021), Dapin and Ella, (2023), (Adornado and Yoshida, 2010) and Blanco and Nadaoka (2006) with related concern on erosion estimation and lacking of conservation practice data. The assumption of having a value of P = 1 means that there is no conservation practice employed in PCW. This P factor was used in raster calculations of soil erosion estimates collectively with R, K, LS, and C factor.

Estimation and delineation of soil erosion in PCW

The resulting raster files of rainfall erosivity factor (R), soil erodibility factor (K), slope length (L) and steepness (S) factor, and 2010, 2015, and 2020 cover and management factor (C), and the value of 1 for conservation support practice factor (P), were used to estimate the soil erosion of Pantabangan-Carranglan Watershed. The generated raster files of R, K, LS, and C and the value of P were multiplied with each other following Equation 1 and using the raster calculator in ArcGIS Pro to estimate and delineate average soil loss in PCW. The value in each factor is in SI units resulting in estimated soil loss unit of tons per hectare per year ($t \cdot ha^{-1} \cdot yr^{-1}$). The resulting

Table 2. C value used in each land cover type

Land cover categories	C values reference (David, 1988)	C value used
Annual crop	Diversified crops (0.2–0.4)	0.3
Brush/Shrubs	Shrubs with patches of open, disturbed grasslands (0.15)	0.15
Built-up	Built up areas with home gardens (0.2)	0.2
Closed forest	Second growth forest with good undergrowth (0.003)	0.003
Grassland	Grassland moderately grazed, burned occasionally (0.2–0.4)	0.3
Inland water	Inland water (0)	0
Open forest	Second growth forest with patches of shrubs and plantation crops of 5 years or more (0.006)	0.006
Open/Barren	Bare soil (1.0)	1
Perennial crop	Mixed stand of agroforestry species, 5 years or more with goodcover (0.08)	0.08

Table 3. Different soil erosion level (Hernando and Romana, 2015)

Soil erosion level	Soil loss rate (t ha^{-1} $year^{-1}$)
Insignificant	< 50
Slight	50–200
Moderate	200–500
Severe	500–1000
Very severe	1000–2000
Catastrophic	> 2000

raster file representing the 2010, 2015 and 2020 soil erosion map was reclassified in different erosion level. The soil erosion probability zone was classified based on different soil erosion level proposed for cut and fill slope by Hernando and Romana (2015) as shown in Table 3. This soil erosion levels were used to determine what specific land cover types has the smallest and largest area with insignificant, slight, moderate, severe, very severe, and catastrophic level of erosion.

RESULTS AND DISCUSSION

Land cover types in PCW

Land use/land cover types provide vital roles in watershed to various ecosystem services. Soil erosion differs from a certain land cover to another. Closed forest tends to be less erosive than open/barren which is more prone to soil erosion. Changes within the land area size of different land cover types greatly affect the soil erosion within the watershed.

Table 4 shows the calculated area of each land cover categories using ArcGIS Pro. There is an increase of land area from 2010 to 2015 and 2015 to 2020 of annual crop, built-up, grassland, inland water, open/barren, and perennial crop land cover types. Conversely, there is a continuous decrease in brush/shrubs land area from 2010 to 2015 to 2020. For closed forest land cover, there is an increase in land area from 2010 to 2015 but decrease from 2015 to 2020. Reverse from closed forest land area, open forest decrease from 2010

Table 4. Total area (ha) of different land cover type in PCW though time

Land cover categories	Land area (ha)		
	2010	2015	2020
Annual crop	7738.9	7877.3	7970.9
Brush/Shrubs	30381.6	27147.5	19886.5
Built-up	405.5	530.0	694.2
Closed forest	13743.0	15748.9	15241.4
Grassland	20438.2	21177.2	27478.2
Inland water	3864.7	4082.6	4503.7
Open forest	9420.5	9132.1	9620.6
Open/Barren	1170.5	1376.1	1445.2
Perennial crop	113.9	205.2	436.0

Table 5. Crosstabulation of area (ha) changes of different land cover types from 2010 to 2015

Land cover types		2015									Total
		Annual crop	Brush/ shrubs	Built-up	Closed forest	Grassland	Inland water	Open forest	Open/ Barren	Perennial crop	
2010	Annual crop	6518.8	440.3	142.5	0.0	439.6	85.5	10.1	82.7	19.5	7738.9
	Brush/ Shrubs	619.3	22939.3	111.3	693.5	3747.1	208.1	1675.8	282.2	104.9	30381.6
	Built-up	35.8	94.2	261.9	0.0	2.9	1.0	0.0	4.8	4.9	405.5
	Closed forest	11.2	360.1	0.0	11779.7	617.6	0.4	974.1	0.0	0.0	13743.0
	Grassland	508.7	2655.1	8.9	454.8	15982.0	133.1	601.8	73.0	20.8	20438.2
	Inland water	62.3	92.6	4.6	0.0	28.7	3362.2	0.6	313.3	0.3	3864.7
	Open forest	20.1	435.8	0.2	2820.9	273.8	0.0	5869.7	0.0	0.0	9420.5
	Open/Barren	80.2	91.8	0.6	0.0	85.4	292.3	0.0	620.1	0.0	1170.5
	Perennial crop	20.9	38.2	0.0	0.0	0.0	0.0	0.0	0.0	54.7	113.9
Total		7877.3	27147.5	530.0	15748.9	21177.2	4082.6	9132.1	1376.1	205.2	

Table 6. Crosstabulation of area (ha) changes of different land cover types from 2015 to 2020

Land cover types		2020									Total
		Annual Crop	Brush/ Shrubs	Built-up	Closed forest	Grassland	Inland water	Open forest	Open/ Barren	Perennial crop	
2015	Annual Crop	6204.3	437.2	113.6	0.2	678.1	172.5	21.5	185.3	64.7	7877.3
	Brush/ Shrubs	584.0	15901.0	173.5	138.8	9047.1	152.0	778.7	166.5	206.0	27147.5
	Built-up	88.3	54.1	342.7	0.0	26.9	1.9	1.1	9.8	5.1	530.0
	Closed forest	0.1	149.8	0.0	14660.1	113.4	0.2	824.2	1.2	0.0	15748.9
	Grassland	917.6	2464.1	49.2	130.8	17121.5	56.2	230.2	185.1	22.3	21177.2
	Inland water	56.0	38.2	2.9	0.6	58.2	3698.1	1.2	227.5	0.1	4082.6
	Open forest	17.0	756.7	4.1	310.9	271.0	8.9	7761.5	1.1	0.8	9132.1
	Open/ Barren	64.3	65.0	4.3	0.0	159.9	413.8	0.0	668.7	0.1	1376.1
	Perennial crop	39.4	20.5	3.9	0.0	2.1	0.1	2.3	0.0	136.9	205.2
Total		7970.9	19886.5	694.2	15241.4	27478.2	4503.7	9620.6	1445.2	436.0	

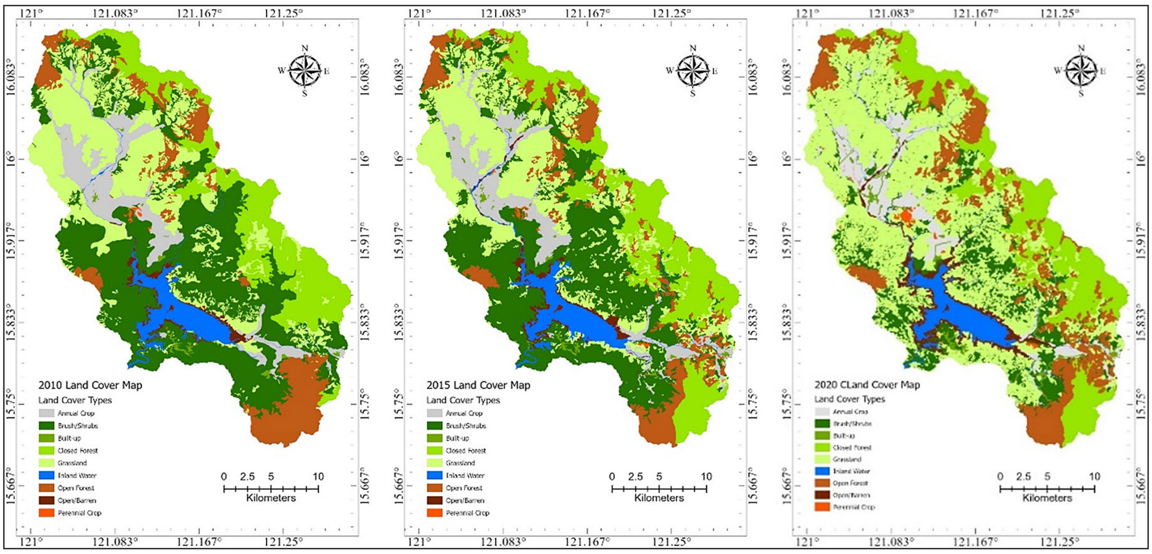

Figure 9. Land cover map of PCW in (a) 2010, (b) 2015, and (c) 2020

to 2015 but increase from 2015 to 2020 (Table 5 and 6). To better understand the spatial distribution of land cover changes within the watershed, see Figure 9 for land cover types of PCW in 2010, 2015, and 2020, respectively. Land cover area changes from 2010 to 2015 and 2015 to 2020 indicate similarity. Changes in closed forest land area is greatly affected by area changes in open forest and vice versa. This is similar with inland water to open/barren and brush/shrubs to grassland which greatly affects one another in terms of land area changes. For built-up areas, mostly annual crops and brush/shrubs land areas are converted into residential, commercial buildings and other infrastructures that promotes soil sealing.

Physical and chemical properties of soil

Table 7 shows that all soil samples have below neutral (7.0) pH. All the soil samples are acidic in pH, specifically soil sample PCWSS8 and PCWSS14 have pH values of 3.92 and 3.96, respectively, both pH values are below 4.0 and considered to be very strongly acid. Strongly acid soil with the pH value of 4.0 to 5.0 is recorded in most of the soil samples. The soil samples with pH value of 5.0–6.0 are considered to be moderately acidic and was recorded on PCWSS1, 2, 9, 16, and 18. Remaining soil samples have pH range close to neutral have a pH value of 6.0–6.9 which is considered as slightly acidic. The soils of PCW

Table 7. Soil sample physicochemical properties and calculated K value

Sample code	pH	%OM	%Sand	%Silt	%Clay	Soil texture	K value
PCWSS1	5.21	2.46	46.58	33.07	20.35	Loam	0.283
PCWSS2	5.53	0.95	62.58	23.07	14.35	Sandy loam	0.324
PCWSS3	4.73	0.12	64.58	21.07	14.35	Sandy loam	1.243
PCWSS4	4.69	0.15	70.58	17.07	12.35	Sandy loam	0.839
PCWSS5	6.97	0.90	42.58	37.07	20.35	Loam	0.495
PCWSS6	4.71	0.62	62.58	25.07	12.35	Sandy clay loam	0.430
PCWSS7	6.95	1.62	24.58	45.07	30.35	Clay loam	0.397
PCWSS8	3.92	2.24	42.58	35.07	22.35	Loam	0.278
PCWSS9	5.08	3.81	48.58	33.07	18.35	Loam	0.257
PCWSS10	4.74	3.25	59.14	27.07	13.79	Sandy loam	0.238
PCWSS11	4.34	2.61	29.14	45.07	25.79	Loam	0.298
PCWSS12	4.62	4.56	49.14	29.07	21.79	Loam	0.214
PCWSS13	4.23	0.81	57.14	25.07	17.79	Sandy loam	0.355
PCWSS14	3.96	3.22	49.14	31.07	19.79	Loam	0.237
PCWSS15	4.24	0.85	69.14	19.07	11.79	Sandy loam	0.282
PCWSS16	5.08	3.27	49.14	35.07	15.79	Loam	0.284
PCWSS17	4.37	2.39	53.14	29.07	17.79	Sandy loam	0.256
PCWSS18	5.19	2.11	47.14	35.07	17.79	Loam	0.316

with moderately acidic soil pH are considered suitable for most agricultural crops as they required a pH range 5.0 to 7.0. Soil pH, aside from its effects to plant as well as organisms' growth and development, provides information regarding the nutrient element contents of the soil. Soil pH, percent organic matter and textural distribution of soil samples within PCW were determined.

The percent organic matter of soil samples is presented in Table 7. Results showed that PCWS3 and 4, have the lowest organic matter with only 0.12% and 0.15%, respectively. Among all the soil samples, PCWSS12 collected from Annam sandy clay loam has the highest organic matter content with 4.56%. Calculating the average percent organic matter of 18 soil samples within PCW, it resulted in 1.99%. On this average, eight soil samples have lower than 1.99% while 10 soil samples are higher than the average. The organic matter content of soil is important in formation of soil aggregates. It promotes cohesion between soil particles when entered the soil pore spaces which decreases water permeability of soil making the resistance of soil to erosion increase (National Academies of Sciences, 2019).

The soil textural distribution of different soil samples within the PCW are presented in Table 7. There are four different soil textures identified within the PCW, compared to only three soil textural types cited in the NAMRIA soil type map (Fig. 3). Clay loam, loam, sandy clay loam, and sandy loam are the four soil textures identified within the PCW. Among all the soil samples PCWSS4 which is situated near the Pantabangan lake has the highest amount of sand with 70.58%, with a soil texture of sandy loam. Sandy clay loam soil was analyzed in PCWSS6 located southeast of the Annam clay loam soil type. PCWSS7 has a soil texture of clay loam located southwest of the Annam clay loam soil type. Sandy loam was analyzed on seven soil sampling sites, while loam was recorded on nine soil samples. Loam textured soil is considered to be the most desirable texture for most agricultural crops, as it is composed of proper proportions of sand, silt, and clay favorable for the requirements of crops.

Spatio-temporal estimates of soil erosion in PCW

The R.K.LS and C factor map were rasterized to compute for estimated soil erosion using raster calculator. The R, K, LS factor map and P value of 1 were multiplied to C factor map of 2010, 2015, and 2020 separately, resulting in 2010, 2015, and 2020 soil erosion map of PCW, respectively (Fig. 10)

The generated soil erosion maps for 2010, 2015, and 2020 using raster calculator were used

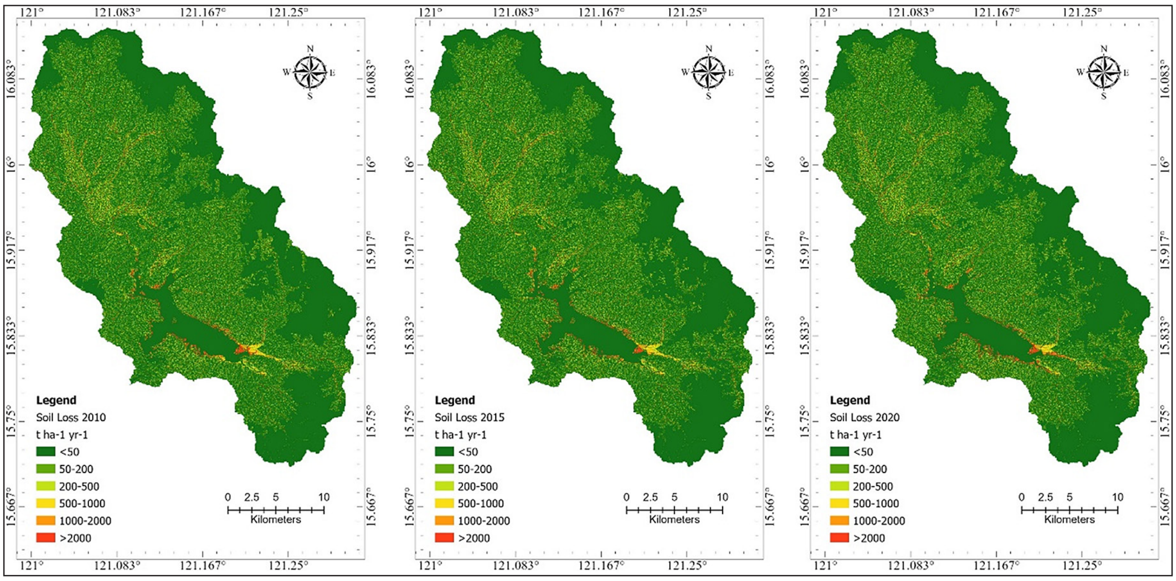

Figure 10. Soil erosion maps of PCW in (a) 2010, (b) 2015, and (c) 2020

Table 8. Spatio-temporal estimates of soil erosion in PCW

Year	Soil erosion (tons ha^{-1} yr^{-1})			
	Average	Minimum	Maximum	Standard deviation
2010	134	0	283057	1449
2015	141	0	286509	1824
2020	154	0	342889	1970

in determining the estimated average soil erosion rate of PCW in 2010, 2015, and 2020, respectively. Statistics of the raster files shows that the estimated soil erosion rate in 2010 was 134 tons·ha^{-1}·yr^{-1}. As it is shown in Table 8, there is an increase in soil erosion rate from 2010 to 2015, as soil erosion in 2015 was estimated to be 141 tons·ha^{-1}·yr^{-1}. In 2020, the estimated soil erosion is higher than both the 2010 and 2015 estimates with 154 tons·ha^{-1}·yr^{-1} average soil erosion.

In Table 8, the estimated average soil erosion in PCW is presented. The results are higher compared to 108 tons ha^{-1}·yr^{-1} soil erosion estimates of David and Collado Jr., (1987) in PCW. It is also higher than the estimated soil erosion of Elkaduwa (1994) which is 112 tons·ha^{-1}·yr^{-1}. From 1987 to 1994 references to 2010, 2015, and 2020, soil erosion estimates in PCW are increasing.

Estimated soil erosion in different land cover type

The soil erosion maps produced after combining all factors of soil erosion through raster calculator were clipped per land cover type to determine their average soil erosion through time. In 2010, as it is shown in Table 9, open/barren land cover type has the highest average soil erosion rate of 2.159 tons ha^{-1}·yr^{-1}. This is under the catastrophic level of soil erosion which has range of > 2000 tons·ha^{-1}·yr^{-1}. The mean average soil erosion rate of annual crop is the second highest with 416 tons·ha^{-1}·yr^{-1} which is under moderate soil erosion level. Brush/shrubs, built-up area, and grassland have an average soil erosion between 50–200 tons·ha^{-1}·yr^{-1},

Table 9. Soil erosion estimates of different land cover types in 2010, 2015 and 2020

Land cover type	Average soil erosion rate (tons·ha^{-1}·yr^{-1})		
	2010	2015	2020
Annual crop	416	420	387
Brush/Shrubs	103	94	99
Built-up	151	104	92
Closed forest	2	1	2
Grassland	128	132	132
Open forest	3	3	4
Open/Barren	2159	2452	2856
Perennial crop	32	50	41

which is under slight level of soil erosion same with the average soil erosion within the PCW. Inland water, closed forest, open forest, and perennial crops have an average soil erosion of < 50 tons·ha^{-1}·yr^{-1} which is under insignificant level of erosion.

Area in PCW with massive soil erosion

Within the Pantabangan-Carranglan Watershed area with concentrated, high soil erosion level was zoomed in. As it is shown in Figure 11, intense soil erosion level is located above

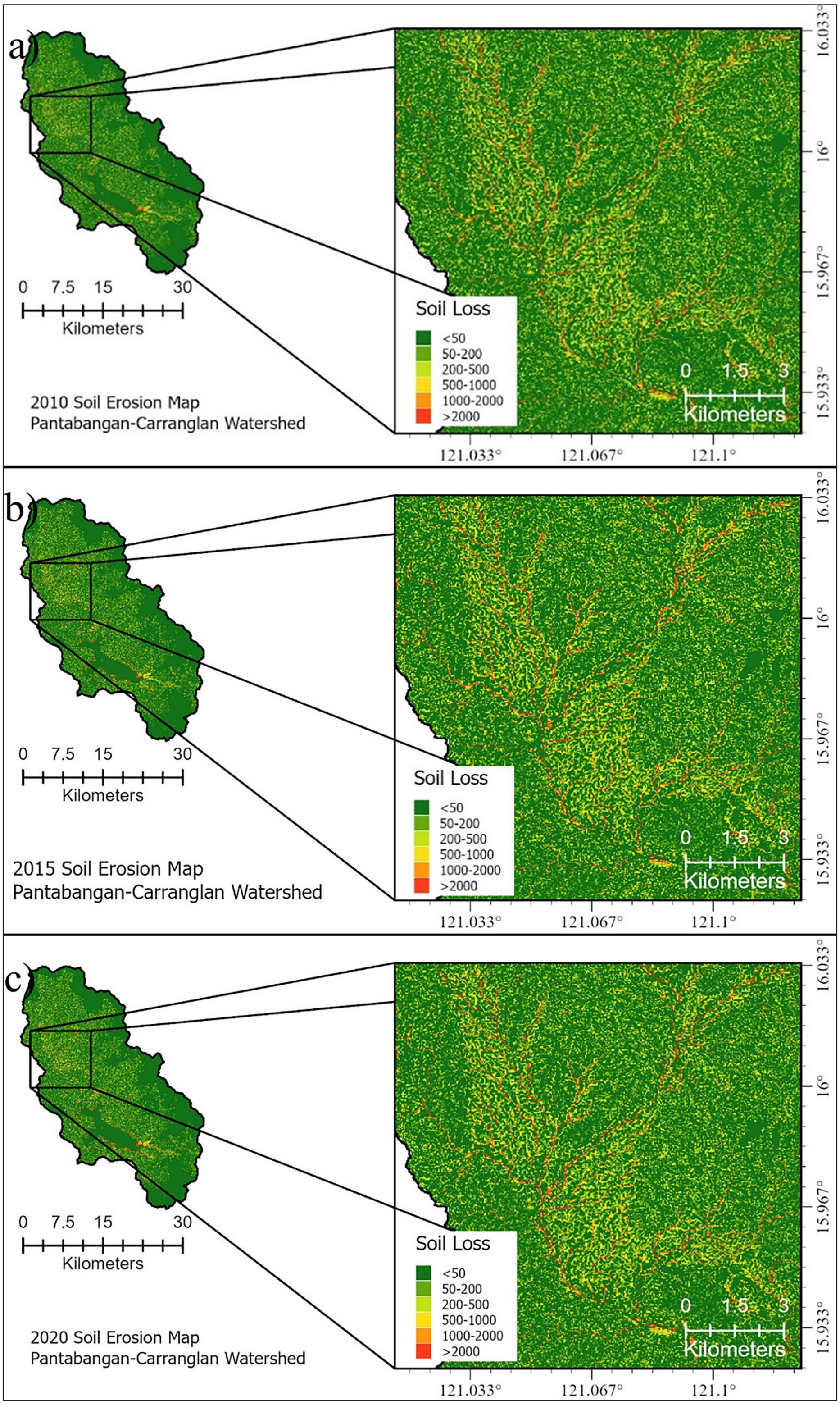

Figure 11. Soil erosion maps where massive soil erosion occurs (a) 2010, (b) 2015, and (c) 2020

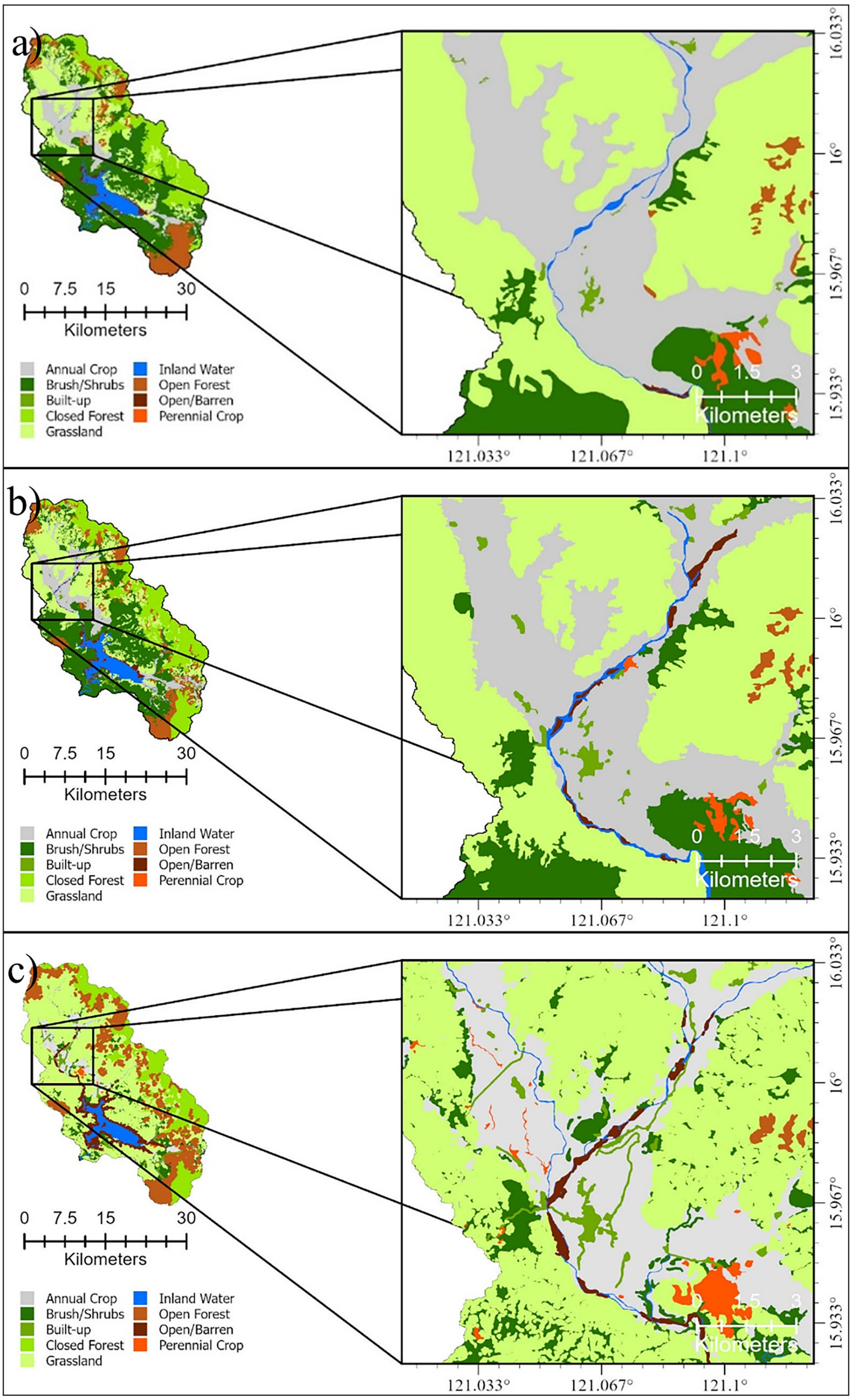

Figure 12. Land cover maps where massive soil erosion occurs with reference to Figure 11 (a) 2010, (b) 2015, and (c) 2020

the Pantabangan Lake. This land area is situated mostly within the municipality of Carranglan. In reference to the focused area where massive soil erosion occurs, Figure 12 shows the land cover types where it was estimated. It was observed that this area is mainly devoted to annual crops. These are agricultural lands where planted crops are harvested within a year. It means that every year, the soil within the area undergoes cultivation and other land preparation practices that destroy soil structures. The destruction of soil structure from aggregated to disaggregated soil particles can increase soil erosion. In distress of soil erosion from annual crop land cover, based on the land area changes of all land cover types within the PCW, annual crop land area is increasing with time. This can be attributed that with the continuous increase of annual crop land area in PCW soil erosion also increased. To reduce or minimize the effects of annual crop in increasing soil erosion within the PCW, the agricultural practices that promote soil conservation should be applied and adopted within the area where massive soil erosion occurs.

CONCLUSIONS

The model used same raster file and value for (R) rainfall erosivity, (K) soil erodibility (LS) steepness and length of slope, and (P) conservation support practice in the calculation of average soil erosion in 2010, 2015 and 2020. The only variable factor was the (C) cover management factor. It indicates that the increase in the average soil erosion of PCW was caused by land cover changes through time. Land cover changes in PCW include increased land area of annual crop and open barren land cover types. Annual crop land cover has an average estimated soil erosion rate ranging from 200 to 500 tons·ha^{-1} ·yr^{-1} while open/barren land cover has a catastrophic level of average soil erosion rate (> 2000 tons·ha^{-1}·yr^{-1}). The increase in land area of this land cover greatly affects the increase in the estimated average soil erosion rate of PCW.

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