

Volumetric computation of resource and sediment replenishment rate estimates of Tamlang River Basin, Palawan Island, Philippines, using field methods, GIS, and RUSLE-SDR Equation

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ABSTRACT

The revised universal soil loss equation–sediment delivery ratio (RUSLE-SDR) method was used to determine the replenishment rate of a portion of the Tamlang River Basin in Palawan Island, Philippines. Before performing the calculations, one must obtain the following data: (1) watershed vector file, (2) rainfall erosivity factor (R), (3) soil erodibility factor (K), (4) topographic factor (LS), (5) cover management factor (C), and (6) conservation practice factor (P). Data numbered 2-6 must be converted into vector format, and then into a raster format using free GIS software to apply the RUSLE equation $A = R \times K \times LS \times C \times P$, where A is annual sediment yield in t/ha. Replenishment rate is derived by multiplying SDR by the average soil loss and watershed area. Ground survey using open traverse and sectioning/slicing method yielded a resource estimate of 3,787.79 m³ (10,037.65 t) and a replenishment rate of 29,456.58 m³ (78,059.94 t/year). The method is an effective approach to determine resource reserve estimates and a basis for taxation and other policies.

Keywords: *Replenishment rate, GIS, RUSLE-SDR*

INTRODUCTION

This paper aims to establish an assessment methodology for proponents of sand and gravel extraction who need to comply with Environmental Management Bureau Memorandum Circular 2020-27, requiring them to submit an Environmental Impact Assessment (EIA) as a requirement for issuance of an Environmental Compliance Certificate and an extraction permit. The proposed methods constitute the following:

- a. To describe the stream, its watershed, and the geological rock units in the study area
- b. To identify rock aggregates and their grain sizes in the study area.
- c. To compute the estimated volume of aggregate resources identified, annual soil loss, and sediment yield using the RUSLE-SDR method.

Location and Accessibility

The study area is 9 km southwest of the municipal center of Brooke's Point. It can be accessed through the national highway and paved road toward the interior portions of Barangay Saraza. Barangay Center of Saraza is 2 km from the proposed sand and gravel extraction area. Travel time from the municipal center is around 30 minutes. The study area lies between 40 m and 50 m contour lines based on SRTM 30 x 30 elevation data provided by the National Aeronautics Space Administration of the United States of America, which is freely accessible through this link: <https://dwtkns.com/srtm30m/>.

Topography and Drainage

Based on DEM-generated watersheds of Palawan Island, the study area is on the riverbed of the Tamlang River, a southeast-trending stream that drains into the Sulu Sea. The Tamlang River exhibits a relatively straight flow with very few meanders and low sinuosity. The river watershed is generally ovate, having its greatest basin width near the headwaters at around 3.5 km. As the drainage nears the exit point to the Sulu Sea, the basin width sharply decreases to around 500-600 m.

Vegetation Cover and Land Use

Based on 2020 data from geoportal.gov.ph (2022) and verification using satellite images, there are three (3) major vegetative covers of the watershed considered in this study: (1) closed canopy with mature trees covering >50%, (2) open canopy with

mature trees covering <50%, and (3) cultivated area mixed with bushland/grassland (Figure 1).

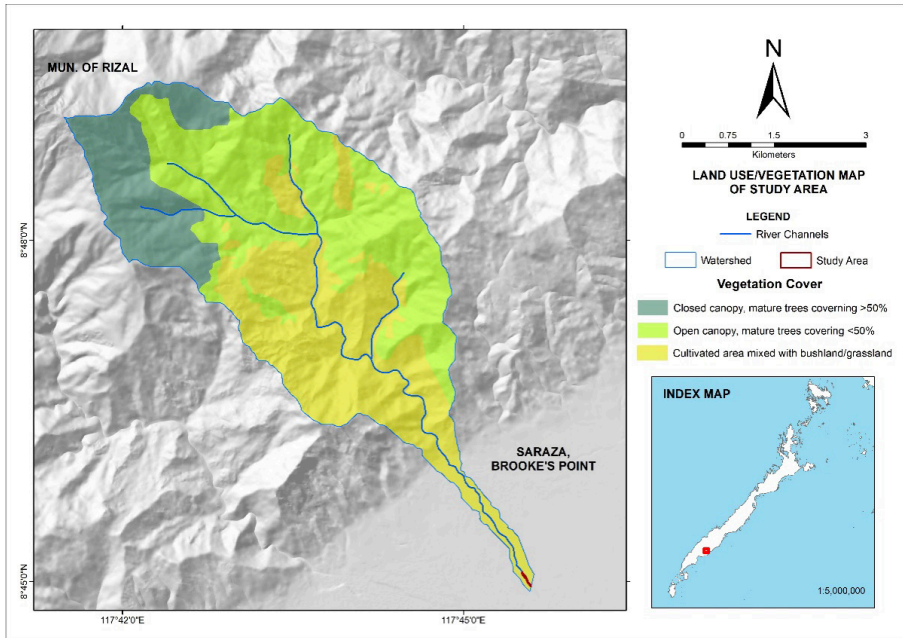


Figure 1. Vegetation cover map derived from *geoportal.gov.ph* and verified from Google satellite images.

General Geology

Southern Palawan, particularly areas south of Puerto Princesa City, is characterized by an ophiolitic terrane. Hence, rocks present in the area are representative of uplifted oceanic crust and upper mantle. Based on fieldwork and map analysis, there are good aggregate sources in the area, including basalt, gabbro, and related rocks (Aurelio & Peña, 2010).

Based on maps from DENR-MIMAROPA Region derived from MMAJ-JICA (1989), the geological rock units at the source of the river are the Espina Formation and Mt. Beaufort Ultramafic Complex. The Espina formation is aged Late Cretaceous and composed of basalt with intercalated shale, limestone, and chert. It is believed to be part of the basement rocks of Palawan Island. The said formation is overlain by the

Eocene Panas Formation and the Sumiling Limestone. Meanwhile, the Cretaceous Mt. Beaufort Ultramafic complex is composed of harzburgite, dunite, pyroxenite, and peridotite. This rock unit underlies Stavely Gabbro (Aurelio & Peña, 2010; Metal Mining Agency of Japan-Japan International Cooperation Agency., 1989)

Local Geology

Riverbank and Riverbed Character

The study area is underlain by Quaternary alluvium. No mesoscopic rock exposures were observed along the site and its vicinity. Riverbanks were found to be around 1 – 1.5 m tall. Bank exposures are composed primarily of sub-angular cobble to boulder-sized rocks with characteristics like those of the riverbed embedded in matrix of mud and silt. These features indicate high river velocity and recent occurrences of channelized flows.

Stream Morphology

The stream within the study area is generally meandering with low sinuosity. Slopes are roughly uniform since the applied area is within a wide floodplain.

Results of upstream sections indicate depositional areas, including point bars and small islands in the middle of the river channel (**Figure 2**). The river is relatively shallow with maximum depths of channels at 0.2–0.3m. In contrast, the midstream sections are narrower than the upstream sections with an average width of 20 meters. Water gets deeper midstream to a maximum of 0.5 m. Steep bank exposures were observed in these sections. Point bars are generally less than 1 m in width.

Finally, the downstream sections exhibit similar characteristics to those of the midstream stations, as depths range from 0.3 m to around 0.6m. Channel width, in contrast with the midstream, is wider at around 15 m. Point bars remain 1–2 m wide.



Figure 2. Representative photo of the upstream section described “small island” or depositional feature

METHODOLOGY

The RUSLE-SDR Model

The RUSLE-SDR model was refined by Renard and others in 1997 (Renard, Foster, Weesies, & McCool, 1997). This method quantifies sheetwash, rill, and bank erosion, as well as subsequent sediment delivery out of the catchment (Salvacion, 2020). The following are considered in the model:

1. Rainfall erosivity (R)
2. Soil erodibility factor (K)
3. Topographic factor (LS)
4. Cover management factor (C)
5. Conservation practice factor (P)

The aforementioned factors can be quantified spatially into vectors and then converted to raster, which may be used to calculate annual sediment yield (A) using GIS Software through the equation below.

Equation 1. RUSLE Equation

$$A = R \times K \times LS \times C \times P$$

where the unit of A is in t/ha/year

Rainfall Erosivity Factor (R)

This factor refers to the effect of rainfall in the form of kinetic energy. Also, it is predictive of the amount of run-off associated with precipitation (Ghosal & Das Bhattacharya, 2020). It is assumed to be uniform in the entire watershed.

Figure 3 shows 30-year precipitation data from the Puerto Princesa station in Palawan that can be used to compute for rainfall erosivity factor (R). The figure suggests that the average annual rainfall from the recent 30-year rainfall data is 1,555.4 mm/year.

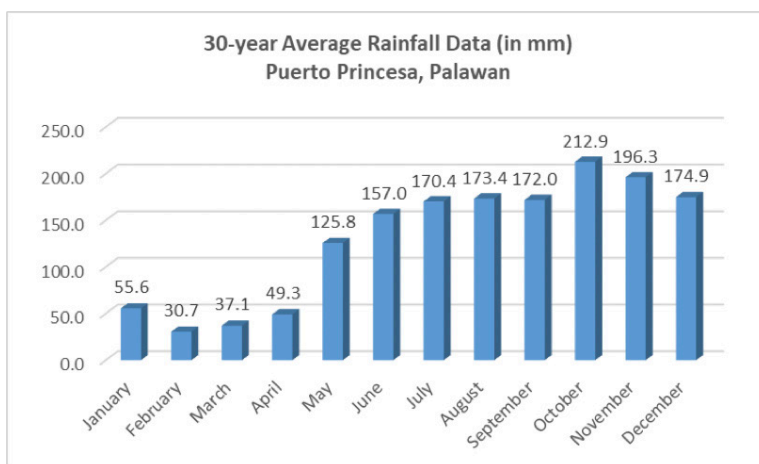


Figure 3. Average monthly precipitation over 30 years recorded in Puerto Princesa station, Palawan (from pagasa.dost.gov.ph/climate/climatological-normals)

The equation below is proposed by El-Swaify et al. (1987) and cited in Benavidez et al. in 2018 (Benavidez, Jackson, Maxwell, & Norton, 2018; El-Swaify, 1987), can be used to determine annual precipitation:

Equation 2 $R = 38.5 + 0.35 P$

The data used in this study represented a 30-year average from the DOST-PAGASA website sourced from the Puerto Princesa City station. Although nearer rain gauges exist in Brooke’s Point and Rizal, Palawan, 30-year average data are not available for these stations.

Given P (precipitation) = 1,555.4 mm, the calculated value of R is **582.89 mm/yr.**

Soil Erodibility Factor (K)

This factor shows the resistance of soil due to the impact of raindrops and the rate and amount of run-off produced under standard conditions. Unit used for K is t/ha (Ghosal & Das Bhattacharya, 2020).

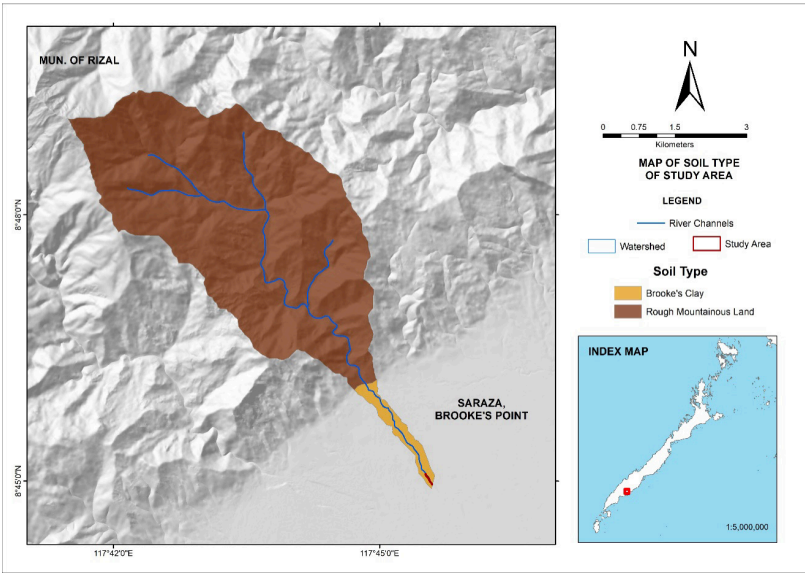


Figure 4. Map showing soil types from the Department of Agriculture extracted from *geoportal.gov.ph*.

Table 1.

Soil types from geoportal.gov.ph with their corresponding soil erodibility factor, K, according to various authors (Francisco, Cruz, & Conway, 1988; Panagos, et al., 2015; Benavidez, Jackson, Maxwell, & Norton, 2018)

Soil type	Soil erodibility factor (K)
Rough mountainous land	0.23
Brooke's clay	0.13

The soil map was obtained from the Department of Agriculture (accessed in geoportal.gov.ph) and is shown in **Figure 4**. Corresponding soil types and K values (t/ha) according to Francisco in 1988 (Francisco, Cruz, & Conway, 1988) are presented in **Table 1**. K value for rough mountainous land was inferred from sandy loam character observed in satellite images of the watershed exhibiting this soil zonation. Other consultants also recognize the study area as having sandy loam (Rabang, 2018).

Topographic Factor (LS)

This is a dimensionless factor determined by the length and steepness of a slope, which is related to the velocity of runoff. Water moves faster on steep slopes compared to gentle ones. Hence, faster flow will mean higher LS values. GIS advancements have allowed to obtain flow accumulation rates, which are vital for computing the LS per raster pixel (Chadli, 2016). To get this data for the watershed used, we need to process a 30 m x 30 m DEM from NASA into slope % (**Figure 5**), which is then subjected to the works of several researchers (Wischmeier & Smith, 1957; Benavidez, Jackson, Maxwell, & Norton, 2018).

Equation SEQ Equation*ARABIC 3

$$LS = \left\{ (flow\ acc. \cdot \frac{Length\ of\ transport}{22.10})^{0.5} \cdot (0.065 + 0.045 \cdot slope\ \% + 0.0065 \cdot slope\ \%^2) \right\}$$

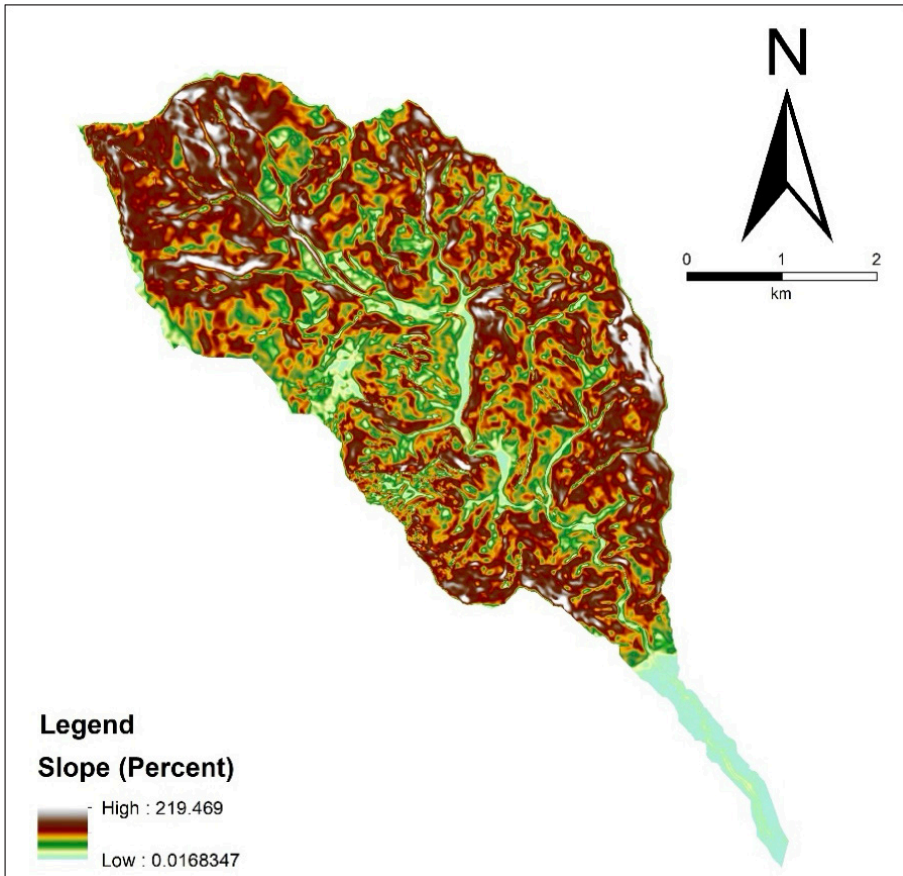


Figure 5. Map showing slope (%) of the study area, derived from processing 30 m x 30 m DEM

Flow accumulation was obtained by subjecting the DEM to hydrogeological processes in GIS software. The steps in getting the raster were: (1) perform fill raster, (2) use fill raster to make flow direction raster, and (3) use flow direction raster to get flow accumulation data. The Raster Calculator tool was subsequently used for obtaining LS raster. The resulting raster in **Figure 6** shows large values at high altitude and steep locations in areas near the central portions of the Tamlang River Watershed. Most values for LS range from 70 – 230. Final LS raster is reflected in **Figure 7**.

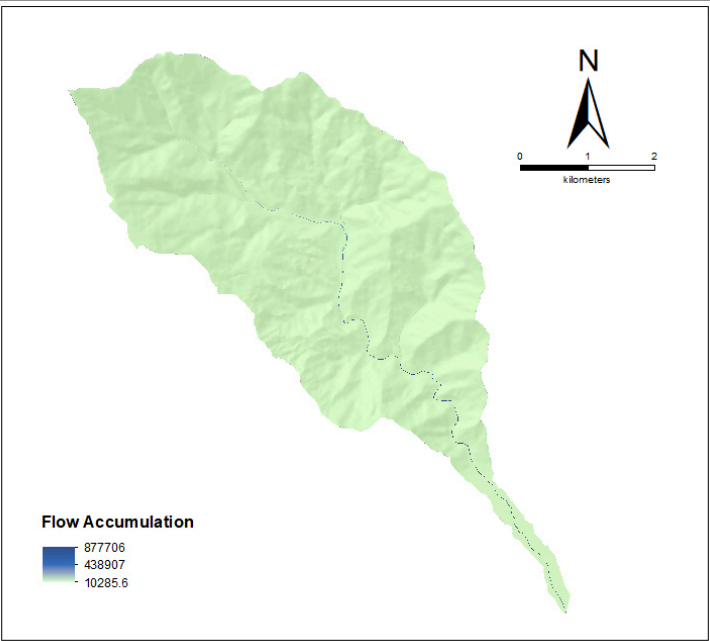


Figure 6. Flow accumulation raster derived from SRTM-DEM

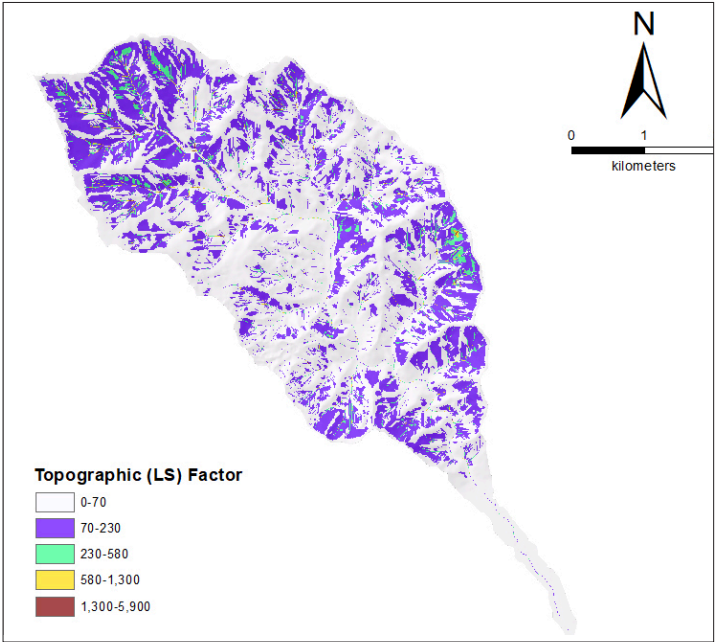


Figure 7. LS Computed from flow accumulation and slope raster

Cover Management Factor (C)

Cover management factor (C) considers the type of natural and anthropogenic cover that affects the erodibility of soil. C values in this study are empirically derived from research (Panagos, et al., 2015; Francisco, Cruz, & Conway, 1988) based on the latest land cover maps from the Department of Information and Communications Technology through geoportal.gov.ph (Figure 8). Table 2 shows the adapted C values indicate. Higher C factors indicate greater susceptibility to erosion.

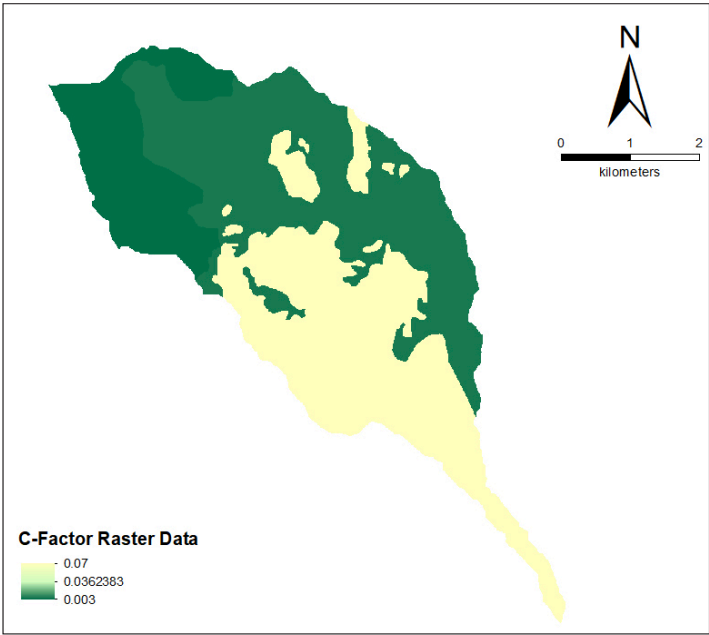


Figure 8. Map of C-factor raster data used in the RUSLE equation based on values in Table 2

Conservation Practice Factor (P)

This factor refers to mitigation practices implemented to reduce run-off. Since the study area is nearly 80–90% rough mountainous land, and apparently forested, it was assumed that the **P value** is **1.0** (Balabathina, Raju, Muluaem, & Tadele, 2020). No further survey was conducted to determine mitigation practices and tillage.

Table 2. Land cover from *geoportal.gov.ph* with corresponding *C* values according to various research (Francisco, Cruz, & Conway, 1988; Panagos, et al., 2015; Benavidez, Jackson, Maxwell, & Norton, 2018)

Land cover	C
Closed canopy, mature trees covering >50% (Francisco, Cruz, & Conway, 1988)	0.003
Open canopy, mature trees covering <50% (Francisco, Cruz, & Conway, 1988)	0.006
Cultivated area mixed with brushland/grassland (Panagos et. al, 2015)	0.07

RUSLE Computations

Vector data of the factors mentioned were converted to raster through nearest neighbor method and subsequently used to arrive estimate annual soil loss (t/ha/year). Before multiplying all raster datasets of the parameters needed using the Raster Calculator tool, all datasets were standardized to the same cell size (30 x 30). The RUSLE equation was used in the raster calculations to obtain an annual soil loss raster ($A = R \times K \times LS \times C \times P$). The image produced can be viewed in **Figure 9**.

High soil loss values are located near the geographical center of the Tamlang River Basin. These areas are characterized by $K=0.23$, $C=0.07$ (cultivated areas), and slopes of around 200%. Average soil loss based on the Zonal Statistics tool is at 218.5902 t/ha/year. Meanwhile, calculations using the GIS Calculate Geometry tool show the studied watershed has an area of 22.03 km² or 2,203 ha.

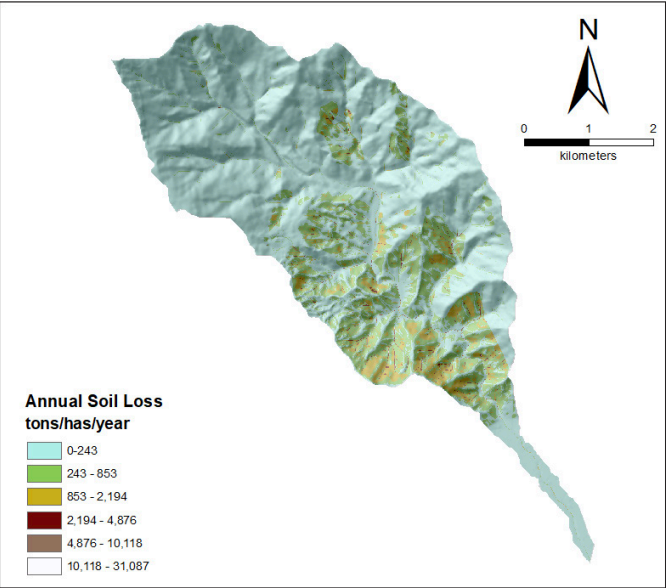


Figure 9. The raster results of RUSLE computations show that annual soil loss is highest near the geographical center where $C=0.07$ and slopes range from 100-200%.

Sediment Delivery Ratio (SDR)

To get the sediment yield, computed soil loss is multiplied by the sediment delivery ratio (SDR). The SDR, therefore, is a scaling factor used to accommodate differences in averaged sediment yields across measurement scales. It refers to the transported sediments from the eroding sources to the catchment outlet compared to the total amount of soil that is detached over the same area above that location. It is also the ratio of the sediments reaching the outlet of a watershed to the soil loss of the watershed. The equation presented below Julien (2002) and modified from Boyce (1975) (Julien, 2002) was used to determine SDR. The SDR is multiplied by watershed soil loss to arrive at sediment yield or replenishment rate.

Equation 4 $SDR = 0.41A_T^{-0.3}$
 where A_T = area of watershed in km^2
 Since $A_T = 22.03 \text{ km}^2$, **SDR = 0.1621.**

DISCUSSION

Calculated Values

Average soil loss was derived using the GIS Zonal Statistics function, which is then multiplied to the watershed area for the determination of soil loss of the entire watershed. SDR was then used to determine the sediment yield or replenishment rate of 29,456.58 t/year (78,059.94 t/year), assuming average specific gravity is 2.65 (National Resources Conservation Service of the United States of America, 2005), obtained by getting the mean of the specific gravities of natural aggregates. Solutions are reflected in below.

Table 3. Summary values for the replenishment rate calculation

Value computed	Method used/ formula	Computed value
Average soil loss SL_{AVE}	Zonal Statistics $\frac{\sum \text{pixel values } SL_{AVE}}{\sum \text{pixels within watershed}}$	218.5902 t/ha/year
Watershed area A_t		22.03 km ² or 2,203 ha
Watershed soil loss SL_{ws}	$SL_{AVE} \times A_t$	481,554.2106 ton/year
Sediment delivery ratio SDR	$0.41A_t^{-0.3}$	0.1621
Sediment yield (replenishment rate)	$SL_{ws} \times SDR$	29,456.58 m ³ /year 78,059.94 t/year

RESOURCE ASSESSMENT RESULTS

Volume Computation

A total of seven (7) sections were established during the site assessment. Dimensions of point bars and stream depth were conducted in the field, while distances between sections along with azimuth were determined using GIS.

Deposit volume can be calculated using average sediment cross-sectional area and stream length, given that the area is part of the alluvial deposits of the Tamlang River channel. The depth of the deposit was inferred to be around 1 m. Although sand, gravel, and other aggregate deposits are much thicker, given that the area is within Quaternary alluvium deposit, 1 meter was used to constrain the depth of extraction.

The deposit volume of deposit per section was computed using the equation below

Equation 5 $\text{Volume (m}^3\text{)} = \text{ASCSA} \times \text{SL}$

Where ASCSA is the average sediment cross-sectional area, and
 SL is the stream length

The resulting deposit volume is expressed in cubic meters. Stream length was derived from GIS, while the sediment cross-sectional area was calculated by subtracting

the area covered by stream inundation, derived from data obtained during stream sectioning, from the cross-sectional area. In detail:

$$\text{Equation 6} \quad ACSA (m^2) = \frac{SCSA \text{ for Station } n + SCSA \text{ for Station } (n+1)}{2}$$

$$\text{Equation 7} \quad SCSA (m^2) = CSA - AIS, \text{ Visualized in Figure 10}$$

$$\text{Equation 8} \quad CSA (m^2) = SW \times AD$$

$$\text{Equation 9} \quad AIS (m^2) = AFSD \times SW$$

Where: n is the number of stations being studied

$ACSA$ is the average cross-sectional area

$SCSA$ is the sediment cross-sectional area

CSA is the cross-sectional area

AIS is the area inundated by stream

AD is the assumed depth of resource deposit = 1 m

SW is the section width

$AFSD$ is the average full section depth

Sieving and Grain Analysis

Random sediment samples from point bars of 7 stations, where sections were established, were sieved using makeshift materials and then analyzed. Stations 1 and 2 were designated as upstream sections. Stations 3–5 as midstream sections, and Sections 6 and 7 as downstream sections. The sediments were dried and sieved using 20 mm, 4 mm, and 2mm sieves, and the weight fraction was obtained thereafter.

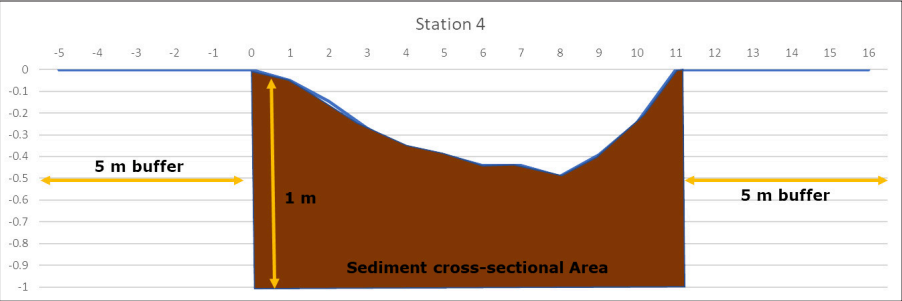


Figure 10. Schematic diagram of sediment cross-sectional area used for inundation volume calculation

Sediment Distribution

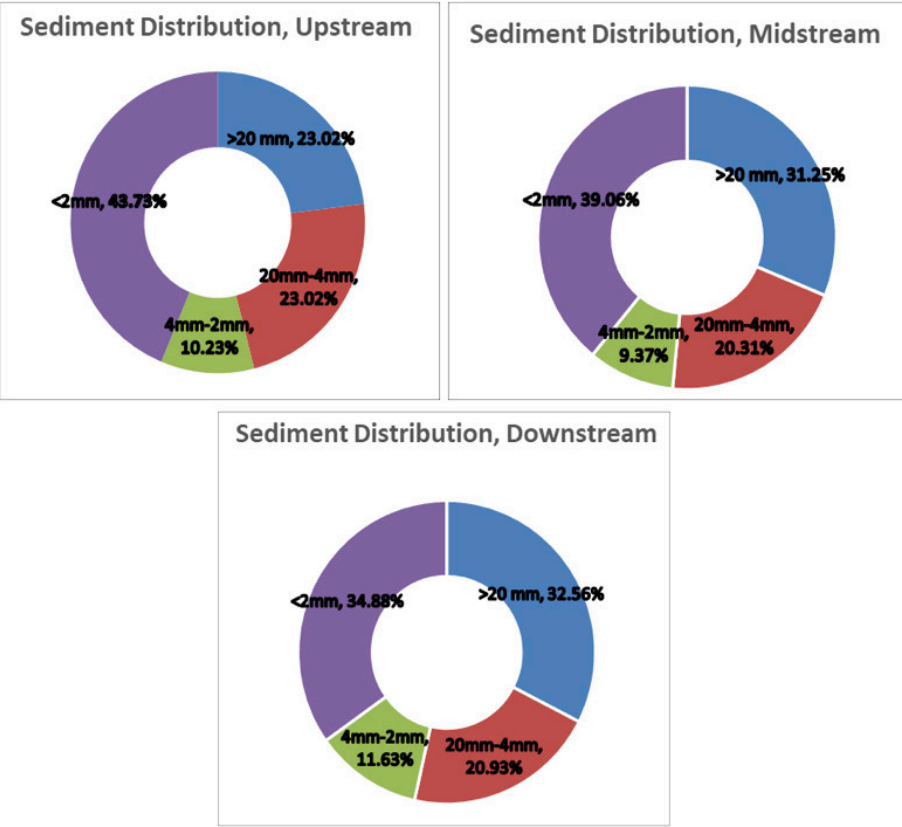


Figure 11. Pie charts showing sediment distribution in upstream, midstream, and downstream sections, derived from sieving data. Upstream distribution represents the mean percentages from Stations 1 and 2, midstream from Stations 3–5, and downstream from Stations 6 and 7.

Sediment distribution in the upstream, midstream, and downstream sections indicates that the most abundant sediments in the river channel are those with a diameter of <2 mm (43.73% in upstream sections, 39.06% in midstream sections, and 34.88% in downstream sections). This is followed by >20 mm grains (23.32% in upstream sections, 31.25% in midstream sections, and 32.56% in downstream sections). Sediments with 20 – 4mm grain size have an average of nearly 20%, and those in the 4 – 2mm range account 10% in all sections. Thus, it can be inferred that the stream is dominantly gravel (grain size of >2 mm) with a significant sand fraction (<2 mm grains with a weight % of around 40%). The data discussed is reflected in **Figure 11**.

Data show that the quantity of sediments >20 mm increases upstream to downstream. Meanwhile, grains with size <2 mm decreases upstream to downstream. However, the changes are not significant and do not indicate a clear trend for the entire river channel. Grains with a size of 4–2 mm in breadth are significantly lower in amount compared to others, accounting for 10.23% upstream, 9.37% midstream, and 11.63% downstream.

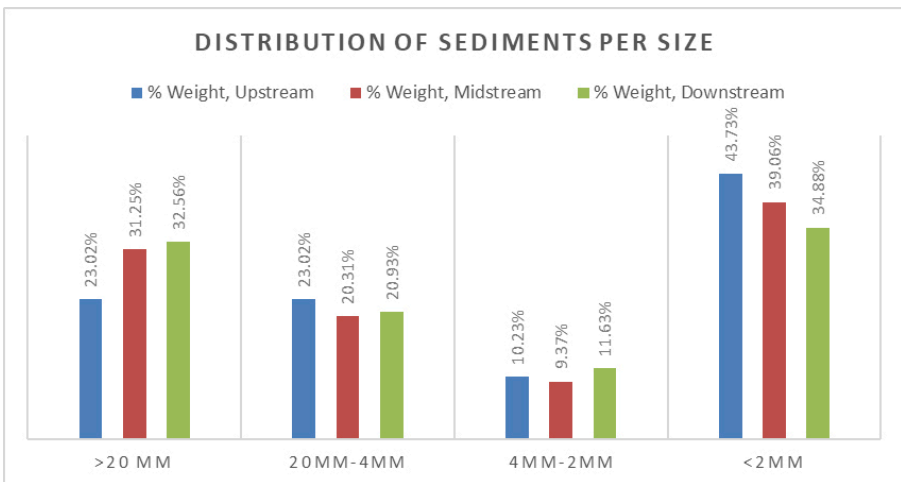


Figure 12. Histogram showing grain size distributions in upstream, midstream, and downstream.

Estimated Volume of Sand & Gravel Resources

Based on calculations, the estimated volume of sand and gravel in the study area is 3,787.79 m³ or 10,037.65 t.

Table 4 . Computed volume estimates using cross-sections measured during field work show a total of 3,787.79 m3 or 10,037.65 t without accounting for the rate of replenishment.

Segment	Section Length (m)	Average Sediment Cross-Sectional Area (m²)	Volume m³	Tonnage
1-2	45	29.09	1,309.05	3,468.98**
2-3	47	17.43	819.21	2,170.91
3-4	63	9.69	610.47	1,617.75
4-5	36	8.06	290.16	768.92
5-6	40	10.34	413.60	1096.04
6-7	30	11.51	345.30	915.05
TOTAL			3,787.79	10,037.65

***Assuming average specific gravity is 2.65 (National Resources Conservation Service of the USA, 2003)*

Extractable amounts based on grain size are presented in Table 4. The computation was performed using data from the sieving analysis. Data show that the extractable sand fraction is significant at 1,485.95 m³ without considering replenishment rates. Information for other grain sizes is presented in *Table 5*.

SUMMARY AND CONCLUSION

The study area is located near the mid-stream portion of the Tamlang River system within the Tamlang River Watershed. In general, the entire river system has meanders with low sinuosity. This area, specifically, is characterized by depositional features and slightly arcuate river bends. During the fieldwork, the rocks found in the riverbed are basalt, peridotite, gabbro, and chert. Resource estimates from river sections indicate an estimated volume of 3,787.79 m³ or 10,037.65 metric tons and a replenishment rate of 29,456.58 m³/year or 78,059.94 based on the RUSLE-SDR method. This method takes only into account sheetwash, rill and bank erosion, and does not consider extreme rainfall, flooding, or landslides.

Table 5. Extractable amounts of sediments without considering replenishment rates are computed by multiplying the average percentage of sediments obtained from sieving analysis.

Size	Size term		Average	Extractable amount (m³)	Extractable amount (t)
>20mm	gravel	Coarse pebble to cobble	28.94%	1,096.19	2,904.89
20 – 4mm		Coarse to fine pebble	21.42%	811.34	2,150.06
4 – 2 mm		granule	10.41%	394.30	1,044.92
<2mm	sand		39.23%	1485.95	3,937.77

Replenishment rate is 2.92x greater than the extractable volume, hence, sand and gravel extraction is viable. Recommended extraction rate is 3,787.79 m³ or 10,037.65 t, which is the volume computed from sectioning during fieldwork. This approach ensures that least amount of change is introduced to the river extraction site.

RECOMMENDATIONS

Although the replenishment rate is high, mitigating measures must still be established to prevent disturbance of the river systems. Dredging or using heavy equipment causes armor to be removed, and siltation may occur. As a result, areas downstream of the extraction area may be adversely affected. Hence, it is recommended that extraction be done manually and limited only to a depth of 1 m. In connection with monitoring water quality, the total dissolved solids (TDS) must be monitored before (pre-operation), during (operation stage), and after (rehabilitation) the extraction activities.

In view of higher sedimentation rates and natural and anthropogenic siltation during monsoons, production rates may be decreased during the wet season. Moreover, it is recommended that extraction areas be alternating to give time for sediment replenishment. A 5-meter buffer zone of the active extraction/quarry site may be

considered to prevent bank erosion. Installations of boulder dikes, or sandbags, may be done if necessary to protect riverbanks. Planting of appropriate vegetal mitigation may also be undertaken to avoid erosion (Malaysia Ministry of Natural Resources and Environment, 2009).

Re-evaluation of sediment depositions and sections during the extraction process must be done by obtaining cross-sections periodically (per month or every other month as deemed necessary). This allows monitoring of changes in river morphology of the disturbed sediments, which may regulate the allowable sediment extraction rates. Furthermore, this report recommends extracting below the replenishment rate to ensure minimal effects on the river system.

Sedimentation is erratic and is not constant for any river system. Large river sediments, particularly gravel and cobble, were deposited during extreme weather conditions or high flow events. A more comprehensive study that spans at least 2 years may be made to have an accurate replenishment rate.

In the interest of monitoring, baseline data must be gathered before and during operations to determine significant changes that may adversely affect the river system and the host community, which include, among others, aerial photographs, cross-sections, water, and sediment discharge.

ETHICAL CONSIDERATIONS

This research is not in conflict with any policies, rules, and regulations of the Department of Environment and Natural Resources. It is an initiative of the researcher/professional consultant to establish a methodology for a nationally implemented policy. Mapping and other software used in this research are all open source.

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REFERENCES

- Aurelio, M., & Peña, R. (2010). *Geology of the Philippines, 2nd Edition*. Geological Society of the Philippines.
- Balabathina, V. N., Raju, R. P., Mulualet, W., & Tadele, G. (2020). Estimation of soil loss using remote sensing and GIS-based universal soil loss equation in northern catchment of Lake Tana Sub-basin, Upper Blue Nile Basin, Northwest Ethiopia. *Environmental Systems Research*, 9(1). doi:<https://doi.org/10.1186/s40068-020-00203-3>
- Benavidez, R., Jackson, B., Maxwell, D., & Norton, K. (2018). A review of the (Revised) Universal Soil Loss Equation ((R)USLE): with a view to increasing its global applicability and improving soil loss estimates. *Hydrology and Earth System Sciences*, 22(11), 6059–6086. doi: <https://doi.org/10.5194/hess-22-6059-2018>
- Boyce, R. (1975). *Sediment routing and sediment delivery ratios, in present and prospective technology for predicting sediment yields and sources*. Washington, D.C.: U.S. Dept. of Agriculture.
- Chadli, K. (2016). Estimation of soil loss using RUSLE model for Sebou watershed (Morocco). *Modeling Earth Systems and Environment*. 2(2). doi:<https://doi.org/10.1007/s40808-016-0105-y>
- El-Swaify, S. G. (1987). Recent advances in soil conservation in steepland in humid tropics., 87–100. *Proceedings of the International Conference on Steepland Agriculture in the Humid Tropics*, 87-100.
- Environmental Management Bureau. (n.d.). EMB-Memorandum Circular 2020-07.
- Francisco, H., Cruz, W., & Conway, Z. (1988). Soil and Water Conservation Planning: Policy Issues and Recommendations . *Philippine Journal of Development*, 15(1). doi:<https://doi.org/10.62986/pjd1988.15.1c>
- Ghosal, K., & Das Bhattacharya, S. (2020). A Review of RUSLE Model. *J Indian Soc Remote Sens*, 48(4), 689-707. doi:<https://doi.org/10.1007/s12524-019-01097-0>
- Julien, P. Y. (2002). *River Mechanics*. Cambridge University Press. doi:<https://doi.org/10.1017/cbo9781139164016>
- Malaysia Ministry of Natural Resources and Environment. (2009). *River Sand Mining Management Guideline*. Department of Irrigation and Drainage - Malaysia.
- Metal Mining Agency of Japan-Japan International Cooperation Agency. (1989). *The Mineral-Exploration Mineral Deposits and Tectonics of Two Contrasting Geologic Environments in the Republic of the Philippines - Consolidated Reports on Northern Sierra Madre*.
- National Aeronautics Space Administration - USA. (2013). *Shuttle Radar Topography Mission (SRTM) Global*. doi:<https://doi.org/10.5069/G9445JDF>

- National Resources Conservation Service of the United States of America. (2005). *Fundamentals of Concrete Mix Design*. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_024034.pdf
- Panagos, P., Borrelli, P., Meusburger, K., Alewell, C., Lugato, E., & Montanarella, L. (2015). Estimating the soil erosion cover-management factor at the European scale. *Land Use Policy*, 48, 38–50. doi:<https://doi.org/10.1016/j.landusepol.2015.05.021>
- Rabang, D. (2018). *Geological Assessment of CPA-PLW-918 in Pulot Interior, Sofronio Espanola, Palawan*.
- Renard, K., Foster, G., Weesies, G., & McCool. (1997). *Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation RUSLE*. Handbook No. 703. . US Department of Agriculture.
- Salvacion, A. R. (2020). Delineating soil erosion risk in Marinduque, Philippines using RUSLE. *GeoJournal* , 87(2), 423–435. doi:<https://doi.org/10.1007/s10708-020-10264-7>
- Technology, D. o. (2022, October 18). *Land Cover and Soil Map of Palawan* . Retrieved from Geoportal: <https://www.geoportal.gov.ph/>
- The Philippine Atmospheric Geophysical and Astronomical Space Administration. (n.d.). *Climatological Normals*. Retrieved October 2022, from <https://www.pagasa.dost.gov.ph/climate/climatological-normals>
- Wischmeier, W., & Smith, D. (1957). Factors affecting sheet and rill erosion. . *Transactions*., 38(6), 889-896.