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SOIL LOSS AND PHYSICO-CHEMICAL DYNAMICS IN A SMALLHOLDER-PROTECTED WATERSHED IN MIDWESTERN LEYTE, PHILIPPINES*

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ABSTRACT

The study assessed soil loss and physico-chemical dynamics of the west-oriented watershed within the Community-Based Forest Management (CBFM) Project in Cienda, Gabas, Baybay, Leyte, Philippines. Results showed that, on the average, surface runoff was 10.35 m^3/hectare with associated sediments of 0.169 Mg/hectare. Average percentage of nutrients flowing with surface runoff was 1.97% and 1.27% along the streamflow compared to soil nutrients as baseline. Average infiltration rate during the dry season was 326.10 ml/min and 68.09 ml/min during the wet season. Turbidity of streamflow was 2.96 ntu and the associated sediments 16.0 mg/L. pH of streamflow ranged from 7.50 to 7.0 while total hardness from 7.84 to 15.16 mg/L. The average nitrite (NO_2) content was 11.115mg/L while nitrate (NO_3) was 1.05 mg/L. Phosphorous (P) ranged from 2.20 to 4.46 mg/kg or parts per million (ppm) while potassium (K) ranged from 3.71 to 3.90 ppm. Sodium (Na), calcium (Ca), and magnesium (Mg) were of low concentrations but sufficient to support plant growth.

KEYWORDS: Soil and water conservation. Nutrient loss. CBFM

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INTRODUCTION

Soil and water conservation is an integral land use management scheme in the tropics to keep soil in its sustainable productive condition. The objective of sustainable land use is the continuation of production over a long period. Given the food shortage in less-developed world and the virtually inevitable population increase, the present calls for forms of land use that will not only allow maintenance of current levels of production but will sustain production at higher levels than the present (Young, 1989). Despite various initiatives however, it is sad to note that soil erosion and nutrient loss is still one of the most serious environmental problems in the Philippines today. In the recent past, about 9 million hectares of alienable and disposable land throughout the country are already eroded (Paningbatan, 1989). Forests and watersheds are likewise suffering similar pressure as sadly manifested by the Ormoc tragedy, Southern Leyte flashfloods, Quezon Province disaster, and many others. At present, the remaining old growth dipterocarp forest is only 0.80 million ha (Rebugio et al., 2005) due to commercial logging, land use conversion and upland agricultural cultivation. Such cases are common throughout the tropics including the Philippines which worsen soil and nutrient loss rendering these essential resources useless for agricultural production. If soil nutrients from the uplands are slowly brought down to the lowlands, there could be sufficient time for lowland agricultural crops to absorb such nutrients and increase annual yield. Soil and water conservation therefore is essential in view of its enormous implications to agricultural production and human survival.

The implication of soil erosion to climate change has also become clearer. About 62 pentagrams[1] of carbon stored in the world soils returns to the atmosphere and one-half pentagram drains to the oceans annually

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[1] 1 pentagram=1^{15} grams

(Brady and Weil, 1999). Further destruction of the remaining forest ecosystems in watersheds would enhance these releases thereby escalating global warming. Currently, 20% of the global CO_2 emissions are coming from degraded forestlands. Thus, the Philippine government realized the need to rehabilitate degraded uplands through reforestation and protect the remaining forestlands. To this effect, the Philippine government implemented various programs to arrest soil erosion, nutrient loss, and livelihood problems in the uplands[2]. The Community-Based Forest Management Program (CBFMP) introduced in 1995 in particular recognized the indispensable role of the local people in managing the remaining forest resources in the country. However, assessing the capability of the CBFM project in conserving soil and nutrients is necessary to produce factual data that would validate that the project indeed provides such environmental service. Determining soil erosion and nutrient loss is essential so that soil and water conservation measures can be formulated and implemented, hence this study was conducted. Data generated from this study is anticipated to provide valuable information for policy formulation involving climate change, smallholders, watersheds, soil erosion and nutrient loss.

RESEARCH METHODS

Site of the Study

The study site was the southwest-oriented watershed ecosystem within the 2236 ha Community-Based Forest Management (CBFM) in Cienda, Gabas, Baybay, Leyte, the Philippines. The site is rugged and

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[2] These include the Integrated Social Forestry Program (ISFP), Upland Development Program (UDP), National Forestation Program (NFP), Forest Land Management Program (FLMP), Low Income Upland Communities Project (LIUCP), Community Forestry Program (CFP), Regional Resources Management Project (RRMP), Forestry Sector Project (FSP), and Community-Based Forest Management Program (CBFMP) (Harrison *et al.* 2005).

mountainous with slope ranging from 30 to 80 percent and lies between $124^{0}50'$ longitude and $10^{0}44'$ latitude having a climatic type IV with more or less evenly distributed rainfall throughout the year. Average annual rainfall is 2500 mm while the average annual minimum temperature is 22.3^{0}C and maximum is 33.67^{0}C (PAGASA 2007). The monthly average wind velocity is 2.17 m per second with the highest occurring during February to March and July that is attributed to the northeast and southeast monsoon (CRMF, c2002).

Sampling site 1 (upper portion) was within the protected zone, the second sampling site (middle portion) within the buffer zone, and the third sampling site (lower portion) within the multiple-use zone. The protected zone, located in the northeast portion of the CBFM project site, is a wilderness area protected against human interventions. The buffer zone, located immediately below the protected zone along the southwest orientation, is the portion of the project site where regulated use is permitted. The multiple-use zone is the lower most portion of the project site where traditional cultivation like abaca and coconut plantations is found (Figures 1 and 2).

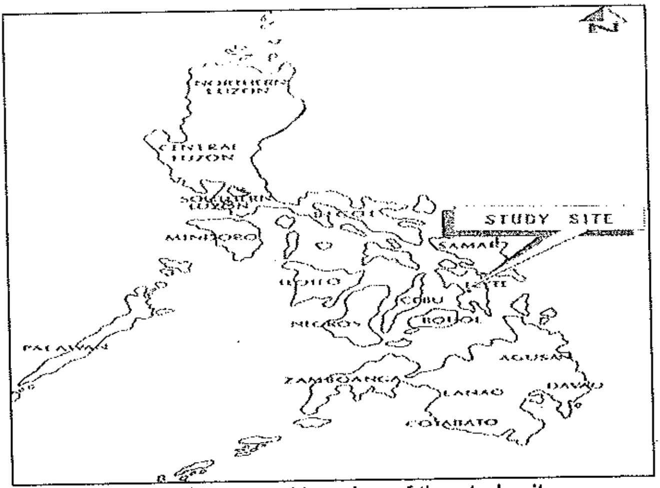

Figure 1. General location of the study site

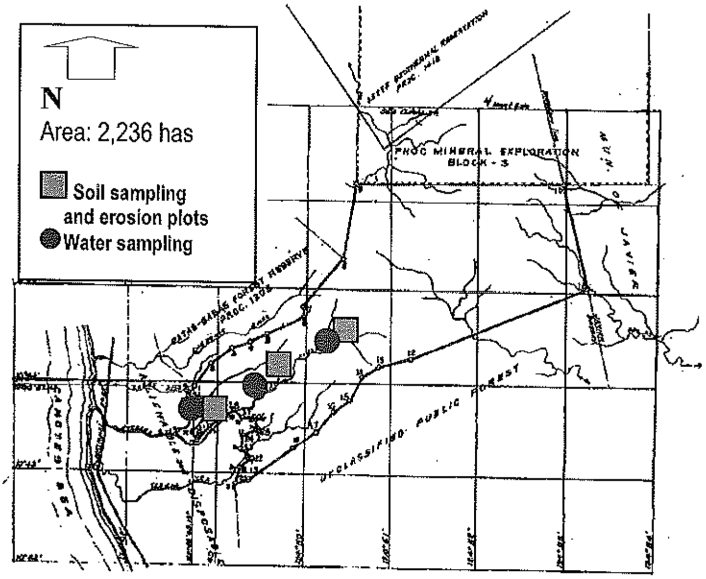

Figure 2. Specific location of the study sites

Field and Laboratory Methods

Soil physico-chemical analysis

To determine the physico-chemical status of the study site, soil samples were obtained from the three randomly selected 'floral diversity assessment'[3] plots within each zone using core samplers. The said samples were brought to the Soil Science and Analytical Service Laboratory of the Philippine Root Crops Research Center (ASL-PRCRTC)

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[3] Floral diversity was also assessed during the conduct of the study. Three randomly selected plots out of the nine plots established for such purpose were used as soil sampling site.

and analyzed for texture, pH, bulk density, organic matter, carbon (10-20 cm), nitrogen, phosphorus, potassium, calcium, magnesium, and sodium content using the digital Orion pH meter, Soil and Water Digestor, Orbeco-Hillige Water Analyzer, Atomic Absorption Spectrometer and other equipment. Organic matter was analyzed using the Wakly-Black Method, total nitrogen using the Kjeldahl Method, available phosphorous using Bray No.2 method and other routine methods for soil and water analysis.

Infiltration rate analysis

Infiltration rate was assessed using the single-ring infiltrometer made of galvanized iron (GI) pipe. One-third of its total height (10 cm) was driven unto the ground and a measured volume of water (300 ml) was poured into it. Time spent for water infiltration was read simultaneously. The first assessment was done during summer while the second assessment was conducted during the rainy season.

Surface runoff analyses

To determine soil loss and nutrient dynamics in the study site, surface runoff and the associated sediment yield were assessed using the runoff plots described by Cruz (1994), Kelly and Gomez (1998), and Ciesiolka and Rose (1998). In each zone, three runoff plots measuring 4 m x 8 m were laid out parallel to the slopes. Thirty-cm wide plane galvanized iron (GI) strips were used as boundary on all its sides with the lower portion strategically opened and connected to a gutter directed towards a receiving 100-L drum or container. About half of the width of GI sheets (15 cm) was buried into the soil while the remaining half extended above the soil surface to prevent the outflow and inflow of water from and to the plots. These runoff plots were established along the three zones with more or less homogenous slopes (approximately 50%) to facilitate the comparative analyses.

Surface runoff produced after rainfall event was measured from the receiving drum or container below each plot. Eroded soil sediments from the said plots were determined (volumetrically and gravimetrically) at the end of every rainfall event. One-L aliquots from the thoroughly agitated runoff from the receiving drums were taken for sediment determination and analyses. All the receiving drums were then drained of runoff water for the next runoff and sediment samplings.

The sediment yield and associated nutrients from the 1-L aliquots was determined at the ASL-PRCRTC. The Whatman micro-fiber filter paper was used to sieve the soil sediments from the samples. The filtered soil sediments were oven-dried and weighed. The total amount of sediments per plot and per ha was calculated using the formula used by Ayson (1997):

$$\text{Sediment yield/plot} = \frac{\text{Oven-dried wt of filtered soil}}{1\text{ L}} \times \text{Total runoff volume (L)} \quad \text{(equation 1)}$$

$$\text{Sediment yield/ha} = \frac{\text{Sediment yield/plot}}{\text{Area of plot (m}^2\text{)}} \times \frac{10{,}000\text{m}^2}{1\text{ ha}} \quad \text{(equation 2)}$$

Streamflow analysis

Water samples were collected, employing stratified sampling technique, at strategic locations within the river system of the study site using sterilized plastic bottles. Samples were immediately brought and analyzed for the associated nutrients, sediments, hardness, and turbidity at the ASL-PRCRTC of the Visayas State University, Baybay, Leyte. Sample collections for physico-chemical properties were replicated three times while streamflow discharge and velocity were determined seven times within the study period.

RESULTS AND DISCUSSION

Soil physico-chemical Properties

The site had a soil pH ranging from 5.10 to 6.57 based from the pH category of Landon (1991). The study of Asio (1996) on the soils of the adjacent mountain ecosystem corroborates such findings. In his analysis, he obtained pH values ranging from 4.0 to 5.20.

Soil texture ranged from silt loam, sandy loam to clayey. The protected zone contained the highest percentage of silt; the multiple-use zone had the highest percentage of sand; and the buffer zone had the highest percentage of clay. Bulk density ranged only from 0.61 to 0.78 Mg/m3 implying that the area was not subjected to various forms of compaction-enhancing perturbations. The protected zone contained the highest percentage of carbon and organic matter followed by the buffer zone and then the multiple-use zone.

As the presence of organic matter is also indicative of the nitrogen present in the soil, it was noticed that nitrogen level within the different zones showed the same trend as the organic matter. Other nutrients were also present at low with variable concentrations but sufficient enough to support the growth of plants (Table 1).

Infiltration rate

The different zones showed different infiltration rates. The protected zone had an average infiltration rate of 498.58 ml/min during the summer period but only 86.34 ml/min during the wet season. The buffer zone had the lowest infiltration rate among the three zones possibly because of the high clay percentage of the soil in the area. Clay has finer particles characterized by high cohesion and retention of water molecules, therefore limiting the movement of such substance into and within the ground. The multiple-use zone, on the other hand, which had sandy loam to clay loam, had higher infiltration rates than the buffer zone (Table 2).

Table 1. Physico-chemical properties of soil within the different zones of the study site

PARAMETERS	LOCATION		
	Protected Zone	Buffer Zone	Multiple-use Zone
pH	5.97	5.10	6.57
Texture			
Upper slope	Silt loam	Clay	Sandy loam
Middle slope	Loam	Silt loam	Clay loam
Lower slope	Silt loam	Loam	Sandy loam
Bulk Density (Mg/m^3)	0.72	0.61	0.78
Carbon % (10-20 cm depth)	5.80	4.59	2.98
Organic matter (%)	10.00	7.92	5.14
Total N (%)	0.67	0.58	0.29
P (mg/kg)	144.00	162.00	256.00
K (mg/kg)	627.83	260.97	269.05
Na (mg/kg)	159.80	125.79	136.77
Ca (mg/kg)	2107.50	1354.25	5208.25
Mg (mg/kg)	471.53	359.95	848.54

Table 2. Infiltration rate of the ground surface within the different zones of the study site

PARAMETERS	LOCATION		
	Protected Zone	Buffer Zone	Multiple-use Zone
Dry Season			
Infiltration Rate (mL/min)	498.58	110.28	369.43
Soil moisture (%)	51.42	62.23	22.07
Wet Season			
Infiltration Rate (mL/min)	86.34	6.89	111.04
Soil moisture (%)	69.59	77.37	34.36

Surface runoff and sediment yield

The buffer zone generated the highest amount of surface runoff (SRO) among the three observation sites (Table 3) followed by the protected zone and then the multiple-use zone. As surmised earlier, the clayey soils in the buffer zone could have impeded the infiltration process, thus causing more surface runoff. The high surface runoff from the buffer zone also carried the highest yield of sediments amounting to 23.83 g/L. Basically, the higher the rainfall, the higher the surface runoff as shown in Figure 3. The amount of sediments associated with surface runoff also showed a similar trend except for the protected zone which generated only a very trace amount (Figure 4). The presence of plant debris on the forest floor as well as the varied stratification of vegetation could be responsible for the diverse results.

Table 3. Surface runoff and the associated sediment yield within the study site

	LOCATION		
PARAMETERS	Protected Zone	Buffer Zone	Multiple-Use Zone
Surface Runoff (L/plot)	25.14	57.10	17.16
Surface runoff (m3/ha)	7.86	17.84	5.36
Sediment Yield (g/L)	0.51	23.83	14.53
Sediment Yield (Mg/ha)	0.004	0.425	0.078

Results revealed the lowest surface runoff occurred within the multiple-use zone followed by the protected zone and then the buffer zone. As to the soil type, the multiple-use zone was dominated largely by sandy loam soil which is expected to absorb or infiltrate considerable volume of water, hence the lesser surface runoff. The protected zone, on the other hand, had silt loam soil with lesser infiltration but with higher surface runoff than the soil in the multiple-use zone. The buffer zone, having the highest amount of clay, showed the highest amount of surface runoff and least infiltration rate. Such findings corroborated the observations of Ward (1967). Overall results showed that soil erosion within the study site is below the tolerable limit of 10 tons per hectare per year.

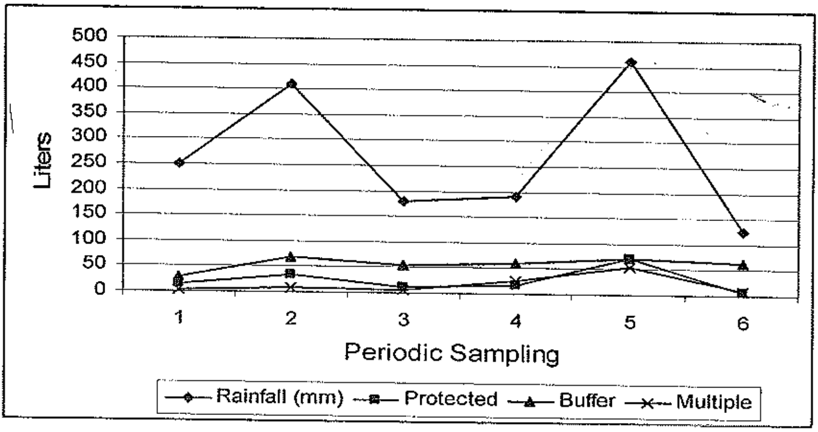


Figure 3. Rainfall and resultant surface runoff within the three zones

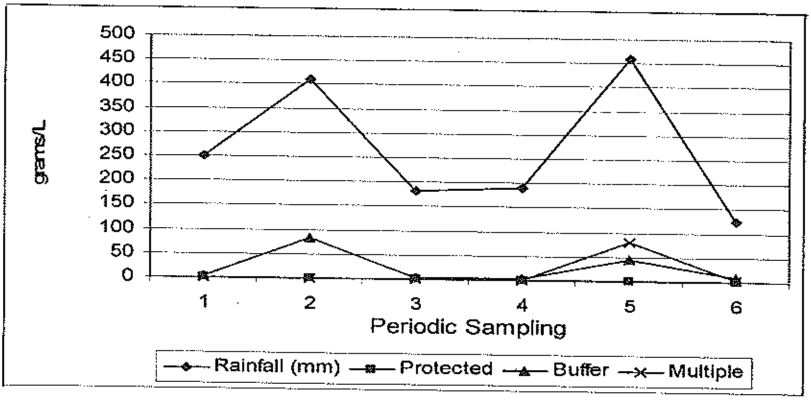


Figure 4. Rainfall and the associated sediment yield from surface runoff

The pH of runoff water ranged from 7.05 to 7.12, a bit higher than the soil pH values. The nitrogen present was very low (Table 4). Nitrogen is lower compared to the soil nitrogen content. Within the soil, nitrogen is largely stored in the organic matter or decaying debris. Hence, the soil nitrogen was higher compared with the nitrogen in the runoff water. Phosphorus, potassium, sodium, calcium, and magnesium also had lower concentration in runoff water compared with that in the soil.

Table 4. Chemical properties of surface runoff water within the different zones of the study site

PARAMETERS	LOCATION		
	Protected Zone	Buffer Zone	Multiple-use Zone
pH	7.120	7.070	7.050
Total N (%)	0.010	0.011	0.019
Total P (mg/kg)	0.194	0.039	0.178
Total K (mg/kg)	54.725	16.478	18.314
Total Na (mg/kg)	2.822	1.208	1.980
Total Ca (mg/kg)	12.596	5.969	10.623
Total Mg (mg/kg)	1.984	1.015	2.096

Streamflow Characteristics

The pH value of water along the river system ranged from 7.504 to 7.610 (Table 5). Based from DAO 34 (S 1990) and WHO (1993), such value is still within the allowable range for class AA waters. This means that the river water within the study site is in superior condition in terms of pH. Such condition could be attributed to basaltic geochemistry of the parent material of the site as revealed by Asio (1996).

The turbidity level was below the maximum limit at 5 NTU indicating low sediment and suspended solid concentrations. Average velocity was 0.303 m/sec and average volume of 0.318 m³/sec (Figures 5 and 6). It was obvious that the multiple-use zone had the highest volume because of the accumulation of water from the upper tributaries. In addition, the associated sediment yield on streamflow ranged only from 0.011 to 0.021 g/L while total hardness ranged only from 7.843 to 15.164 mg/L (Table 5). Based on DAO 34-S 1990 and WHO 1993, the site's sediment yield and hardness of water are within the acceptable level.

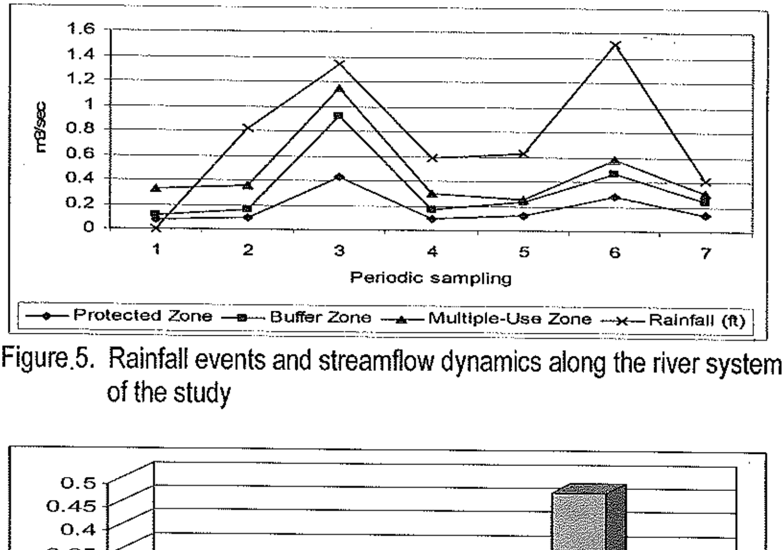


Figure 5. Rainfall events and streamflow dynamics along the river system of the study

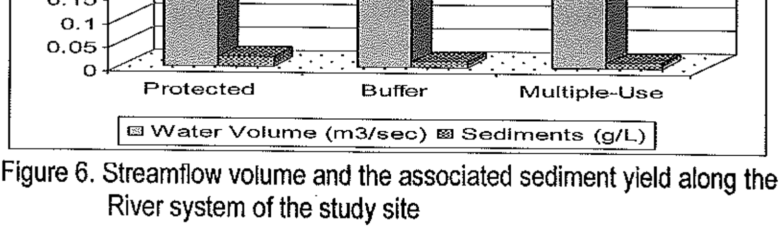


Figure 6. Streamflow volume and the associated sediment yield along the River system of the study site

Table 5. Physico-chemical properties of streamflow or surface water along the river system of the study site

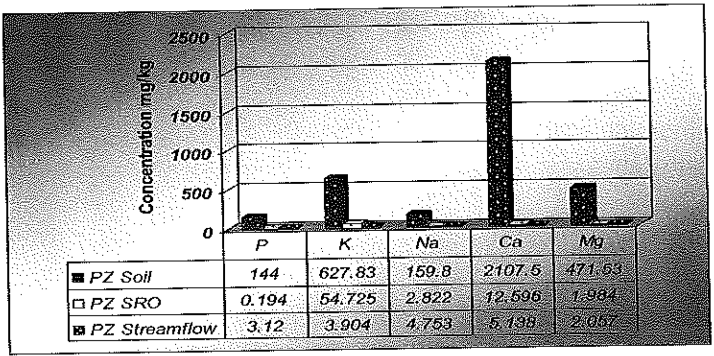
PARAMETERS	LOCATION		
	Protected Zone	Buffer Zone	Multiple-use Zone
pH	7.510	7.504	7.610
Turbidity (FTU)	3.260	3.250	2.650
Sediments (g/L)	0.021	0.012	0.011
Total Hardness (mg/L)	7.843	8.172	15.164
NO2 (ug/L)	7.740	6.906	15.321
NO3 (mg/L)	1.282	1.696	0.820
Total P (mg/kg)	3.120	2.200	4.460
Total K (mg/kg)	3.904	3.708	3.884
Total Na (mg/kg)	4.753	3.969	4.902
Total Ca (mg/kg)	5.138	5.944	4.894
Total Mg (mg/kg)	2.057	1.545	1.879

The nitrite (NO_2) content of streamflow ranged only from 6.906 to 15.321 ug/L which is far below based on the WHO's 1993 acceptable levels while nitrate (NO_3) ranged from only 0.820 to 1.282 mg/L, which is also far below from the WHO's 1990 standards. According to the World Resources Institute (1988-1989) cited by Lean et al., (1990), nitrates in drinking water may cause blood poisoning in infants, hypertension in children, gastric cancer in adults, and fetal malformations. The combination of high nitrates with pesticides is carcinogenic (cancer-forming) and mutagenic (causing birth defects). Thus, high concentration of such substance in water is hazardous to the consuming public particularly in many upland communities that rely on rivers for their drinking water. Results of this study nevertheless revealed the safe quality of water from nitrite and nitrate content (which are actually pollutants) in the study site.

The amount of nutrients along the streamflow was also very low. Potassium (K) ranged only from 3.708 to 3.904 mg/kg or ppm. Sodium (Na), calcium (Ca), and magnesium (Mg) concentrations were also very low (Table 5). This indicates the good quality of water in terms of nutrient level along the site's river system. As pointed earlier, the hardness of water was also very low, implying the low concentration of nutrients/minerals. Algal bloom therefore is not a threat within the study site. Phosphorous (P) however ranged from 2.20 to 4.46 mg/kg which is high than the limit set under Philippines' DAO 34 S 1990. Further study on this substance in the near future seems essential.

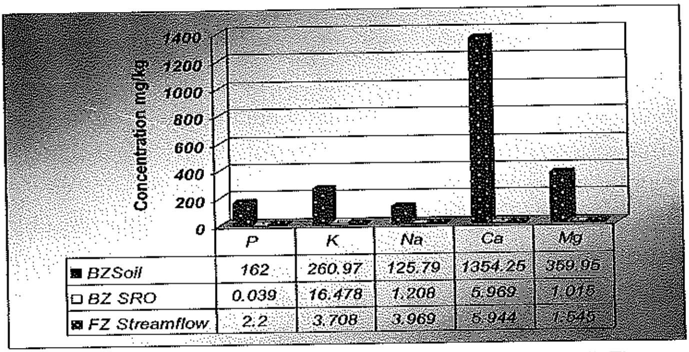
Nutrient Dynamics

The overall nutrient movement within the study site was highly dynamic. For example, P is low along the surface runoff but higher within the streamflow or surface water. Thus, there is no clear pattern of nutrient movement from the soil complex down to surface runoff up to surface water or streamflow. It was however apparent that nutrient movement from the soil down to the surface water is very minimal (Figures 7a-7c and Tables 6a-6c). In all zones, nutrients associated with surface runoff ranged only from 0.024% to 8.716% and streamflow from 0.094% to 3.584%. It was hypothesized before the conduct of the study that streamflow could have the highest nutrient levels in view of the highly possible downward movement of nutrients from the soil complex down to the river system. This is however not the case. This means that nutrients along the streamflow could be due to the nutrients originating from the parent or geologic materials from where the water emanates. The intact riparian vegetation which acted as filter for soil erosion and nutrient movement could also be reason for the highly variable results.



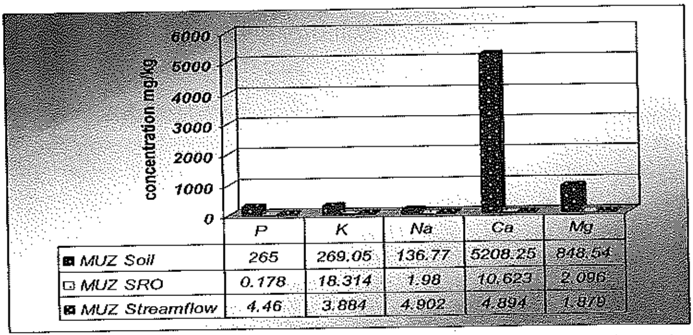
	P	K	Na	Ca	Mg
■ PZ Soil	144	627.83	159.8	2107.5	471.53
□ PZ SRO	0.194	54.725	2.822	12.596	1.984
▨ PZ Streamflow	3.12	3.904	4.753	5.138	2.057

Figure 7a. Nutrient dynamics at the Protected Zone (PZ)



	P	K	Na	Ca	Mg
■ BZSoil	162	260.97	125.79	1354.25	359.95
□ BZ SRO	0.039	16.478	1.208	5.969	1.015
▨ FZ Streamflow	2.2	3.708	3.969	5.944	1.545

Figure 7b. Nutrient dynamics at the Buffer Zone (BZ)



	P	K	Na	Ca	Mg
▨ MUZ Soil	265	269.05	136.77	5208.25	848.54
□ MUZ SRO	0.178	18.314	1.98	10.623	2.096
▨ MUZ Streamflow	4.46	3.884	4.902	4.894	1.879

Figure 7c. Nutrient dynamics at the Multiple-Use Zone (MUZ)

Table 6a. Nutrient dynamics in the protected zone calculated as percentage of soil nutrient

NUTRIENTS	PROTECTED ZONE		
	Soil Nutrients	Surface Runoff*	Streamflow Nutrients*
Total P (mg/kg)	144.00	0.135	2.167
Total K (mg/kg)	627.83	8.716	0.622
Total Na (mg/kg)	159.80	1.766	2.974
Total Ca (mg/kg)	2107.50	0.598	0.244
Total Mg (mg/kg)	471.53	1.545	0.436

**Calculated as percentage of soil nutrients (values obtained over soil nutrient values as baseline*

Table 6b. Nutrient dynamics in the buffer zone calculated as percentage of soil nutrient

NUTRIENTS	BUFFER ZONE		
	Soil Nutrients	Surface Runoff*	Streamflow Nutrients*
Total P (mg/kg)	162.00	0.024	1.358
Total K (mg/kg)	260.97	6.314	1.421
Total Na (mg/kg)	125.79	0.960	3.155
Total Ca (mg/kg)	1354.25	0.441	0.439
Total Mg (mg/kg)	359.95	0.282	0.429

**Calculated as percentage of soil nutrients*

Table 6C. Nutrient dynamics in the multiple-use zone calculated as percentage of soil nutrient

NUTRIENTS	MULTIPLE-USE ZONE		
	Soil Nutrients	Surface Runoff*	Streamflow Nutrients*
Total P (mg/kg)	265.00	0.067	0.551
Total K (mg/kg)	269.05	6.807	1.444
Total Na (mg/kg)	136.77	1.448	3.584
Total Ca (mg/kg)	5208.25	0.204	0.094
Total Mg (mg/kg)	848.54 0.247	0.221	

**Calculated as percentage of soil nutrients*

Some Implications

Soil erosion within the study site is below the tolerable limit (i.e. 5-12 tons per hectare per year as suggested by USDA in 1950s (Schertz,1983)) which could be attributed to its intact vegetation. Soil erosion is one of the major problems in tropical countries like the Philippines. It is thus essential to keep soil erosion to its minimum to minimize soil nutrient loss and CO_2 emission. Carbon dioxide reacts in the soil to produce carbonic acid (H_2CO_3) and the carbonates and bicarbonates of calcium, potassium, magnesium, and other base-forming cations. The bicarbonates are readily soluble and may be removed in drainage. Eventually, much of the carbon in the carbonates and bicarbonates is also returned to the atmosphere as carbon dioxide (Brady and Weil 1999). Thus accelerating soil erosion will enhance the release of carbon dioxide to the atmosphere. Findings from this study showed favourable result implying that the CBFM project through the effort of the local people is able to keep soil erosion to its minimum.

The associated nutrient flow was highly dynamic which could be due to the nutrients from the geologic materials and riparian vegetation acting as filter for soil erosion and nutrients. Results showed only trace amount of nutrients along the river system. Too much nutrients in water bodies would cause eutrophication. Engelking (2007) pointed out that phosphates and nitrates can fertilize the algae that grow in lakes or rivers. When algae grow, in the presence of sunlight, they produce oxygen. But if algae grow too much or too fast, they consume great amounts of oxygen, both when the sun is not shining and when the algae die and begin to decay. Lack of oxygen eventually suffocates other life; some living things may be poisoned by toxins contained in the algae. This process of algal overgrowth, called *eutrophication*, can kill life in lakes and rivers. In some cases, particular algae can also poison the drinking water of people and livestock (Engelking, 2007). Frequent death and decay would mean frequent CO_2 emission, thus eutrophication has climate change implication.

The overall result of this study thus revealed the natural capability of forests and watershed to conserve soil and water resources, an important forest environmental service with climate change implication. And this is made possible through the effort of the smallholders who are protecting the watershed against illegal logging and other forms of destruction. In fact, they were able to apprehend about 18 cases of illegal logging activities and dozens of river poisoning. Hence the said project was nominated as one of the "exemplary forest management in Asia and the Pacific" (see RAP Publication 2005/02). Sustaining the enthusiasm of smallholders to keep protecting the watershed remains a great challenge. About one-fourth of the total population in the country is situated in the Philippine uplands and their contribution in watershed protection and climate change mitigation is therefore significant. It is suggested that the government would consider rewards or livelihood opportunities for smallholders in relation to watershed protection. The government may consider the emerging opportunities on this aspect in view of the global political commitment of halving poverty by 2015. May the government also consider for the benefit of the smallholders the globally emerging initiative on Payment for Environmental Services (PES) program and the Reduced Emissions from Deforestation and Forest Degradation (REDD) which will be included during the COP 15 meeting in Copenhagen by December 2009.

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