Environmental assessment of soil erosion in Inabanga watershed (Bohol, Philippines)

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Abstract Analysis of soil redistribution patterns in watershed areas provides information for understanding soil erosion and deposition for implementing management practices to improve agricultural land conditions and reduce sediment loads in river systems. This paper has demonstrated the use of Cesium-137 (^{137}Cs) in estimating retrospective medium-term soil erosion rates in selected cassava cultivated areas in Pilar, a sub-watershed within the Inabanga watershed. To estimate erosion and deposition rates and elucidate the factors affecting the soil redistribution, samples were collected from a total of ninety-eight grid intersections representative of the local land use and slope gradients in the presence or absence of soil conservation practices. A proportional model was used to deduce soil redistribution rate estimates from ^{137}Cs inventories measured from individual soil samples. Soil measurements of ^{137}Cs activity-generated soil erosion rate gave values of $13.15 \text{ t ha}^{-1} \text{ year}^{-1}$ in cultivated areas practicing conservation measures and $22.23 \text{ t ha}^{-1} \text{ year}^{-1}$ in those with typical upland plantation, with the former corresponding to slight erosion case and the latter to moderate erosion case. The obtained values have provided an overview of the pattern of soil redistribution in the watershed area and reflect the impact of strategic soil erosion management being applied. Interestingly, in light of recent severe meteorological events befalling the region, e.g., super typhoon Haiyan and the 7.3 magnitude earthquake, the data obtained may serve as benchmark values for ^{137}Cs activities against which changes in the soil

movement and soil redistribution pattern along the watershed areas can be evaluated.

Keywords Agriculture · Cesium-137 radioactivity · Environment · Sediments · Soil redistribution · Typhoon · Water resources

1 Introduction

Soil erosion problem has been increasingly recognized to impact on both agricultural productivity and freshwater resources. The expanding population and growing concern for food supply has resulted in the rapid deforestation and clearing of lands to give way to agricultural cultivation. The Philippines and other countries in Asia are particularly threatened by the serious problems of soil degradation (Lapar and Pandey 1999). Visible evidences of soil erosion resulting from massive agricultural activities and poor farming practices are most prevalent in the uplands and sloping areas, since much of subsistence farming is carried out without soil conservation measures. Consequently, the continuous removal of surface soil due to erosion has led to soil degradation as reflected by poor soil fertility, breakdown of soil structure and increasing sediment loads in rivers and water reservoirs (Clark et al. 1985). Soil erosion has been a major environmental concern, and several studies have been well documented throughout the history of agriculture (IAEA-TECDOC 1741 2014; Buccheri et al. 2014; Mabit et al. 2007; Pimentel et al. 1995).

In the Philippines, the severity of the soil erosion problem, exacerbated by the country's vulnerability to drought and land degradation as a result of recurring

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incidence of El Nino and La Nina, can have disastrous consequences. Furthermore, tropical soils are of particular threat since they are less stable than those in temperate climates because of their properties and climatic conditions (Steiner 1996). The occurrence of flashfloods and landslides brought about by incessant rains and strong winds may accelerate soil erosion, thereby reducing cropland productivity and contributing to the pollution of adjacent water resources. With the order reversed, the loss of soil leads to a decline in organic matter and nutrient content, the breakdown of soil structure and possibly a reduction of the available soil water stored, can likewise lead to an enhanced risk of flooding and landslides in contiguous areas. Removal of the natural vegetation cover due to practices such as deforestation, overgrazing or industrial farming practices (e.g., tillage) leaves the soil exposed to the action of climatic factors, such as rain and wind (MEA 2005). The mobilization and deposition of soil can significantly alter the nutrient and carbon cycling (Quinton et al. 2010), as eroded soil may lose 75–80 % of its carbon content, with consequent release of carbon to the atmosphere (Morgan 2005).

Soil erosion impacts strongly on the environment and consequences for society are relatively severe. The high economic cost is estimated at \$44 billion each year in the USA (Pimentel et al. 1995). In Europe, erosion has been estimated to affect 115 million ha (SOER 2010; Kibblewhite et al. 2012). According to the U.N. Millennium Ecosystem Assessment, approximately 40 % of the world's agricultural land is seriously degraded. FAO (2000) estimated that 79 % of Philippine lands are threatened by severe degradation, using the Global Assessment of Soil Degradation database.

Efforts have been made to revive agricultural productivity in the Inabanga watershed in Bohol Island, Philippines. Bohol is the tenth largest island in the country with more than 80 % of the population dependent on agriculture. The Philippine Council for Agriculture and Resources, Research and Development reported that more than half of the island is already eroded (PCARRD 1984). Poor land-use practices have caused soil erosion and runoff, leading to a decline in agricultural productivity. Fisheries and coastal mangroves have also been affected by these land degradation problems due to subsequent erosion that contributes to the decline of water quality in the river system. To make a bad situation worse, the impact of recent environmental catastrophic events (shock of the earthquake and the super typhoon Haiyan) left substantial damages to infrastructures, wiping out agriculture and fisheries. At present, there is very limited information on soil loss and redistribution rates in the watershed areas. There are erosion measurements conducted using conventional methodologies; however, there is currently no long-term assessment and quantitative information

on soil erosion and redistribution, and how these factors impact the quality and quantity of water in the river systems. In addition, the application of ^{137}Cs technique had not previously been carried out in the Inabanga watershed. The inclusion of ^{137}Cs -based erosion study in this paper will enrich the evaluation of erosion and sedimentation processes occurring in the watershed.

In a country that experiences scores of annual floods, landslides and strong typhoons, it is vital to have long-term soil erosion rate measurements. This may be a valuable tool for planners by providing them with information needed to assist in developing strategies to address key issues on agricultural productivity and water resources management in the Inabanga watershed. This report gives an initial data on spatial distribution of soil erosion and redistribution rates in selected cultivated areas. More importantly, the (pre-disaster) data presented here will serve as a reference guide that can be used to monitor and identify areas that are vulnerable to soil erosion—essential in undertaking future studies in the watershed areas about the extent of the areas affected and, ultimately, for developing measures for possible remedial action to keep the problem under control and as an urgent requirement for ongoing rehabilitation efforts.

2 Materials and methods

2.1 Description of the study site

The Inabanga watershed is the largest watershed in the island of Bohol, located (9°50'N and 124°10'E) in the central part of the Philippines (Fig. 1). The area is about 61,000 ha, covering 16 municipalities and 98 barangays. Agricultural land constitutes more than 50 % of the watershed of which more than 60 % of the uphill land have a slope of more than 18 % susceptible to erosion. The estimated rate of land erosion is $10 \text{ m}^3 \text{ ha}^{-1}$ annually (PPDP 1997). This is attributed to the lack of sufficient vegetative cover in the upland areas. Improper upland farming practices and deforestation were also identified as the major causes of the problem.

The climate in Bohol is characterized by two distinct seasons. The dry season occurs from late January to May, while the wet season is from June to December. The weather varies in different areas—warm and dry along the coast; cold and humid in the interior. The average rainfall is about 2000.0 mm which is evenly distributed in the island. The watershed is also one of the most important sources of water for agriculture and domestic use (ACIAR Report 2001).

The upper Inabanga watershed is the drainage basin of the Malinao Dam Reservoir (Fig. 1). The two major tributaries converging into the dam are the Pamacsalan River in the eastern part and the Wahig River in the

Fig. 1 Study site (Inabanga watershed)

southwestern side. The dam was designed to serve about 5000 ha of adjoining agricultural land since 1996 and has a catchment area of about 13,800 ha including a 140-ha reservoir. The reservoir is situated at an altitude of about 140 m above mean sea level, while the highest elevation of the catchment is at 861 m (PPDP 1997).

Soil samples were collected in the municipality of Pilar, a sub-watershed of the Inabanga watershed on July 2008. Pilar has a total land area of about 11,599 ha, 62 % of which is devoted for agricultural purposes with land use mainly for cassava, corn, rain-fed and irrigated rice. Reconnaissance and site exploration of the Inabanga watershed revealed that soil conservation measures are implemented only in certain areas in Pilar. The study site chosen was cultivated with cassava. Two sampling sites, namely Site 1, cultivated with conservation measures, and Site 2, cultivated without conservation measures, have been used in the study. The chosen site is located 200 meters above sea level with an area of about 3273 ha, and the general topography is gently sloping to undulating and undulating to rolling, with slope ranging from 10 to 15 %

and 5 to 20 %, for Site 1 and Site 2, respectively. The contour map in the sampling site is shown in Fig. 2. The dominant soil type in the sampling area is the Ubay clay loam (51.18 %) and Ubay clay (44.95 %). These soil types are generally fertile and suited for cultivation to a number of crops (BSWM 1992).

2.2 Methodology

The insidious impact of soil erosion is more difficult to evaluate using the conventional erosion measurement method, i.e., erosion plot, as it possesses many important limitations. It involves tedious simulation of rainfall and prolonged observation and the data derived from such plot may be unrepresentative of the natural landscape as it is limited by the area covered by the plot (Longmore et al. 1983). The use of environmental radionuclides, more particularly ^{137}Cs measurement, has attracted increasing attention as a means of obtaining spatially distributed information on rates of erosion and redistribution (Loughran 1989; Owens and Walling 1996; Walling 1998). ^{137}Cs is an

Fig. 2 General topography in the sampling sites

artificial radionuclide with a half-life of 30.2 years. It was released into the atmosphere and distributed globally during the nuclear weapons testing in the late 1950s and early 1960s and strongly adsorbed in the soil surface upon fallout. Any subsequent redistribution of ^{137}Cs within the landscape will therefore reflect redistribution of soil particles, making ^{137}Cs an effective sediment tracer and providing a basis for estimating erosion and deposition rates (Zapata 2003).

2.2.1 Determining the ^{137}Cs reference inventory

One of the major considerations for ^{137}Cs -based measurements of soil erosion is the identification of suitable reference inventory value. The accuracy of soil loss estimates using this technique depends on obtaining reliable estimates of the ^{137}Cs in soils of reference sites that have experienced no soil redistribution since the time of fallout. The local reference inventory value represents the cumulative atmospheric ^{137}Cs fallout of the study site. The assessment of ^{137}Cs redistribution is commonly based upon comparison between the measured inventory at individual sampling points and an equivalent estimate of this reference inventory value (Ritchie 1998).

Soil samples most suitable for establishing the reference inventories were sampled in flat, non-eroding and undisturbed open grassland area. Since reference sites are often considered as undisturbed sites, the behavior of the ^{137}Cs as a function of depth in a particular landscape could be determined through collection of soil samples at incremental depths. Initially, soil samples were collected using a scraper plate with a surface area of 989.0 cm². The metal frame was inserted into the soil to define the sampling area,

and the maximum depth was up to 42 cm. ^{137}Cs activity was measured every 2-cm layer from top to bottom of the sample to determine the necessary depth for further sampling. After establishing the maximum depth with significant ^{137}Cs activity reading, six bulk samples were subsequently collected in 2 m by 2 m grid pattern using a 40-cm-long steel corer with a surface area of 50.0 cm². The total ^{137}Cs inventory in each core was averaged to obtain the local reference inventory in the site. The soil cores were collected according to the recommendations of Zapata and Garcia Agudo (1999).

2.2.2 Soil collection and ^{137}Cs radioactivity measurements

Soil samples were collected using a steel corer with a length of 40 cm and diameter of 10 cm. Based on the initial data obtained, the maximum depth was decided to be the particular layer at which ^{137}Cs radioactivity was expected to be detected. The sample was laid out in a 10.0 m by 10.0 m grid, and this design was used in both the study sites, namely cassava cultivated farm with conservation measures (Site 1) and cassava cultivated farm without conservation measures (Site 2). The total area sampled is about 0.50 and 0.66 ha, in Site 1 and Site 2, respectively. Soil core samples were collected from a total ninety-eight individual grid intersections. Figure 3 shows the detailed location of the sampling points and the topography of the study sites.

Soil samples collected were prepared for ^{137}Cs radioactivity measurement after drying and sieving. The <2.0-mm fraction was analyzed in the Chemistry Research Section Laboratory, Philippine Nuclear Research Institute. The activities in the soil samples, placed in one-liter Marinelli beaker, were counted using a high-purity germanium detector of 35 % relative efficiency.

2.2.3 Runoff and water quality

The location for measurement and sampling collection station is shown in Fig. 1. Automatic water sampler/flowmeter (AWaS) was installed strategically in the upper Inabanga watershed to conduct stream flow measurements (contributing sub-watersheds of Pamacsalan and Wahig to Malinao dam reservoir). In order to correlate stream flow measured from AWaS with rainfall, automatic weather stations (AWeS) were also installed.

The AWaS is equipped with 24 1-l sampling bottles. Water collection was programmed to collect samples at specified time intervals. Parameters such as pH and electrical conductivity (EC) were done in situ. Other water quality parameters such as total suspended solids (TSS), total phosphorus/nitrogen (TP/TN) and pesticide residue were sent to laboratory for analysis.

Fig. 3 Detailed sampling points and topography of the study sites

2.2.4 Estimating erosion and deposition rates

There is no established long-term soil erosion and deposition data available for Inabanga watershed or any other prediction models applied for this area that can be used for independent correlation. Several approaches have been used to convert ^{137}Cs radioactivity measurements to quantitative estimates of erosion and deposition rates (Walling and Quine 1995; Walling and He 2000; Walling and He 1999). In this study, the technique that is used was based on the method described in detail by Walling and Quine (1991). This method is based on the successful identification and estimation of local reference inventory within the vicinity of the study area (Zapata and Garcia Agudo 1999). Hence, the establishment of a link between ^{137}Cs loss or gain in each sampling point and the soil redistribution rate is imperative. In this method, the spatial pattern obtained from the difference between the ^{137}Cs reference inventory and the measured inventory for each soil sampling point will be used to assess and evaluate the pattern of soil erosion and deposition in all the individual soil cores along the sampling grid.

In order to calculate the net soil loss in the sampled area, a conversion model was used to estimate soil redistribution rates from the measured ^{137}Cs inventories of the sampling points within the study site. The proportional model (PM), developed at the University of Exeter, England (Walling and He 1999), is applicable to cultivated areas and assumes that ^{137}Cs fallout inputs are completely mixed within the cultivation layer. In this model, soil loss is directly proportional to the amount of ^{137}Cs removed from the soil profile since the beginning of ^{137}Cs accumulation or the onset of cultivation, whichever is later (Vanden Berghe and Gulinck 1987). Hence, if half of the ^{137}Cs input has been removed, the total soil loss over the period is assumed to be 50 % of the cultivation depth. The model can be presented as:

$$Y = 10 \frac{BdX}{100TP} \quad (1)$$

where Y is the mean annual soil loss ($\text{t ha}^{-1} \text{ year}^{-1}$), d is the depth of the cultivation layer (m), B is the bulk density of soil (kg m^{-3}), X is the percentage reduction in total ^{137}Cs inventory (defined as $[(A_{\text{ref}} - A)/A_{\text{ref}}] \times 100$), T is the time elapsed since the initiation of ^{137}Cs accumulation

or commencement of cultivation whichever is later (year), A_{ref} is the local ^{137}Cs reference inventory (Bq m^{-2}), A is the measured total ^{137}Cs inventory at the sampling point (Bq m^{-2}), and P is the particle size correction factor.

An inference from the assumptions of the PM is that the ^{137}Cs concentration of the eroded sediment remains constant throughout time. The ^{137}Cs concentration of deposited sediment at a depositional point may therefore be assumed to be constant. In cases where the ^{137}Cs inventory A for a sampling point is greater than the local reference inventory A_{ref} , deposition of sediment may be assumed and the annual deposition rate Y' ($\text{t ha}^{-1} \text{ year}^{-1}$) may be estimated using the equation:

$$Y' = 10 \frac{BdX'}{100TP'} \quad (2)$$

where X' is the percentage increase in total ^{137}Cs inventory (defined as $[(A - A_{\text{ref}})/A_{\text{ref}}] \times 100$), P' is the particle size correction factor for deposition, and d and T are as defined in Eq. (1). The PM only requires information on plow depth in addition to the values of ^{137}Cs inventory for the sampling points and the local reference inventory.

3 Results and discussion

3.1 Establishment of the ^{137}Cs reference inventory

Figure 4 shows the initial profile of ^{137}Cs inventory of the soils sampled using the scraper plate method in the reference site. ^{137}Cs were detected up to a depth of 25.8 cm of the core sample. Table 1 summarizes the individual values of ^{137}Cs inventory of cores collected at the undisturbed reference location. The average total ^{137}Cs inventory from the cores is about $418.0 \pm 43.24 \text{ Bq m}^{-2}$ giving to about 10 % coefficient of variation. This reference value is in agreement with theoretical ^{137}Cs reference values obtained

Table 1 ^{137}Cs reference inventory (Grassland)

Sample code	^{137}Cs inventory (Bq m^{-2})
Core 1	380
Core 2	356
Core 3	473
Core 4	433
Core 5	446
Core 6	412
Average	418 ± 43.24

using the radioactivity prediction model (Walling and Quine 1993). This prediction model gives an estimate of the reference values by inputting the coordinates of the sampling site and the amount of rainfall.

3.2 Establishment of erosion rates

The ^{137}Cs radioactivity measurements of all the soil samples were converted to estimated rates of erosion and sedimentation using the PM. In Site 1, the ^{137}Cs inventory of the soil samples collected from 44 grid intersections ranged from 235.3 Bq m^{-2} (for the most eroded point in the 110 m by 60 m sampling area) to 1250.6 Bq m^{-2} (for the most deposition activity across the sampling site). A measured inventory for individual sampling point which is less than the interval of $\pm 10\%$ of the reference value is indicative of erosion, whereas an inventory greater than the reference value is indicative of deposition. Those within the interval were indicated to have no significant net soil movement. From Eqs. (1) and (2) of the PM model, the erosion and deposition rates were calculated. Table 2 lists the summary of results obtained from the studied sampling sites. Figure 5 shows the spatial distribution of ^{137}Cs inventory measurements and the corresponding soil redistribution rates obtained after applying the conversion

Fig. 4 ^{137}Cs profile in the soil samples collected from the reference site

Table 2 Summary of result from the sampling sites

Study sites	Site 1	Site 2
No. of sampling points	44	54
No. of transition points	7	9
No. of erosion points	9	29
Ave. erosion rate ($\text{t ha}^{-1} \text{ year}^{-1}$)	16.67	22.23
Gross erosion rate	3.98	13.25
No. of deposition points	28	16
Ave. deposition rate ($\text{t ha}^{-1} \text{ year}^{-1}$)	49.11	26.33
Gross deposition rate	32.21	10.63
Net soil loss	-28.23	2.62
Sediment delivery ratio	-	0.2

model. In the redistribution plot, positive values account for erosion rates and negative values represent deposition rates as calculated by the theoretical model. The spatial distribution pattern of soil-associated redistribution rates indicate that 27 % of the field was subjected to soil loss at average erosion rate of $13.2 \text{ t ha}^{-1} \text{ year}^{-1}$. The reduction in the ^{137}Cs inventory is evident in some soil core samples that have experienced significant net erosion over time. Erosion values ranged from 3.0 to $31.0 \text{ t ha}^{-1} \text{ year}^{-1}$ which corresponds to a classification of low-to-moderate erosion as defined by FAO-PNUMA-UNESCO (1980) (as cited in Giménez and Martín 2012). Site 1 is a cultivated area practicing conservation measures through contoured hedges or the use of vegetative strip, fence-forming a row of closely planted shrubs or bushes, which hold the movement of eroding soil particles. In this case, the gross erosion was estimated at $3.98 \text{ t ha}^{-1} \text{ year}^{-1}$ and the gross deposition is higher at $32.21 \text{ t ha}^{-1} \text{ year}^{-1}$, giving a negative value for net soil loss of $28.23 \text{ t ha}^{-1} \text{ year}^{-1}$, hence a negative sediment delivery ratio (SDR). The presence of negative value for net soil loss may indicate the deposition of sediment from other areas upslope that were not being accounted by the erosion studies within the sampling grid

framework. The data show that the practice of using contoured hedges may have affected the soil redistribution and possibly contained all depositing sediments within the area instead of losing eroded soil. The presence of contoured hedges may have effectively reduced erosion runoff and improved soil retention. Table 2 lists the summary of results obtained from the sampling sites. The average erosion rate is equal to the mass of soil removed from the area subject to net loss divided by the area subject to net loss. The gross erosion rate is equal to the total mass of soil removed divided by the total area. The rate for deposition is calculated in the same way, and the net soil loss is equal to the difference between the gross rate of erosion and the gross rate of deposition. SDR is calculated by dividing the net soil loss by the gross erosion rate.

In Site 2, the ^{137}Cs radioactivity in soil cores collected from 54 grid intersections ranged from 0.39 to 1.78 Bq kg^{-1} and individual inventories range from 141.0 to 1024.6 Bq m^{-2} . Figure 6 shows the spatial distribution of ^{137}Cs and the corresponding estimates of soil redistribution rates from soil samples obtained within the cultivated areas without traditional soil conservation measures. The erosion rates ranged from 6.25 to $34.5 \text{ t ha}^{-1} \text{ year}^{-1}$, and an average rate of about $22.0 \text{ t ha}^{-1} \text{ year}^{-1}$ is observed in about 60 % of the total soil core samples. A significant reduction in the inventory was evident in most cores which indicate that these points have experienced appreciable erosion since the major ^{137}Cs fallout. The obtained average erosion rate is in good agreement with values obtained through conventional erosion plots of the same land use (Gesite et al. 2007). The deposition rate ranged from 11.0 to $81.0 \text{ t ha}^{-1} \text{ year}^{-1}$ with a mean rate of about $26.0 \text{ t ha}^{-1} \text{ year}^{-1}$. For this area, the gross erosion is estimated at $13.25 \text{ t ha}^{-1} \text{ year}^{-1}$ and the gross deposition is lower at $10.63 \text{ t ha}^{-1} \text{ year}^{-1}$. The pattern of maximum soil loss from areas along the top layers indicates that tillage and water erosion may have played an important role in soil redistribution (Govers et al. 1996).

Fig. 5 Spatial distribution of ^{137}Cs and soil redistribution map in Site 1

Fig. 6 Spatial distribution of ^{137}Cs and soil redistribution map in Site 2

However, the presence of deposition in areas diagonally across the field suggests that soil movement from the top to the concavity near the footslope can be indicative of water erosion, since the net soil erosion obtained in Site 2 is estimated at $2.62 \text{ t ha}^{-1} \text{ year}^{-1}$ despite the observed soil deposition at the base of the field. SDR is computed at 20 %, which suggests that soil delivery in surrounding river areas may be high since disturbances in the upper areas of a watershed are translated into the downstream areas through the hydrologic process (Pereira 1989).

The major cause of high soil loss was attributed to farm soil management and cropping operations, which disturbed and exposed the soil surface to the impact of rainfall. It has been known that ^{137}Cs is preferentially adsorbed into fine sediment (Walling and Quine 1993); therefore, we cannot disregard the significant effect of the combined water runoff and tillage displacement on the soil redistribution pattern especially in sloping areas. Soil loss is generally observed in cultivated areas with high gradient slope where soil redistribution rates showed a maximum loss at the upslope and maximum gain at downslope areas and slope concavities. Figures 5 and 6 show the detailed pattern of soil redistribution at both cultivated fields, emphasizing the spatial variability of erosion. The absence of net soil loss in Site 1 indicates the effectiveness of soil conservation measures being applied. The average soil erosion rate is much lower than the rate measured in Site 2. Likewise, deposition is greater in Site 1 compared to deposition rate obtained in Site 2. The mean erosion rate in excess of $20 \text{ t ha}^{-1} \text{ year}^{-1}$ obtained in Site 2 represents a significant loss of soil and may indicate a possible reduction in productivity over some parts of the field. Soil redistribution is a major determinant of changes in nutrient status (Pennock and Frick 2001). Cultivated soils are matured and characterized by a high nutrient content, and such rate of loss will have important implications for productivity, not to mention the effect if eroded sediment reaches the river and freshwater systems. Nevertheless, the Global Assessment of Human-Induced Soil

Degradation database indicated that the degree of soil degradation can still be suitable for use in local farming systems (Sonneveld and Dent 2009; Oldeman et al. 1991). Major improvements are required to restore productivity through modifications of the management system.

3.3 Soil erosion and the water quality in Inabanga watershed

Agricultural land-use practices have major effect in the quantity and quality of both surface and groundwater. Agricultural pollutants enter surface water in dissolved form through surface runoff during storm or flood events and are exported to surface water in particulate form and reach groundwater through infiltration. Water is the main agent of soil erosion in the Philippines which is more pronounced during heavy rainfall events. Exposure of disturbed soil surface to the impact of rainfall was considered to be the major factor of high erosion rates (Morgan 1995) and further enhanced by the topography of the country with sloping lands occupying about one-third of the country's total land area. Studies conducted using conventional erosion plots indicated that the increase in the amount of rainfall also translates to an increase in the erosion rate (Gesite et al. 2007).

To initially assess the impact of soil erosion on the water resources, the estimation and measurement of water quantity (river discharge, surface run off) and water quality (pH, electrical conductivity, total suspended solids, and total nitrogen/phosphorus) was conducted by collecting samples of river discharges draining into the Malinao dam reservoir. These parameters were then correlated with the erosion processes within the Inabanga watershed. Figure 7 shows the correlation plot between river discharges (Q , $\text{m}^3 \text{ s}^{-1}$) from Pamacsalan River and Wahig River and the amount of total suspended solids. The initial analyses indicated that the water quality pattern showed similar behavior from river discharges and suggests the probability

Fig. 7 Correlation plot between river discharges with selected water quality parameter

Fig. 8 Correlation ratios between river discharges over selected water quality parameter

of losing nutrients from cultivated areas due to surface runoff and to the low retention capacity of the soil. Since clay soil has an extremely fine texture, it has the ability to retain large amounts of water and store plant nutrients at the surface. Previous study has found a significant correlation between the ¹³⁷Cs and soil organic matter contents (Mabit and Bernard 1998), and both moves along similar physical pathways (Ritchie and McCarty 2003).

The suspended sediment concentration measured from both river discharges ranged from 20 to 800 mg L⁻¹.

Based on the data collected, the water quality in the upper Inabanga watershed is heavily influenced by high suspended loads particularly during rainy months. This contributes to the accumulation of significant volume of sediment in Malinao dam reservoir. Similar study indicated significant erosion taking place within the sub-watersheds and sediment concentrations were as high as 782.0 mg L⁻¹ during high rainfall event (Genson 2006). This high sediment concentration is suggested to reflect agricultural activities inside the sub-watershed. An increase in sediment

concentration was observed at the rising of the discharge curve. It is observed that most of the sediments are eroded during the initial phase and the concentration decreases at the receding phase (Lee et al. 2006). Basing on the criteria for class D water usage for conventional and other pollutants contributing to aesthetics and oxygen demand, the average sediment concentrations obtained during flood events exceeded the acceptable value of $<60 \text{ mg L}^{-1}$ (DAO 34 1990). Nevertheless, the upstream of Inabanga river can still be classified as good water for agricultural use, i.e., EC values = 250–750 $\mu\text{S/cm}$ (Ayers and Westcot 1985). Figure 8 shows the correlation ratios of river discharges over electrical conductivity and dissolved phosphorus. Electrical conductivity is a good measure of salinity hazard to crops, as it reflects the total dissolved solids in the river system. On the other hand, the values obtained for total dissolved phosphorus signifies that there is no over-enrichment of dissolved nutrients in both Pamacsalan and Wahig rivers. However, the moderate levels of nutrients tend to increase significantly during flood events. Phosphorus is a common constituent of agricultural fertilizers, manure and organic wastes in sewage and industrial effluent. It is deduced that the major cause of high soil loss was attributed to farm soil management and cropping operations, which disturbed and exposed the soil surface to the impact of rainfall. It is important to understand, generally, that economic activities, land-use change and changes in weather pattern within the watershed will reflect or may affect the quality of river water or hydrology of the whole watershed.

4 Conclusion

The assessment of soil erosion and redistribution rates in the cultivated areas in Pilar sub-watershed in Inabanga has demonstrated the potential of the ^{137}Cs technique in improving future management of the watershed and protecting the catchment systems from siltation and eutrophication. Based on the results, the gross erosion rates predicted using the proportional model varied from 3.98 to 13.25 $\text{t ha}^{-1} \text{ year}^{-1}$ and the gross deposition rates varied from 32.21 to 10.63 $\text{t ha}^{-1} \text{ year}^{-1}$ for Site 1 (with conservation measures) and Site 2 (without conservation measures), respectively. The results also indicated that in Site 2, the gross erosion rate is higher than the gross deposition rate; hence, the net soil loss is 2.62 $\text{t ha}^{-1} \text{ year}^{-1}$. The sediment delivery ratio value of 0.2 also suggests that sediment delivery to the streams is high in Site 2. On the other hand, the use of contour hedges as conservation measures in Site 1 significantly decreases the net erosion rate and results in a negative value for net soil loss. Alternatively, intensive cultivation without conservation

measures can generate significant soil losses due to shallow soil depth and agricultural practices must be carefully managed to limit soil erosion and depletion. In Site 2, results further indicate that soil erosion may become a serious problem. However, restoration to full productivity is possible by modifications of the management system. The data presented here may serve as a guide that can be used to monitor and identify areas that are vulnerable to soil erosion, especially since the country is frequently visited by extreme weather events (e.g., typhoons, heavy rainfall and flashflood), which may accelerate soil movement and redistribution. In addition, the level of radioactivity obtained may also serve as reference values for ^{137}Cs activities against which changes that will be occurring along the watershed can be assessed, i.e., inputs from nuclear proliferation activities, weapons testing, and nuclear power accidents.

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