ASSESSING SOIL EROSION RATES FOR A LARGE CATCHMENT IN THE CENTRAL HIGHLANDS OF VIETNAM USING FALLOUT RADIONUCLIDES

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3. Phan Son Hai, et al., Assessing the effectiveness of soil conservation measures to reduce soil erosion rates for sloping land in the Central Highlands of Vietnam using fallout radionuclides, S*ubmitted to Newsletter of WOCAT/LADA.*

ABSTRACT: Fallout radionuclides Be-7 and Cs-137 were applied to assess soil erosion rates for a 270.5 km^2 catchment with a variety of slope (from 0^o to more than 45º), crops or vegetation (natural forest, artificial forest, perennial crops, annual crops) and a variety of tillage and soil conservation measures. Soil erosion rates were estimated at 90 areas within the catchment. Each sampling area has at least one feature of the slope, rainfall, crops, farming practice different from others. Soil erosion rates in this region depend significantly on the slope, crops and farming techniques. Averaging over crops, soil erosion rates by slopes 0 - 5º, 5 - 15º, 15 - 25º and 25 - 35º are 5.0, 12.8, 18.9 and 21.3 t ha^{-1} y^{-1}, respectively. Forest land has the least soil erosion rates, ranging between 0.5 t ha^{-1} y^{-1} and 14 t ha^{-1} y^{-1} depending on the slope. Annual crops land has the highest soil erosion rates, ranging between 6 t ha^{-1} y^{-1} and 42 t ha^{-1} y^{-1} when slope varies from < 5^o to 32^o. Perennial crop land has soil erosion rates in the range of 5 t ha^{-1} y^{-1} and 39 t ha^{-1} y^{-1}. In areas with the same slope, the soil erosion rate is the highest for cashew plantations, lower for mulberry field and the lowest for tea or coffee plantations. Soil erosion has resulted in losing a significant quantity of plant nutrients such as OM, N, P_2O_5 and K_2O every year. Generally, lost nutrient quantities due to soil erosion are proportional to erosion rates. Some areas of annual crop land lost a large amount of nutrients every year, up to 1435 kg OM, 79 kg N, 54 kg P_2O_5 and 36 kg K_2O. Similarly, perennial crop lands in this region could lost up to 1736 kg OM, 91 kg N, 66 kg P_2O_5 and 40 kg K_2O every year. Owing to soil erosion, the catchment has lost about 211200 tons of surface soil per year during last 50 years, corresponding to the rate of 7.8 t ha^{-1} y^{-1}. This amount of eroded soil was deposited in drainage of the catchment and in reservoirs. Consequently, the drainage capacity was reduced and the frequency of flooding increased during rainy season. Additionally, life-span of irrigative or hydroelectric reservoirs considerably decreased. Ham Thuan reservoir supplying water to a 300 MW hydroelectric power plant in this region is a typical example with the loss of capacity of about 418 970 m^3 per year. There is an existence of farming practice models which could reduce soil erosion rates by 30% - 45% in comparison with others having the same slope and rainfall. Although these models did not give the effectiveness as good as

those developed by researchers, they have been created and accepted by farmers. Popularizing these optimal farming practices for farmer’s imitation is feasible for this region. This approach is probably suitable to current farming culture of local farmers.

I. INTRODUCTION

About 75% of Vietnam territory is sloping land where the third of population are living with the major practice of farming. Owing to the demand of economic growth, the use of sloping land is more intensified with time in term of both the frequence of land use and expansion of cultivated area. Meanwhile, soil conservation measures have not been implemented. The loss of nutrients owing to soil erosion has been compensated by adding chemical fertilizers and growing stimulators. By this way, the Vietnamese agricultural system has contributed to contamination of surface and ground water in catchments. The establishment of sustainable agriculture in sloping land is essential for our country in this stage. Soil erosion rates for different land uses at catchment level and the effectiveness of soil conservation measures are useful informations to help set up and maintain sustainable agriculture.

For assessment of soil erosion rates, different techniques have been applied in Vietnam. Conventional methods have been applied for several decades, of wich runoff plots have been being the most widely used (Thai Phien, 1998). Radionuclide Cs-137 has been applied for estimation of soil erosion rates for more than ten years (Phan Son Hai et al., 2000, 2003, 2004, 2006; Trinh Cong Tu et al., 2005; Nguyen Hao Quang, 2000; Nguyen Quang Long, 2004; Bui Đac Dung et al., 2005). The combined use of Be-7 and Cs-137 to assess soil erosion rates for different periods of time, as well as to assess the effectiveness of soil conservation measures at landscape level has been carried out in the Central Highlads (P.S. Hai, et al., 2006, 2007, 2011).

In general, soil erosion investigations were carried out for small areas and based mainly on runoff plots. Fallout radionuclides were also used to assess soil erosion rates for some fields with the area of several hectares only.

This project was set up to study soil erosion for a large catchment of about 300 km^2 using fallout radionuclides. The experimental results in detail were given in the “Report on implementation of the MOST's scientific and technological project, period of 2012 - 2013”. Only main results of the project were presented briefly in this report.

II. STUDY AREA

The study catchment located in Lamdong province has the area of 270.52 km^2. It consists of three communes of Bao Lam District (Tan Lac, Loc Thanh, Loc Nam) and three communes of Di Linh District (Hoa Bac, Hoa Nam, Hoa Ninh) as showed on Figure 1. It is a part of the 1280 km^2 catchment of Ham Thuan hydroelectric reservoir. This region has the average elevation in the range of 600 - 800 m asl and the annual rainfall varying from 2400 mm to 3000 mm, of which the total rainfall in rainy season makes up about 60 - 91%.

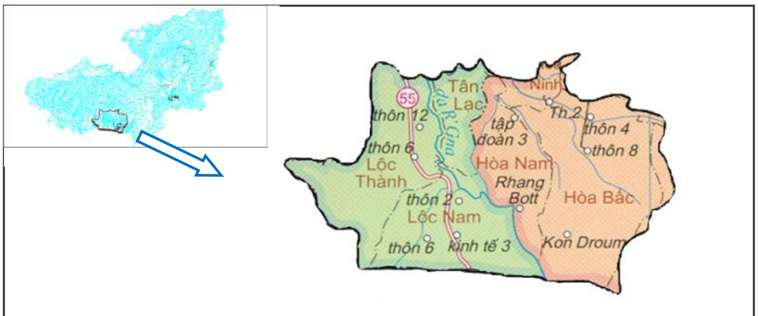

Fig. 1. The location of study catchment in Lam Dong

III. METHODS OF STUDY

3.1. Classification of catchment area according to the slope

The Degital Elevation Model (DEM) of the study catchment was established based on the topographic map of Lamdong province scaling 1:10 000 and then the catchment area was divided into parts with following slopes: < 5º, 5-15^o, 15-25^o, 25-35^o and > 35^o.

3.2. Classification of catchment area according to plantations

Based on land use maps of lamdong province, the whole area of study catchment was classified in to four categories: (i) Natural forest land; (ii) Artificial forest land; (iii) Perennial crop land (Tea, coffee, strawberry, cashew); (iv) Annual crop land.

3.3. Selection of representative sampling sites

Based on the digital maps of the study catchment classified by slope, plantation mentioned above, together with rainfall, 90 sampling sites were selected according to criterions: (i) Each location has at least one of four characteristics of slope, plantation, rainfall and soil conservation measure different from others; (iii) To be able to go these location for collecting samples.

3.4. Sampling method

a) Sampling at referent sites

At each referent location, depth incremental samples at 2 cm intervals were collected down to 35cm for assessment of the vertical distribution of ^{137}Cs and depth incremental samples at 1 cm intervals were collected down to 5cm for assessment of the vertical distribution of ^{7}Be. Then 3 – 5 bulk soil samples were collected for determination of the reference value with the uncertainty of about 8 – 12% (Phan Son Hai et al., 2003). For ^{137}Cs measurement, soil cores (diameter 10 cm and depth 30 cm) were collected. For ^{7}Be measurement, soil samples were collected using a frame made of angle section steel (thickness 5 mm, width 20 mm, height 40 mm).

b) Sampling at study sites

At each study location, bulk soil samples were taken along a sloping line. The distance between two sampling points varied from 10 m to 30 m depending on land form. One soil sample was taken by a cylindrical steel tube (30 cm deep and 10cm in diameter) and the other by a scraper (20 cm wide, 40 cm long and 4 cm deep) at each sampling point for ^{137}Cs and ^{7}Be measurements as mentioned above.

3.5. Analytical methods

a) Analysis of Cs-137 and Be-7

Soil samples were dried, ground into fine powder and put into marinelli beakers with the mass of about 550 gram and then measured for 24 hours using low background gamma spectrometers having relative efficiency of 30%. Be-7 and Cs-137 were analyzed using the 478 keV and 662 keV photo-peaks, respectively. All samples for analysis of Be-7 have been completely counted for about 40 days since sampling date.

b) Analysis of organic carbon and nutrients

- Total organic carbon was determined according to: TCVN 8941 : 2011.
- Total nitrogen was determined according to: TCVN 6498 : 1999.
- Total phosphor was determined according to: TCVN 8940 : 2011.
- Total kalium was determined according to: TCVN 8660 : 2011.

c) Analysis of particle size

Particle size distribution of soil and sediment samples was determined by wet sieving and Robinson method according to TCVN 8567:2010.

3.6. Conversion models in soil erion assessment

Conversion models used for assessment of soil erosion rates in this study were discribed in detail by P.S. Hai et al. (2011).

IV. RESULTS AND DISCUSSION

4.1. The feature of topography and land use for study catchment

The slope distribution infered from DEM for study catchment (Fig. 2) showed that the slope within the catchment varies in a wide range, from several degree to more than 45^o. The classification of catchment area by slope is following: 0 - 5^o accounts for 36.4%; 5 - 15^o accounts for 40.6%; 15 - 25^o accounts for 18.1%; 25 - 35^o accounts for 4.7% and > 35^o accounts for 0.12%. For land use, 31.76% is natural forest; 6.15% is artificial forest; 1.35% is annual crop land and 60.74% is perennial crop land (Tea: 16.60%; coffee: 78.08%; cashew: 0.02%; mulberry: 0.54%; fruit-trees: 4.76%).

By combining the map of slope and the land use map, in taking account of rainfall, 90 locations around the catchment were selected for sampling, of which 14 sites in forest land, 58 sites within perennial land and 18 sites in annual crop land.

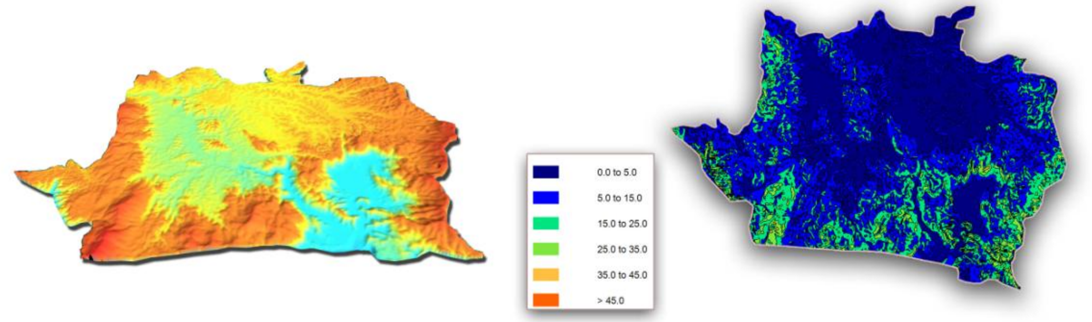

Figure 2: Digital elevation model DEM (a) and sloping map of study catchment (b)

(a) **(b)**

4.2. Inventories of Be-7 and Cs-137 at reference sites

The reference inventory of Be-7 and Cs-137 more and less varies from site to site within the catchment. The reference inventory of Cs-137 is in the range of 385 - 563 Bq/m^2 (Average: 500 Bq/m^2). The variation in the inventory of Cs-137 mainly concerned the variation of rainfall (rainfall: 2400 – 2980 mm). Reference inventories of Be-7 range between 195 Bq/m^2 and 340 Bq/m^2 (Average: 269 Bq/m^2). Owing to short life of Be-7, the inventory value depended on the time of sampling apart from rainfall.

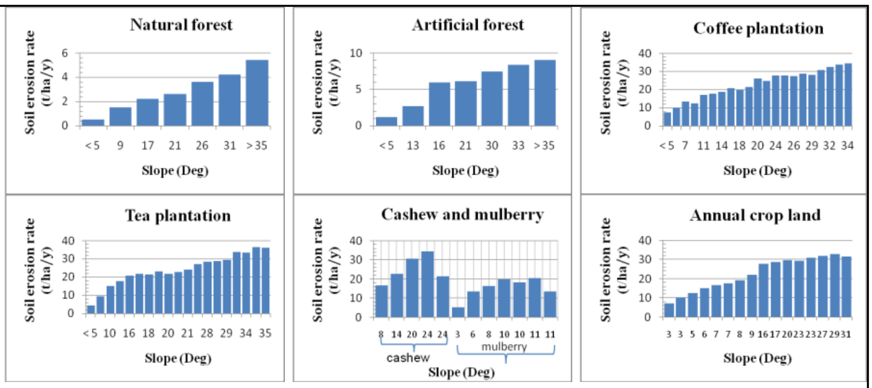

Figure 3: Soil erosion rates over 50 years according to the slope

4.3. Soil erosion rates*a) Soil erosion rates at sampling areas*

Soil erosion rate within study catchment varied from site to site depending on the slope and land use (Figure 3). Soil erosion rates were the lowest of all for natural forest land and vary from 0.5 t ha^{-1} y^{-1} to 9.0 t ha^{-1} y^{-1} depending on the slope. Artificial forest land had soil erosion rates varying from 1.5 t ha^{-1} y^{-1} to 14.0 t ha^{-1} y^{-1} when the slope ranged from < 5^o to > 35^o. For perennials such as tea and coffee plantation, soil erosion rates were comparable and in the range of 5 - 34 t ha^{-1} y^{-1} when the slope ranged from 5^0 to 35^o. On the same slope area soil erosion rate in mulberry fields was higher than that in tea and coffee fields and lower than that in cashew fields. Soil erosion rate in annual crop land was the highest in the all plantations, up to 40 t ha^{-1} y^{-1} at 30^o slope.

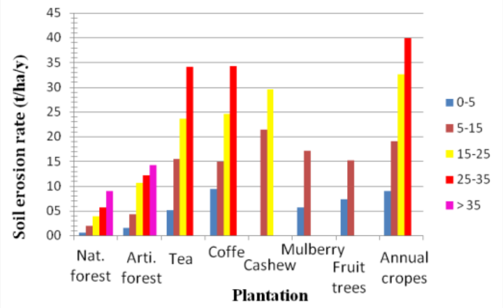

Fig 4: Soil erosion rate averaging over plantations and slope in the 50 year period

b) Soil erosion rates for whole catchment

The average soil erosion rate for areas having the slope of 0 - 5º, 5 - 15º, 15 - 25º, 25 - 35º, > 35º was estimated by averaging soil erosion rate over individual study sites within each gradient group. Long-term soil erosion rates in the period of 50 years by the slope and plantation are given on Figure 4. Mean soil erosion rate at annual crop land is comparable to that at tea and coffee plantations for areas having the slope of more than 25º. These steep areas have been natural forest before they were reclaimed for annual crops several years ago. Therefore, for these steep areas mean long-term soil erosion rates at annual crop fields is not higher than that at tea and coffee plantation fields. This is contrary to results obtained for areas less than 25º.

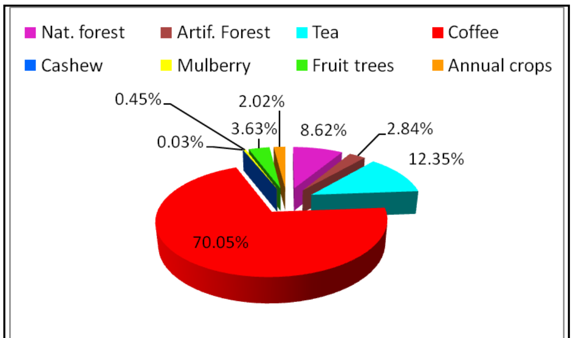

Figure 5: Soil loss structure by plantations

Based on the average soil erosion rates and the area by the slope, the annual total soil loss was assessed for study catchment. Thereby, the annual soil loss was 211,200 tons for whole catchment in the period of last 50 years (corresponing to 7.8 t ha^{-1} y^{-1}). The structure of soil loss (%) by plantations is given on Figure 5. The area of coffee plantation is about 47.4% of the total catchment area but 70% of the total soil loss was derived from coffee fields.

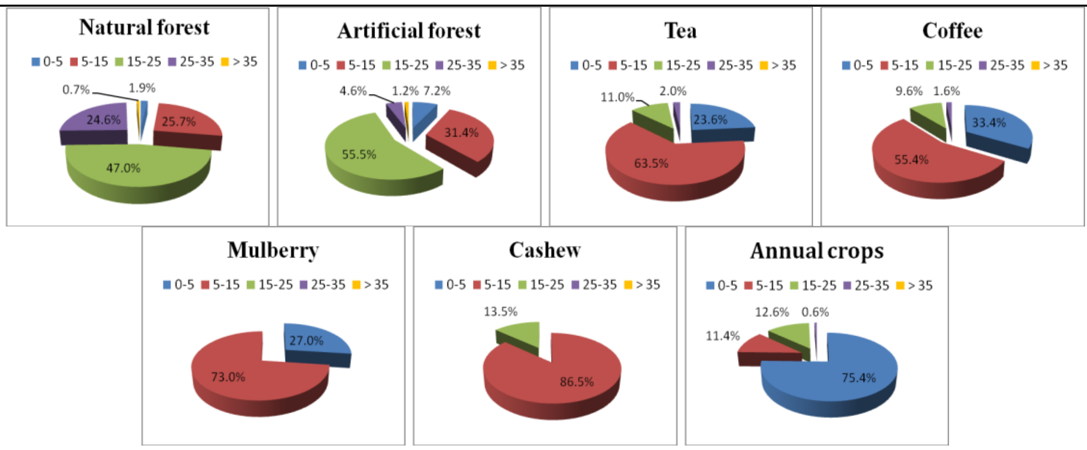

Figure 6: Soil loss structure by the slope for each plantation type

Figure 6 presents thr structure of annual soil loss by the slope corresponding to each plantation within the catchment. The percentage of sediment contribution by slope reflected the status of land use for study catchment in the past.

c) Soil erosion rates according to farming practices

There were several farming practices to be able to reduce soil loss in the catchment: (i) Intercroping pantations to improve ground cover; (ii) Creating basins at the base of coffee trees to retain water and soil; (iii) Contour farming; (iv) Terraced farming. Soil erosion investigations into these farming practices showed that:

- In a sloping area of 23 - 25º, intercroping pineapple with cashew reduced soil erosion rate by 40% in comparison with cashew monoculture (from 35 t ha^{-1} y^{-1} to 21 t ha^{-1} y^{-1}).

- In a sloping area of 18 - 20º, 1.2m contour lines farming decreased soil erosion rate by 36% in comparison with cultivation without contour lines for tea plantation (from 26 t ha^{-1} y^{-1} to 16 t ha^{-1} y^{-1}). Similarly, soil erosion rates at 8 - 10º tea fields with 1.4m contour lines decreased by 40% (from 17 t ha^{-1} y^{-1} to 10 t ha^{-1} y^{-1}).

- For coffee plantation, creating basins reduced soil erosion rate by 32% in comparison with the control at 14 - 16º sloping areas (from 26 t ha^{-1} y^{-1} to 18 t ha^{-1} y^{-1}).

- Contour mulberry rows, together with intercroping corn on 10 - 12º sloping areas decreased soil erosion rate by 33% in comparison with the control (from 23 t ha^{-1} y^{-1} to 15 t ha^{-1} y^{-1}).

4.4 Soil erosion impacts

a) On site impacts

The amount of soil nutrient lost every year due to soil erosion was assessed by using the content of OM, N, P_2O_5 and K_2O in the 0 – 3.5 cm soil layer and soil erosion rates. Generally, lost nutrient quantities due to soil erosion are proportional to erosion rates. For forest land, some areas with high soil erosion rates lost 598 kg OM, 29 kg N, 19 kg P_2O_5 and 12 kg K_2O per hectare every year. Some annual crop areas lost a large amount of nutrients every year, up to 1,435 kg OM, 79 kg N, 54 kg P_2O_5 and 36 kg K_2O per hectare. Similarly, perennial crop areas suffering severe soil erosion lost up to 1,736 kg OM, 91 kg N, 66 kg P_2O_5 and 40 kg K_2O every year.

Results obtained from this study showed that for most study areas OM contents in the 0-30 cm soil layer are greater than the average value in cultivated sloping land in Viet Nam (The average of about 2% by Nguyen Van Bo et al., 2001). However, 20 investigation locations had OM contents less than 2%.

Particle size analysis of soil samples showed that coarse fractions like sand and silt in the 0 – 3.5 cm soil layer are higher than those in the 0 – 30cm soil layer for most sampling points. This means that soil erosion brought about the change in physical property of surface soil. For a long time, the change in particle size compositions can result in changing other chemical and physical properties of surface soil.

b) Off site impacts

As mentioned above, the rate of soil loss for whole catchment is 211,200 tons per year (mean: 7.8 t ha^{-1} y^{-1}). This amount of eroded soil silted the drainage of catchment and reservoirs.

The study catchment is a subcatchment of the Ham Thuan Reservoir's catchment. According to research results in the year 2010, Ham Thuan Reservoir lost it's capacity of about 418,970 m^3 every year owing to sediment from it's catchment. This means that a sediment amount of about 523,710 tons reached the reservoir from it's catchment, corresponding to the average sediment yield of 4.09 t ha^{-1} y^{-1}. With the assumption that the mean soil erosion rate of study subcatchment is comparable to that of Ham Thuan reservoir's catchment, about 52.5% of eroded soil within the whole catchment was deposited in Ham Thuan reservoir. The rest was deposited in the catchment's drainage.

4.5 Main factors affecting soil erosion in the study catchment

Owing to dry season lasting about 5 months with very little rainfall the binding between soil particles by colloids becomes weaker. Therefore, surface soil is more susceptable to erosion under havy rain storms at the begining of rainy season. Investigations on run-off plots by Phan Son Hai et al. (2007) showed that the amount of soil loss in the first month of rainy season could account for 40% to 50% of total soil loss during a year. Leaving bare soil surface or bad ground cover during the first period of rainy season would increase soil erosion rate in comparison with other period of time under the same rainfall. Severe soil erosion at cashew land mentioned above is a typical example on the effect of rain storms at the begining of rainy season. Cashews usually defoliate in dry season, therefore land surface is bare during heavy rainstorms at the beginning of rainy season, resulting in serious soil erosion. For rainfed annual crops cultivation is usually started at the begining of rainy season. Therefore, land surface is almost bare at this time, resulting in severe soil erosion in this stage.

The majority of study catchment area is sloping land, of which about 23% have the slope greater 15^o. During rainy season, surface water flow increases with increasing slope, resulting in intensifying soil erosion rate. A dense tree canopy can reduce the effect of rain drops on soil surface resulting in decreasing rainsplash erosion. However, it do not decrease surface water flow – a factor can bring about soil erosion. Different from forest, residues are usually cleared from soil surface for cultivated land. Therefore, surface water flow at cultivated land is usually greater than that at forest land. Consequently, soil erosion rate at perennial land is much higher than that at forest land unnder the same slope and rainfall. In order to reduce soil erosion rate, many soil conservation techniques have been applied in this catchment such as terraced farming, creating basins at the base of coffee trees, creating contour-hedgerows, contour farming.

V. CONCLUSIONS

Fallout radionuclides Be-7 and Cs-137 were applied to assess soil erosion rates for a 270.5 km^2 catchment with a variety of slope (from 0^o to more than 45º), crops or vegetation (natural forest, artificial forest, perennial crops, annual crops) and a variety of tillage and soil conservation measures. Results obtained from this research have proved the advantages of fallout radionuclide technique in assessing soil erosion rates and the effectiveness of soil conservation measures at large catchment level. Especially, Be-7 technique allows us to estimate quickly the effectiveness of soil conservation techniques at landscape level.

Soil erosion rates were estimated at 90 areas arranged in 5 slope groups: 0 - 5º, 5 - 15º, 15 - 25º, 25 - 35º and > 35^0 within the catchment. Soil erosion rates in the catchment varied in a wide range, from 0.5 t ha^{-1} y^{-1} to 42.2 t ha^{-1} y^{-1} depending on the slope, plantation and farming practices. By plantations, forest land had the lowest soil erosion rate and annual crope land had the highest soil erosion rate in all. For perennial crops, under the same slope soil erosion rates in turn reduced as follows: cashew, mulberry and tea/coffee plantations.

Soil erosion has resulted in losing a significant quantity of plant nutrients such as OM, N, P_2O_5 and K_2O every year. Generally, lost nutrient quantities due to soil erosion are proportional to erosion rates. Some areas of annual crop land lost a large amount of nutrients every year, up to 1,435 kg OM, 79 kg N, 54 kg P_2O_5 and 36 kg K_2O. Perennial crop land suffering severe erosion could lose up to 1,736 kg OM, 91 kg N, 66 kg P_2O_5 and 40 kg K_2O every year.

Owing to soil erosion, the catchment has lost about 211,200 tons of surface soil per year during last 50 years, corresponding to the rate of 7.8 t ha^{-1} y^{-1}. This amount of eroded soil was deposited in drainage of the catchment and in reservoirs. Consequently, life-span of irrigative or hydroelectric reservoirs fast decreased. Ham Thuan reservoir supplying water to a 300 MW hydroelectric power plant in this region is a typical example with the loss of capacity of about 418,970 m^3 per year.

There is an existence of farming practice models which could reduce soil erosion rates by 30% - 45% in comparison with the controls. Although these models did not give the effectiveness as good as those developed by researchers, they have been created and accepted by farmers. Existing soil conservation measures created empirically by farmers. Therefore, the effectiveness of these models varied in a wide range and did not get the optimal conditions.

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