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Estimation of Soil Erosion as a Function of Land Use and Rainfall Using rMMF Model on Amukura Hills, Busia County

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Abstract

Soil erosion by water is considered as the most critical problem on cultivated steeply sloping lands in Kenya. On the Amukura hills in Busia County, Kenya, there have been increased farming activities and indiscriminate infrastructural expansions which are affecting the biophysical environment of the area. The aim of this study was to estimate the amount of soil loss as a synergistic action of rainfall and land use on the hills using the revised Morgan Finney model and compare model generated soil erosion with that obtained from field measurements. One topo-sequence was selected for validating the model. Current soil loss was determined by measuring the dimensions of rills and multiplying the average width, depth and length to get actual volume of soil moved. The model was chosen because of its simplicity in structure, low input requirements semi-empirical basis and distributed application. The equations comprising the model were translated into Microsoft excel spread and the input parameters measured from the field and weather station used. The model calculations were based on daily rainfall time steps and the results presented here were a sum of individual rainfall events. While any amount of Hortonian flow is erosive, it was found that all the detached soil particles go into transport at a rainfall intensity of 7mm/hr in this watershed. The model estimated soil loss was 17 t/ha to 50 t/ha while that from field measurement was 11 t/ha to 107 t/ha for the period studied. There was a positive correlation between field measured and model generated soil loss. The model continuously generated soil erosion data and can be applied to other areas with steep slopes and can be used to extrapolate past and future soil erosion rates based on rainfall, land use and soil properties. On the steep slopes where cultivation has taken place mechanical soil erosion control measures such as terraces and contour stone bunds along with orchard trees should be undertaken.

Keywords: Soil Erosion, Morgan Finney Model, rMMF Model, Rainfall, Rainfall Intensity

INTRODUCTION

The leading drivers of soil erosion are deforestation, poor farming practices, overstocking, improper irrigation, dereliction and poor or lack of preservation of agricultural terraces, land use and cover change, notably associated with urbanization and economic expansion, soil deterioration, and quarrying (Tarolli et al., 2014). Soil erosion by water is the dominant trouble on hills of Amukura with steep slopes where the communities till steep slopes and grow crops more than one season in a year. Soil erosion by water is principally the most severe type of erosion, notably in semi-desert and semi-humid regions of the world ((Martínez-Casasnovas et al., 2016). The existence of bimodal rainfall regime has favored agricultural activities to the extent that the fallow period is short or not at all when the farmers plant other crops like cassava in the maize fields before harvesting.

In Amukura hills the land owners grow crops for two to three seasons in a year, harvest wood for firewood or charcoal, mine natural stones and crush them for building construction.

Land use extensively destabilizes soil aggregates thus being a matter of environmental concern to curb soil erosion (Li et al., 2014).. There has been quick expansion in the construction industry within the region in the urban areas of Malaba and Busia town and in the individual homes within the periphery. The foregoing developments require raw materials like quarry stones, ballast, sand and timber. Whereas the raw are available in many places within the county, the first destination is usually Amukura hills where sand and stones are abundant. Spoil heaps and barren land resulting from mining operation increases the erosion rate during rainy season (Kayet et al., 2018). Improper land utilization in the sloppy fields tends to expedite water erosion leading to loss of soil and land productivity downturn (Hossain et al., 2020). Consequently, regulating soil erosion is necessary to sustain agricultural yields and to scale back environmental damage. Over the years the Government of Kenya (GOK) has rolled out soil and water conservation measures like the National Soil and Water Conservation Program (SWC) in the 1980's.

The compelling forces and strains of land degradation are communal, monetary, ecological and materialistic but they act synergistically (Eswaran et al, 2019). In certain situations, socio-economic circumstances dominate in the manifestation of land deterioration, for instance, where urbanization and its associated pollution take place. Otherwise, socio-economic conditions have hindered the attempts to confront land deterioration (Akhtar-Schuster et al., 2011). Soil erosion is perceived as the major compelling aspect that drives the land degradation paradox the world over (Sadeghi, 2017), and soil erosion by water is principally one of the most stern types of erosion, prevalent in semi-desert and semi-humid areas of the world (Taguas et al., 2015). Whereas soil erosion is inherent in natural processes, its cruelty mainly relies on anthropogenic actions like overgrazing (Angassa, 2014), wildfires or uncontrolled burnings (González-Pelayo et al., 2010), burrowing, quarries, waste disposal, construction sites, land tillage practices and widespread land-utilization changes (Syahli, 2015).

Geographical and calculable knowledge on soil erosion on a regional extent contributes to conservation planning, erosion limitation and regulation of the environment (Bednar et al., 2018). So far no scientific evaluation of soil loss from hillslopes, crop fields and stone quarries or a documentation of sustainable land management practices have been undertaken for Amukura hills. Soil erosion is a symptom of other underlying problems. This study aims to explore the reasons behind the degradation of the landscape by land owners and share the findings with the relevant authorities to take the necessary actions.

METHODOLOGY

This section describes how the research was carried out and how data was collected.

Research Approach

The research approach in this study shall consist of five main steps. These are

(i) Field visit, transect walk and straightforward discussions with farmers decide on appropriate study locations within the landscape.

(ii) Undertaking field based assessment to estimate soil loss based on erosion proxies.

(iii) Translating empirical relations described by the revised Morgan Morgan Finney model (2007) into a spreadsheet to calculate soil dislodgement and conveyance capacity of the total overland runoff per given rainfall event,

(iv) Comparison of model generation soil loss values with actual field measured values.

Description of Study Area

The study area covers a total area of approximately 120 ha and lies between 34.25^0 E and 34.27^0E and 0.57^0 N and 0.59^0N.

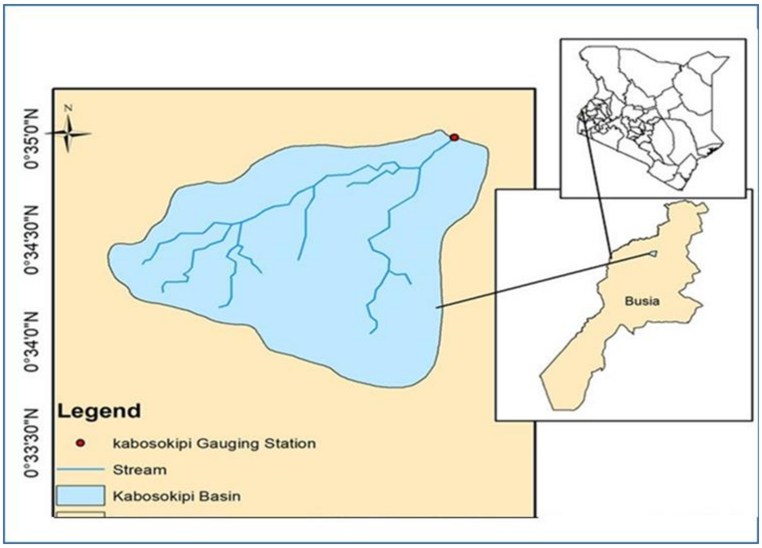


Figure 1: Location of Amukura Hills

Amukura hills lies in the Lower Midland Zone two (LM 2) a marginal sugar cane zone. It has annual average rainfall of 1600mm spread in two seasons. The long rain season is from March to June and short rain season comes in September to November. The average ET_0 is 1850mm which represents 116% of average yearly rainfall. Mean temperature varies from 15^0C to 30^0C. It is dominated by lower-level upland soils. The soils are well drained, somewhat deep to very deep and of depressed fertility (orthic Ferralsols and orthic Acrisols) according to the Farm Management Handbook of Kenya (FMHB). A detailed investigation shall be undertaken to determine the minor variations and their contribution to accelerated erosion.

Materials

i. Topographical map 1:50,000 for Zone 36: Malakisi and Tororo

ii. Computer with GIS software was used to generate the base map, and thematic maps for DEM, permanent infrastructure, agriculture, and rMMF input parameter,

iii. Masonry tool tools including weighing scales and geo-textile shall be used to weigh the eroded soil

iv. The soil testing equipment both for field and laboratory were used to determine the soil aggregates as parameters like Bulk Density (BD), soil texture and organic matter, to input in the rMMF model.

v. ACED field manual.

Evaluation of Erosion Damage of Recent Origin

i. The boundary of the study area was determined from the digital elevation map from the GIS software,

ii. Transect walk were undertaken to identify erosion hot spots.

iii. Open discussion with the land owners was done to find out their level of knowledge on environmental degradation.

iv. Rills and gullies of recent origin were measured, the numbers, average values of length, width and depth taken and the soil loss was computed.

v. The formulae comprising the rMMF model were translated into excel spreadsheet.

vi. Soil loss was estimate by inputting the soil physical properties data gathered from the field and daily rainfall values.

vii. Compare soil erosion rates as measured from the field that generated by the model.

Indicators of Erosion Damage or Severity

Soil erosion was expressed as soil loss (mass) per unit area e.g. 1kg/m^2, which equals 10t/ha. Volume (e.g.m^3/ha) could also be used as an indicator. Soil loss was related to an area, which was usually a specific piece of land with one particular land use type, e.g. a cultivated field. This piece of land was distinguished from its surroundings by its plant type and land management. This was what made it prone to accelerated soil erosion.

Further, not this entire field but only part of it was eroded. This part, the area of actual damage, was likely to be eroded every year. This meant that soil loss on this specific spot was much higher than on the rest of the field.

The procedure for data collection was walking and gathering data from the top of the hills to the valley bottoms mainly streams where the runoff from the peak discharges into streams. This was referred to as topo-sequence.

The data gathered from the field was used to:

a) Calculating soil loss (m^3 or t) that was the volume or mass of soil that had actually been moved from the rill area and possibly accumulated at other sites downslope.

b) Calculating soil loss per field (m^3/ha or t/ha) that related the soil loss (above) to the entire field size of one specific land use.

c) Calculate the soil loss per area of actual damage (m^3/ha), i.e. the area covered by the rills and gullied itself. This was calculated as follows:

$$V = N \times L \times W$$

Where V= Volume of soil eroded

L = average length of rills

W = average width of rills.

d) Calculation of the actual area damaged as a % of the field size expressed as % of the farm eroded. It gave a clue as to whether SWC is needed to cover the whole field (e.g. by terraces, mulching, tree rows, etc.) or if a single measure could do as well (e.g. a drainage ditch, grassed waterway, etc.).

Factors that Influence Erosion; Causes and Subsequent Damage

The factors influencing soil erosion that were considered were: rainfall, vegetation cover, soil texture, slope angle, land management, failure in SWC, uncontrolled drainage from footpaths or settlement areas, tillage direction and soil erosion control structurers.

Social, cultural, economic and political constraints or pressure which limited the application of more sustainable land use practices land by the land owners was also considered by interviewing the farmers.

Assessment of Current Erosion Damage (ACED) field forms were used to document observations, and additional field notebook was used to document personal impressions and notes from interviews.

Erosion Features

Rills and gullies were quantified to determine their volume (m^3), and optionally their mass (t).

Complex erosion features with different sizes and shapes were quantified by dividing the site into sections of similar slope angle and shape. For each section, the rills or gullies were divided into groups with similar average width (cm) and average depth (cm).

The dimensions were filled out in the respective columns on the form.

Slope **-** The slope of surface was determined by use of electronic clinometer.

Vegetation - In order to determine the vegetation cover from the field a representative area of about 4m^2 was selected. By standing in the middle of the representative area almost a perpendicular view of the ground could be obtained. A box representing the type of vegetation cover was picked from one of the boxes below and the % cover recorded.

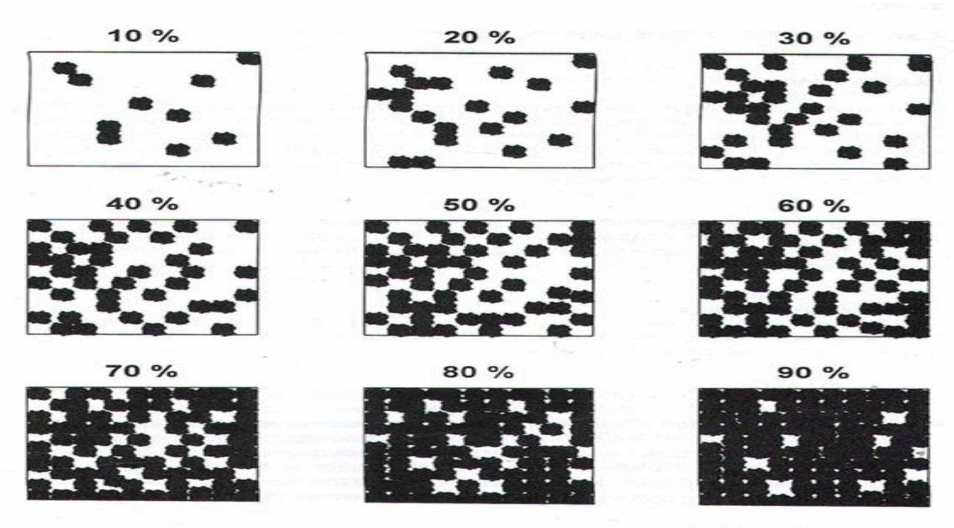


Figure 2: Guiding Chart for Estimation of Vegetation Cover in the Field

The above procedure was repeated on two other plots in the same field and an average value was taken.

Land Management

Land management was considered as being purely the activities of the land owners in two ways:

- The type of management that influenced the soil structure, roughness, infiltration, and prepare the way for vegetation growth to protect the soil or expose the soil to agents of erosion such as:
- Zero tillage
- Minimum tillage
- Harrowing
- Ploughing (and how long ago)
- Broad-bed and furrow system
- Mulching

Or

- The tillage direction that influenced runoff since erosion increased, if tillage was carried out both up and downslope.

But even contour ploughing could also be a source of major damage when runoff collected in rows and furrows and it could not drain, it would break through at the lowest point. The erosive power of the water was then concentrated at this very point. Tillage direction considered included:

- On the contour
- Diagonal
- Crosswise
- Mixed (as a result of non-uniformity of the field)
- Up-/downslope

Soil and Water Conservation Measures

On farms where soil and water management structures were in place, their competencies were evaluated. Of interest were areas with soil conservation measures but also had rills and gullies after heavy rainstorms. Ill-designed or badly maintained measures tent to have one or more weak points where runoff can break through. At these points, all the erosive power of the water is concentrated and so was the damage.

Determination of Soil Textural Classes in the Field The soil textural class was determined by taking a small handful of fine earth, adding small amounts of water, mixing it well and trying form the shapes shown in the table below. The last shape that was able to be formed from the sample gave the texture of the soil being sampled.

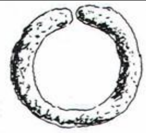
Behavior of soil	**Texture**	**Shape**
The soil continues to be loose and grains are separated. It can be heaped into pyramid	Sand	
Becomes cohesive; and forms a ball that readily falls apart	Loamy Sand	
Can be rolled into a short, thick pencil size circular solid.	Silt Loam	
The solid can be rolled into a slim circular solid about 15cm long with cracks	Loam	
The longer circular solid can be bent into a U-shape having cracks	Clay loam	
The U-shaped cylinder can further be bent into a circle that shows cracks	Light Clay	
The U-shaped cylinder can be turned into a circle with no cracks	Heavy Clay	

Figure 3: Chart Guiding Determination of soil Textural Classes in the Field

Sources of rMMF Input Parameters

The rainfall data (mm) was collected from Amukura District Commissioner, land use, slope, soil textural classes, soil moisture content at field capacity (%w w^{-1}), soil water holding capacity (R_c), effective hydrological depth (EHD) were measured in the field using ACED manual. Soil detachability index (g J^{-1}), bulk density of soil (Kg m^{-3}), cohesion of soil surface (KPa), and ratio of actual to potential evapotranspiration (E/ET_o) were calculated from field data. Slope was determined from the topographic-map available at Survey of Kenya 1969 for Malakisi and Tororo (Universal Traverse Mercator (UTM) Grid Zone 36 and also by use of electronic clinometer.

RESULTS

Transect Walk and Discussions with Land Owners

A reconnaissance survey was undertaken with the collaboration of the land owners. Areas with severe erosion were identified and tagged for further investigations. The topo-sequence selected were as shown in figure 16 below.

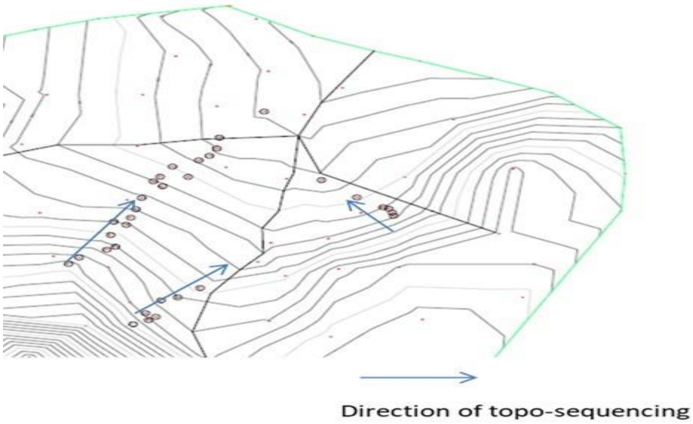


Figure 4: Topo-Sequences (Author, 2018)

During discussions with the land owners it emerged that they practice subsistence farming to feed their families. Gone are the days when they used to grow cotton as a cash crop. Similarly, the land owners no longer grow tobacco after the collapse Malakisi leave factory. The community doesn't have any cash crops to sell and get money for buying clothing and other household goods.

The maize, beans and cassava that they harvest cannot be sold to get money to buy other goods and services. A few farmers grew horticultural crops like tomatoes and kale for sale. But they claimed that the enterprise is expensive and labour intensive. Pests and diseases sometimes wipe away the whole crop.

The land owners said they attempt sand harvesting, crushing the soft rocks to get ballast and mining the stones themselves for sale. This way they claimed they could raise money for buying other goods and services that were not found on their farms.

Field Data Collection and Estimation of Soil Loss

Table 1 shows the soil loss data that had recently occurred on a selected topo-sequence. In areas where the land had been recently ploughed, there were no visible rills and there was no erosion. But this could be misleading. For example element 1 was the peak, it was bushy and element 2 was the plot that was being burned as shown in figure 1.

Table 1: Measured Soil Erosion

Element	Slope (degrees)	Measured soil loss (t/ha)
1	3	0
2	61	0
2	12	19.2
3	20	24
4	21	5.367
5	14	5.52
6	34	0
7	22	0
8	12	5.867
9	19	23.143
10	12	0
11	20	7.556
12	19	0
13	22	102.4
14	22	33.6
15	14	25.38
16	9	25.6

Model Generated Soil Erosion

The soil particle detachment by raindrop impact and runoff were estimated by the model were added together to give total daily detachment rate. The total daily detachment rate was compared with the daily transport capacity of runoff and the lesser of the two values was the daily soil erosion rate (Meyer and Wischmeier 1969).

In order to do proper comparison of the effects of rainfall and activities of man acting in synergy to accelerate soil erosion on Amukura hills, areas of about the same slope were selected. The effect of slope on soil erosion was well catered for in the model but for purposes of this discussion it was considered a constant and therefore not discussed. Mankind without earth moving equipment cannot change the landscape of any given area.

Areas of slope ranging from 19^0 to 22^0 were selected as shown the table below:

Table 2: Soil Detachment and Transport as estimated by rMMF

Element	Slope (S) Deg	Length (L)	Canopy Cover (CC)	Linear Permeability	Effective Hydraulic depth (EHD)	Total detached soil (G)	Transport Capacity
3	20	46	0.8	0.62	0.25	0.484882	3.386577
4	21	32	0.9	0.62	0.36	0.207614	0.788781
9	19	30	0.6	0.21	0.35	0.54959	0.175489
11	20	47	0.8	0.09	0.26	0.293122	1.514629
12	19	34	0.8	0.11	0.33	0.241003	1.462981
13	22	52	0.8	0.44	0.22	0.313285	17.18213
14	22	48	0.8	3.6	0.28	0.380764	21.86796

For element No. 9 the total detached soil was 0.54959t/ha which was more than the transport capacity of 0.175489t/ha and so the soil loss was the lesser of the two i.e. 0.175489t/ha.

DISCUSSION

One of the activities that humans undertake on the Amukura hills that can accelerate soil erosion is clearing vegetation for construction of houses, schools, roads and hospitals. The other one is repeated tillage of land for crop production.

The Effect of Rainfall

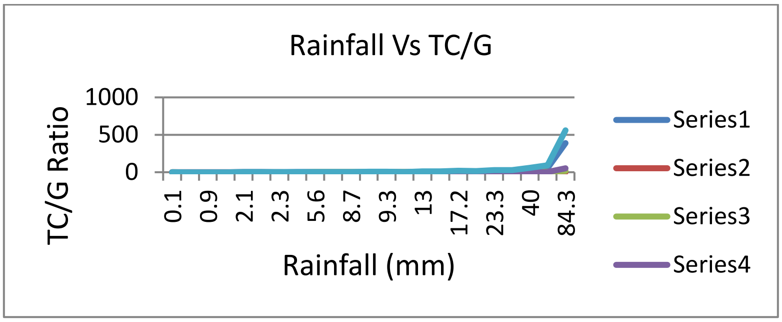


Figure 5: TC/G Ratio versus Rainfall

During any rainfall event there is continuous detachment of soil particles by the kinetic energy of rain drops however these particles will not go into transport until the total rainfall is above 7mm in a single event.

The Effect of Canopy Cover on Soil Erosion

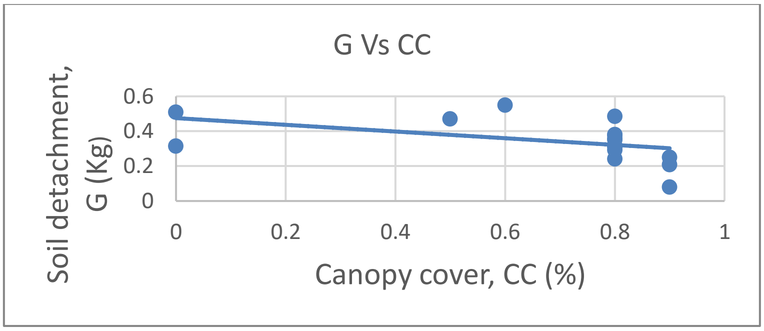


Figure 6: Effect of Canopy Cover Sediment Detachment

The rate of soil detachment varies linearly and inversely with the canopy cover that is the lower the Canopy Cover the higher the soil detachment.

Effect of Linear Permeability on Soil Detachment

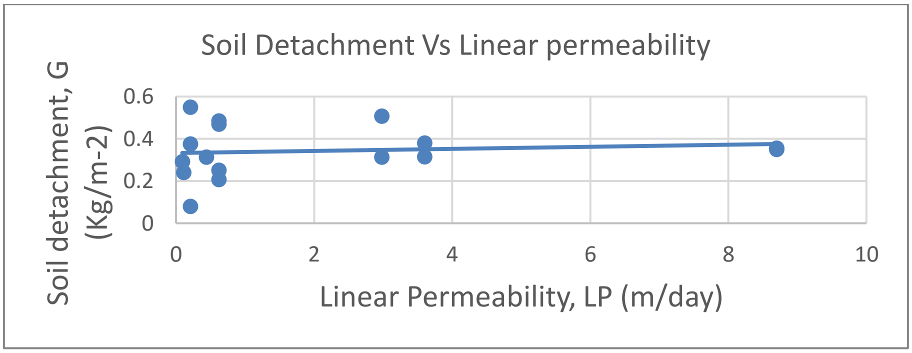


Figure 7: Effect of Linear Permeability on Sediment Detachment

Although linear permeability is intrinsic soil property, in this study area it has been increased by human activity by repeated tilling of the land. It has been observed that the soil detachability increases with increase in linear permeability. It confirms that sandy soils are easily detached than other soils.

Effect of Linear Permeability on Transport Capacity

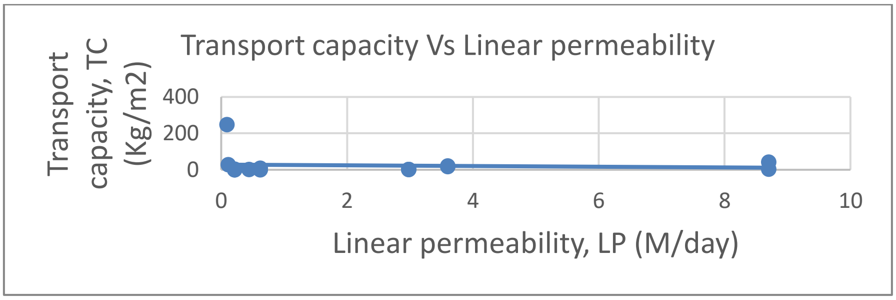


Figure 8:1 Effect of Linear Permeability on Transport Capacity

The transport of the detached soil decreases with increase in linear permeability because as LP increases more water infiltrates the soil and less is available for runoff correspondingly.

Effect of Effective Hydraulic depth on Soil detachment

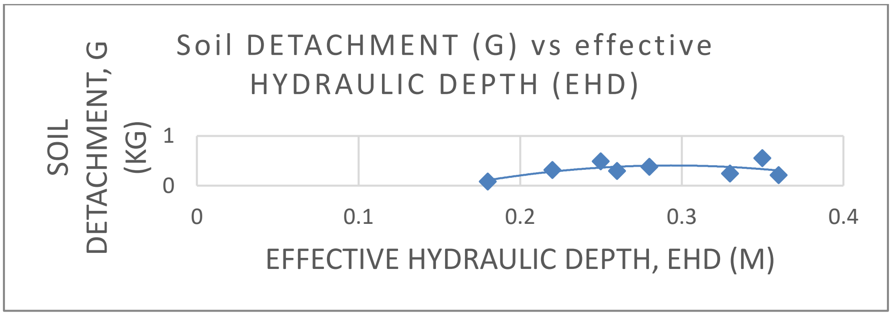


Figure 9: Effective Hydraulic Depth on Soil Detachment

Soil detachment rate increases with effective hydraulic depth till a value of 0.275 and then decreases thereafter.

Effect of Effective Hydraulic Depth on Transport Capacity

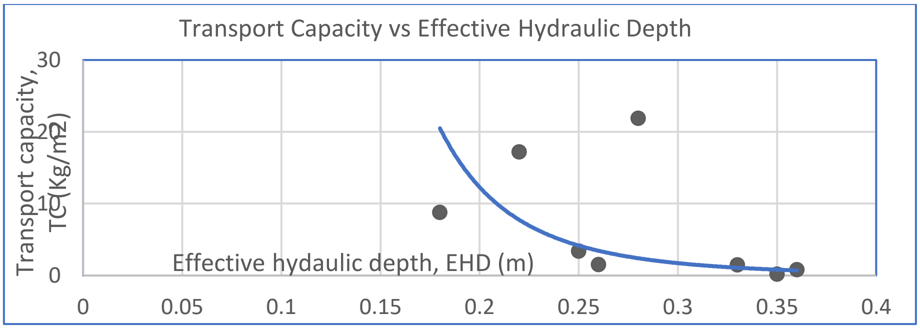


Figure 10: Effect of Effective Hydraulic Depth on Transport Capacity

The graph above shows that the higher the EHD the lower the transport capacity G. This is probably because higher EHD will store more water before it gets saturated to allow overland flow for detachment and lower EHD means more water is available for detachment. The graph is asymptotic to the x-axis because the values of EHD are finite but not zero. It can be observed that at 0.35m (35cm) the TC stabilizes at about 1kg/m^2 for the period the study was carried out.

The EHD is influenced by tillage for crop production and mining of stones for the construction industry by the farmers. As more soil is eroded the EHD progressively decreases.

Regions that undergo land use cover change from native vegetation to crop production often endure a season of soil erosion fluctuation, and indefinite erosion rates that are higher than for undisturbed fields as long as the land is kept under crop production. Average rates of soil erosion under geologic, natural non-cropped setting have been chronicled to be less than 2 mg ha^{-1}yr^{-1}. (Nearing et al., 2017).

Observed and Predicted Soil Loss

Table 3: Observed and Measured Soil Erosion

Element	Slope	Measured (t/ha)	rMMF (t/ha)
1	3	0	0
2	61	0	31.41942
3	12	19.2	35.03317
4	20	24	48.48817
5	21	3.367	20.76137
6	14	5.52	12.57633
7	34	0	25.11566
8	22	0	7.975335
9	12	5.867	31.45403
10	19	23.143	17.54893
11	12	0	37.61429
12	20	7.556	29.31225
13	19	0	24.10025
14	22	102.4	31.32848
15	22	33.6	38.07644
16	14	25.38	35.62207
16	9	25.6	50.83802

Model Validation

The data obtained from the field measurements were compared with model generated soil erosion values and the result is presented in the graph below.

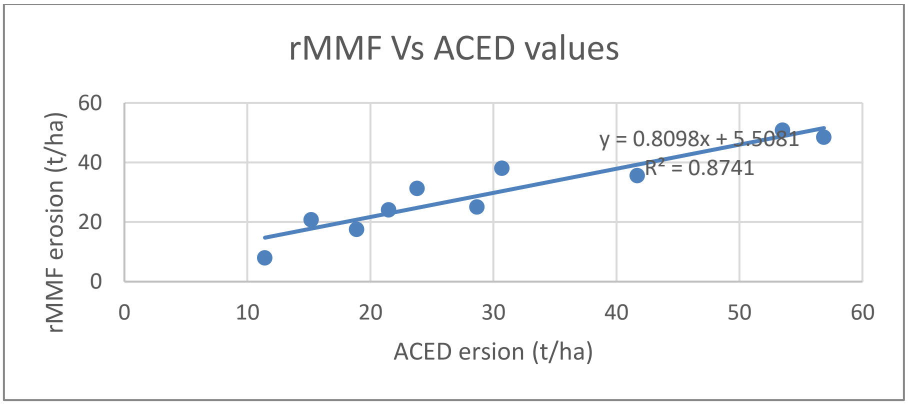


Figure 11: rMMF versus ACED

The measured and model generated soil loss values were assessed quantitatively by checking the weight and dispersion of residuals to reveal patterns and inconsistencies and examining for bias and precision. The formulae used were:

For Relative bias

$$Bias = \frac{\sum_{i=1}^{n}(A_i - \bar{A}_i)}{n} \quad \text{……………………….4.1}$$

Root mean square error

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(A_i - \bar{A}_i)^2}{n}} \quad \text{………………..4.2}$$

Where n is the number of observations, Ai the observed value and $\bar{A}_i$ is the predicted soil loss.

The results indicate that model is biased by 0.24 towards the measured values and the RMSE value is 5.38. In the field work it was found that whereas recently cultivated areas ACED reveals that there was no erosion because no features of soil loss were observed while the model generated values were not zero so long as there was significant rain to initiate soil detachment and transport.

Prove of Hypothesis

It can be proved that the rate of soil detachment and transport is proportional to rainfall intensity and duration except in so far as the total rainfall is not below 7mm (approximately).

Below 7mm/hour of rainfall the detached soil particles are deposited near the point of origin. In this watershed all the soil particles detached are washed by the end the rain season into the rivers or deposited within the gullies when the rainfall recedes.

With increase in canopy cover less soil is made available for transport. On Amukura hills the vegetative cover has been reducing progressively as the farmers increase arable land and mine the stones for the construction industry. This predisposes the soil to water erosion.

In his study of runoff and sediment yield modeling by means of WEPP in Bautzen dam, Germany, Mustafa et al (2014) reported that runoff is highly sensitive to effective hydraulic conductivity, whereas the sediment yield is very sensitive to rill erodibility, critical shear stress and to the effective hydraulic conductivity as well. For case of Amukura hills repeated tillage has loosened the top soil in effect increasing the linear permeability.

From the graph of the effect of Effective Hydraulic Depth on Transport capacity it was observed that as the hydraulic depth increases more water is stored in the soil and less is available for detachment or transport. This was observed in areas where there had been repeated use of ox-plow thus creating a hard pan. Greater effective depth was observed where the farmers use tractor and ox-plow alternately. The graph shows a down ward trend after 0.275m of EHD because there is no more soil to detach at this depth where a hard pan starts to form.

In validating the model Assessment of Current Erosion Damage was undertaken to measure erosion proxies. The rMMF model continuously generated soil loss data so long as rainfall occurred. Actual field measurement on the other hand would give zero erosion values in areas that had been tilled previously. This was because in cases where the land had been ploughed or tilled the previous day the measured soil loss was zero since there were no observable erosion features.

The model predicted soil loss ranges from 17 t/ha to 50 t/ha while those of field measurements range from 11 t/ha to 107 t/ha for the period studied.

CONCLUSION

In this study soil loss from the catchment has been considered as a function of human activity, rainfall and ecological factors. Human land poor land management was recognized as an erosion amplifier. This was because repeated tillage with the same type of implement modified the soil properties. This enhanced the development of hard pans which then increased interflow and subsequently the erosive power of rainfall. Soil erosion was found to be high on shallow tilled steep slopes with minimum or no permanent vegetation cover and farms without (or with failed) soil conservation structures. The communities in the study area are continuously clearing the hill for cultivation and wood and this has contributed greatly to soil erosion and this clearly confirmed that human activity and rainfall play a synergistic role in the soil loss on Amukura hills. It was found that critical rainfall to entrain any detached soil particle was about 7mm. At the end of any rain season all detached is washed away from this catchment. Soil conservation measures should aim at permanent canopy cover and increasing the effective hydraulic depth of the soil through such measures as no tillage, and building bunds with stones, grass strips and terraces

The model predicted soil loss ranges from 17 t/ha to 50 t/ha while those of field measurements range from 11 t/ha to 57 t/ha for the period studied. The fact that there was a linear relationship between soil erosion rates obtained by the field protocol and those generated by the rMMF model it can be concluded that the model can be deployed to estimate soil erosion estimation on steeply sloping areas of a landscape.

REFERENCES

Akhtar-Schuster, M., Thomas, R. J., Stringer, L. C., Chasek, P., & Seely, M. (2011). Improving the enabling environment to combat land degradation: Institutional, financial, legal and science-policy challenges and solutions. *Land Degradation & Development*, *22*(2), 299-312.ater. *Transactions of the ASAE*, *12*(6), 754-0758.*methods* (pp. 127-158). Routledge.

Angassa, A. (2014). Effects of grazing intensity and bush encroachment on herbaceous species and rangeland condition in southern Ethiopia. *Land Degradation & Development*, *25*(5), 438-451.

Bednar, M., & Sarapatka, B. (2018). Relationships between physical–geographical factors and soil degradation on agricultural land. *Environmental research*, *164*, 660-668.

Eswaran, H., Lal, R., & Reich, P. F. (2019). Land degradation: an overview. *Response to land degradation*, 20-35.

González-Pelayo, O., Andreu, V., Gimeno-García, E., Campo, J., & Rubio, J. L. (2010). Rainfall influence on plot-scale runoff and soil loss from repeated burning in a Mediterranean-shrub ecosystem, Valencia, Spain. *Geomorphology*, *118*(3-4), 444-452.

Hari Eswaran, Ratan Lal., Reich P.F Land Degradation: an overview. Retrieved from http://www.scholar.google.com

Hossain, A., Krupnik, T. J., Timsina, J., Mahboob, M. G., Chaki, A. K., Farooq, M., & Hasanuzzaman, M. (2020). Agricultural land degradation: processes and problems undermining future food security. In *Environment, Climate, Plant and Vegetation Growth* (pp. 17-61). Springer, Cham.

Kayet, N., Pathak, K., Chakrabarty, A., & Sahoo, S. (2018). Evaluation of soil loss estimation using the RUSLE model and SCS-CN method in hillslope mining areas. *International Soil and Water Conservation Research*, *6*(1), 31-42.

Li, L., Wang, Y., & Liu, C. (2014). Effects of land use changes on soil erosion in a fast developing area.*International Journal of Environmental Science and Technology*, *11*(6), 1549-1562.

Martínez-Casasnovas, J. A., Ramos, M. C., & Benites, G. (2016). Soil and Water Assessment Tool Soil Loss Simulation at the Sub-Basin Scale in the Alt Penedès–Anoia Vineyard Region (Ne Spain) in the 2000s. *Land Degradation & Development*, *27*(2), 160-170.

Martín-Moreno, C., Martín Duque, J. F., Nicolau Ibarra, J. M., Hernando Rodríguez, N., Sanz Santos, M.A., & Sánchez Castillo, L. (2016). Effects of topography and surface soil cover on erosion for mining reclamation: the experimental spoil heap at El Machorro Mine (Central Spain). *Land Degradation & Development*, *27*(2), 145-159.

Meyer, L. D., & Wischmeier, W. H. (1969). Mathematical simulation of the process of soil erosion by water. *Transactions of the ASAE*, *12*(6), 754-0758.

Morgan, R. P. C., & Duzant, J. H. (2008). Modified MMF (Morgan–Morgan–Finney) model for evaluating effects of crops and vegetation cover on soil erosion. *Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group*, *33*(1), 90-106.

Nearing, M. A., Lane, L. J., & Lopes, V. L. (2017). Modeling soil erosion. In *Soil erosion research*

Sadeghi, S. H. R. (2017). Soil erosion in Iran: state of the art, tendency and solutions. *Poljoprivredai Sumarstvo*, *63*(3), 33-37.

Syahli, F. (2015).*The impact of land use change on soil erosion in Serayu watershed: case study Merawu watershed, Banjarnegara, Central Java* (Master's thesis, University of Twente).

Taguas, E. V., Guzmán, E., Guzmán, G., Vanwalleghem, T., & Gómez, J. A. (2015). Characteristics and importance of rill and gully erosion: a case study in a small catchment of a marginal olive grove. *Cuadernos de investigación geográfica*, *41*(1), 107-126.

Tarolli, P., Preti, F., & Romano, N. (2014). Terraced landscapes: From an old best practice to a potential hazard for soil degradation due to land abandonment. *Anthropocene*, *6*, 10-25.