Impact of forest conversion to agricultural plantation on soil erosion

Nur Athirah Mohamad[1*] , *Mohamad Hidayat* Jamal[1,2] , *Kogila Vani* Annammala[1,3] *Zulkifli* Yusop[1,3], *Nor Eliza* Alias[1] and *Dhinesh* Sugumaran[1]

[1]Department of Water and Environmental Engineering, School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.
[2]Centre for Coastal and Ocean Engineering (COEI), Research Institute for Sustainable Environment, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.
[3]Centre for Environmental Sustainability and Water Security (IPASA), Research Institute for Sustainanble Environment, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.

Abstract. Agriculture in Malaysia makes up to twelve percent of the nation's GDP and is supplying one-third of the world rubber export. Ambitious agriculture demand increases the intensity of forest conversion which is driven to the soil erosion. Thus, this study is to measure and analyse the impact of forest conversion on soil erosion relate to some manipulated variables such as slope, bulk density, soil moisture, canopy openness and ground cover, where rainfall and soil type are constant within the sites. Two different land-uses of High Conservation Value Forest (HCVF) and Mature Rubber Plantation of Timber Latex Clone (MRP) were selected around Kelantan state, due to the high land conversion compared to the other states of West Malaysia. Ground height change was monitored by using Modified Laser Erosion Bridge (MLEB) in between 17 to 48 transects. The result found that the annual soil erosion rate was 76.12 $t.ha^{-1}.yr^{-1}$ for HCVF is higher compared to the MRP was 6.37 $t.ha^{-1}.yr^{-1}$. Terrace soil conservation technique is practiced for MRP helps in reducing soil movement resulted significant low erosion rate compared to the HCVF. The results indicate that even a relatively limited forest conversion can be assumed to have a significant effect on regional soil erosion rate.

1 Introduction

Soil erosion has become an important environmental problem around the world, especially in areas where the intensive use of lands for development. The speeded soil erosion also can either seen as the consequence of logging activities, the introduction of rubber plantation, tin mining activities or deforestation associated with land conversion for other purposes [1]. Deforestation or forest conversion is where the forested areas have been cleared, degraded and fragmented for purpose of timber harvest, conversion to agriculture, urbanization and in myriad others ways [2].

*Corresponding author: kogila@utm.my

Rapid development of agricultural plantations in Malaysia has driven to increase forest conversion that leads to soil erosion process. As instance, approximately 74 thousand hectares of tropical forest have been converted to new timber latex clones (TLC) rubber tree plantation from the year 2005 to 2009 in Peninsular Malaysia [3]. Forest conversion is one of the human impacts on the environment and their effect usually followed by loss of natural vegetation, topography changes, soil erosion and sediment upgrades [4].

Many researches have been studied on the effects of soil erosion around the world but these cases are still less focused and remain unclear in Malaysia, especially for forest conversion to rubber plantation [5-7]. Therefore, the objective of this paper is to estimate the preliminary soil erosion rate in areas affected by forest conversion (ie: High Conservation Value Forest and Rubber Plantation). Then, analyse the impact of ecological factors of slope, bulk density, soil moisture, canopy and ground cover on soil erosion rate.

2 Materials and methods

2.1 Study area

The study was established at two different land-uses in Kelantan state, which is situated at the north eastern of Peninsular Malaysia. The study sites are located around Lebir catchment at Gua Musang, Kelantan as shown in Figure 1. Lebir catcthment have a different soil types, but the majority are covered by sedentary soil on hills and mountains areas, whereas riverine floodplains and river bank comprise of alluvial soil [8]. While, the major land-use of this area is agriculture (paddy, rubber and oil palm) for midstream and downstream and forest for upstream (i.e near to Gua Musang)[9].

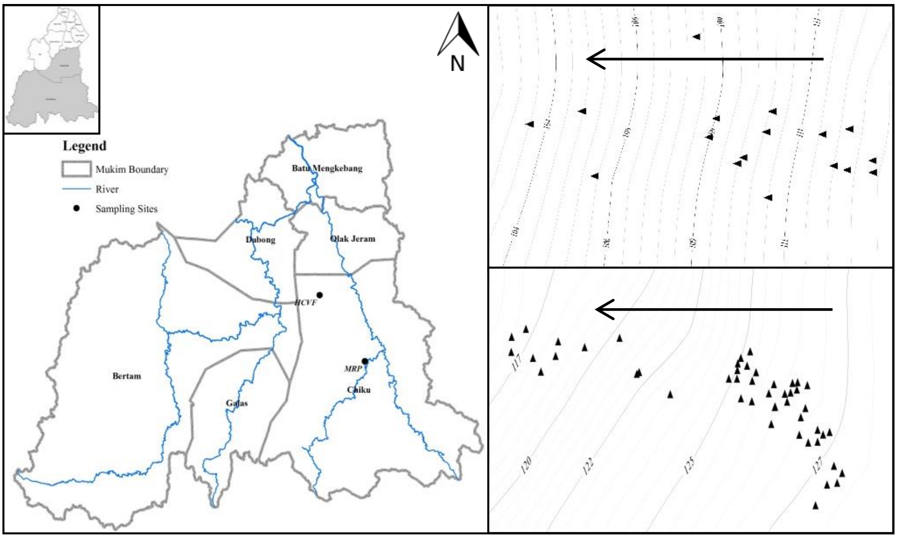


Fig. 1. Maps of the study sites in the Sg. Lebir Catchment.

The study areas were assessed in two different types of land-uses which are High Conservation Value Forest, HCVF located at 5º00.893'N; 102º19.929'E and Mature Rubber Plantation of Timber Latex Clones, MRP located at 05º00.893'N and 102º19.929'E.

HCVF is an area of forest that abandoned from any logging activities to provide basic service of nature in critical erosion control. While MRP is the areas that have been converted into new timber latex clones (TLC) rubber tree plantation. Both of sites are established at sloping and hilly earth surface topography.

2.2 Data collection

Two different land-use sites were identified in order to see the differences of soil erosion impact. Soil erosion transects have been established at the study sites on March 2017 based on the variation of slope range. Data was consists of i) soil erosion measurement and ii) In-situ measurement. These data were monitored in 4 months period time.

2.2.1 Soil erosion measurement

Soil erosion was measured by using a new techniques namely Modified Laser Erosion Bridge (MLEB) as shown in Figure 2, which is improvised from conventional methods (erosion pins) [7,10]. Erosion and deposition were measured by monitored the ground height changes in a type of micro profiler. This technique comprise of two main components which are erosion bridge transect in 3m length (up to 30 points 10cm apart) and two permanent stakes installed firmly into the ground. Erosion bridge transect has been installed and labelled in the ascending number order along the longitudinal direction from the top to the bottom of the hill. The standard error of measurement was found to be less than 1.1mm for a relatively robust soil surface, while measurements will be less accurate and extra precautions have to be taken when measurement conditions meet; i) deep, gradually decaying leaf litter or wood debris layer, ii) the laser light appear a split beam and angular measurement, iii) the soil is very loose and soft and the surface comprised rock, loose stones or also rooted [7,10]. This method is a direct field measurement which offers benefits of economic in cost, simple, effective, and conveniently to carry for field measurement purpose over other erosion measurement methods.

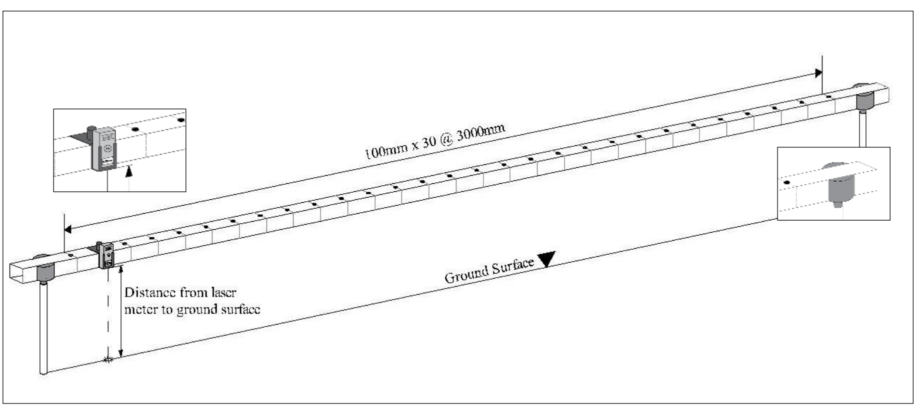


Fig. 2. Modified Laser Erosion Bridge (MLEB)

2.2.2 In-situ measurements

In-situ measurements or as manipulated variables in this study were consists of local slope, bulk density, soil moisture, canopy openness and ground cover. Local slope were determined in order to estimate the erosion potential of the site. Slope degree was measured by using in-clinometer or also called as a clinometer. Despite, the forest canopy cover is the area of ground that receives light from vertical projection of the forest canopy trees. Canopy openness is significant in order to determine the impact of air movements and local precipitation on soil detachment. Forest canopy openness was measured in percentage by using Spherical Densiometer. Whereas, ground cover is the areas covers by vegetation structure such as earth vegetation cover or leaf litter. Then, bare ground was also measured in percentage by using the visual method. The data of soil bulk density and soil moisture are gained simultaneously. The percentage of soil moisture will be obtained in the process of finding soil bulk density. Most common method was used in measuring soil bulk density which by collection a known volume of soil using a metal ring pressed into the soil (intact core) [11].Then, the soil bulk density and soil moisture content was calculated by using the following formula;

$$BD = \frac{W_d}{V_T} \tag{1}$$

$$MC\% = \frac{W_A - W_d}{W_d} \times 100\% \tag{2}$$

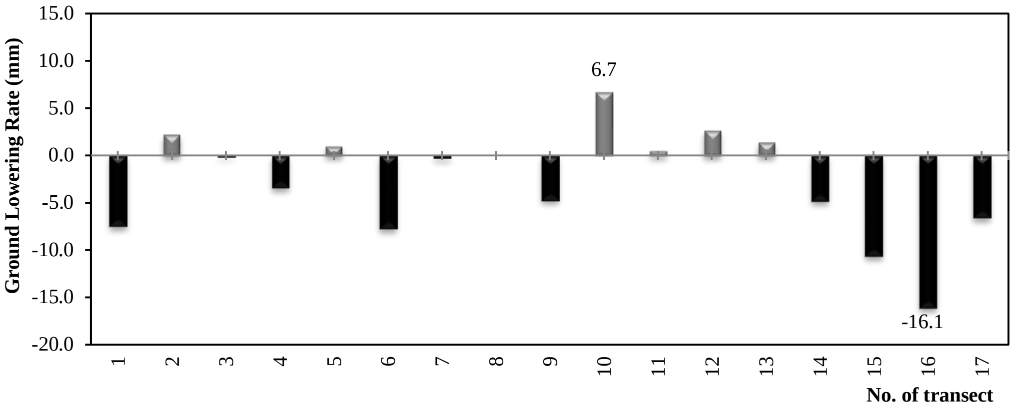
Where BD = the bulk density (in g.cm^{-1}); W_d = weight of dry soil (g); V_T = volume of soil (cm^{-3}); MC = soil moisture content (%); and W_A = weight of wet soil (g).

3 Results and Discussion

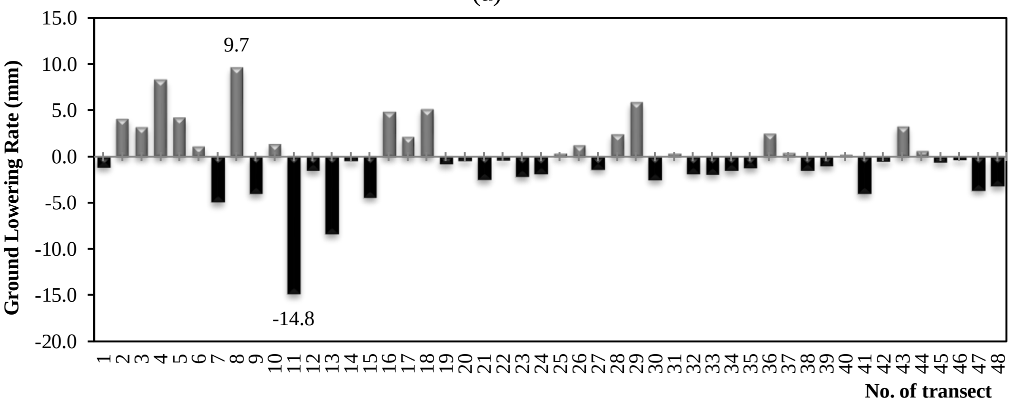
3.1 Comparison of Soil Erosion in High Conservation Values Forest and Mature Rubber Plantation

Total of 17 and 48 transects of Erosion Bridge were established in HCVF and MRP respectively on slopes of 0°-50°. Soil erosion rate data for both of land-uses were measured in 5 month monitored period from March 2017 to July 2017 which is still in preliminary stage. The average monthly rainfall during the observation period was approximately 190mm with the total of 80 rain days. Erosion and deposition rate were measured principally using Erosion Bridges transect method with the length of 3m. Positive (+) values were represented for soil deposition while negative (-) values for soil erosion.

Figure 3 shows the average of ground lowering rate in different transect point for HCVF and MRP. Based on the result presented in the bar graph, it clearly showed that the higher deposition occurred at the transect MRP-8 was +9.7mm compared to HCVF-10 was +6.7mm. While, the critical erosion was observed at HCVF-16 was -16.1 which is higher than MRP-11 was -14.8mm.



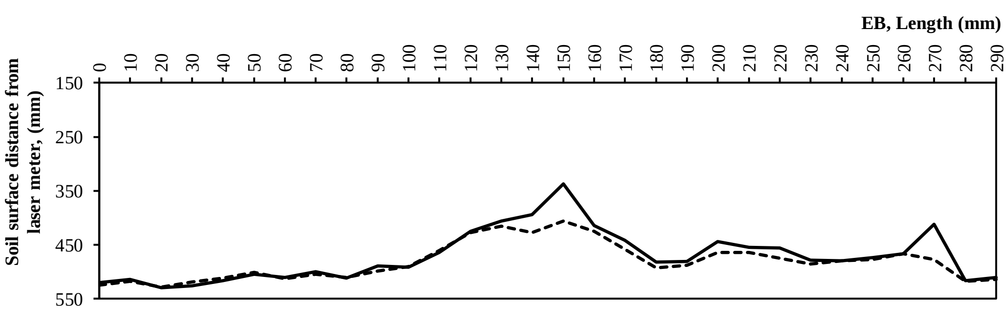
(a)



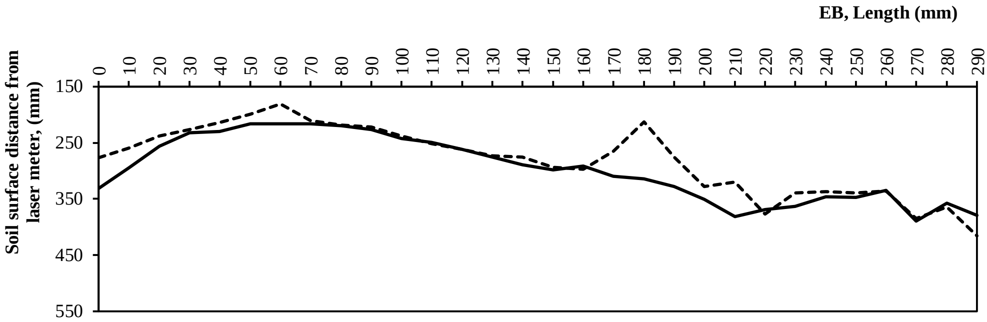
(b)

Fig.3. Average ground lowering rate in mm in each of transects for different land-use type. (a)HCVF; and (b)MRP

The summary of how a reading and trend observed at higher rate of deposition and erosion transect in different land-uses are shown in Figure 4 (a-b). The changes of ground level in minimum or maximum rate are depending on the position of transect, other environmental and topographical factors which in direct or indirect impact towards the detachment of soil surface.



(a)



(b)

Fig.4. Soil profile changes (a) High deposition at MRP- 8; (b) High erosion at HCVF-16. (Solid line: March 2017; Dashed line: July 2017)

The mean ground lowering rate for HCVF of 510 points was -2.98mm.yr^{-1} and 1440 points of MRP was -0.54mm.yr^{-1}. Thus, this case shows that the dominancy of erosion process was happened for both sites. On the other hand, the mean yield annual erosion rate of HCVF was 80.88 t.ha^{-1}.yr^{-1} is extreme higher compared to the MRP was 6.37 t.ha^{-1}.yr^{-1}. In this case, the impact of forest conversion can be seen by comparing the mean yield annual erosion rate of Primary Forest rate in previous study reported by Clark and Walsh (2006) was 3.14 t.ha^{-1}.yr^{-1}. As a result, Primary Forest still shows the lowest erosion rate compared to both land use types in this paper as ascending order as follows Primary Forest < MRP <HCVF.

3.2 Responses of ecological factors on soil erosion

Forest conversion associated with specific ecological variables such as bare ground, soil moisture, slope gradient, canopy cover and bulk density has an accelerating impact of soil loss, particularly in hilly areas as in the study sites. Altering of ecological factors due to forest conversion has resulting to erosion process even in minimum rates. Spider web graph at Figure 5 was used to present the relationship of soil erosion and others ecological variables. Soil loss was low at MRP compared to HCVF. This pattern was related to the low amount of bare ground, slope gradient and soil moisture and high amount of bulk density and canopy openness which is contrariwise to HCVF.

Previous study has found that low bare ground and canopy openness will produce to the low erosion rates [12]. Contradict to this study case, which is low bare ground with the high canopy openness produce to low soil loss. Canopy openness is related to the raindrops erosivity. High canopy openness allows a direct impact of raindrops on ground surface. In this case, even high canopy openness gives a direct impact of raindrops to the ground surface as evident at MRP, high ground cover could prevent the process of soil detachment from happened.

On the other hand, soil erosion rate is positively correlated with the slope gradient in general [13,14]. The result also shows that, high slope gradient produced high soil loss as evident in HCVF. Moreover, the effect of slope factors on soil loss is believed to be influenced by an interaction with soil properties and surface conditions. Whereas, greater soil erosion was evident at the wet soils which causes the time for surface runoff becomes shorten, compared with the dry soil as happened at MRP [15]. While, the soil bulk density less than 1 g/cm^3 has a high organics and some friable clay, so the soil in this condition is easy to loss.

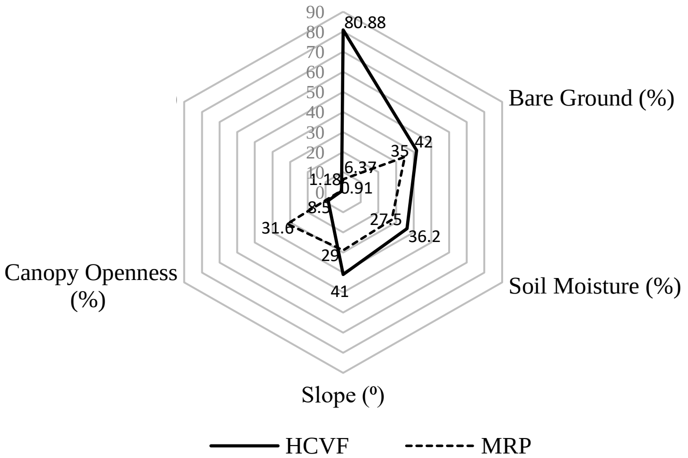


Fig.5. Relationship of soil loss and ecological variables.

4 Conclusions

The research found that forest conversion can contribute to the increases of soil erosion direct or indirect ways. It was justified by comparison of annual yielding soil erosion value of Primary Forest was 3.14 t.ha^{-1}.yr^{-1} , Mature Rubber Plantation (MRP) was 6.37 t.ha^{-1}.yr^{-1} and High Conservation Value Forest (HCVF) was 80.88 t.ha^{-1}.yr^{-1}. As a result, Primary Forest shows the lowest erosion rate compared to both land use types in this paper as ascending order as follows Primary Forest < MRP <HCVF. The extreme high erosion rates for HCVF might be due to the bad land condition impact of forest conversion. However, the impact of forest conversion on increasing of soil erosion rate is believed to be influenced by the interaction with others environmental factors. Nevertheless, the continuous monitoring should be extending as the data presented in this paper is still in the preliminary stage. Therefore, long-term monitoring period, more variation of land use types and rainfall effect need to be considered in order to achieve a critical assessment on the impact of forest conversion towards soil erosion.

The authors would like to acknowledge the Rasmussen Foundation Funds, US for providing project grant entitled Transference from Crime Scene to Forensic Evidence: Linking Land-use, Erosion, Sediment and Quantitative Evaluation of Erosion in Kelantan River Basin, Malaysia and Universiti Teknologi Malaysia (R.J130000.7322.4B243) as financial support of this project. The authors also appreciate Forestry Department Peninsular Malaysia (JPSM) for giving an approval to conduct a trail plot and site sampling.

References

1. B. Gregersen, J. Aalbæk, P.E. Lauridsen, M. Kaas, U. Lopdrup, A. Veihe, & P. van der Keur, Land-use and soil erosion in Tikolod, Sabah, Malaysia, *ASEAN Review of Biodiversity and Environmental conservation (ARBEC)*,1-11(2003).
2. B. Gervet, Deforestation Contributes to Global Warming. Department of Civil and Environmental Engineering LuleaUniversity of Technology Lulea Sweden, (2007).
3. T.W. Lim, Malaysia: Illegalities in Forest Clearance for Large-Scale Commercial Plantations. Forest Trends, Washington, DC, *http://www. forest-trends. org/documents /index. php*. (2013)
4. A. Latocha, M. Szymanowski, J. Jeziorska, M. Stec, & M. Roszczewska, Effects of land abandonment and climate change on soil erosion—An example from depopulated agricultural lands in the Sudetes Mts., SW Poland. *Catena*, **145**, 128-141, (2016).
5. G. M. Hashim, C.A. Ciessiolka, W.A. Yusoff, A.W. Nafis, M.R. Mispan, C.W. Rose & K.J. Caughlan, Soil erosion processes in sloping land in the east coast of Peninsular Malaysia. *Soil Technology*, **8(3)**, 215-233. (1995)
6. M.A. Clark & R.P.D. Walsh, Long term erosion and surface roughness change of rain-forest terrain following selective logging, Danum Valley, Sabah, Malaysia, *Catena*, **68**, 109-123(2006).
7. K.V. Annammala, R.P.D. Walsh, K. Bidin, A. Nainar, Higher erosion rate and enhance sedimentation from disturbed landforms in eastern Sabah, Borneo. *In_Proceedings of the 2nd International Conference on Water Resources in conjunction with 20th UNESCO-IHP Regional Steering Committee Meeting for Southeast Asia and the Pacific*, 5-9, (2012)
8. N.A. Adnan, & P.M. Atkinson, Exploring the impact of climate and land-use changes on stream flow trends in a monsoon catchment. *International journal of climatology*, **31(6)**, 815-831. (2011)
9. TPDC, Malaysia Structure Plan, Malaysia Department of Town and Country Planning. Unpublished report. TCPD: Kuala Lumpur, (2002)
10. R.A. Shakeby, The Soil Erosion Bridge: A device for Micro-Profiling Soil Surfaces. *Earth Surface Processes and Lanforms*, **18**,823-827 (1993).
11. N. McKenzie, R. Isbell, & K. Brown, Australian soils and landscapes: an illustrated compendium. *CSIRO publishing*. (2004).
12. W.Sun,Q. Shao, J. Liu, & J. Zhai, Assessing the effects of land use and topography on soil erosion on the Loess Plateau in China. *Catena*, *121*, 151-163.(2014)
13. H. Fang, L. Sun, & Z. Tang, Effects of rainfall and slope on runoff, soil erosion and rill development: an experimental study using two loess soils. *Hydrological processes*, *29*(11), 2649-2658. (2015).
14. Y. Bao, X. He, A. Wen, P. Gao, Q. Tang, D. Yan, & Y. Long, . Dynamic changes of soil erosion in a typical disturbance zone of China's Three Gorges Reservoir. *CATENA*, *169*, 128-139. (2018)
15. F.M. Ziadat & A.Y. Taimeh, Effect of rainfall intensity, slope, land-use and antecedent soil moisture on soil erosion in an arid environment. *Land Degradation & Development*, **24(6)**, 582-590. (2013).