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Predicting flow direction of soil erosion using Geographic Information System (GIS)

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***Abstract*—Soil loss from one area is normally transferred to and deposited in another by flow processes. The direction of flow, specifically overland flow or runoff, can be determined by finding the direction of steepest descent from each point on the terrain surface. This study aims to determine the flow direction using GIS or, in the case of a raster, digital elevation model (DEM), from each cell in the DEM. The soil flow directions are determined to identify areas from which the soil erodes and where it deposits. In areas such as tropical forest, trees located on the area where the soil erodes should not be harvest as this will accelerate erosion.**

***Keywords*—soil erosion, flow direction, Geographic Information System (GIS), programming, tropical forest**

I. Introduction

Knowledge of the potential soil-erosion risk alone is insufficient to protect and conserve forest soils. Information is also required on soil movement and deposition, which, in the case of non-aeolian erosion, is largely dependent on the direction of water flow across the terrain surface. Normally, soil loss from one area is transferred to and deposited in another by flow processes. The direction of flow, specifically overland flow or runoff, can be determined by finding the direction of steepest descent from each point on the terrain surface or, in the case of a raster DEM, from each cell in the DEM (Desmet & Govers, 1996). This paper therefore investigates the principal directions of flow across the DEM of the study area and combines this with the soil-erosion risk map to identify areas of net erosion and accumulation. It also describes how the raster DEM is manipulated to fill `sinks', to define the Local Drainage Direction (LDD) vectors, and to delineate the watershed boundary for the study area. Consequently, this paper provides information on areas that are exposed to net soil erosion and its magnitude, areas where there is likely to be a net accretion of sediment through deposition, and the effect of the overland movement of soil in relation to tree and road locations. The study discusses how the results of these analyses can help to assist the planning of forest harvesting and road building, because these two activities have significant impacts on forest soils by accelerating the process of soil erosion. Compaction caused by heavy harvesting and extraction machinery, nutrient depletion resulting from whole tree harvesting on infertile sites where rotations are short, and erosion following road building and harvesting on erodible soils are the greatest causes of concern. Therefore, the methods developed in this study, and the results arising from them, could help to identify areas of severe soil erosion risk, where harvesting and road building might best be avoided. It is also hoped that the results of this work would lead to innovations in the way that forest managers go about the process of estimating potential or actual soil loss in the forest, as there is a continuing need to improve the capability to predict soil erosion in Malaysian forests.

II. Materials and Method

The procedures carried out to determine the LDD and perform hydrological modeling were primarily conducted using Spatial Analyst in ArcMap^{TM}. These procedures require the development of three general utility data sets, namely: (i) a DEM in which the `sinks' (i.e. points for which there is no direction of outward flow) are filled, so that the LDD vectors can be properly determined; (ii) a set of vectors indicating the soil flow direction from each cell in the DEM; and (iii) a flow accumulation data set in which each cell receives a value equal to the total number of cells that drain into it. Sinks in a DEM prohibit proper determination of flow routing across the terrain and need to be resolved prior to developing the soil flow direction and flow accumulation grids. Most sinks need to be eliminated because they are artefacts of the DEM creation process, but some may be faithful reflections of the actual terrain. In this study area, however, no natural sinks are expected, and so a process of sink removal is conducted. The algorithm on how to obtain the soil flow direction is given in a flow chart in Figure 1.

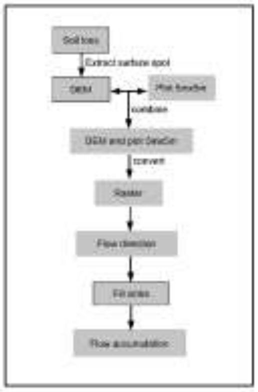

Fig 1 Soil flow direction flow chart.

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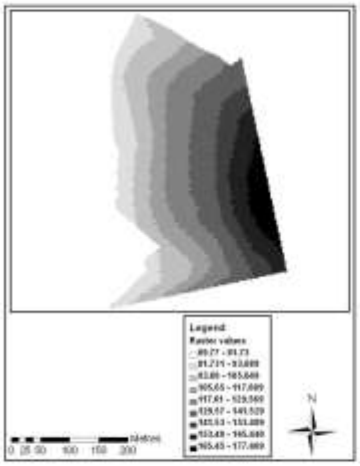


Fig 2 Raster of joint soil loss.

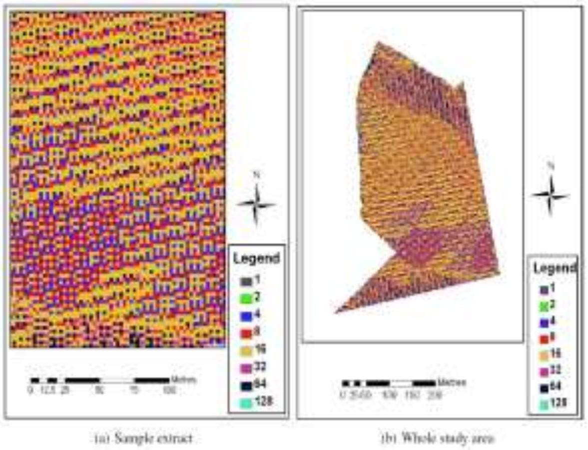
Before the soil loss flow direction could be determined, DEM from the soil loss layer has to be generated first. This was carried out in ArcMap^{TM} by extracting surface spots from the soil loss layer. However, the surface spots could not be displayed in the layer itself but added in a new field in the soil loss attribute table. The data of the soil loss with the surface spots are then combined with the 5mx5m plot data, which acted as cell size in this case, before they are converted to raster which produced the map in Figure 2. These features are converted to raster in order to obtain a continuous surface and to remove any blank cells which might result in no data values and hinder further processing. This was followed by computing the soil flow direction for the study area. Using spatial analyst tool in ArcMap^{TM}, raster of soil flow direction are created from each cell to its steepest downslope neighbour. The output of the soil flow direction tool is an integer raster whose values range from 1 to 255. The values for each direction from the center are shown in Figure 3. For example, if the direction of steepest drop is to the left of the current processing cell, its soil flow direction would be coded as 16.

III. Results and Discussion

The result of soil flow direction for the whole study area and a zoom graphic of the sample extract are presented in Figure 4. The purpose of zooming the output map is to visualize more clearly the flow direction of the soil loss from one cell to the nearest cell and sink areas. It is clearly shown from sample extract in Figure 5(a) that most of the soil loss flow towards the cells which have values of 4, 8 and 16.

32	64	128
16		1
8	4	2

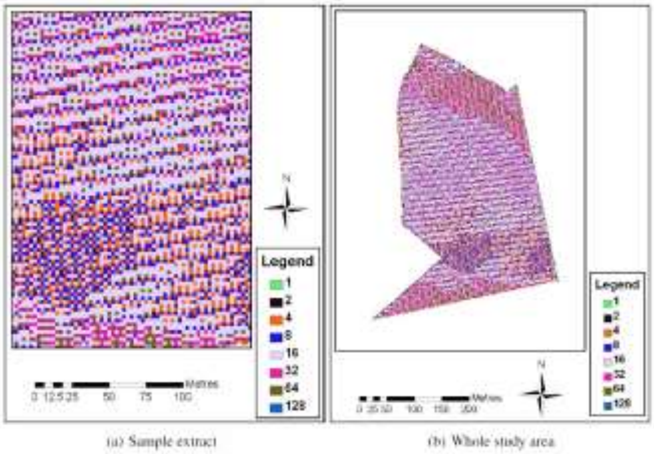
Fig 3 Integer raster values for each soil flow direction from the centre.



(a) Sample extract (b) Whole study area

Fig 4 Soil flow direction of the study area.

Besides, from Figure 5(b), the whole study area shows that the soil flow direction is towards the southwest. If a cell or set of spatially connected cells whose soil flow direction cannot be assigned one of the eight valid values in a flow direction raster, it is called sink and the value is 255. This can occur when all neighbouring cells are higher than the processing cell or when two cells flow into each other, creating a two-cell loop. Sinks are considered to have undefined flow directions and are assigned a value that is the sum of their possible directions. For instance, if the steepest drop and, therefore, soil flow direction, are the same to both the right (1) and left (16), the value 17 would be assigned as the soil flow direction for that cell (Mark, 1988). In this study, where perturbed soil flow direction exists and to remove small imperfections in the data, the sinks are filled and the result is shown in Figure 5. Soil loss that flow from its origin would ultimately be deposited somewhere along its flow direction and finally accumulated at the lowest point of the surface. Therefore, once the soil flow direction is known, where the soil loss accumulates could be investigate. Flow accumulation is a raster of accumulated flow to each cell, as determined by accumulating the weight for all cells that flow into each down slope cell. When computed in ArcMap^{TM}, the result of flow accumulation of the study area is



(a) Sample extract (b) Whole study area

Fig 5 Fill of sinks in the soil flow direction.

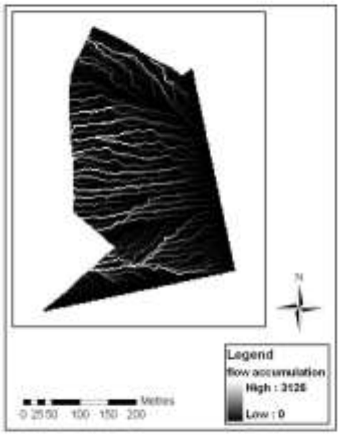


Fig 6 Soil loss accumulation

derived and shown in Figure 6. The result demonstrates that most of the soil loss is generated from east part of the study area and flowed towards the west while gradually increased its volume during the accumulation process. This is in line with the contour of the study area which range from 180m in the east to 70m in the west. Output cells with high flow accumulation values are areas of concentrated flow and may be used to identify stream channels whereas output cells with flow accumulation values of zero are local topographic highs and may be used to identify ridges (Jenson and Domingue, 1988; Tarboton et al., 1991).When mapped in the ArcMap^{TM}, the derived values of *length and slope (LS)* factor are found to be proportional to slope of the study area where steep slopes resulted in high *LS* factor. Similarly, as predicted, the map indicates relatively high erosion in areas where steep slopes exist, especially at the southern part of the study area. Besides that, it shows spatial information about the plot sensitivity with respect to the parameters that affect erosion and, hence, shows the zones likely to experience critical soil loss. A total of 0:1325 ha of the study area is identified as being of high erosion risk. This implies that about 1:5% of the study area has to be excluded from timber harvesting for soil conservation purposes because of soil erosion risk alone. If other features like trees and water bodies that have to be conserved are taken into account, then the area that has to be excluded or protected would become larger. Information of the flow direction of soil loss are vital in this study as it helps in avoiding the soil loss flow area when aligning and building of forest roads are carried out. If this information is not known prior to the forest road construction and the road are built in the soil loss flow pathways, volume of soil loss would be increased and the process would be accelerated. In addition, there are possibilities that the constructed road might be washed away especially during rainy season due to sudden increase in soil and water flow. Soil gain and soil loss computed in the analysis support result of flow accumulation obtained earlier as they showed that in the process of soil erosion, there is soil moved and deposited along the soil flow direction. The deposition increase with time and hence soil accumulation took place. These analyses also enable the amount of soil gain and soil loss to be measured. In this study, contrary to the standard Universal Soil Loss Equation (USLE) slope steepness of 9% and slope length of 22:13m, the soil loss is calculated from slopes which are divided into smaller sectors along the slope because the cell size has been determined to be the same as the plot size of 5mx5m. Thus, grid-based does not support Modified Soil Loss Equation (MSLE) and the soil loss and soil gain results might be affected. Probably a grid-based soil erosion model could be applied to obtain more accurate result.

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Flow direction of soil erosion in a tropical forest in Malaysia