TREEMAP ALGORITHM FOR DYNAMIC STORMWATER INFILTRATION MOVEMENT INTO SOIL SURFACE

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ABSTRACT: Plenty of researches have been carried out focusing on the real time movement of objects such as the movement of animals, humans, vehicle, clouds and water. However, real time movement of water in soil particles that leads to other natural processes (landslides and soil erosion) should be emphasized and given adequate attention through 3 Dimensional (3D) modelling of this event to provide prediction and analysis. To date, 3D research has focused on city models and Building Information Modeling (BIM) but studies that involve 3D modelling of natural processes (movement of air and fluid) is rare. Water flows in many directions and it is most suitably represented in form of 3D. Applying 2 Dimensional (2D) tools to 3D situation limits the scientist works in many ways in terms of understanding, viewing and analysing. 2D model focuses solely on x axis (horizontal) and y axis (vertical). This research applies tree algorithm to model a dynamic stormwater infiltration movement spatially that flow through the soil by additional z axis which represents the depth of the soil. Tree algorithm is used to re-class and provides hierarchical depth of the soil where the depth are divided into five hierarchies (40cm, 80cm, 120cm, 160cm and 20cm) based on subsurface flow wetting range. Required information concerning rainfall and soil types were translated into a model based on the infiltration process occurred at the study area. Although most of the previous studies use Tree algorithm for 2D analysis, this study highlights the capability of the algorithm in 3D analysis by producing hierarchy for soil depth.
Keywords: 3 dimensional, indeterminate spatial extend, fluid flow, Tree algorithm

INTRODUCTION

Briefly, landslide in Malaysia usually occurs on the cut slopes or embankments along the highways or road in hilly area and in residential area and high-rise apartment that cause death (Pradhan and Lee, 2009). Field investigation by Matori et al. (2012) has proven that most of landslide occurred in Cameron Highlands happened along the road where surrounding slopes are cut or modified. Flash floods and tropical rainfall are the main trigger of landslide in Malaysia where they trigger failure of the rock surface along joint, fracture and cleavage planes (Pradhan and Lee, 2009). The research on new model development done by Chan (1998) suggest the need to obtain the most accurate result in landslide hazard analysis. Accurate results are needed in landslide hazard analysis to attain the best prediction models essential for evacuation and warning system since landslide that occurs along the highways, residential and developed areas can leads to life threatening situations and fatality. Malaysian Government is paying serious attention on this matter by launching a program - National Slope Master Plan in 2009. However, there are still on-going development that leads to environmental destruction and hillslope instability. The crucial landslide triggering factor is the movement of water in the soil due to rain. As the water that move through the soil effect the soil surface changes, this study focuses on representing the process in 3D by maintaining the interest of spatial GIS. GIS's strengths have made it an almost compulsory tool in assessing landslide hazard and risk (Westen, 2004). During National Geospatial Information Symposium 6 (NGIS6), Mamit (2014) mentions that GIS technique is vital for sustainable management of natural resources for expedient and accurate decision-making. Tree algorithm technique adopted to divide the depth of the soil allows the modelling of fluid spread gravitationally deeper into the ground. The idea was translated into a model by using 3D GIS technique where the locations of the flow become a concern. This paper highlights two main objectives which are to identify the algorithm that best represent fluid flow movement in soil due to stormwater and to design the flow movement pattern of fluid that distribute deeper into the ground in the form of 3D model.

TREEMAP ALGORITHM FOR STORMWATER MODELLING

Precipitation is the main source that triggers stormwater that flow as surface runoff, retain in the soil, infiltrate in the soil as subsurface flow or flow down to the groundwater. The infiltration of stormwater into the soil involves fluid movement in the porous media of soil. Pores in the soil allow water infiltration into deeper layer of soil. On high rate of precipitation, the infiltration rate becomes higher and cause excessive movement of water in soil that lead to changes happen on the surface terrain such as road crumbling, soil erosion, flood and landslide. The movement of stormwater that infiltrate the soil is due to gravitational and capillary forces. However, this study only focus on gravitational force and concentrate on the movement of water infiltration downward which produces subsurface flow.

Treemap was previously used to divide the region to visualize and navigate hierarchy on map (Auber et al., 2013). However the division of hierarchy is based on the representation of repartition of tax money in the US over time shown in ordinary map. This study adopted the same tool but Treemap is instead used to distinguish hierarchy for specific group of data to segregate the soil layer depth. The soil layer depth segregation is required to show the flow water movement of infiltration process where the water move from soil surface to deeper layers. Treemap in this study is modified to represent the hierarchical information of soil that is divided into six ranges of 0 cm, 40 cm, 80 cm, 120 cm, 160 and 200 cm according to the wetting range of subsurface soil.

Space Filling-curve (SFC) is used to store and retrieve multidimensional data in a spatial database. A few changes on Gosper's curve is required (including the flow pattern and Voronoy shaped volumetric polygon) to present a dynamic flow of stormwater infiltration in this study. Gosper's curve provides a pattern of soil water movement in the soil. GIS software is able to represent 2D spatial features. However, it cannot support dynamic and probabilistic model. Data represented visually enable readers to comprehend the content faster than those represented in the form of text (Kamada and Kawai, 1991). Moving from 2D to 3D landscape is suggested by Raper (2000) that provide valuable step to the end users. Precipitation and infiltration are real time data that require integration of GIS and 3D model to show the actual model based on temporal data. The best way to represent the indeterminate spatial extend of stormwater infiltration is through 3D modelling.

STUDY AREA

The study area for this research is located at N 5º 35' 24.27'' and E 101º 20' 34.25'' at East West Gerik-Jeli Highway heading to Kelantan. The slope circled in Figure 1 show the exact location of the research. On last December 2014, there was an incident where the road slide down due to heavy rainfall. Ongoing monitoring is conducted to detect any changes on the surface of the terrain due to high rate of precipitation. The soil type of this area is clayed and located at the area of high risk soil erosion as reported by the Department of Agriculture Malaysia.

Figure 1: The study area located at East-West, Gerik-Jeli Highway
Source: Google Earth, 2015

METHODOLOGY

The data required for this research are real-time rainfall data, soil type, soil structure, land use and spatial data of contour, Digital Terrain Model (DTM) and triangular Irregular Network (TIN). The data were manipulated to create a model of fluid flow. However, algorithm is needed to isolate the flow path and create a flow pattern sequence. This study introduced the use of Tree algorithm in 3D modelling process. Algorithm, usually used for giving a division of data was used as the soil segregation with flow pattern and depth hierarchy. The hierarchy of soil depth helps the process of modelling fluid that is flowing down with uncertain direction. Figure 2a shows Tree algorithm that create a different depth for soil water flow that integrate Gosper curve and as a result a new pattern of soil water flow (see Figure 2b) through soil successfully invaded in this study. The sequence of water flow in the soil is shown in Figure 2c.

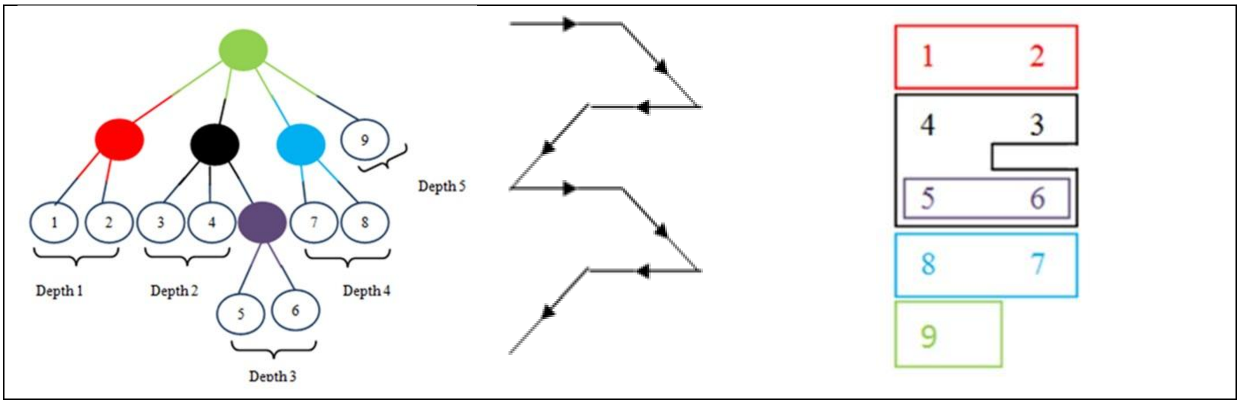


Figure 2: (a) Tree algorithm of soil depth segregation (b) Soil water infiltration pattern (c) Pattern of soil water flow

The Treemap allows interactive control that can display both content and structural information (spatial modelling). The Treemap in this study divide soil into 6 main depths starting with 0 cm, 40 cm, 80 cm, 120 cm, 160 cm and 200 cm. The division of soil depth is presented in Figure 3.

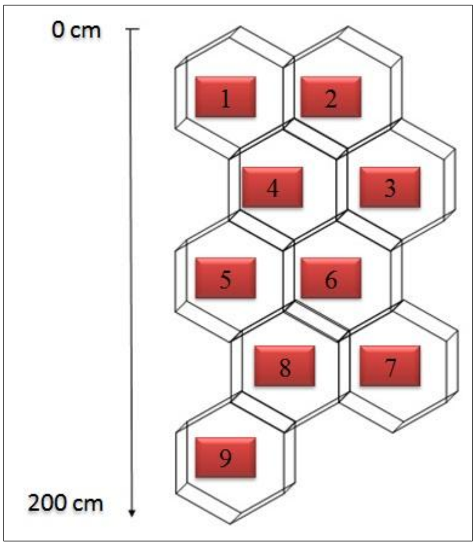
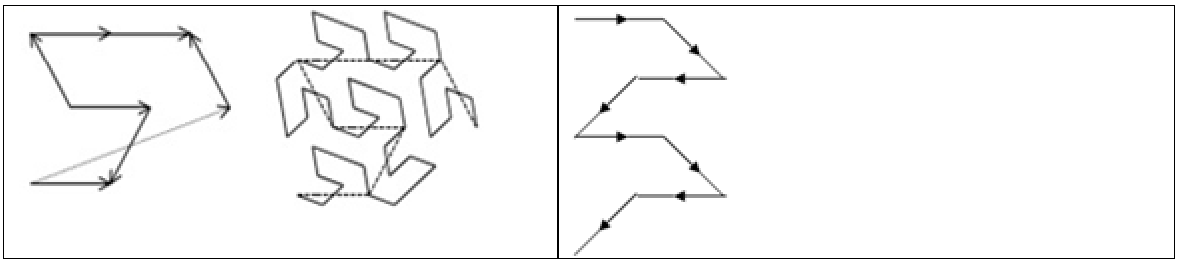


Figure 3: Nine nodes represent soil water flow sequence

As mentioned earlier, the curve used in this study is based on Gosper Curve. Every curve repeats the same pattern based on its angle, axiom and replacement rules that create a distinctive pattern shape. Gosper curve divides plane into hexagons where the obtuse angles lead to smoother boundaries (Asano et al., 1997) and provide simple flow water movement representation based on Treemap soil segregation layer. As shown in Figure 4, Gosper Curve becomes the reference curve that has similar angle and axiom with 3D SWI Curve but with different shape and replacement rule. The shape of 3D SWI curve will never repeat upward as it follows the rules of soil water gravitational force. Thus the curve and flow of water will flow deeper into the ground until it reaches the level of soil wetting point.



Angle: 60'	Angle: 60'
Axiom : AB	Axiom : AB
Replacement Rule:	Replacement rule:
$A \mapsto A - B - -B + A + +AA + B-$ $B \mapsto +A - BB - -B - A + +A + B$	$A \longmapsto A + B - A - B + A + B - A - B$
Gosper curve	3D Soil Water Infiltration Curve (3D SWI Curve)

Figure 4: Comparison of Gosper curve with 3D Soil water Infiltration Curve

RESULTS

This study applies Treemap algorithm that is usually used to explain 2D analysis is able to represent the fluid movement in form of 3D. By using the pattern of 3D SWI Curve, this model provides flow path with nine nodes where every node comprises 12 non-overlapping Tetrahedral Network (TEN) (see Figure 5). This non-overlapping TEN acts as a smaller volume of soil in the nodes that gives a more realistic soil water flow direction path where the TEN has specific volume of water that can be occupied. The water flow from node 1 to node 9 but the location of water stop flowing depending on the rate of rainfall. All data stored in the database and the fluid movement depends on the changes of the real time data.

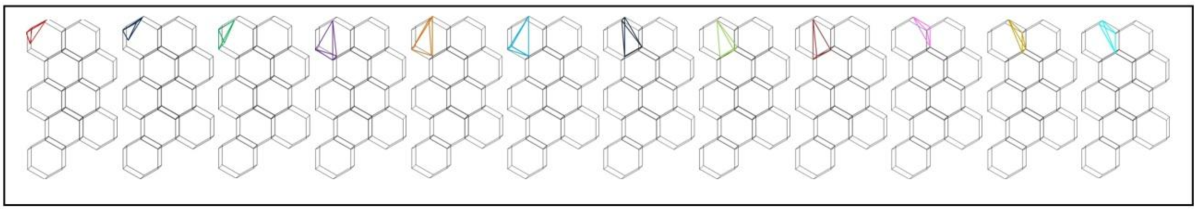


Figure 5: Node that comprising of 12 non-overlapping Tetrahedral Network (TEN)

The water that infiltrate the soil will partially remain in the soil and the rate depends on soil type. The water that infiltrate and remain in the soil is measured to calculate the volume of water that accumulate as subsurface flow that later will flow out towards downhill. The remaining water that successfully flows down until node 9 is collected to calculate the overall volume of subsurface flow. The rate of infiltration of water in porous media of soil is calculated using Horton equation (Horton, 1933):

$f_t = f_c + (f_0 - f_c)e^{-kt}$

Where:

f_t infiltration rate at time *t*

f_0 initial infiltration rate or maximum infiltration rate

f_c constant or equilibrium infiltration rate after the soil has been saturated or minimum infiltration rate

k decay constant specific to the soil

The final output of the research is shown in Figure 6. The yellow and brown nodes represent one of the flow paths underneath the surface terrain. Three different colours indicate the different soil depth of nodes. Black rectangle represents surface terrain. This model is created based on soil water infiltration due to gravitational forces. Capillary forces are not included in this study.

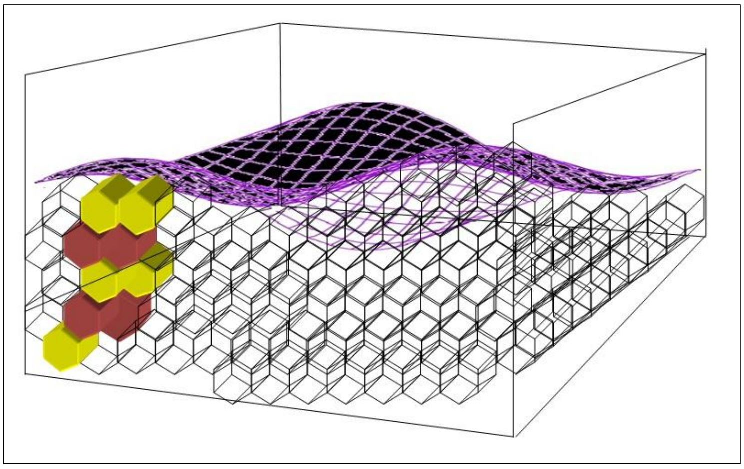


Figure 6: The final output of soil water infiltration movement model

CONCLUSION

In conclusion, indeterminate spatial extent (stormwater infiltration movement) is appropriate and suitable to be represented in form of 3D models because this process occurs underneath the earth surface and requires better understanding and representation. The current available patterns can help in representing any other type of movement. However, the stormwater infiltration movement that flow downwards needs a pattern that can represent the movement according to its nature that flow down due to gravitational force. By applying Tree algorithm and 3D SWI Curve, it will ease future analysis and prediction on stormwater infiltration process.

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