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A 3D VOLUMETRIC SOFT GEO-OBJECTS DATA MODEL FOR DYNAMIC STREAMFLOW GENERATING PROCESSES

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Soft geo-objects have been useful for investigating spatial patterns of the Geographic Information System (GIS) based overland flow mechanism, but have suffered from a lack of ability to realistically visualize the dynamic aspects of the volumetric Streamflow Generating Processes (SGP). Existing 2D soft geo-objects data models are insufficient for analyzing the dynamism of the Infiltration Excess Overland Flow (IEOF) volumetrically, which is the major process contributing towards SGP. At present, there is still no unifying evidence available that provides a coherent explanation for the integration of the 3D Volumetric Soft Geo-objects (VSG) data model for infiltration excess mechanisms. This study aims to visualize areas and overland flow volume generated from the IEOF process dynamically using a 3D VSG data model, which is driven by the Green-Ampt infiltration equation. Inclusion of a 3D VSG data model offers substantial value towards representing 3D soft geo-objects simulating IEOF dynamically within a catchment, estimating overland flow capacity, and routing and diversions to reduce landslides and flood disaster.

INTRODUCTION

The use of Geographical Information Systems (GISs) in Streamflow Generating Process (SGP) modelling has advantages towards expanding various kinds of simulation bases, spatial representation and temporal representation models to display streamflow, overland flow and channel flow capacity results based on site specific measurements and experiments (Garbrecht et al. 2001; Dingman, 2002; and Goodchild, 2003). Such models have been used by many individuals specialized in civil engineering, environmental sciences, town planning, geologists and meteorologists to handle, analyze and manage spatial information of stormwater rate infiltrated into soil profile, total saturated areas, surface runoff generated due to urban growth, floodplain analysis, and channelizing (Isenbies et al. 2007). SGP consists of five main processes; Infiltration Excess Overland Flow (IEOF), Saturation Excess Overland Flow (SEOF), Shallow Subsurface Flow (SSF), Direct Precipitation onto Stream Surface (DPOSS) and Evapotranspiration (ET) (Moore and Daniel, 2005). In this study, the IEOF process is selected for analyzing the capability of a 3D VSG data model to represent the dynamism and continuity of infiltration and overland flow volume. Such selection is due to the IEOF mechanism on the land surface.

Many catchments in the developed and developing countries, including Malaysia, are now under intense pressure from urban, industrial, and infrastructural development where downstream receiving water bodies such as rivers, lakes, ponds, reservoirs, and estuary and coastal waters have become sensitive to increased rates and volumes of runoff and pollutant discharge (MSMA, 2000). Since the volume, rate and velocity of runoff from a particular rain event will depend upon the characteristics of the surfaces on which the rain falls, changes to these surfaces can significantly change the resultant overland flow volume, runoff rate and velocity (Wang et al. 2007).

GISs have started to evolve from 2D based spatial hydrologic information system towards 3D applications and most recently from a static manner (3D) towards dynamic systems that incorporate a temporal element, which is the 4D (Drummond et al. 2007). At present, the large variation in behavior of a drainage basin causes difficulties producing general relationships to identify and quantify the physical soft geometrical characteristics (e.g. streamflow, sediment, pollutant load) that visualize the simulated SGP either in rural or urbanized basins. The existing approach represents 3D GIS modelling into three geometry types; the surface-based (e.g. grid modelling); volume-based (e.g. tetrahedron network (TEN) modelling) and hybrids (e.g. TIN-Octree modelling) (Gong, et al. 2004). These approaches can appropriately visualize rigid geo-objects such as mountains, roads, and buildings, but soft geo-objects are less well represented. Shen et al. (2006) developed a method for representing 3D simulation of soft geo-objects visualizing overland flow based on the GIS Flow Element (FE) concept, which can be performed using particle system and metaball approach. Adaptation of a soft geo-objects data model by including the aspect of 3D volumetric data model for SGP (mainly IEOF) offers a valuable contribution towards reducing landslides and flash floods. The 3D VSG techniques in this study provide the means to improve the SGP realistically and allow hydrologists, environmentalists and other relevant scientists to include these in the decision-making process. Moving from a 2D map to a 3D landscape image of SGP modelling provides a valuable step for end-users envisioning complex streamflow, infiltrated and saturated land cover, overland flow and channel flow routing information.

This paper describes the 3D visualization techniques for simulating SGP dynamically using a VSG data model. Simulation is performed within selected basin boundaries driven by focusing on physically based Green-Ampt infiltration equation for IEOF modelling using a metaball approach.

The concepts of 3D dynamic IEOF simulation and VSG are explained in the following sub-section. The experiment of determining VSG simulation for IEOF is highlighted in the next section. Determination of IEOF areas and 3D dynamic IEOF simulation results are explained in the later sections.

3D VSG FOR SGP SIMULATION

3D modelling has grown rapidly among hydrologists, environmentalists and land practitioners for visualizing, simulating and simplifying complex geometry surfaces. The context "soft geo-objects" refers to the visualization of floods, landslides, mudflows, lava flows, wind, clouds, smoke, fire and other "soft" objects in the real world. The critical characteristic of a soft geo-object is that the object will change shape when influenced by forces or collisions. However, how to appropriately represent soft geo-objects in GISs is still a challenge even though traditional GIS modelling approaches such as TIN, grid, tetrahedron and octree can well represent rigid geo-objects (Shen, et al. 2006). Current 3D based SGP modelling (e.g. 3D polyhedron, 3D freeform and 3D tetrahedron data types) are insufficient in terms of representing fluids as soft geo-objects. The main difference between these data types and the VSG data model is that the VSG has the capability to represent the continuity of streamflow movement horizontally and semi-vertically based on specific streamflow equation.

IEOF occurs from the portion of rainfall, irrigation water, or wastewater that does not infiltrate into the soil and reaches streams and channels (ranging from the large permanent streams to the tiny rills and rivulets) by travelling over the surface of the soil (Ward and Trimble, 2004). As the overland flow path is determined from the soil surface, the surface topographic factor is accepted as dominant physical factor towards stormwater movement. Flood management initiatives intend to include the general public within the decision-making process through consultation, but this remains a difficult task because of dynamic complexities of land surface. Identifying present or historic patterns of surface runoff process may be less appropriate due to changes in driving forces and climate influences.

Previous studies such as those reported by Maidment et al. (2005) linked HEC-HMS (Hydrologic Engineering Centre-Hydrologic Modelling System) and HEC-RAS (Hydrologic Engineering Centre-River Analysis System) with ArcGIS in a case study of flood simulation for Rosillo Creek in San Antonio, Texas have the limitation of analyzing and modelling multidimensional data sets within GIS software. Although commercial GIS software is valuable representing 2D spatial features, it did not support dynamic and probabilistic modelling. Significant contribution of a 3D VSG data model for SGP modelling can be determined by its ability to integrate the soft geometrical spatial data with the infiltration and saturation equation, and the influences between layers. For instance, the generation of overland flow and saturated flow requires soils to reach maximum permeable rate, exceeding the depression storage and flow (in 3D VSG form) towards low elevation area through soil layers and channelized stormwater network.

Wang et al. (2007) developed Flood Region Spreading Algorithm (FRSA) to explore the pseudo-intensity profile for potential flood spreading. The flood region search and merge process is conducted by a weighted cell region adjacency graph. The similarity measure associated with two neighboring cells is found by first calculating the mean intensity values of all vertices associated for each cell, and then for the boundary between the two. A connected cell is identified as part of a flooded cell of the flood region if its elevation level is under a dam threshold of a neighboring flooded cell. The processes are conducted in all eight neighboring directions around the cell assessed. Flooded cells are merged to become a large cell. The configured flood region consists of all flooded cells connected together and used as a flooding field. As for this study, the spreading of overland flow and the influences with buildings, roads and other hardscape objects are visualized through the connectivity of Green-Ampt equation via 3D VSG data model.

Current GIS commercial software is used for handling aspects of 2D and 2.5D of TIN and raster surfaces with single z values on each point data. Advanced GIS software could represent well with 3D objects on surfaces, but to access true volumetric analysis requires domain-specific packages (Drummond et al. 2007). Existing GIS products are in a very static map-based analysis and successfully implemented for managing natural and physical resources as assets. However, the SGP process is fuzzy, uncertain and dynamic. Hence, successful SGP modelling using a 3D VSG data model requires multi-dimensional space-time modelling.

VSG DYNAMISM AND SGP VISUALIZATION

The land use surface is a dynamic zone, representing at any time a net balance between changing processes and landforms, with complex scale-dependent interactions. Inclusion of dynamic representation of geographic features and time in GIS began in the late 80s and early 90s to analyze and predict future behavior and change. Several researchers proposed event-based models (Worboys and Hornsby, 2004) which move from geographic feature identification and location characterization to an explicit focus on changes. Current policy initiatives in Malaysia, such as Urban Stormwater Management recognize this dynamism and are encouraging longer planning horizons as well to improve SGP. Worboys and Hornsby (2004) proposed event-based models which move from geographic feature identification and location characterization to an explicit focus on changes. Appropriate temporal data streams from monitoring and sensor networks provide tremendous scientific values but are not fully exploitable due to difficulties in integrating across the heterogeneous spatial and temporal sampling regimes and assimilating across a large multi-variant space.

Beni et al. (2007) proposed a data structure based on 3D Delaunay tetrahedralization that can deal with discrete objects and continuous phenomena (fields) at the same time and have an interactive topological mesh for numerical simulation. It has the ability to represent both discrete objects and continuous phenomena, and to deal with static and dynamic 3D objects. Moreover, it can generate an optimal mesh for numerical simulation because it is an adaptive method (e.g. the size of the mesh elements depends on the distribution of the data points). In this mesh, after any change (event), local updates of topology are possible. Using this mesh, a fluid flow such as a flood and or a forest fire can efficiently be simulated within GIS if the Free-Lagrange method is used as the numerical model solution. In this study, the VSG enables the dynamism of IEOF direction by merging soft geo-objects of overland flow. The Green-Ampt method provides the foundation of dynamic overland and saturated flow process. Such methods require new visualization techniques to fully address the spatial detail of streamflow shape movement and changes.

Simulating soft geo-objects can be performed using a particle system, which uses small particles as basic elements representing soft geo-objects; and the metaball approach, which displays different formations when more metaballs collide with each other. Shen et al. (2006) introduced the soft geo-objects concept by performing GIS FE based on pixel imagery and controlled by geoscientific models. The GIS FE concept has position, velocity and direction but neglects volume. Hence, this paper intends to model one of the SGP components, the IEOF process, which deals with calculation of total overland flow volume towards existing land forms and drainage systems. VSG are simulated using the metaball approach, which visualizes a continuous surface that is formed when various overland flow sources meet. The contribution from all VSGs are collected and merged into ordinary rendered settings and represented in shape of volume and flow direction.

IEOF DETERMINATION

Freeze and Cherry (1979) stated two conditions must be fulfilled for distribution of IEOF flow; the delivery of surface water input in excess of the hydraulic conductivity on the soil surface and duration of rainfall must be longer than the time required to saturate the soil surface as is shown in Figure 1. Due to spatial variability of the soil properties affecting infiltration capacity and surface water inputs, IEOF does not necessarily occur over a whole drainage basin during a rainfall event (Tarboton, 2003). Moreover, the exception to localized Horton flow in temperate areas occurs on exposed bedrock (Allan and Roulet, 1994), anthropogenic effects such as urban development (Dunne and Leopold, 1978), agriculture and removal of vegetation due to air pollution (Dingman, 1994). IEOF is produced on catchment ridges and extended downslope until

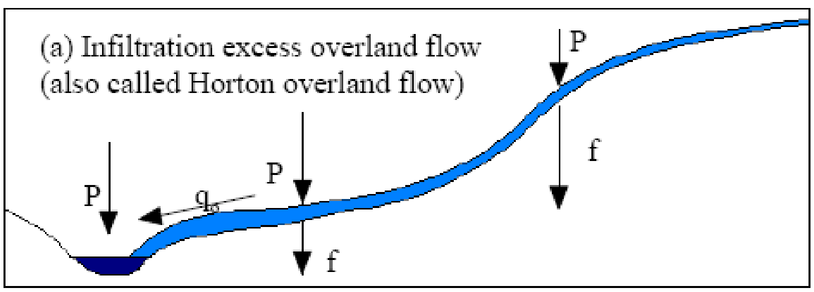

Figure 1. Generation of IEOF mechanism (Beven, 2000).

the entire catchment generates runoff, low slope angle and high saturated hydraulic conductivity (Bonell, 1986).

MATHEMATICAL GREEN-AMPT INFILTRATION COMPUTATION

Green and Ampt (1911) developed the Green-Ampt method of determining the amount of rainfall that infiltrates into the soil during rainfall event. The Green-Ampt infiltration model is a physical model which relates the rate of infiltration to measurable soil properties such as the porosity, hydraulic conductivity and the moisture content of a particular soil based on simplified solutions to the Richards equation. The equation for infiltration under constant rainfall based on Darcy's law and assumes a capillary tube analogy for flow in a porous soil as follows:

$$f = K(H_o + S_w + L)/L \quad (1)$$

where K is the hydraulic conductivity of the transmission zone, H_o is the depth of flow ponded at the surface, S_w is the effective suction at the wetting front, and L is the depth from the surface to the wetting front. The method assumes piston flow (water moving down as a front with no mixing) and a distinct wetting front between the infiltration zone and soil at the initial water content. Smemoe (1999) stated the basic Green and Ampt equation for calculating soil infiltration rate as:

$$f = K_s\,(1 + [\Psi\theta / F]) \quad (2)$$

where K_s is the saturated hydraulic conductivity, Ψ is average capillary suction in the wetted zone, θ is soil moisture deficit (dimensionless), equal to the effective soil porosity times the difference in final and initial volumetric soil saturations and F = depth of rainfall that has infiltrated into the soil since the beginning of rainfall.

Proper information delivery and prediction capabilities of Green-Ampt equation are vital to integrate 3D GIS mapping procedures for IEOF modelling. This is done by using the VSG data model under appropriate projection plane to compute amount of infiltrated urban stormwater runoff and overland flow. The capability of GIS techniques to analyze overland flow as its characteristics mentioned by Allan and Roulet (1994) may produce certain features on each layer to perform overlay, intersect, union and merge of VSGs to produce a new volume, which is the determined overland flow volume.

METHODOLOGY

Description of Study Area

The Sungai Pinang basin lies between the Latitude of 5° 21’ 32” to 5° 26’ 48” North and Longitude from 100° 14’ 26” to 100° 19’ 42” East. Sungai Pinang is the main river system in the Penang Island with a basin size of approximately 51 km^2 which mainly comprises the urban areas of George Town, Air Hitam and Paya Terubong as shown in Figure 2. Penang Island is located at the West Coast of Peninsular Malaysia and experiences convective storms generated by the inter monsoon seasons (Sumatra wind system) in the months of April/May and October/November. The South-West Monsoon (normally from May to September) produces less rain in the West Coast of the Peninsula whilst the North-East Monsoon, from November to March, carries longer and heavier rains to the East Coast of the Peninsula, North Sabah, and inland Sarawak (MSMA, 2000). Penang Island is characterized by an equatorial climate, which is warm and humid throughout the year and has an average annual rainfall of more than 2477 mm; with the lowest monthly average around 60 mm for February and the highest around 210 mm for August and October. The Sungai Pinang basin is a highly developed area comprised of more than 40 percent urban areas in Penang Island. Sungai Pinang basin has been selected to determine overland flow and the saturated flow volume process due to the continuity of development that has affected the physical characteristics of land use and soils and a degrading of the water quality and water quantity of the entire basin. Moreover, flash floods and water pollution are major problems occurring in highly urbanized areas such as Georgetown, Jelutong and Air Hitam.

In this study, the procedure for linking the 3D VSG data model, IEOF and 3D dynamic simulation involves the following steps: (1) acquisition and development of GIS map data layers of the Sungai Pinang basin under conformal MRSO and equidistant Cassini-Soldner projection plane; (2) pre-processing of Green-Ampt data input, parameter and computation results, and (3) post-processing of all dynamic flow volume components resulting from 3D VSG simulation displaying overland flow volume. The Green-Ampt parameters are linked into a PC-based GIS package called ArcView GIS and commercial 3D modelling software to store and display dynamic VSG for IEOF modelling.

Digital topography with 1:20 000 scale is used to extract layers of buildings, contours, DEMs, road network and river network. The land use and soil map is used to evaluate the soil condition at the place of interest. In this study, the rainfall data dated 14 September 2007 were used to determine overland flow generated from IEOF area using Green-Ampt indicators. Topographic

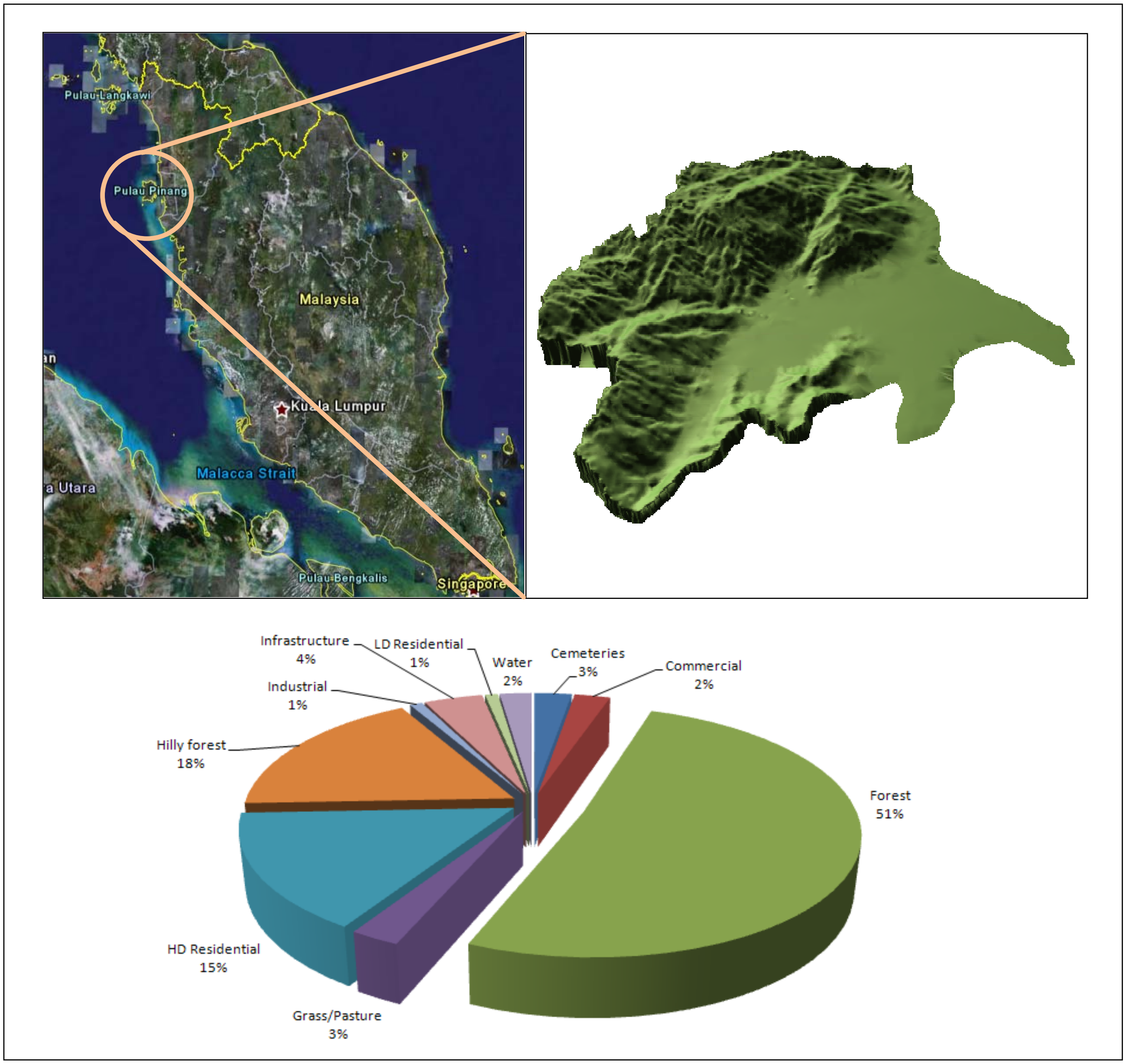

Figure 2. (a) Location of Sungai Pinang basin and (b) Land use pattern in 2007.

information such as slope, aspect, flow length, contributing area, drainage divides and channel network can be reliably extracted from DEM with 5 meter grid resolution.

Determining Potential IEOF Areas

The analysis is performed in two phases. The first phase is to model spatial data layers by overlaying layers of rainfall, land use, slope, soils, buildings and road network based on criteria mentioned by Bonell (1986) to map potential IEOF area. The second phase is to intersect selected layers to map potential location of IEOF. A schematic diagram for determining IEOF area is depicted in Figure 3.

Computation of Infiltration and Overland Flow Volume within IEOF Area

The parameter required for Green-Ampt method is soil hydraulic conductivity (K_s), soil percent impervious (R_s), percent effective soil area (*Eff*), the initial abstraction (I_a), land percent impervious (R_l), percent vegetation (*Veg*) and the degree of saturation (dry, normal or saturated)

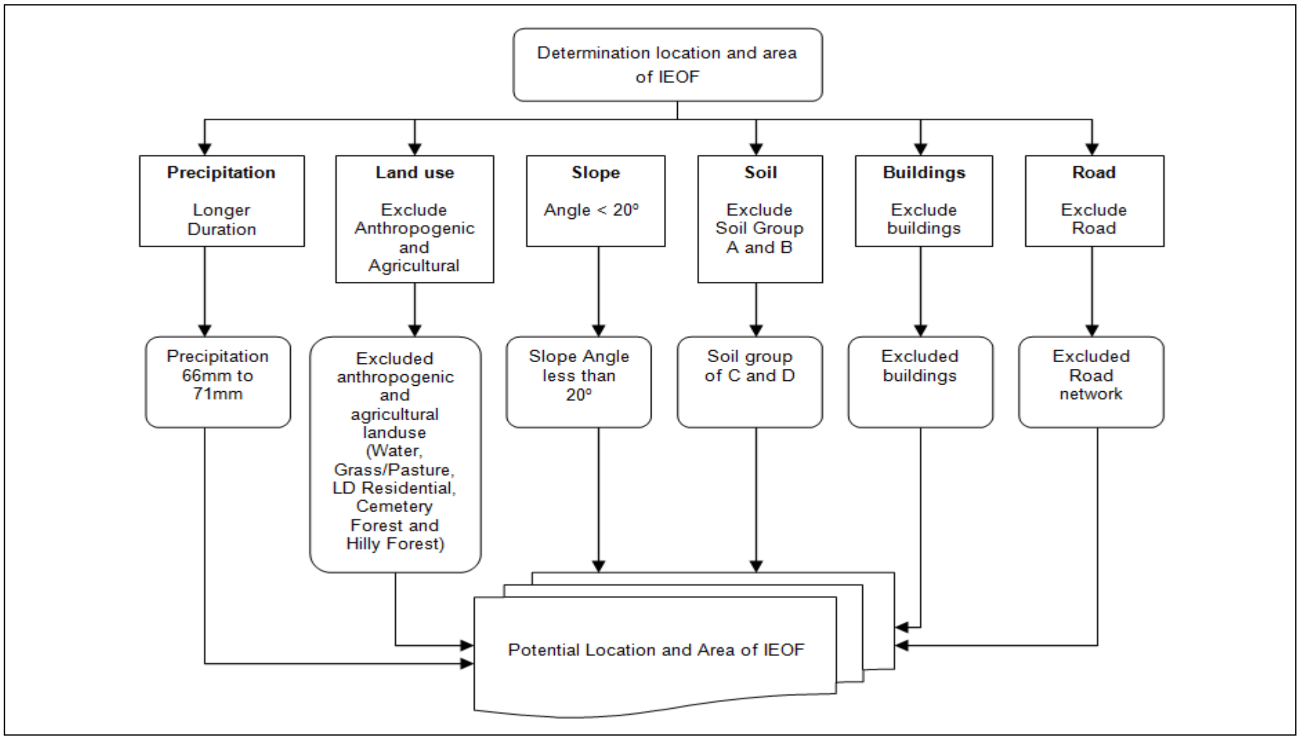

Figure 3. Schematic diagrams for determining IEOF area.

are obtained through ground observation and assigned to each pixel (Smemoe, 1999). Simulations of VSG are performed based on soil infiltration rate by referring to Equations (1) and (2). Total of overland flow within IEOF areas are computed by subtracting rainfall volume with the infiltrated rainfall volume using the rainfall data recorded on 14 September 2007.

Integrating VSG with Green-Ampt Infiltration Equation

The key objective of designing the VSG data model is to represent the continuous spreading of overland flow with time, the soft geometry connection and influences with buildings, roads and other 3D hardscape objects. The distribution of VSG is rendered as a volume and reflects the dynamic by merging volumes of overland flow, changes of velocity and directions as depicted in Figure 4. However, dynamic VSG flow bases are identified by using eight neighboring pixels (D8) to determine flow direction and velocity based on slope gradient.

The designation of volumetric component is based on the defined grid cell of saturated areas. For IEOF modelling, the depression storage is the major indicator that the stormwater has begun

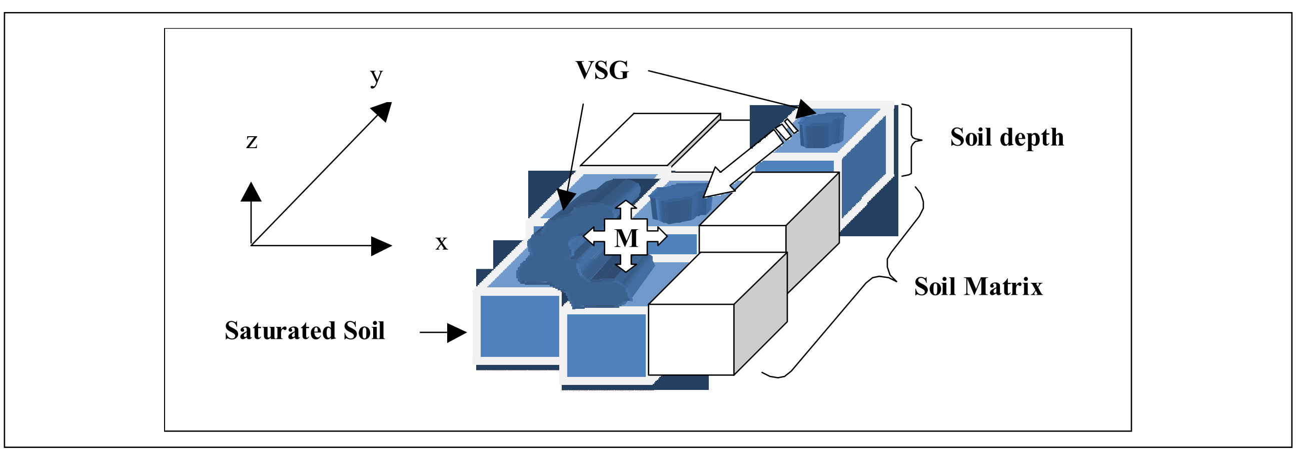

Figure 4. VSG generated due to saturated soil layer, flows towards low elevation and merges (M).

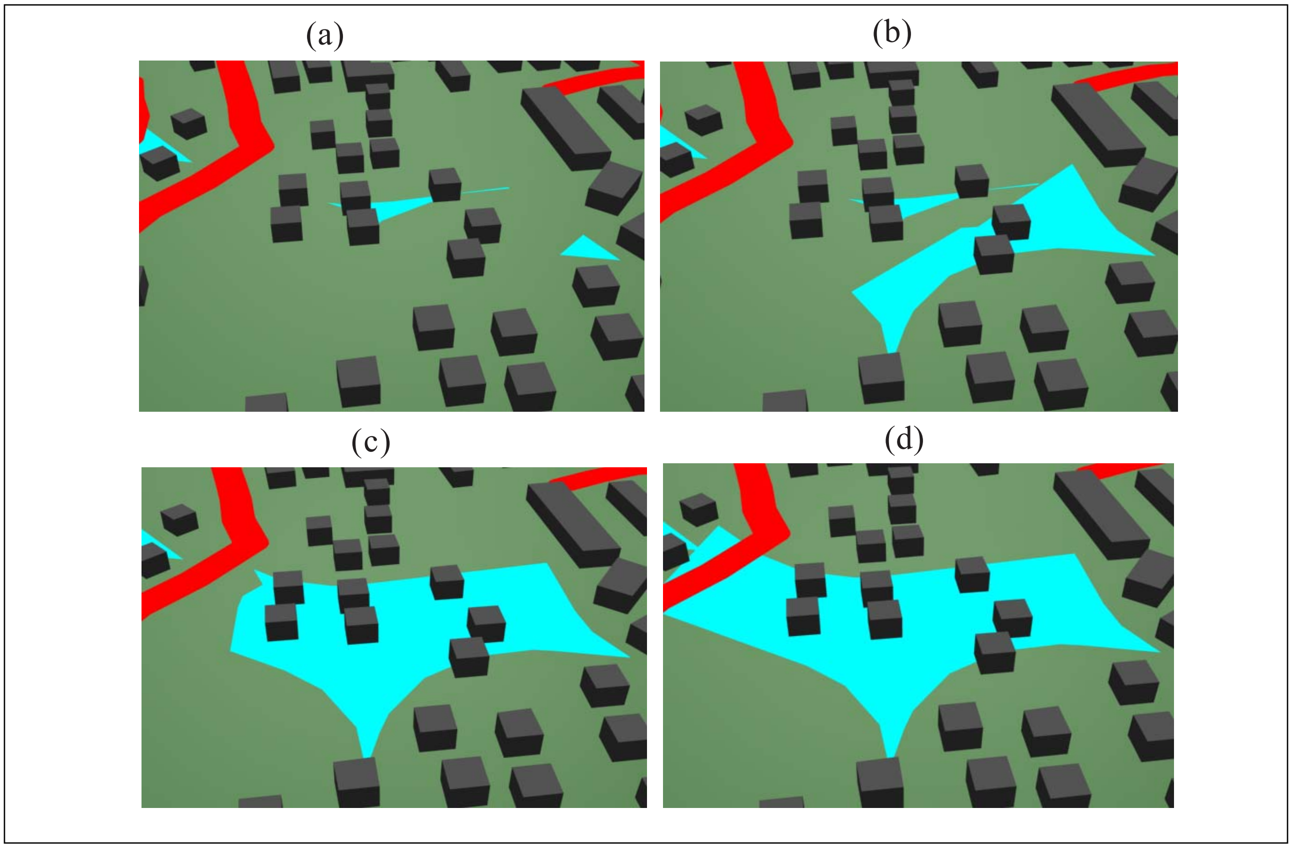

Figure 5. The expansion of VSG from (a) to (d) with rainfall input and the level of saturated soils.

to fill the soil particle surface. Continuous rainfall input on saturated soil causes the stormwater to exceed the soil infiltration capacity using Equation (1) and (2); and distribute VSGs, which carries values of overland flow (rainfall minus infiltration). The shape and depth of VSG is proportional to the topographic surface of the soil particle (e.g. slope angle, slope friction, saturated soil) as illustrated in Figure 5.

VSGs are integrated with the method and shapes according to topographic and slope designation as given in Equation (2). 3D dynamic simulation consists of merging VSGs and visualizing overland flow, open channel flow and flow direction on top soils with time. The volumes of overland flow particles are computed by calculating the extent of surface coverage and multiplied with the runoff depth. As rainfall input decreases, VSGs are omitted due to re-infiltration of top soils. Additional textures on VSGs would deliver information such as the high and low infiltrated stormwater runoff and overland flow within the basin area. The steps of rendering IEOF simulation via VSG data model are shown in Figure 6.

RESULTS AND DISCUSSION

Potential Areas Contributing SGP (IEOF) Areas

The experiment on determining IEOF area is depicted in Figure 7. The IEOF area (shaded with white) is based on 14 September 2007 rainfall data. Approximately 5.2 km^2 of IEOF area is identified. Most of the IEOF coverage lies in areas of Paya Terubong, Air Hitam, Air Terjun River, Kebun Bunga, Green Lane and partly in Gelugur and Jelutong. The differential amount of calculated IEOF area under conformal MRSO and equidistant Cassini-Soldner projection plane is summarized in Table 1. The location of IEOF lies on the sub-humid to humid regions, which is the major control

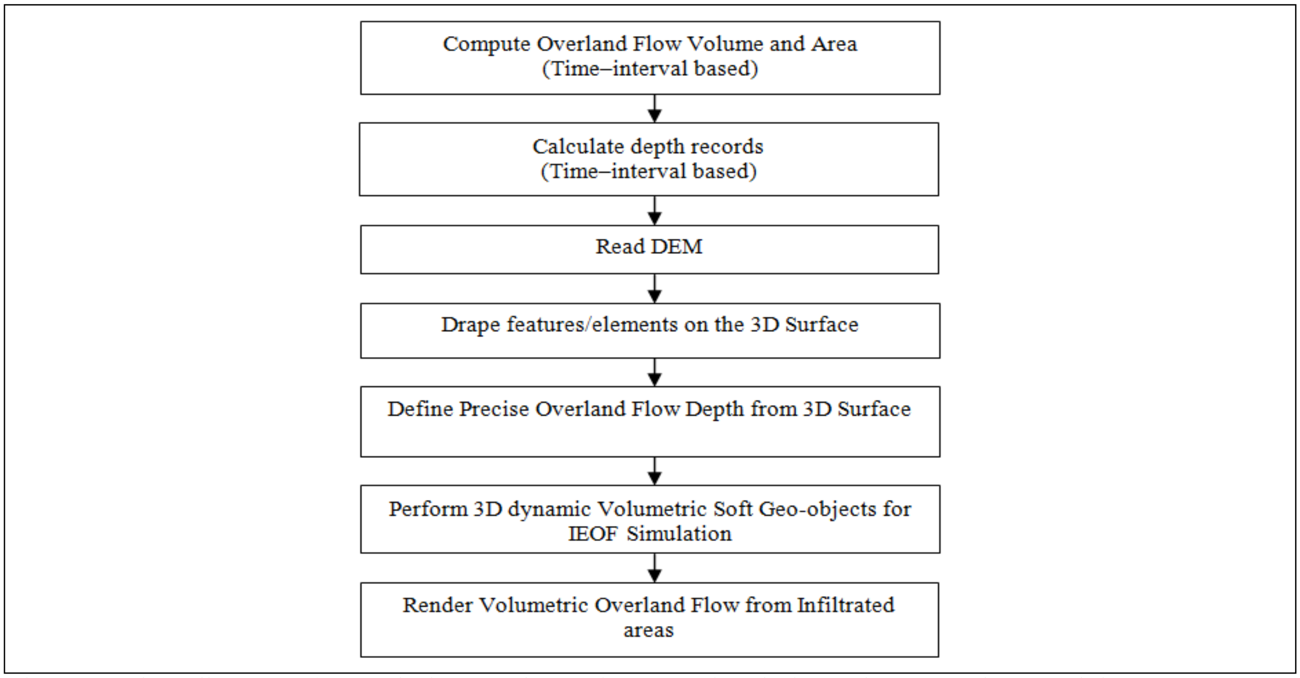

Figure 6. Flow diagrams for rendering 3D dynamic IEOF simulation using VSG data model.

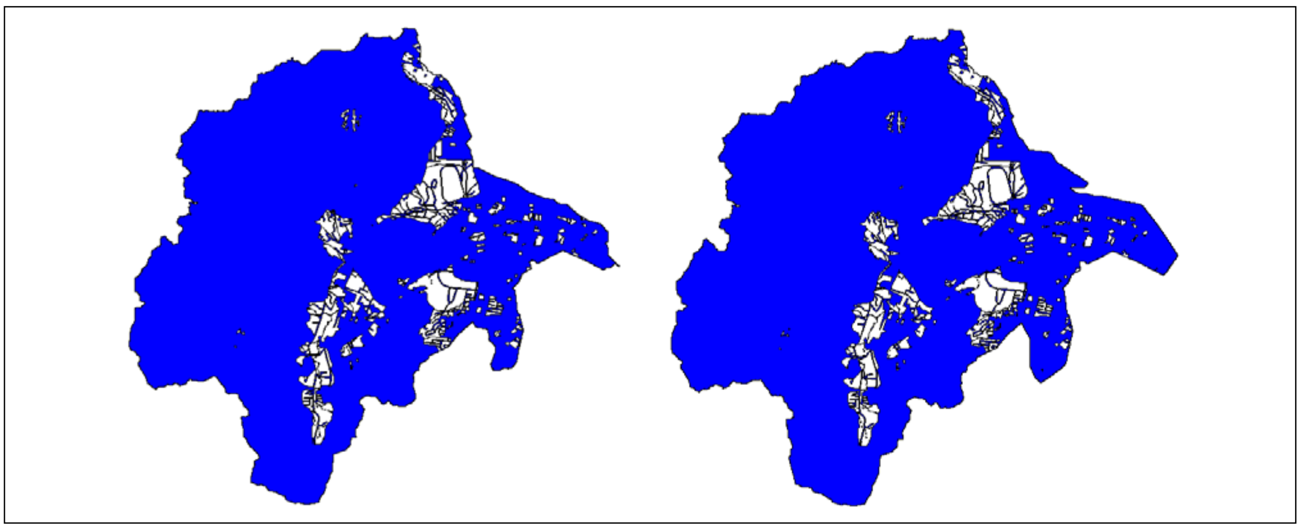

Figure 7. Potential area of IEOF within Sungai Pinang basin under (a) conformal MRSO and (b) equidistant Cassini-Soldner projection plane.

on the various runoff processes, based on climate data, land use, soil topography and rainfall characteristics as stated by Tarboton (2003). Based on the simulated result, the calculated IEOF area and perimeter shows slight differences between conformal MRSO and equidistant Cassini-Soldner projection plane. Such differences are due to the insignificant IEOF process occurring on the small basin area. However, different large scale basin areas might contribute significant changes under different projection planes.

The Green-Ampt infiltration computation correlates significantly to the delineated DEM. The same source of DEM shows significant changes under different types of projection planes. Hence, the Green-Ampt computation is inaccurate, mainly at the Eastern side of the basin area. Such changes should alert the GIS practitioners to not just rely on the preparation of accurate DEM data (e.g. LiDAR, Radar, Digital Photogrammetric, etc.), but to consider the physical characteristics of appropriate projection plane as well to preserve the DEM datasets.

Table 1. Summary of identified IEOF area, rainfall, infiltration and overland flow volume under MRSO and Cassini-Soldner projection plane.

Analysis and Results	Projection	
	Conformal MRSO	Equidistant Cassini-Soldner
1. Total area of IEOF (m^2)	5,253,950.00	5,255,650.00
Difference (m^2)	± 1,700.00	
2. Total Rainfall Volume within IEOF area (m^3)	353,944.18	354,357.93
Difference (m^3)	± 413.75	
3. Total Infiltration Volume (m^3)	129,679.17	129,163.25
Difference (m^3)	± 515.92	
4. Total Overland Flow (Green-Ampt Equation under MRSO Projection), (m^3)	223,436.83	222,991.50
Difference (m^3)	± 445.33	

3D Dynamic VSG Simulation of SGP (IEOF)

Approximately 355,000 m^3 of rainfall volume were recorded within the IEOF boundaries within 4 hours rainfall time (see Figure 8). The estimated volume of rainfall infiltrated into the soil is 129,700 m^3. The total of overland flow simulated by VSG within IEOF area is estimated at approximately 223,700 m^3. A full summary of analyzed IEOF area, infiltration and overland flow volume based on physical based Green-Ampt method are listed in Table 1.

Figure 9 shows the overland flow volume visualized using VSG data model driven by physically based Green-Ampt equation. Continuous input from rainfall increases the height and coverage of overland flow volume, mainly on downslope and flat areas. The volume of infiltrated stormwater and overland flow is proportional to the Green-Ampt method and physical characteristics of conformal MRSO and equidistant Cassini-Soldner projection, which results in a differential on the area, shape, flow path, slope and deformation of VSG. Such conditions are tightly connected with delineated DEMs on a projection plane, where different values of upslope areas are obtained during computation in Equation (1). Thus would greatly affect the physical shape, distance, area and direction of VSGs and computation of total infiltrated rainfall into the ground surface, change of physical soil parameters (soil porosity, conductivity, path of subsurface flow, return flow) with different soil types; and amount of overland flow generated in the study area.

In addition, it can be seen that the dynamical process and simulation period of IEOF process using the VSG data model visualizes the differential spreading extent of overland flow coverage under different projection planes. The 3D dynamic simulation and visualization of IEOF process in this study denotes how critical the projection plane is to the dynamism and spread of VSG. Besides analyzing the VSG data model towards IEOF modelling, such experimental work also raises awareness amongst GIS users, hydrologists and other relevant scientists regarding the importance of analyzing the projection plane to be accounted in the first place before any GIS based modelling is performed.

CONCLUDING REMARKS

This paper discusses the definition, mathematical expression and representation of 3D dynamic simulation of 3D based SGP (IEOF) modelling using a preliminary VSG data model approach by estimating the potential locations of overland flow, saturated flow volume and urban runoff areas,

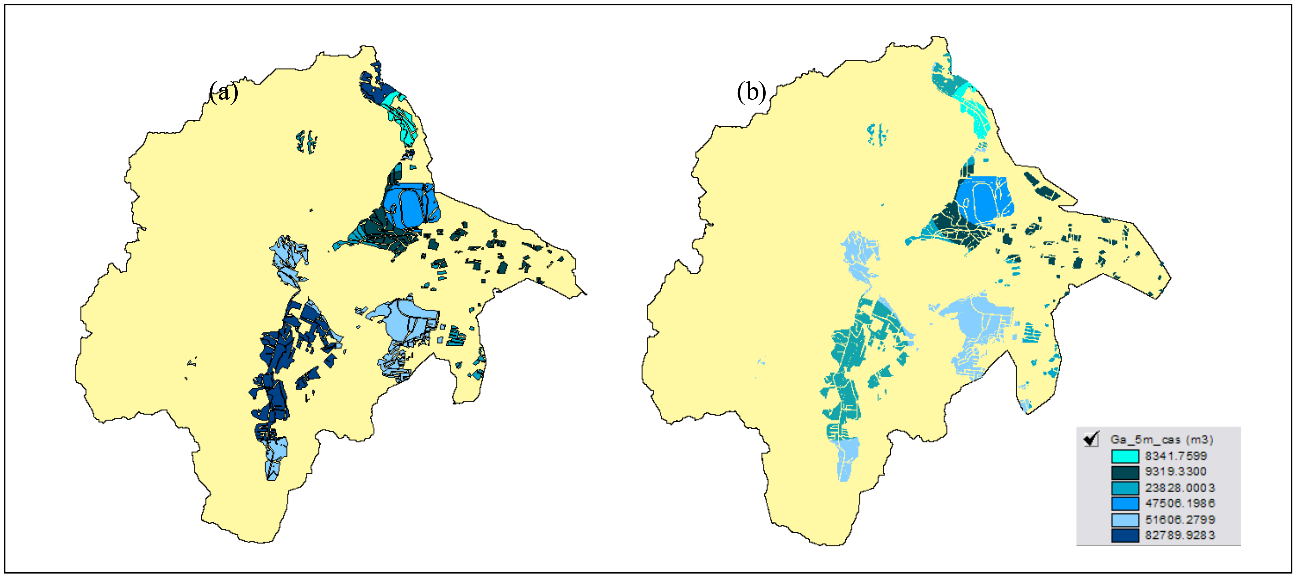

Figure 8. Amount of Overland Flow generated from IEOF area using Green-Ampt equation under (a) conformal MRSO and (b) equidistant Cassini-Soldner projection plane based on 14th September 2007 rainfall data.

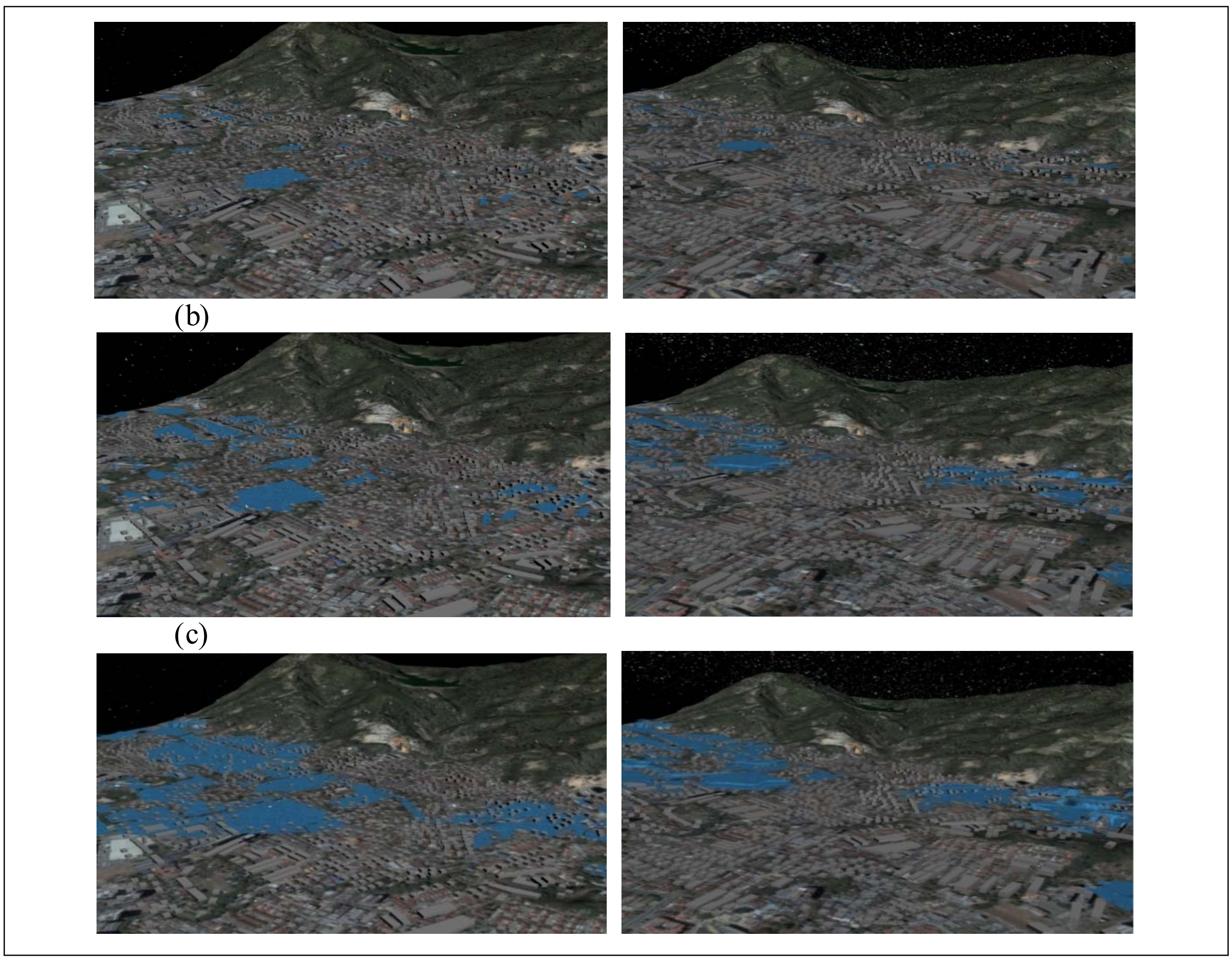

Figure 9. 3D dynamic VSG simulation of IEOF process visualized at (a) 1 hour, (b) 2 hours and (c) 4 hours rainfall duration using conformal MRSO projection (left) and equidistant Cassini-Soldner (right) for Sungai Pinang basin, Penang.

which is driven by the Green-Ampt method. The spatial layers of channel networks, streamflow, land use, soils, rainfall and type of projection plane are all important sub-basin parameters that result in significant changes of infiltrated urban stormwater, overland flow and open channel flow volume at various location. Although the method involves some identifiable sources of uncertainty, the results nevertheless provide an initial indication of the VSG data model envisioning SGP process. A thorough understanding needs to be addressed in terms of physical geographic influences in flow routing process and visualization. Determining the 3D GIS properties (e.g. 3D topological aspects, 3D spatial indexing, 3D generalization) that can be utilized to represent SGP properties of a river basin is one such approach.

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REFERENCES

Allan, C., and N. Roulet. 1994. Runoff Generation in zero order Precambrian Shield Catchment: The stormflow response of a Heterogeneous Landscape. Hydrological Processes. Vol. 8, pp. 369-388.

Bedient, P.B., and W.C. Huber, 2002. Hydrology and Floodplain Analysis. New Jersey; Prentice Hall.

Beni, L.H., M.A. Mostafavi, and J. Pouliot, 2007. 3D Dynamic Simulation within GIS in Support of Disaster Management. Geomatics Solutions for Disaster Management, Lecture Notes in Geoinformation and Cartography. Springer. pp. 165-184.

Beven, K.J. 2000. Rainfall-Runoff Modeling: The Primer. New York; .John Wiley & Sons.

Bonell, M. 1986. Applications of Hillslope Process Hydrology in Forest Land Management Issues: The Tropical North-EastAustralianExperience,.http://www.unesco.org.uy/phi/libros/manaos/5.html

Dingman, S.L. 1994. Physical Hydrology. New York; Macmillan.

Dingman, S.L. 2002. Physical Hydrology. New Jersey; Prentice Hall.

Drummond, J., R. Billen, E. Joao, and D. Forrest, 2007. Dynamic and Mobile GIS: InvestigatingChanges in Space and Time. Boca Raton, FL : CRC Press.

Dunne, T., and L.B. Leopold, 1978. Water in Environmental Planning. San Francisco; Freeman and Co.

Freeze, R.A., and J.A. Cherry. Groundwater. 1979. New Jersey; Prentice-Hall.

Garbrecht, J., F.L. Ogden, P.A. DeBarry, and D.R. Maidment. 2001. GIS and Distributed Watershed Models I : Data Coverages and Sources. Journal of Hydrologic Engineering, Vol 6(6), pp. 506-514.

Garen, D., C. Moore, and S. Daniel. 2005. Curve Number Hydrology in Water Quality Modeling: Uses, Abuses and Future Directions. Journal of the American Water Resources Association (JAWRA), Vol 41(2), pp. 377-388.

Gong, J.Y., P.G. Cheng, and Y.D. Wang. 2004. Three-Dimensional Modelling and Application in Geological Exploration Engineering. Computers & Geosciences, Vol. 30(4), pp. 391-404.

Goodchild, M.F. 2003. Geographic Information Science and Systems for Environmental Management. Annual Revision Environment Resources Vol. (28), pp. 493-519.

Green, W.H. and G. Ampt. 1911. Studies of Soil Physics. Part I - The Flow of Air and Water throughSoils. Journal of Agricultural Science, Vol. (4), pp. 1-24.

Isenbies, M.H., W.M. Aust, J.A. Burger, and M.B. Adams. 2007. Forest operations, extreme floodingevents and considerations for hydrologic modelling in the Appalachians - a review. Journal of Forest Ecology and Management, Vol. 242, pp. 77-98.

Maidment, D.R., O. Robayo, and H. Merwade. 2005. Hydrologic Modelling. In Maguire, D, J., M. Batty, and M.F. Goodchild (eds), GIS, Spatial Analysis and Modelling, Redlands, CA : Esri Press, pp. 319-332.

MSMA. 2000. Manual Saliran Mesra Alam. Vol. 1 – 20. Kuala Lumpur; Department of Irrigation Drainage, Malaysia.

Shen, D.Y., K. Takara, Y. Tachikawa, and Y.L. Liu. 2006. 3D Simulation of Soft Geo-objects. International Journal of Geographical Information Science, Vol. 20, pp. 261-271.

Smemoe, C.M. 1999. The Spatial Computation of Sub-basin Green and Ampt Parameters. http://emrl.byu.edu/chris/documents/greenampt.PDF

Tarboton, G.D. 2003. Rainfall-Runoff Process. Utah State University.

Wang, C., T.R. Wan, and I.J. Palmer. 2007. A Real-time Dynamic Simulation Scheme for Large Scale Flood Hazard using 3D Real World Data. Proceeding of the 11th International Conference Information Visualization (IV'07), IEEE Xplore., pp. 607-612.

Ward, A.D. and S.W. Trimble. 2004. Environmental Hydrology. (2nd ed.), Washington; Lewis Publishers.

Worboys, M., and K. Hornsby, 2004. From Objects to Events: GEM, The Geospatial Event Model. Third International Conference on GIScience, Springer Lecture Notes, pp. 327-344.

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