BULETIN Geospatial SEKTOR AWAM

Edisi 1/2011
ISSN 1823 7762

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Article submitted to BULETIN GEOSPATIAL SEKTOR AWAM, **ISSN 1823 7762, Mac 2010**

A Simple Method for Watershed Delineation in Ayer Hitam Forest Reserve using GIS

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ABSTRACT

Planning of the water resource management is evolving from simple local-scale problems toward complex spatially explicit regional scale. Such problems have to be addressed with distributed models that can compute runoff and erosion at different spatial and temporal scales. In general watershed can range from as little as one hectare to hundreds of thousands of square kilometers. The spatial scale for which a model is designed can influence the specific processes of hydrological cycle. This paper seeks to estimate watershed delineation from topographical map using standard Digital Elevation Model (DEM) in ArcGIS 9.1. A simple automatic delineation technique in computer vision application was carried out at Ayer Hiram forest Reserve, Selangor. Results showed that by using watershed function in ArcGIS 9.1 watershed delineation for the Ayer Hitam Forest Reserve can be determined. This exercise is mainly a case-study of simple applicability of GIS as a tool of watershed delineation. However, the results obtained is should not be wise to be utilized in other watershed area.

INTRODUCTION

A watershed is an area that drains surface water to a common outlet. Watershed analysis refers to the process of using DEMs (Digital Elevation Models) and raster operations to delineate watersheds and to derive topographic features such as stream networks (Kang, 2008). Previously, watershed delineation was mainly conducted by the method of hand delineation. Therefore water catchments area is determined based on the topographical landscape of the area (William, 2000). The watershed boundary can be determined using contour line map, hydrological regime, by calculation procedure and dot grid by a planimeter. A maps with 1:50 000 or 1: 20 000 standard scales are use to determine the area. In order to successfully delineate the watershed boundary, the evaluator needs to visualize the landscape as represented by each of the contour lines in the map. The steepness of the area which can be determined from the contour interval is related to the water flow.

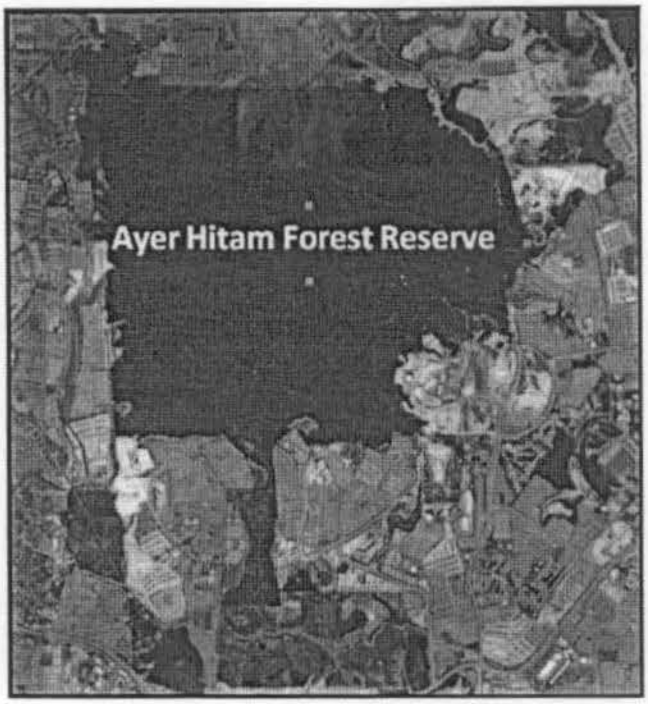
Nowadays, applying topographical information in digital form is advantage in estimate a watershed area. On the other hand, it enables for accurate representation of stream flow path and contributing areas. It was found that the delineated area from the use of computerised approach is better compared to area determined by the topographical map (Guarav *et al.*, 2002). ArcGIS provide a multipurpose hydrologic analysis system for use by watershed, water resource and land use. The GIS framework is ideally suited for watershed-based analysis or both deriving model input and presenting model results. The techniques used for delineation of the watershed boundary by surface drainage are ultimately dependent on topographical information generated in a local neighborhood on the DEM. The raster data used in GIS carry spatial information and one of it is the coordinate of the earth surface. With the information of contour lines and river layer, it is enough for the GIS to manipulate it to determined the watershed area and delineate the boundary. Advances in the analysis of flow direction and flow networks from DEMs have led to several automated methods for watershed and stream delineation (Jenson and Domingue, 1988; Tarboton, 1997). The simple rule in this exercise is simplicity where the operation is transparent when an operator can examine its source code and comprehend how it works. It is simple when its operation is sufficiently, uncomplicated that a programmer can visualize with little effort of all the potential situations that it might encounter. This paper provides simple method to estimate watershed delineation automatically from topographical map using standard Digital Elevation Model (DEM) in ArcGIS 9.1.

METHODOLOGY

Study area and data description

The study area is located at Latitude of 2°56'N - 3°16'N and Longitude of 101°30'E - 101°46'E in the state of Selangor, Peninsular Malaysia (Figure 1). Ayer Hitam Forest Reserve is a University Forest that has being allocated as an education and research forest by the Selangor State in June 1994. The Ayer Hitam Forest Reserve covers an area about 1,217.90 hectares. The average temperature is 26.6° C and the relative moisture is 83%. The main rivers here are Sungai Rasau and Sungai Bohol. The geology in this forest contains the igneous rock and the main component of granite. The average temperature is 26.6° C and the relative moisture is 83%. Permatang Kumbang is the highest point in this forest with 233 meters above sea level and slope is 10%-20%.

The data used are the contour layer which contain the height of each contour line and the river layer. Both layers are represented in shapefile (shp) format, *ahcont.shp* and *sung.shp* for contour and river layer respectively. All of the data are projected using the coordinate system Kertau RSO Malaya Meters.

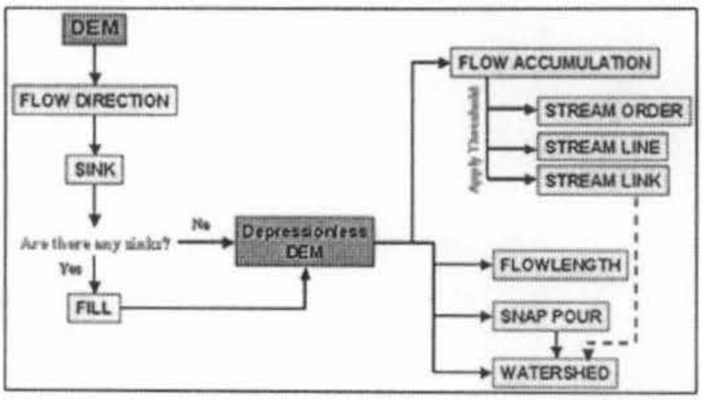


(Source: Google Earth)

Figure 1: Quickbird Image satellite showing of Ayer Hitam Forest Reserve in Puchong, Selangor

Methods

ArcGIS 9.2 provides the toolbox for hydrology analysis containing some functions: flow analysis, stream analysis and watershed. Watersheds were delineated from a DEM by computing the flow direction or flow accumulation and using it in the Watershed function. The process of extracting hydrological information is showing in Figure 2. Raster data of a flow direction was used to delineate watershed and later on the pour points has to be determined.



(Source: ArcGIS 9.2 Desktop Help)

Figure 2: Process of extracting hydrologic information such as watershed boundaries and stream networks, from DEM

There are two input layers in this work: contour and river represented in shp format. The flow chart for producing watershed delineation map is provided in Figure 3. Table 1 showing the input data and output for the processes conducted in this work. Below are some steps in constructing the final map for watershed delineation:

1. Create the raster DEM (Digital Elevation Model) format from the layer contour (shp format). We applied the sub menu *TopoToRaster* in ArcMap included in the menu *Interpolation* in the feature *Spatial Analyst Tools*. Some parameters selected in this task:
   - Feature layer: contour (ahcont.shp)
   - Field: contour height (HTMETER)
   - Type: Contour
2. Apply the *Fill* operation in the menu *Hydrology* in the *Spatial Analyst Tools* to remove small imperfections the raster layer Contour.
3. Create flow direction layer from the layer Contour using the sub menu *Flow Direction* in the menu *Hydrology* in the *Spatial Analyst Tools*.
4. Calculate the flow accumulation layer from the flow direction layer by applying the sub menu *Flow Accumulation* in the menu *Hydrology* in the *Spatial Analyst Tools*.
5. Create the Pour point which is the discharge water to the reservoir. The pour point layer is created in ArcCatalog. The Kertau RSO Malaya meter is selected as the geographic projection for the layer. Then we add XY coordinates to the pour point layer by applying the sub menu *Add XY Coordinates* in the menu *Features* in *Data Management Tools*. The new coordinate obtained from the study area will be added to the Pour point layer. The selected point is the lowest area in the contour line that intersects with the river. The point is drawn using the Drawing Tool. To obtain the coordinate of the point we apply sub menu *Location* in the menu *Properties*. By selecting the *Editor* menu, the location is then inserted to field Point_X and Point_Y in the table of pour point layer. From the table containing point X and point Y, we create a point layer using the sub menu in *Make XY Even Layer* in Arc Toolbox. Again a The Kertau RSO Malaya meter is selected as the geographic projection for the new layer.
6. Create Watershed using the sub menu *Watershed* in the menu *Hydrology* in the Spatial *Analyst Tools*. The inputs are a raster of flow direction and the pour point layer.
7. Convert the Watershed layer in raster format to shp format.
8. Product the final map representing the watershed overlaying with the contour and the river layer. We display the contour and the river layer that are completely within the watershed area.

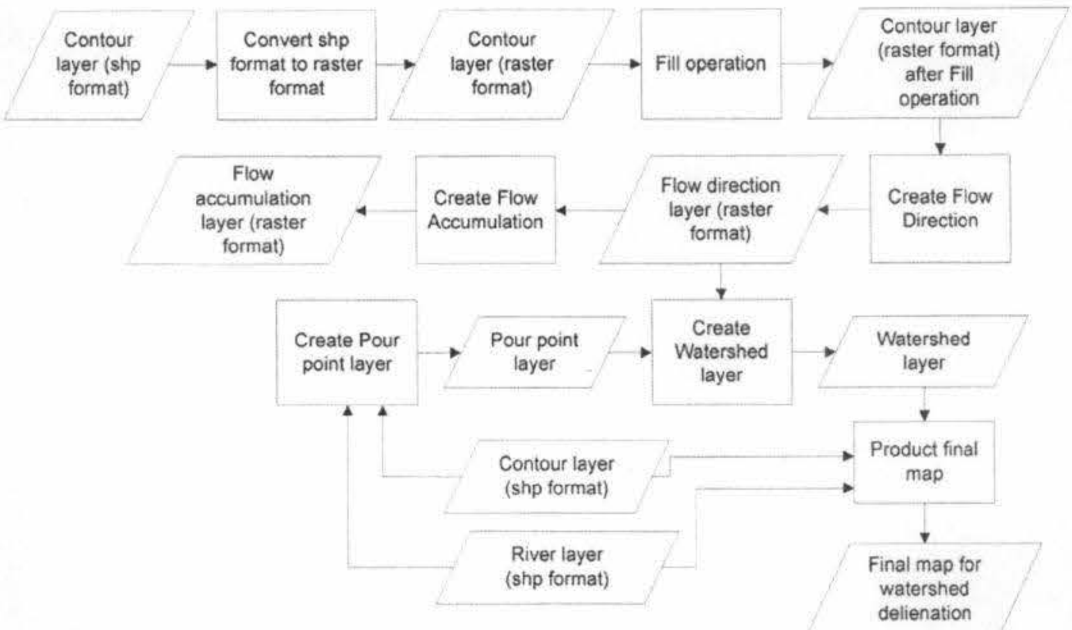


Figure 3: Flow chart for producing watershed delineation map.

Table 1: Input, processes and output.

No	Input	Process	Output
1	Contour layer (shp format)	Create the raster DEM format	Contour layer (raster format), see Figure 4.
2	Contour layer (raster format)	Apply Fill operation	Contour layer (raster format) after the fill operation, see Figure 5.
3	Contour layer (raster format) after the fill operation	Create flow direction layer	Flow direction (raster format), see Figure 6.
4	Flow direction (raster format)	Create Flow Accumulation layer	Flow accumulation (raster format), see Figure 7.
5	Contour and river layer (shp format)	Create pour point layer	Pour point layer (shp format)
6	Flow direction (raster format) and Pour point layer (shp format)	Create watershed layer	Watershed layer (raster format), see Figure 8.
7	Watershed layer (raster format)	Convert Raster to Polygon	Watershed layer (shp format), see Figure 9.
8	Watershed layer (shp format), Contour layer (shp format), River layer (shp format)	Product final map	Final watershed layer (shp format).

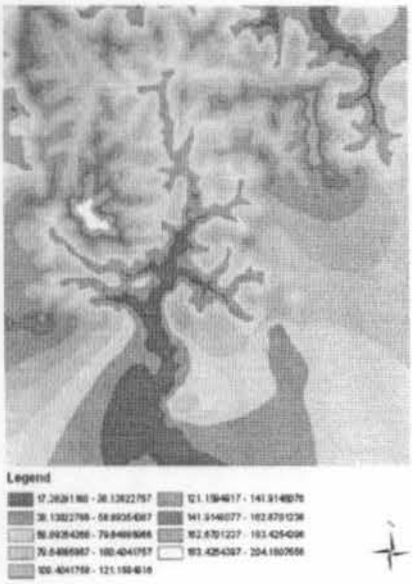


Figure 4: Contour layer in Raster format

Figure 5: Contour layer in Raster format after Fill operation

Figure 6: Flow direction

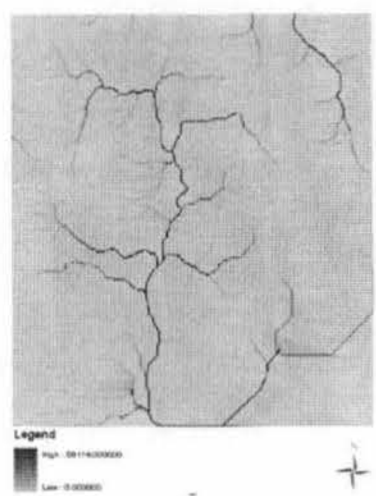


Figure 7: Flow accumulation

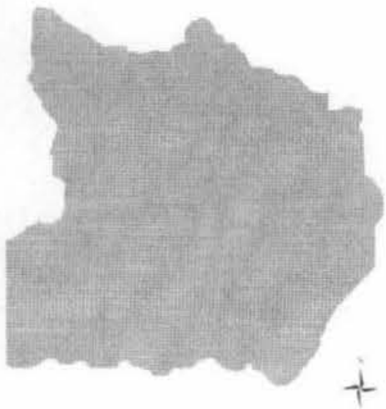


Figure 8: Watershed in raster format

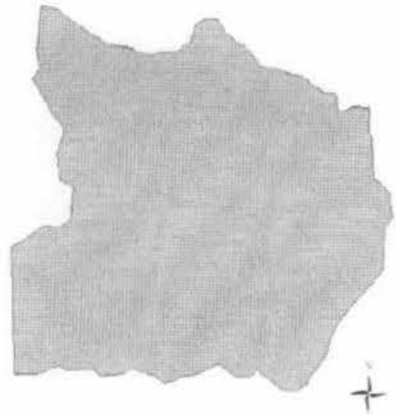


Figure 9: Watershed in shp format

RESULTS AND DISCUSSION

This section discusses some important maps related to watershed delineation. The maps are flow direction, flow accumulation, pour point, and watershed delineation.

Flow Direction

According to Kang (2008), a flow direction raster shows the direction water which is flow out from each cell of a filled elevation raster. There are eight distinct values in the flow direction raster as illustrated in Figure 10. Each value indicates the direction code showing the direction of flow out of each cell. ArcGIS uses the eight direction (D8) flow model. This method assigns a cell's flow direction to one of its eight surrounding cells that have the steepest distance-weighted gradient. The eight output directions relate to the eight adjacent cells into which flow could travel. As an illustration, in a small part of the study area (indicated in red ellipse in Figure 11) most of cells have the flow direction to neighboring cells located in the west part of the cells. The value of these cells is 16 displayed in dark blue in the map.

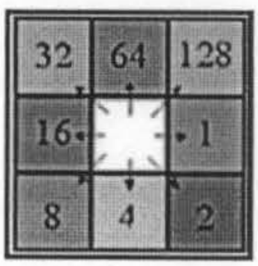


Figure 10: Direction coding

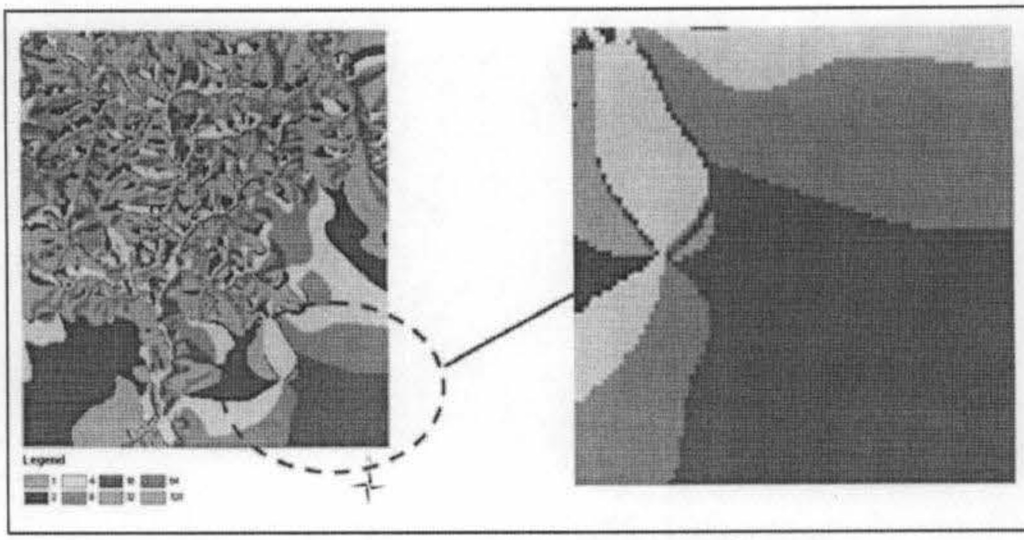


Figure 11: Flow direction in the south east part of the map.

Flow Accumulation

A flow accumulation raster tabulates for each cell of the number of cells that will flow to it. A flow accumulation raster can be interpreted in two ways (Kang, 2008):

1. Cells having high accumulation values generally correspond to stream channels, whereas cells having an accumulation value of zero generally correspond to ridge lines.
2. If multiplied by the cell size, the accumulation value equals the drainage area.

In ArcGIS, the Flow Accumulation function calculates accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster (ArcGIS 9.2 Desktop Help). If no weight raster is provided, a weight of one is applied to each cell, and the value of cells in the output raster will be the number of cells that flow into each cell.

Figure 6 shows flow accumulation in a small part of study area indicated in red ellipse. Each cell in dark blue area has high value. For example, the point A indicates a cell having the value 8249. It means there are 8249 cells flow to the point A. We can consider such area as stream channels. This area has low elevation indicated by light blue area in the contour layer. The contour layers are provided in Figure 4 and Figure 5. The water flows from higher point (dark blue) to the lower point (light blue). Point B has the value 2 meaning that only two cells flow to that point. There are no cells that flow to the point C (the value is 0). We can state that this area is a ridge line.

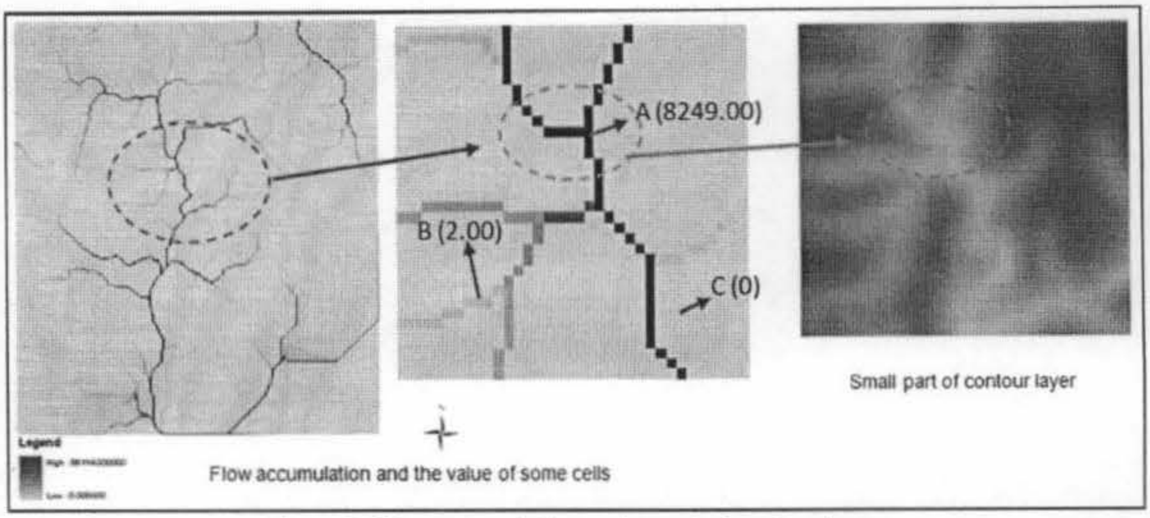


Figure 6: Flow accumulation and a part of contour layer.

Pour Point

Delineating watershed was performed based on the points of interest called pour points. A pour point is the point at which water flows out of an area. This point may be a gauge station or a dam. In this work the pour point is a point in the lowest area that intersects with the river. Figure 7 shows the pour points that is located in the area having the elevation 22.5 meters and intersect with the river (blue line). Water will flow out or discharge from other area to this point.

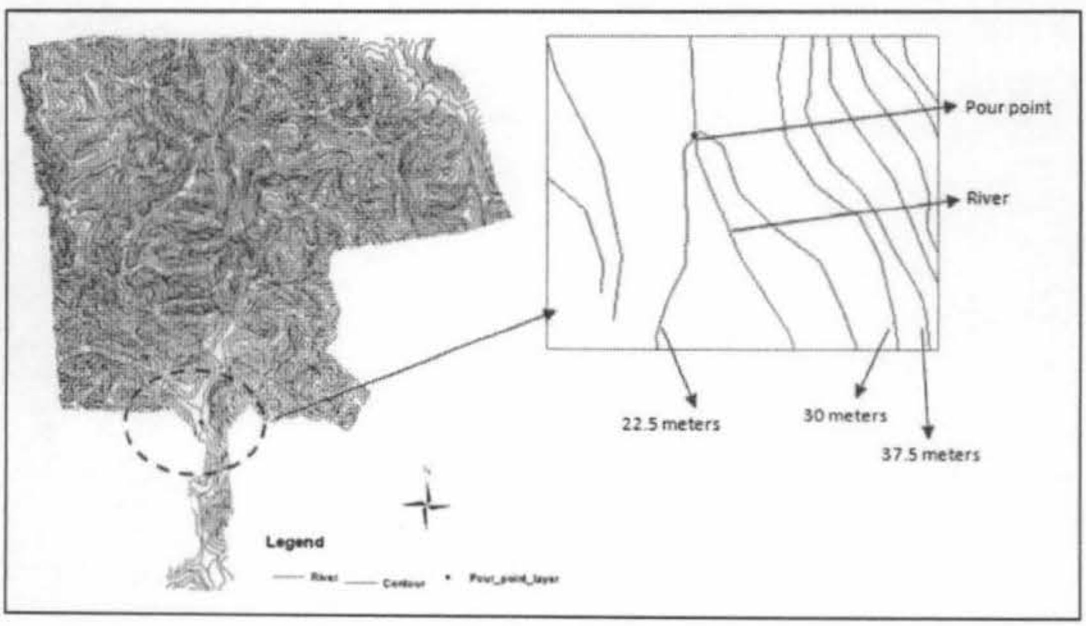


Figure 7: Pour point.

Watershed Delineation

The delineation of watershed boundary was created from the total area of flowing accumulation to a given pour point. The watershed map for the Ayer Hitam Forest Reserve that created based on the flow direction raster and a pour point is illustrated in Figure 8. The total area of watershed calculated from watershed layer is about 9,532,076.38386 meter^2.

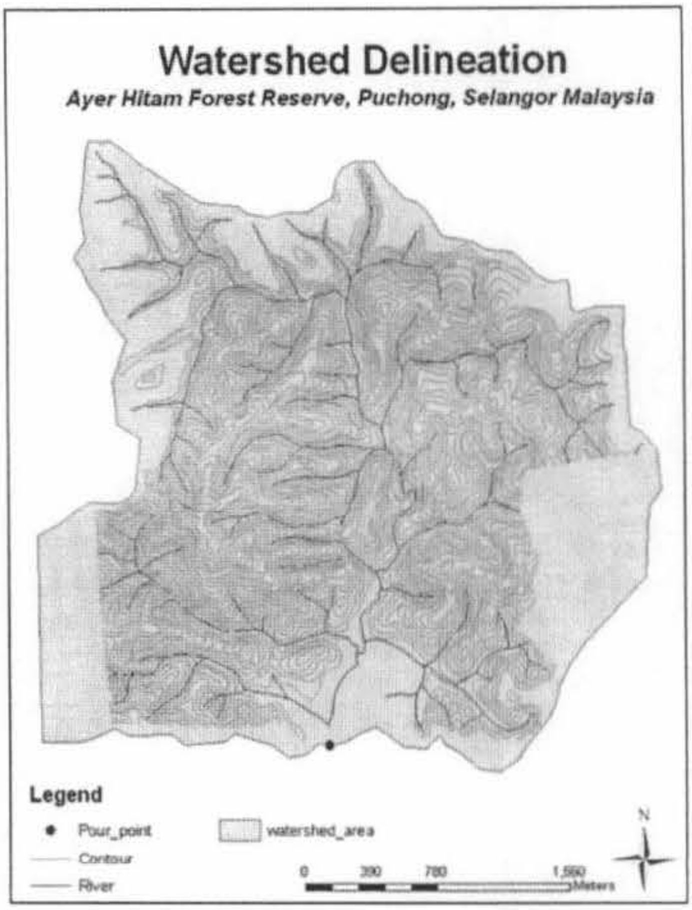


Figure 8: Watershed delineation map.

CONCLUSION

As conclusion by using GIS-computerised approach, an area of watershed boundary can be delineated automatically. This paper has concluded several important points in estimation techniques in computer application. Despite its potential advantages, automated generation of watershed boundaries involves several practical challenges. Errors arise because spatial data are numerous and may corrupt by noise. Topographical map rarely align perfectly, especially in moderate to low-relief terrain. Such error can to very different interpretations of watershed flow pathways. Therefore, a simple and rapid estimation is an important though incompletely solved problem in geospatial analysis. This exercise is mainly a case-study of simple applicability of GIS as a tool of watershed delineation. However, the results obtained is only a simple outcome for Ayer Hitam forest Reserve exercise and should not be wise to be utilized in other watershed area.

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