Automatic Delineation of Drainage Networks and Catchments using DEM data and GIS Capabilities: a case study

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Abstract

Catchment and drainage network delineation is an important step of hydrologic model development that represents hydrologic boundary. Due to spatial and temporal variations of the characteristics of a watershed, it is often necessary to delineate a watershed into smaller-sized model areas where variables can be considered homogeneous. Catchments are scale independent delineations to capture surface water in an area of interest. Generally there are two types of delineation; manual and automatic. The traditional manual catchment delineation method for large-scale watersheds is time consuming. Using an elevation raster or digital elevation model (DEM) as input, it is possible to automatically delineate a drainage system and quantify the characteristics of the system. With the development of computer and information technology, automatic catchment delineation becomes widely popular. For accurate delineation, the quality of grid based DEM is vital. The DEM quality depends on two important aspects i.e. horizontal resolution and vertical accuracy. In this paper catchment and drainage network have been delineated for a case study area 'Rockhampton Golf Course'. A rainfall runoff model was needed to develop in the study area and catchment delineation is a prerequisite to get the model boundary. In this study 3sec DEM data and 1sec DEM data were used for automatic delineation along with hydrologic analysis tools in ArcGIS Spatial Analyst. The hydrologic analysis tools described the physical components of a surface through some major functions like flow direction, flow accumulation and determining watersheds from a given source. Moreover the channel shape file generated by Geoscience Australia was also used as reference data of delineation to fix up the flow accumulation threshold area value. The delineated catchment and drainage networks using the two DEM data and their comparison are plotted and discussed in this paper. Besides consideration regarding automatic catchment or drainage network delineation found in this study are discussed here.

Keywords: Automatic Delineation, DEM, Catchment, Drainage networks, GIS, Grid spacing, threshold value

Introduction

A catchment is the smallest spatial unit of the delineated area in a watershed where integrated water management can be accomplished [1, 2]. Catchment delineation based on digital elevation models (DEM) is the prerequisite to set up physically based distributed hydrologic models [3]. The size of a model area depends on the details of the study so that the watershed characteristics can be assumed as homogeneous. The smallest area that a hydrologic model can be applied to is called a catchment. There is no size limit as to how small the delineation may be, catchments are scale independent delineations, delineated to capture surface water in an area of interest [4]. An individual catchment in the data set may represent the drainage area of a 1-acre prairie wetland or a 100 acre recreational lake. The traditional manual catchment delineation method for large-scale watersheds where more than hundreds catchments are delineated in a watershed is time consuming and very tedious.

Currently the traditional manual catchment delineation methods are quickly replaced by automated approaches, for the introduction of software algorithms that can do quick and efficient processing. Advantages of automatic catchment delineation methods include process reliability and reproducibility, savings of time and labour, and results within a digital domain, can be linked to other data sets easily. Before the advent of Geographic Information System (GIS), delineation of drainage network and catchment was done from contour lines on topographical maps or from aerial photo-interpretation [5-8]. These are substituted by digital representations in the form of digital elevation models for the sake of GIS [9, 10]. In this paper drainage network and catchment have been delineated automatically for a case study area using 1sec (30mx30m grid spacing) DEM data and 3sec (90mx90m grid spacing) DEM data with the help of Hydrology tools of Spatial Analyst of Arc GIS 10.

Study Area

In this study the case study area is a 'Golf Coarse' which is located in Rockhampton city, 40 kilometers away from the coast on the Fitzroy river. During wet season huge storm water enter into Golf course from northeast corner and passes through the Course and falls into the marry lagoon situated at the southwest corner of Golf Course. In order to reuse that stormwater at dry season for irrigation purpose the quantification of stormwater is needed. Therefore development of a rainfall runoff model for the study area is required to assess the stormwater quantity. To get the model boundary of the study area delineation of catchment and drainage network is essential. The location of the study area is shown in Figure 1.
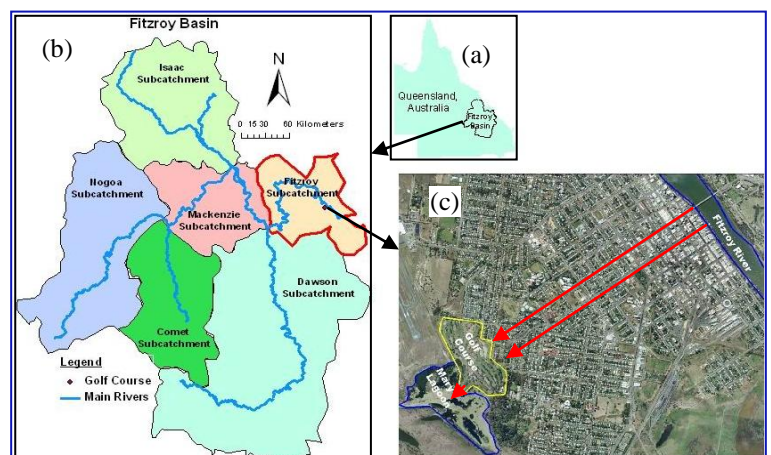

Figure 1. Study Area – Rockhampton Golf Course.

The Rockhampton Golf Course is situated at the Fitzroy Basin (Figure 1) which is the largest river basin on the east coast of Queensland [figure 1 (a)] and the second largest basin of Australia. There are six subcatchment of Fitzroy basin (figure 1 (b). Among these the study area lies on Fitzroy sub-catchment which is bounded by the red line in figure 1 (b) and the study

area is pointed out by a red diamond in figure 1 (b). The enlarged view of the study area is shown in figure 1 (c). Figure 1 (c) shows the area of interest 'Golf Course' by yellow line boundary, Murray Lagoon by blue line boundary and the Fitzroy River by two parallel blue lines. In figure 1 (c) the red arrows show the direction of water during the wet season. To develop a rainfall runoff model for the case study area, Fitzroy sub-catchment is too big to get the hydrological boundary. So, reasonably small catchment is required for model boundary. Thereby this study is done to get the catchment and drainage flow directions using DEM and GIS capabilities.

The latitude (Lat) and longitude (Long) of the four corner points of the study area are shown in Table 1;

Left Top	Lat: -23.387988;	Right Top	Lat: -23.389323;
	Long: 150.481691		Long: 150.489814
Left Bottom	Lat: -23.397065;	Right Bottom	Lat: -23.397068;
	Long: 150.484869		Long: 150.490709

Table 1. Four corner points of the study area.

Digital Elevation Models (DEMs)

Digital elevation model (DEM) can be defined as numeric or digital representation of terrain elevation specified as a function of geographic location. DEM is the fundamental data for the automatic delineation of catchment and drainage network for spatially distributed hydrological model [11]. These topographic frames are used to divide the watershed into a set of elements, runoff producing sub-catchments, each of which drains into one channel [12, 13]. There is only one method of catchment delineation where DEM is not required. This method is based on automated river network overlay [13, 14]. It requires a well-defined river network database.

Quality DEM is the precondition of successful and accurate catchment delineation. The quality of readily available DEM depends on some important factors [15 - 19]. They are outlined below;

• The source of the elevation data which includes: the measuring techniques of elevation - either on the ground or remotely; the locations of samples; and the density of samples

• Methods used for creating the DEM from elevation data

• Data model or structure of the elevation data: grid, contour or triangular irregular network (TIN)

• Horizontal resolution and vertical precision to represent elevation data

• Topographic complexity of the landscape being represented and

• The algorithms used to calculate different terrain attributes

Among the three types of elevation data structures, grid based DEM forms are most simple matrics that record topological relations between data points implicitly. Besides it is more available and easy for computer implementation. For these reasons, Grid DEMS are becoming most widely used during the past decade [19 -22]. Catchment delineation from contour lines and triangulated irregular networks are reliable but they need extensive data storage and computation time.

With the development of effective spatial data acquisition tools, the DEMs are more readily available nationally from the United States Geological Survey (USGS) [23, 24]. For this study, the 3sec DEM (90m x 90m) data of USGS HydroSHEDS were collected and used for the derivation of catchment and drainage flow direction. This data is freely available electronically from the EROS (Earth Resources Observation and Science) data center at http://hydrosheds.cr.usgs.gov. That DEM data was in a large area. For the easiness of operation and maintenance, the DEM data for Fitzroy subcatchment only was taken from the large DEM using ArcGIS.

For better understanding of the study, again 1sec DEM (30m x 30m) data were collected from the Queensland Government Information Service (QGIS). That DEM data was for the total Fitzroy Basin. For this study only DEM data of Fitzroy sub-catchment was taken for delineation of the catchment and drainage flow direction was. The shape file of stream channel was also collected from Geoscience Australia and used as reference data for automatic delineation.

Delineation of Drainage Networks and Catchments

The sequential steps followed in this study for delineation of catchment and stream network using DEM data are presented below:

1. Fill Sinks: It is the first step of DEM pre-processing. The objective of this step is to make a depression less elevation model. Here sinks in the original DEM were identified using the Sink tool. A sink is usually an incorrect value lower than the values of its surroundings. These depressions points create problem as any water that flows into them cannot flow out. To ensure proper drainage mapping, these depressions were filled using the Fill tool and a fill DEM has found. Sinks are removed from DEMs using the standard flooding approach described by Jenson and Domingue [25]. Depressions are filled by increasing elevations of depression points to their lowest outflow point.

2. Calculate Flow Direction: In this step, the direction in which water would flow out of each cell has been determined. The fill DEM found in the previous step is treated as input here and the Flow Direction tool is used for this job. The output is an integer raster whose values ranges from 1 to 255. Flow directions were calculated using the eight-direction (D8) flow model which assigns flow from each grid cell to one of its eight adjacent cells, in the direction with a steepest downward slope. The D8 method which was introduced by O'Callaghan and Mark [26], currently being widely used [12, 21, 27 & 28].

3. Calculate Flow Accumulation: It is the initial stage of defining the stream network system. Using the Flow Accumulation tool, the number of upslope cells flowing to a location were calculated here. The output flow direction raster created in the previous step has been used as input here.

4. Define Stream Network: The correct automatic derivation of stream is an unsolved problem [13]. The most common method of extracting channel networks from DEM is to specify a critical support area that defines the minimum drainage area required to initiate a channel using a threshold value [12, 13, 25 & 29]. In practice this threshold value is often selected on the basis of visual similarity between the extracted network and the lines depicted on topographic maps. The threshold value has been specified on the raster of flow accumulation that derived from the previous step. This task has been accomplished with the Con tool of spatial analyst tools. As a result, all cells with more than 'threshold value' cell flowing into them have been part of the stream network. For this study many trials were run with different threshold value and tried to match the DEM extracted channel with a reference channel of Geoscience Australia. An analytical method for determining an appropriate

threshold value for stream network delineation can be found in Tarboton and Daniel [11].

5. Stream Segmentation: After derivation of stream network, a unique value was assigned for each section of the stream raster line, associated with a flow direction. The stream Link tool has been used on two raster file that are extracted from the above step 2 and step 3 as input.

6. Catchment Grid Delineation: Using the Watershed tool, the catchments have been delineated for specified locations. The flow direction raster and the flow accumulation raster based on fill DEM data those are found from the outputs of step 2 and step 5 respectably have been used as input.

7. Catchment Polygon Processing: Finally catchment polygons have been found. Among them the polygon on which the study area situated is the catchment of interest.

Results and Discussions

Following the above steps catchment and drainage networks have been delineated for the study area using 1sec DEM data and 3sec DEM data. The delineated catchment is shown in Figure 2. Figure 2 (a) and 2 (b) show the catchments made by 1sec DEM data and 3sec DEM data respectively.

During catchment delineation the main challenging job was the fixation of threshold value which is referred as flow accumulation threshold area (A_t). After several trials with different threshold values, this study found that the catchment generated for the study area in Figure 2 (a) had no change in shape for the threshold value ranges from 35000 to 250000. Finally the threshold value of '250000' was taken for the final catchment delineation. Here total 27 catchments were found within Fitzroy sub-catchment and among those red coloured catchment is the catchment of the area of interest of the study area. The area of this catchment is approximately 164 km^2.

On the other hand in Figure 2 (c), the catchment was delineated for the threshold value of '26000' which is approximately 9 times smaller than the previous threshold value of '250000'. The notable thing is the DEM data grid spacing of Figure 2 (a) is 9 times finer than that of Figure 2 (c). Here total 17 catchments were generated within Fitzroy sub-catchment. The red coloured catchment is the catchment of the study area. The area of this catchment is approximately 226 km^2. Therefore, for a same watershed area more catchments have been found with finer DEM data than coarser one and area of catchment is smaller in Figure 2 (a) than Figure 2 (c).

Figure 2 (b) shows the overlapping of two catchments produced for the study area from 1sec DEM data and 3sec DEM data. The two catchments found from two DEM data of different grid spacing are not same but a significant part has overlapping. It also makes a sense that the catchment delineation done with DEM is quite good.

The delineated drainage networks generated using 1sec DEM (30m x 30m) data of QGIS, and 3sec DEM (90m x 90m) data of USGS HydroSHEDS are shown in Figure 3(a) and 3(b) respectively. In both the Figures 3 (a) and 3 (b), light blue firm line represents channel shape file collected from Geoscience Australia. This stream was used as reference data to compare the extracted channel from DEM and this comparison helped to fix up the threshold value for drainage network delineation. The pink dotted line represents the delineated drainage networks extracted from DEM.
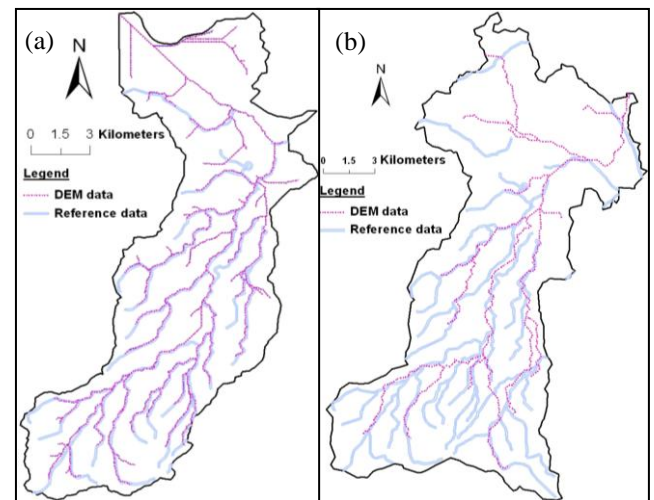

Figure 3. Drainage Network Delineation (a) using 3sec DEM (90m x 90m) data of USGS HydroSHEDS, (b) using 1sec DEM (30m x 30m) data of QGIS

Figure 3 (a) shows good matching of drainage networks but in Figure 3 (b), matching of drainage is not so good. The reason behind this result is in Figure 3 (b) 90m grid spacing were used which is too coarse to extract real drainage flow. When the size of a drainage feature is much smaller than the grid cell size of the DEM, the channels cannot be captured.
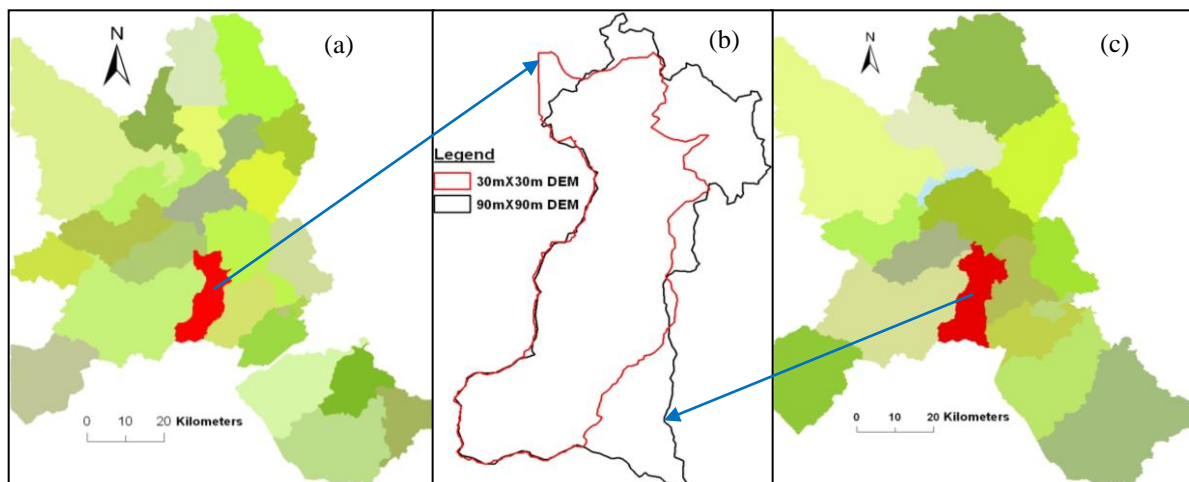

Figure 2. Catchment Delineation (a) using 1sec DEM (30m x 30m) data of QGIS, (c) using 3sec DEM (90m x 90m) data of USGS HydroSHEDS, (b) overlapping of two catchments made from two DEMs

Consideration during Automatic Delineation of Catchment and Drainage Network

- In automatic drainage network or catchment delineation using DEM, the selection of threshold area value is vital. Wrong threshold area value generates inaccurate delineation.

- Regular gridded DEM has fixed grid cell size which cannot always portray the topography accurately, especially in varying landscapes. As a result errors are introduced through any type of interpolation procedure. These errors are spatially auto correlated. Besides, gridded elevation data are often rounded to the nearest meter to save memory. As a consequence, regions with gentle slopes are represented as stairs i.e. flat areas with abrupt changes. This limitation has direct impacts on channel network and catchment delineation.

- Generally a difficulty has arisen while assigning drainage directions to flat areas. It is really hard to discriminate between flat areas drained by incised channels and truly flat areas carrying sheet flow.

- For successful model development, manual refinement of the initial delineated catchments by automatic method is needed to make a final product. The level of manual refinement depends on the modeling objectives and project-specific level of details.

Conclusions

Accuracy of catchment delineations played an important role in the hydrologic and hydraulic model development and calibration. A successful GIS based automatic catchment delineation depends on some factors like; the extent and accessibility of the data sources, the type and unique features of the modeled area, and the accuracy and competence of the GIS database. In this study catchment and drainage network were delineated, using DEM and GIS capabilities, for a case study area 'Rockhampton Golf Course'. A simple approach of automatic delineation was followed in this study. For better understanding and performance 1sec and 3sec DEM data were used for delineation and comparison among them was made. During drainage network delineation, a channel shape file of Geoscience Australia was used as reference data. The study found that grid spacing of DEM data plays a vital role in automatic delineation. Delineation using DEM data of 30m grid spacing provided a better result than that of 90m grid spacing, which is quite normal. However the coarse DEM data (90m grid spacing) helped to increase the confidence of delineation. Again, during delineation of the catchment and drainage network, the fixation of 'flow accumulation threshold area value' was found to be very important. In this study this value was adjusted by several trials and comparing the DEM extracted channel with reference channel. Finally the threshold value found in delineation using 1sec DEM data is around 9 times bigger than that of 3sec DEM data, where 30m grid spacing of 1sec DEM data is 9 times finer than 90m grid spacing of 3sec DEM data. The automatic delineation of catchment and drainage networks, described in this paper will provide a means to extensively accelerate the process of developing initial catchment delineations for new researchers who are novice in this field.

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