REMOTE SENSING AND GEOSPATIAL APPLICATIONS FOR WATER CATCHMENT MAPPING AND ASSESSMENT

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ABSTRACT

Identifying and mapping water catchment features that occur in mostly forest areas from aerial photography is a challenging task, but the use of remotely sensed data and data processing techniques can improve the process of providing preliminary data for modeling land use and land cover changes and assessment their impact on the catchemnt. Landscapes where the land use is predominately vegetation typically have land cover in a complex mixture of pasture grassland, agricultural crops, trees, shrubs, and grasses; rural development and residences; and well-developed or improved drainage. In these areas, small streams may be completely obscured by the canopy of trees that feature. Multi-resolution image data were collected for an area located in Ulu Kinta Catchment. To determine the utility of such data for the preliminary identification of areas of changes, methods of data synthesis, fusion, digital elevation modeling, spatial analysis, and comparison using geospatial and remote sensing technologies were developed. These methods are incorporated into GIS to visualize spatial information, document watershed conditions, delineate subbasins and streams, and construct inputs to hydrologic models.

KEYWORDS: catchment, dem, classification

INTRODUCTION

Water resources and hydrology problems are commonly studied using distributed watershed models. These watershed models require physiographic information such as configuration of the drainage network, location of drainage divides, channel length and slope, and subcatchment geometric properties. Traditionally, these parameters are obtained from maps or field surveys. Over the last two decades these information has been increasingly derived directly from digital representations of the catchment or commonly known as Digital Elevation Model (DEM) (Jenson and Domingue, 1988; Moore et al., 1991; Martz and Garbrecht, 1998).

The automated derivation of topographic watershed data from DEMs is faster, less subjective and provides more accurate measurements than traditional manual techniques applied to topographic maps (Tribe, 1992). Digital data generated by this approach also have the advantage as they can be readily imported and analyzed by Geographic Information Systems (GIS). The technological advances provided by GIS and the increasing availability and quality of DEMs have greatly expanded the application potential of DEMs to many hydrological, hydraulic, water resources and environmental investigations (Moore et al., 1991).

In the field of water resources and hydrology, the main uses of DEM data are watershed segmentation, definition of drainage divides and channel networks, determination of catchment geometry, and parameterization of landscape properties such as terrain slope and aspect (Jenson and Domingue, 1988, Martz and garbrecht, 1998).

The main goal of this research paper is to illustrate the applicability of different image processing and information extraction techniques that are integrated within GIS to derive watershed parameters and document watershed conditions for integrated assessment and application in hydrologic modeling and land-use decision-making and planning.

Study Area

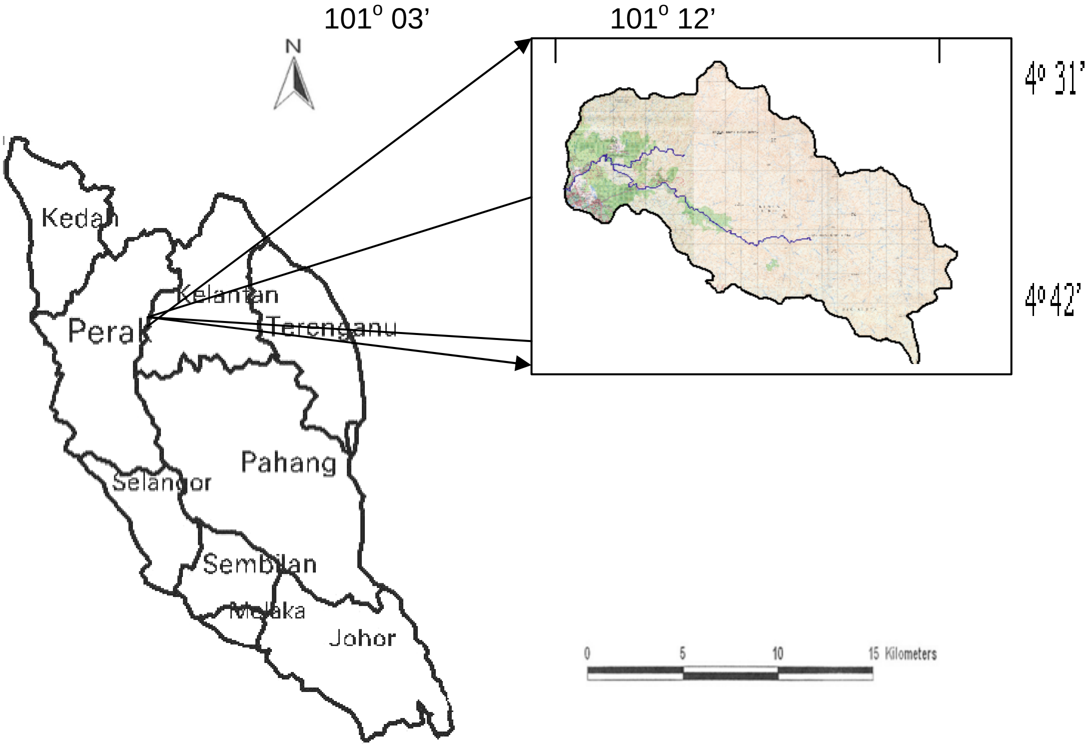


Figure 1: Location of the study area

The study area is located in Kinta District, in the state of Perak, Peninsular Malaysia. The geographical extent of this area shown in Fig. 1 is from 4^o 29' 30" N latitude and 178^o 27' 45" W longitude to 4^o 36' 30" N latitude and 178^o 22' 46" W longitude.

The Ulu Kinta Catchment is approximately 24, 360 hectares in area is a sub-catchment for the Kinta River. The catchment highlands rise to over 2000m above sea level. The East parts of the hilly area are covered by forest, medium slopes are covered by different agricultural crops and the flat area covered by barren land and urban area. The upstream area consists of very steep slopes covered in primary jungle (Azlin et al, 2002).

The annual rainfall in the catchment is approximately 2500 mm and is well distributed throughout the year. Higher rainfall occurs in the inter monsoon periods of October to November and March to May.

A dam is currently being built in the catchment for storing water which will be used to supply raw water for the water treatment plant nearby to cater for the nearby Ipoh city.

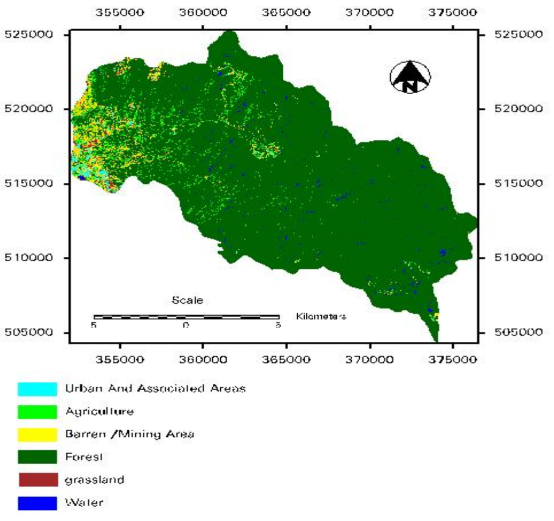
Image Preprocessing

The TM image was geometrically rectified using the 1:50000 topographic map of the study area.Topographic, land use maps for the study area were used for identification of ground control points (GCPs). More than 30 GCPs were located on Landsat TM of 1998 to identify the RSO projection easting and northing of each point as data input. Consequently, according to their row and column coordinate the GCPs were identified in the base topographic map as reference data. The total RMS errors achieved were 0.4752 pixels which correspond 14.3 meters in the ground. The image was then resampled to allocate the existing data into the new raster space. The nearest neighbour method was applied to resample the dataset. The output cell size was chosen as 30 x 30 to match the spatial resolution of the Landsat TM image. Finally, a subset of the rectified image covering the entire Kinta River Basin was extracted.

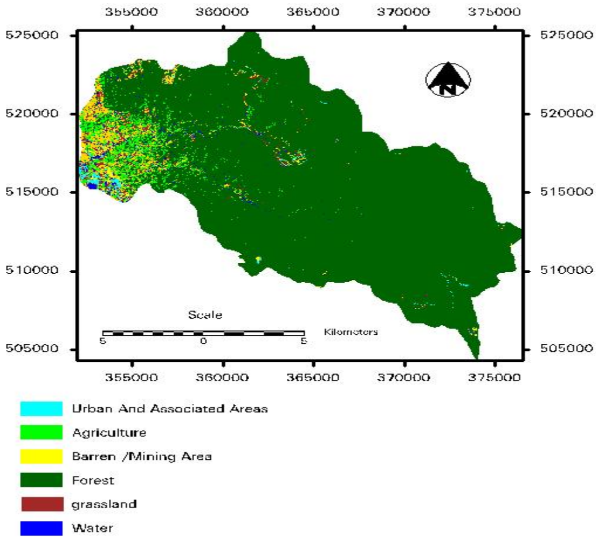
Classification of Satellite Data

Land use and land cover patterns of the study area were determined by classifiying the subset of the TM image. Two classification methods were used in this study and compared. The first was unsupervised ISODATA (Iterative Self-Organizing Data Analysis Technique) method was used to identify the spectral clusters from image data. The optimum class number was selected to be 50 with 0.95 convergence value. The resultant clusters of ISODATA algorithm were identified; clusters with similar reflectances were grouped and labeled as five land cover classes namely: water, forest, agriculture, urban area and barren lands (Figure 2a)

The second was supervised maximum likelihood (ML) decision rule. This method has generally proven to be the one that obtained the best results for classification of remotely sensed data (Mather, 1999). TM bands 1, 3, and 4 were selected to be the best combination of the total number of bands to discriminate between the classes of interest (Jensen, 1996).



a



b

Figure 2 Land use/Land cover using: a) Unsupervised, and b) Supervised classification methods.

Maximum likelihood decision rule classifier was applied on the three selected TM bands for both images to produce six classes (Figure 2b). The ISODATA classifier produced poor results in comparison with ML decision rule classifier (Table 1and Table2).

Table1 Overall accuracy for unsupervised classification of 1998 Landsat TM data

Class Name	Reference Data totals	Classified totals	Number Correct	Producer's Accuracy (%)	User's Accuracy (%)
Urban	115	90	69	76.7	60.0
Agriculture	140	182	109	59.8	77.8
Barren/Mining	62	83	53	63.9	85.5
Forest	280	256	194	75.8	69.3
Grassland	145	139	98	70.5	67.6
Water	98	92	71	77.1	72.4
Totals	840	840	594		
Overall Accuracy = 70.7%			Kappa Coefficient = 52.8%		

Table 2 Overall accuracy for supervised classification of 1998 Landsat TM data

Class Name	Reference Data totals	Classified totals	Number Correct	Producer's Accuracy (%)	User's Accuracy (%)
Urban	115	112	101	90.2	87.8
Agriculture	140	181	123	67.9	88.0
Barren/Mining	62	64	51	79.7	82.3
Forest	280	249	211	84.7	75.4
Grassland	145	133	113	84.9	77.9
Water	98	103	84	81.6	85.7
Totals	840	840	683		
Overall Accuracy = 81.3%			Kappa Coefficient = 70.9%		

Digital Elevation Model Generation

There are various ways of representing continuous surfaces in digital form using a finite amount of computer memory capacity. For the purposes of GIS models, Digital Elevation Models (DEMs) are the most convenient means for representing the earth's surface. DEM only has information regarding elevation on the ground surface. Because of their matrix nature, DEMs are stored in grid or raster format, which is a data structure composed of square cells or pixels of equal size arranged in rows and columns (Olivera, 2001). Among other things, certain software can display DEMs to show the terrain surface in three dimensions and from a choice of viewpoints (Petrie, 1990).

Data used for generating DEMs is normally obtained by field surveys, GPS surveys, Photogrammetry, Satellite Remote Sensing, Airborne Laser Altimetry and by digitizing of existing maps and plans. The primary elevation data used in this study was developed by interpolating the elevation values between the elevation contour lines extracted by on screen digitizing of topographic map of the study area (Figure 3a) and then using ERDAS Imagine 3D surfacing module to create the DEM as can be shown in Figure 3b. 3D spatial visualisation of the terrain features of Kinta catchment is represented in Figure3c.

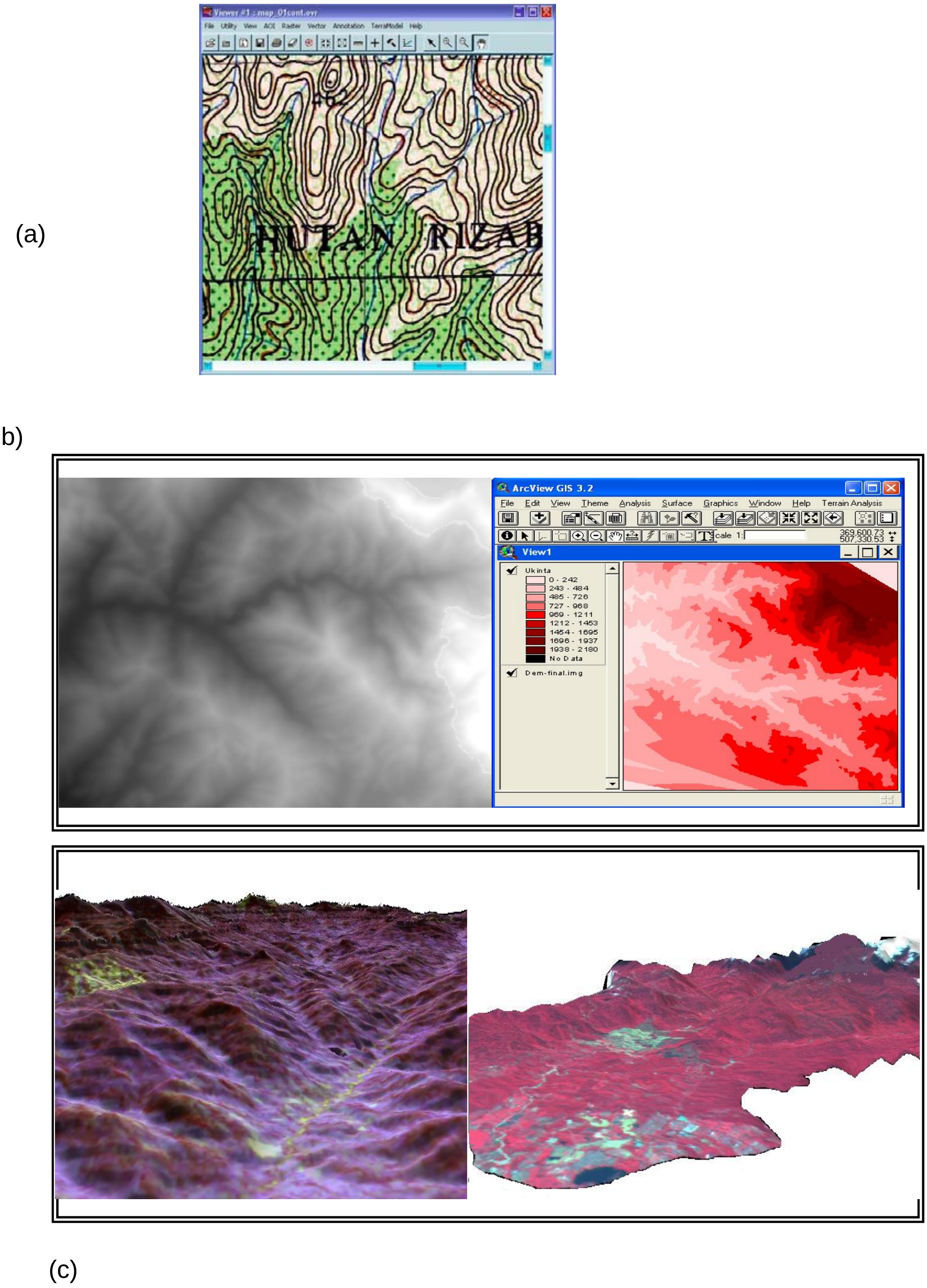


Figure 3. a) Digitized Contour from topographic map of the study area b) Different representation of DEM using different GIS software, and c) TM image draped on DEM of the study area.

Basin Characteristics Derived from DEM

Using GIS techniques additional analysis of the DEM was conducted to derive physical characteristics of the study area from the elevation data, including area, elevation parameters, and perimeter of watershed. All theses parameters were calculated using the Hydro modeling v.1.1 ArcView extension and the public domain AGWA (Automatic Geospatial Watershed Assessment) Arcview tool:
http:www.tucsion.ars.ag.gov/agwa/.

Example of parameters derived for Kinta Basin is summarized in Table 3. Other physical characteristics of sub catchments are given in Table 4.

Drainage Pattern Extraction

Accurate extraction of the drainage pattern, watershed boundary and other hydrologic data from DEMs plays an extremely important role in the management of the watershed. The delineated boundaries form the nucleus around which the management efforts such as land use, land change, soil types, geology and river flows are analyzed and appropriate conclusions drawn. Current remote sensing and graphic information system technologies provide ways for rapid collection of field data and prompt data processing.

Four essential steps are needed to delineate the drainage network using elevation data:
1) Removing sinks in DEM;
2) Assigning flow direction per cell;
3) Assigning flow accumulation value per cell; and
4) Defining the threshold flow accumulation value that best represented the drainage pattern (Jenson and Dominique, 1988).

Table 3. Basin physical characteristics derived from DEM

Parameter	Value
Area (km^2)	*263.74*
Slope max (degree)	*88.33*
Elevation max (m)	*2180*
Elevation min (m)	*243*
Perimeter (km)	*113,27*

During pit filling, local sinks are assumed to be artifacts, resulting from DEM generation. They are filled up to the level of the lowest grid cell on the rim of the sink with a defined flow direction. As a consequence, also natural sinks (e.g., in karstic landscapes) are filled up and the technique often results in extended areas of flat terrain (Vogt, et. al, 2003). Common approaches are based on the techniques as defined by Jenson and Domingue, 1988; O'Callaghan and Mark (1984), and Martz and Garbrecht (1998).

The filled DEM used as input to calculate flow direction grid is calculated. The following step is calculation of the flow accumulation data set from the flow direction grid, where each cell is assigned a value equal to the number of cells that flow to it (O'Callaghan and Mark, 1984). From the flow accumulation grid the drainage area can be delineated (Vogt et al, 2003).

For some hydrologic applications, it is necessary to divide a watershed into sub-watersheds defined by major tributaries. Band (1986) developed a technique to delineate sub-watersheds by isolating ridgelines in deeply incised terrain and assuming that depressions and flats were to significant features. Definition of a major tributary is data-set and application dependent; however, it may be related to the area of the tributary's sub-watershed. Thirteen subwatersheds were delineated and identified (Figure 4) and their attributes calculated and presented in Table 4.

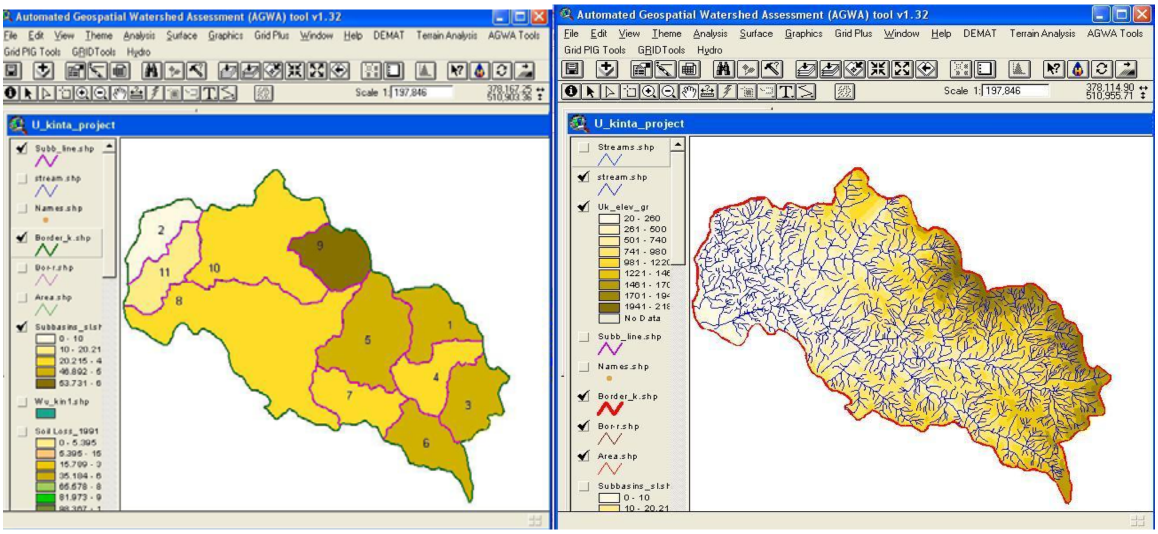
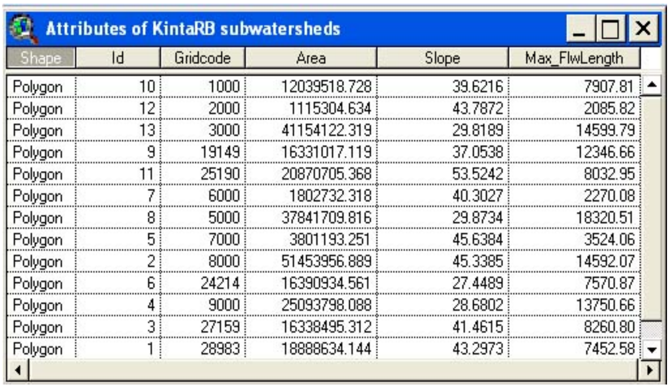


Figure 4. Drainage pattern extraction and stream network delineation from the DEM in ARCVIEW interface.

Table 4 Attributes of the 11 sub-watersheds comprised the study area.



Shape	Id	Gridcode	Area	Slope	Max_FlwLength
Polygon	10	1000	12039518.728	39.6216	7907.81
Polygon	12	2000	1115304.634	43.7872	2085.82
Polygon	13	3000	41154122.319	29.8189	14599.79
Polygon	9	19149	16331017.119	37.0538	12346.66
Polygon	11	25190	20870705.368	53.5242	8032.95
Polygon	7	6000	1802732.318	40.3027	2270.08
Polygon	8	5000	37841709.816	29.8734	18320.51
Polygon	5	7000	3801193.251	45.6384	3524.06
Polygon	2	8000	51453956.889	45.3385	14592.07
Polygon	6	24214	16390934.561	27.4489	7570.87
Polygon	4	9000	25093798.088	28.6802	13750.66
Polygon	3	27159	16338495.312	41.4615	8260.80
Polygon	1	28983	18888634.144	43.2973	7452.58

Information derived from DEM data provided flexibility and analysis capabilities in a timely fashion. Although the DEM provided a large number spatial data, errors were existed. This was clear when the extracted watershed was overlaid on the 1:50000 scale topographic map and analyzed using ERDAS utilities. Errors such as non-systematic correspondence of the location of the drainage area. This can be attributed the coarse resolution of the DEM used (100x100m) and the level of sophistication of GIS software tools used.

CONCLUSION

Integration satellite remote sensing data with GIS techniques proved to be a powerful tool to generate essential quantitative information on land use and cover studies for decision makers in the future planning and watershed management. Such planning may seem difficult for large areas but geographic information systems (GIS) can provide the tools and the efficient scientific way to analysis, manipulate, and store spatial information, which cannot be provided by fieldwork.

Digital Elevation Models (DEMs) are often used as a source of topographic data for distributed watershed models. This increasing popularity of DEM data is attributed in part to: 1) the cost effective and easy access to the data; 2) advanced capabilities of Geographic Information Systems (GIS) to process the data. However, as with most data, DEMs have shortcomings and limitations that must be understood before using the data in water resources modeling applications. DEM quality and resolution are two important DEM characteristics that can impact application results. Quality refers to the accuracy with which elevation values are reported, and resolution refers to the spacing and precision of the elevation values. DEM quality and resolution must be consistent with the scale of the application and of the processes that are modeled, the size of the land surface features that are to be resolved, the type of watershed model (physical process, empirical, lumped, etc), and the study objectives. The user must insure that relevant and important topographic features are accurately resolved by the selected DEM. Remote sensing data available for this study were sufficient. The resolution and quality of the DEM data affected the derivation of watershed characteristics. The data used in this study and the procedure outlined can be served as an example for watershed modeling and management studies especially in the case of lack of spatial data.

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