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Full Length Research Paper

Determination of watershed's hydrological parameters using remote sensing and geographical information system (GIS) techniques: Case study of Wadi Al-kangar, Sudan

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The need for information in user friendly formats and which is easy to update, query, manage and utilize, has popularized the use of geographical information system (GIS). Remote sensing and GIS techniques are increasingly becoming an important tool in hydrology and water resources development. This is due to the fact that most of the data required for hydrological analysis can easily be obtained from remotely sensed images. The main objective of this applied research is to implement new sound technologies such as remote sensing, GIS and global positioning system (GPS) to determine the hydrological parameters. Digital elevation model (DEM) of 30 m resolution was used to drive the flow direction, flow accumulation, watershed boundaries, sub basins and drainage network. The catchment area was determined and found to be 475 km^2.The longest flow path was calculated and found to be 43.7 km. The drainage area centroid was determined. The derivation of such information through using remote sensing and GIS would be very useful in site selection and designing of water harvesting project with minimum cost, efforts and time compared to the traditional methods in addition to giving an accurate results.

Key words: Water harvesting, geographical information system, global positioning system, remote sensing, digital elevation model, watershed parameters.

INTRODUCTION

Internally produced water resources in Sudan are rather limited. The erratic nature of the rainfall and its concentration in a short season places Sudan in a vulnerable situation, especially in rained areas. Water harvesting is the process of diverting, collecting, and storing rainwater from surface runoff and effectively using the water for beneficial purposes. It has many benefits, as it is considered as an ideal solution of water problem in areas having inadequate water resources. It contributes in raising the ground water level, mitigates the effect of drought and achieves drought proofing, reduces the runoff which causes flooding, improves the quality of water and reduces soil erosion. The need for information in user friendly formats and which is easy to update, query, manage and utilize, has popularized the use of geographical information system (GIS).

Remote sensing and GIS techniques are increasingly becoming an important tool in hydrology and water resources development; this is due to the fact that most of the data required for hydrological analysis can easily be obtained from remotely sensed images. Moreover, remote sensing can provide a measurement of many hydrological variables used in hydrological and environmental models applications, either as direct measurements comparable to traditional forms.

The possibility of rapidly combining data of different types such as spatial and tabular data in GIS, has led to significant increase in its use in hydrological applications.

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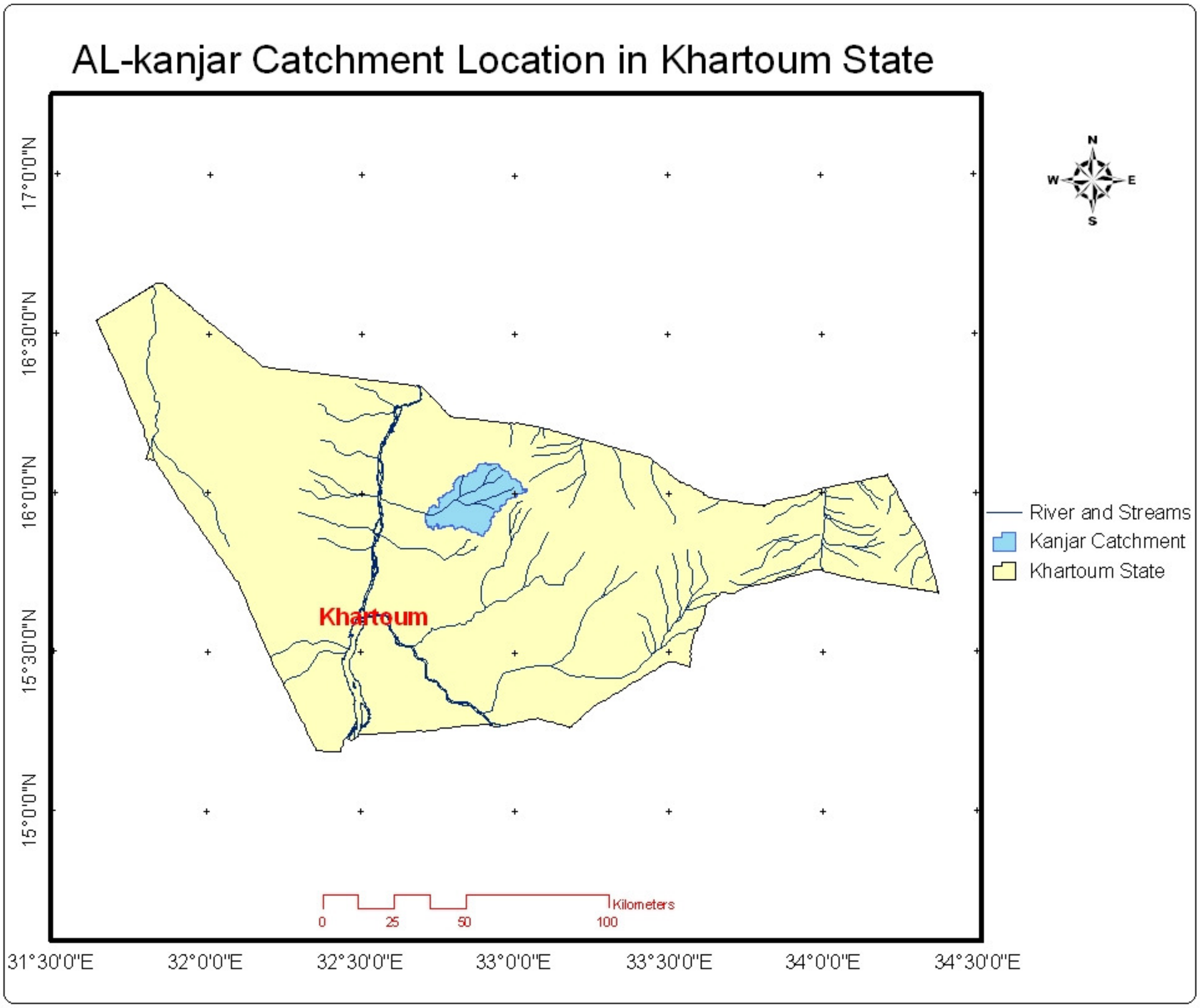

Figure 1. Location of the study area.

These tools can be used in hydrology through determining the watershed geometry, drainage network, and other map-type information and providing input data such as soil moisture or delineated land use classes that are used to define runoff coefficients. GIS applications are becoming popular in application of hydrologic modeling for parameters estimation and watershed partitioning; this feature of the GIS makes it a suitable tool to be used in this study.

METHODOLOGY

This study was conducted in Wadi Al-kangar, which located 65 km North of Khartoum, Sudan (Figure 1). The area is characterized by annual rainfall of 200 mm. Where it rains, the rainy season is limited to 2 to 3 months with the rest of the year virtually dry. Rainfall usually occurs in isolated showers, which vary considerably in duration, location, and from year to year. The coefficient of variation of the annual rainfall in this Northern half of the country could be as high as 100%. The mean temperature ranges from 30 to 40°C in summer and from 10 to 25°C in winter. Digital GIS data input was gathered from relevant authorities and developed from different sources that is, local organizations and relevant ministries.

All spatial manipulations, analyses, and representations, were done in a GIS environment that was used to produce pertinent spatial coverage. These included base map, topographic map and hydrological maps. For the first step, all needed spatial data were assembled either from paper source or digital format. Flow direction, flow accumulation, streams network and watershed boundaries were processed from the DEM using a predefined outlet point. ARCHYDRO tool module in the ARCGIS 9.3 environment was used to process the DEM and produce the fore saying maps. From the field visit the location of the outlet point was determined using the global positioning system (GPS) device (Danna, 1999). This outlet was used as a source to delineate the watershed

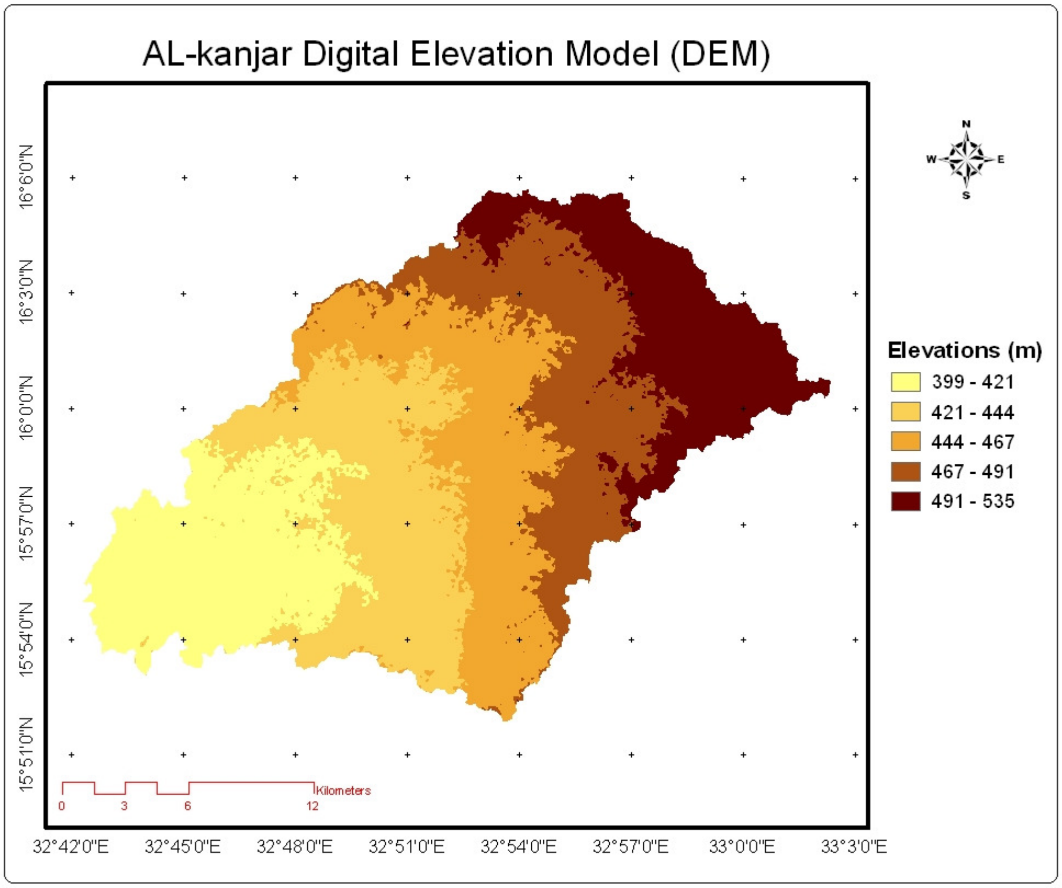

Figure 2. Digital elevation model for the study area.

boundary. It was observed that there are four water pipes with diameter of one meter installed in the outlet point in the middle of the dam body.

RESULTS AND DISCUSSION

The main objective of this applied research is to implement new sound technologies such as remote sensing, GIS and GPS determine the hydrological parameters. Much research has focused on stream and watershed delineation and, in general, on watershed analysis based on topographic data. Digital elevation model (DEM) is generally produced by photogrammetric techniques from stereo-photo pairs, stereo satellite images or interpolation of elevation data. Procedures for delineating streams and watersheds from DEMs were followed in the study. A DEM of 30 m resolution was used to drive the needed hydrological parameters. The flow direction grids were computed from the conditioned DEM. With the flow directions assigned for each DEM point, the flow accumulation at each point was computed, the flow accumulation for a given point was defined as the number of DEM points whose flow paths eventually pass through that point. Using the flow accumulations and the location of the watershed outlet, the watershed boundaries were defined and thereafter the sub-basins were delineated using selected outlet points. The watershed was divided into number of sub-basins, sub-watershed boundaries are delineated from outlets at each stream junction, which produces a drainage network with a single stream for each sub watershed.

Based on the grid cells system, the DEM technique can be used to provide basic input data. Flow direction, slope and aspect of grids can be computed from DEM based on the terrain analysis and relative hydrological parameter determination methods (Baillard et al., 1998, 2000).

Many input parameters required are terrain-based and could be obtained directly or indirectly by GIS techniques, such as land slope, aspect, slope shape factor, field slope length, and soil texture. In this study, only some of these parameters, including, flow directions, flow accumulation, land and channel slopes, flow lengths, slope shapes, and upslope contributing areas, were studied.

The DEM with 30 m resolution was processed to remove depressions that cause non-contributing area to be formed in the basin. Figure 2 represents the DEM for the study area. From this figure, the highest point in the

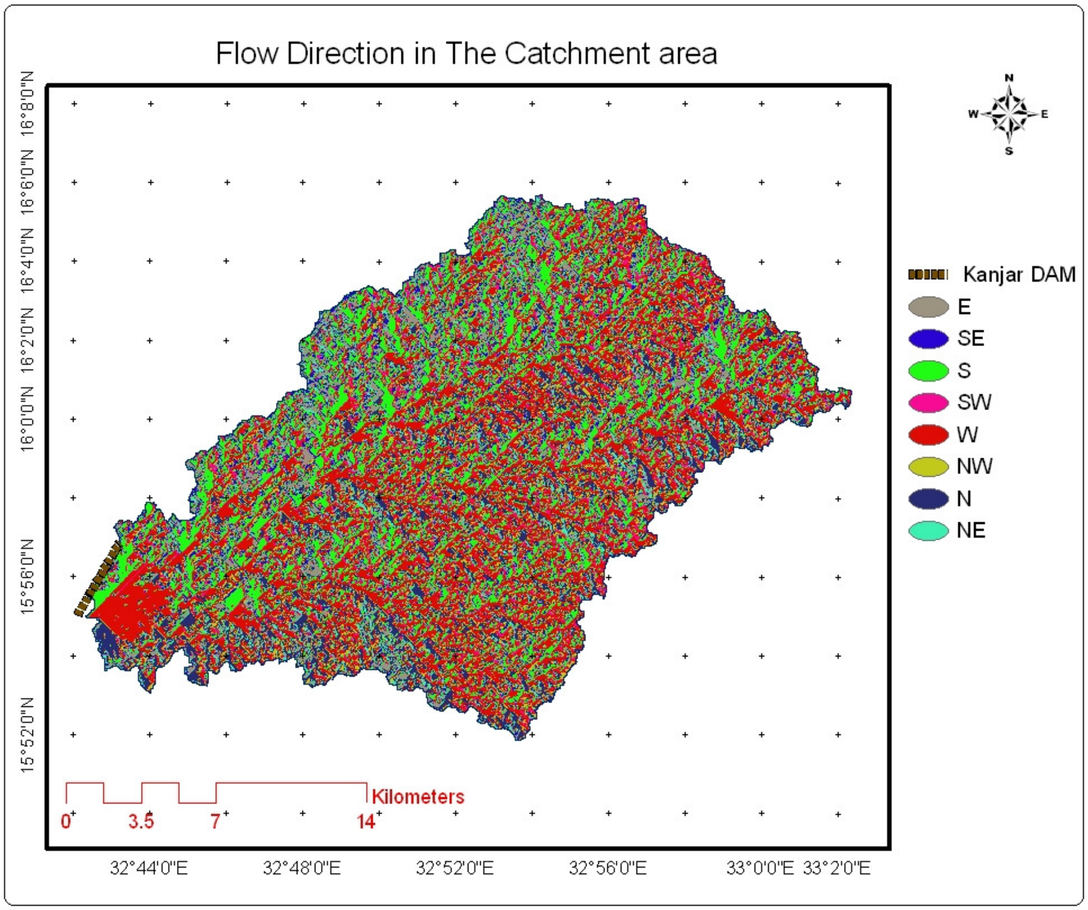

Figure 3. Flow directions in the catchment.

catchment area is 535 m above the mean sea level while the lowest point has a height of 399 m.

Flow directions are needed in hydrology to determine the paths of water movement. A grid representing flow direction is produced from the DEM. The values of grid cells in the flow direction grid represent a code for defining one of eight possible directions for water to move out of that cell. The directions of this grid define a unique path from each cell to the DEM outlet. Figure 3 represents the flow directions in the watershed. From the flow direction grid, the flow accumulation grid was formed. By tracing the unique downstream path of each cell, the total number of upstream cells draining through each cell is calculated.

Once the pits have been filled and the flow directions were known, the drainage area in units of cells is calculated by the flow accumulation. The flow accumulation grid stores the number of cells located upstream of each cell (the cell itself is not counted) and, if multiplied by the cell area, equals the drainage area. The resulted flow accumulation map for the study area is shown in Figure 4. Once the flow accumulation grid is formed, the stream grid is usually defined as the grid cells where the flow accumulation grid exceeds a certain threshold of contributing area, these streams (in raster format) were then vectorized to form a set of stream lines as shown in Figure 5.

A watershed is the upslope area contributing flow to a given location. Such an area is also referred to as a basin, catchment or contributing area. Watersheds can be delineated from the DEM by computing the flow direction and using it in the watershed function. The watershed function uses a raster of flow direction to determine contributing area.

The pour point was used with the flow accumulation threshold to delineate the watershed. When the threshold is used to define a watershed, the pour points for the watershed will be the junctions of a stream network derived from flow accumulation. Therefore, a flow accumulation raster must be specified as well as the minimum number of cells that constitute a stream (the threshold value), When a feature dataset is used to define a watershed, the features identify the pour point. Figure 6 shows the delineated watershed with the pour point. The sub watershed is simply part of a hierarchy, implying that a given watershed is part of a larger

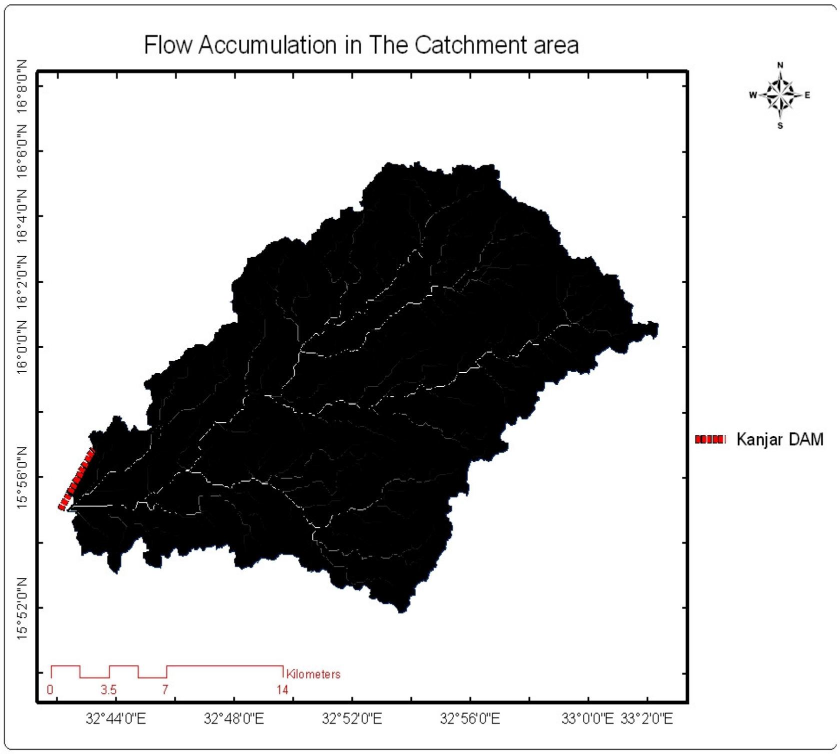

Figure 4. Flow accumulation in the study area.

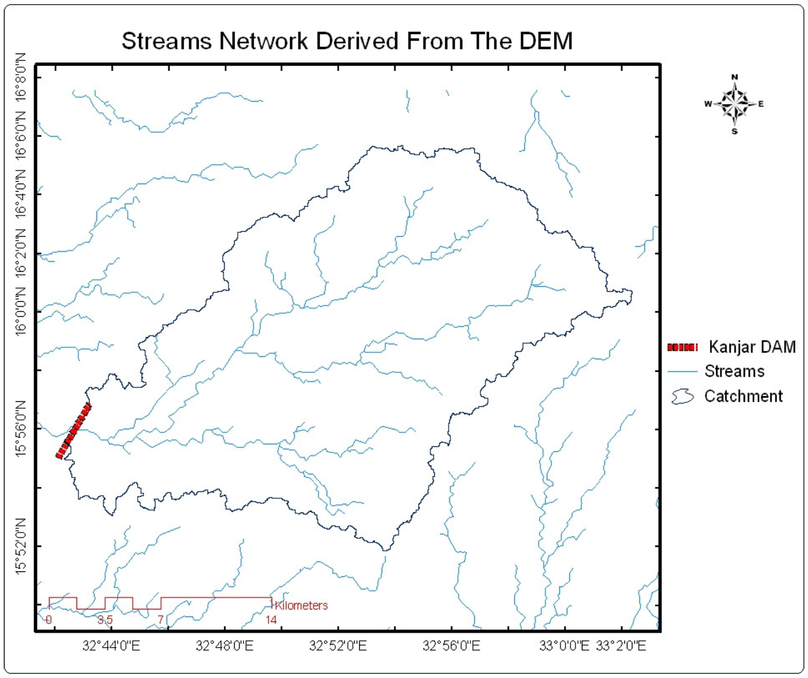

Figure 5. Streams network in the watershed.

watershed. From the flow simulation studies it was found that using the distributed hydrological models usually give more accurate results than the lump models (Mustafa, 2006).

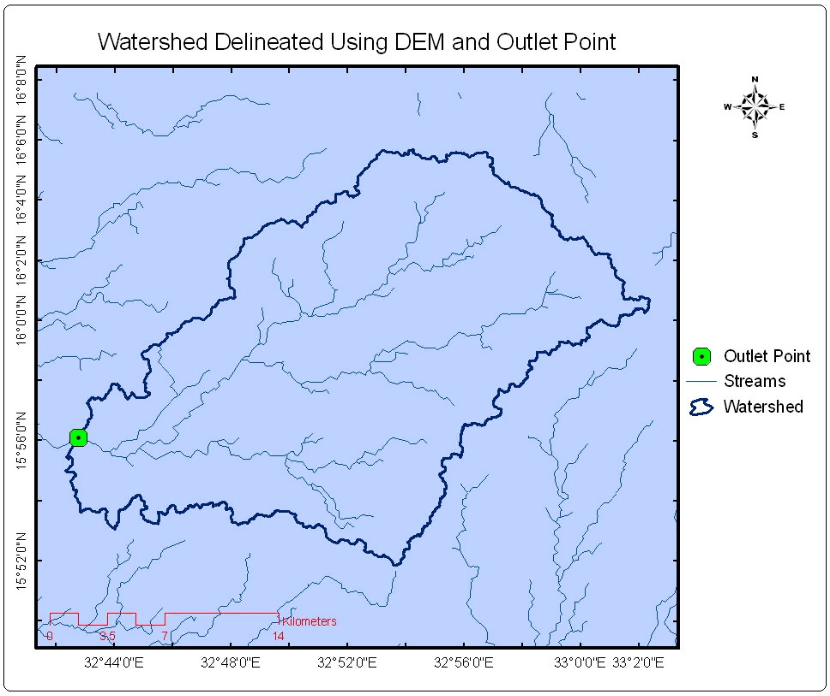

Figure 6. Delineated watershed.

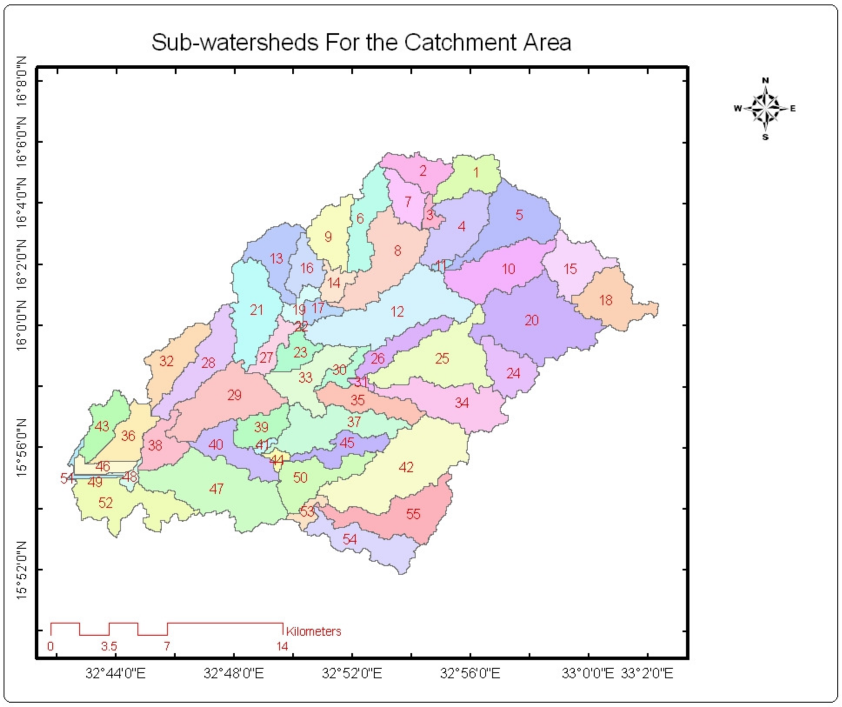

Figure 7. Dividing the watershed into Sub watershed.

In the GIS environment the distributed model can be run very easily compared to traditional methods. This encourages partitioning the watershed to small sub-watersheds in order to cover all the spatial variation in the catchment area that is (land use, soil, topography, slopes…etc) that can appear in the watershed. In this study the catchment area was subdivided into 55 sub catchments based on the drainage points in the area. Figure 7 shows the sub-catchment areas.

The longest flow path identifies and computes the

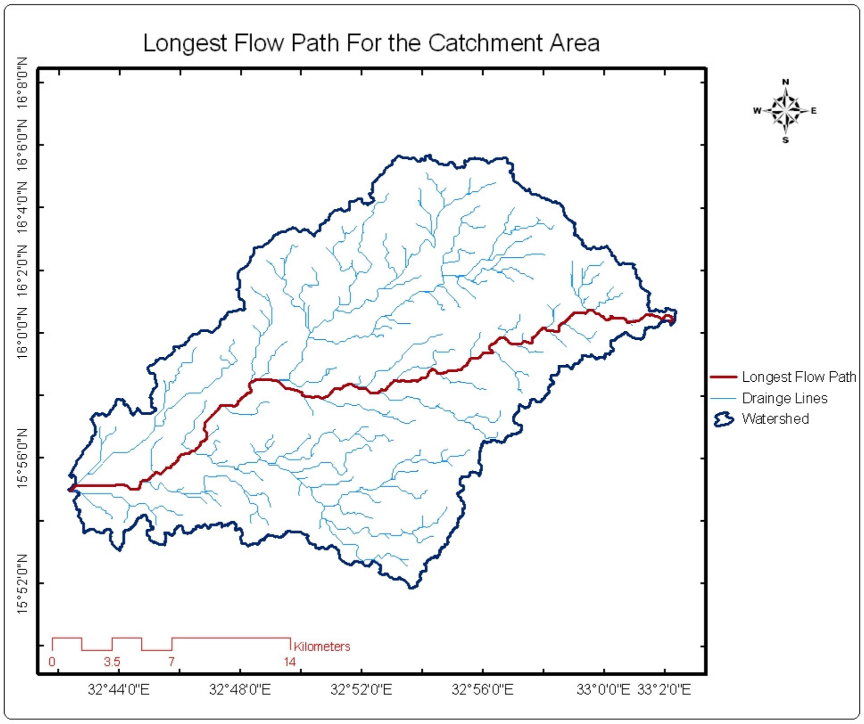

Figure 8. Longest flow path for the catchment area.

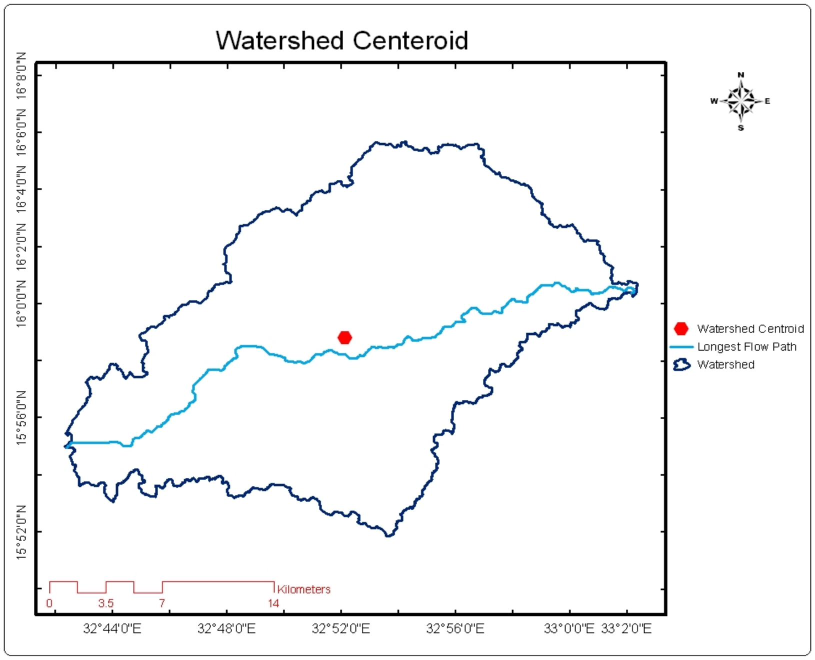

Figure 9. Watershed centroid point.

length of the longest flow path in the drainage areas. The longest flow path for this watershed was calculated and found to be 43.7 km; this means the maximum length of the watershed is 43.7 km as shown in Figure 8. The drainage area centroid generates the centroid of drainage areas as centers of gravity. The centroids were defined for both watershed and sub-watershed as shown in Figures 9 and 10 respectively. All the above findings

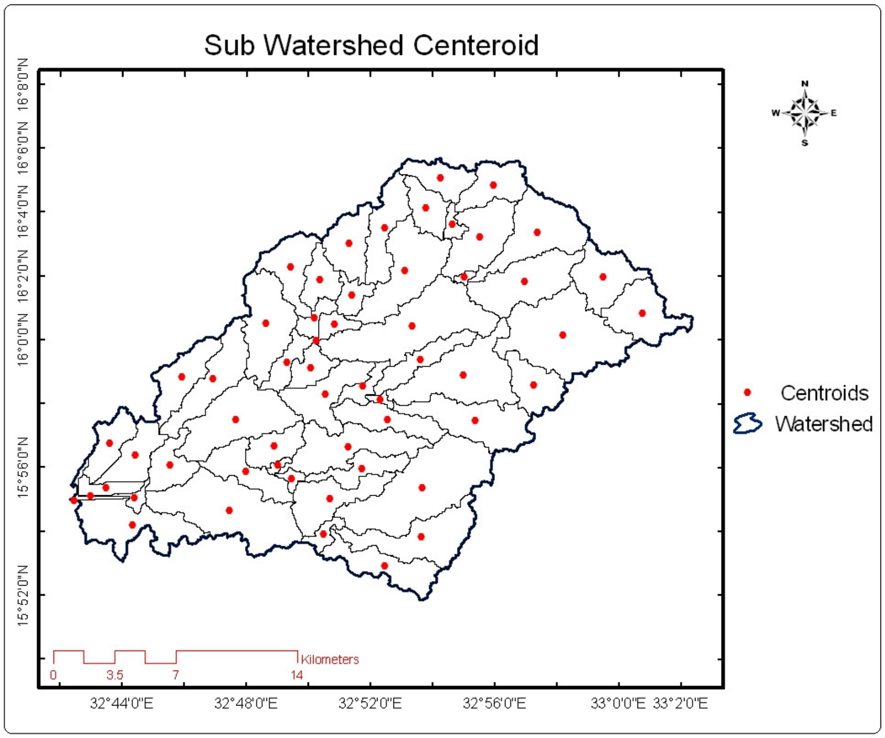

Figure 10. Sub-watershed centroid points.

were found to be accepted compared to the field data, therefore the use of these technologies is use full in this area.

Conclusion

Remote sensing and GIS techniques are increasingly becoming an important tool in hydrology and water resources development. The possibility of rapidly combining data of different types in a GIS has led to significant increase in its use in hydrological applications. These tools can be used in hydrology through determining the watershed geometry and other map type information and providing input data that are used in hydrological simulation. DEM was used to drive the flow direction, flow accumulation, watershed boundaries, sub basins and drainage network. The derivation of such information through the using remote sensing and GIS would be very useful in site selection and designing of water harvesting project with minimum cost, efforts and time compared to the traditional methods in addition to giving an accurate results.

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