Hydrological Information Extraction for Dams Site Selection using Remote Sensing Techniques and Geographical Information System

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ABSTRACT

The aim of this study is to investigate and demonstrate the use of remote sensing and geographic information system (GIS) techniques to create a thematic assessment in order to locate a best dam site in Al-Tharthar basin northern Iraq. Automated derivation of multi thematic layers to describe the characteristics of the catchment was performed with aid of several softwares (Erdas 9.1, Arc GIS 9.3, Global Mapper 11 and Surfer 9). Gathering all these data has to construct database of the catchment area to decide the locations of the proposed dams. Three locations were chosen. Dam site one was chosen to be the best site since it is provide lesser length with more lake storage and has substantial of foundation material for dam construction. Furthermore, various calculation regarding the design of the dam, its parameters was investigated.

Keywords: Remote sensing, GIS, DEM, Dams sites selection.

استخلاص المعلومات الهيدرولوجية اللازمة لاختيار مواقع السدود باستخدام تقنيات التحسس النائي ونظم المعلومات الجغرافية.

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الملخص

إن الهدف من هذه الدراسة هو استخدام تقنيات التحسس النائي ونظام المعلومات الجغرافية لبناء قاعدة بيانات للتقييم الموضوعي لاختيار أفضل موقع لإنشاء سد في حوض وادي الثرثار شمال العراق. تم تكوين الطبقات الرقمية الموضوعية بصورة أوتوماتيكية باستخدام برمجيات متعددة (Erdas 9.1, Arc GIS 9.3, Global Mapper 11 and Surfer 9) لوصف خصائص منطقة الدراسة. تم تكوين قاعدة البيانات بدمج كافة الطبقات لغرض اختيار عدة مواقع ملائمة لإقامة للسدود. تم تحديد ثلاثة مواقع ملائمة لإنشاء السدود، ومن خلال مناقشة النتائج تبين أن الموقع الأول هو الأفضل كونه يعطي اقل طول للسد مع اكبر كمية خزين وملائمة نوعية التربة في منطقة الأساس. بالإضافة إلى ذلك تم تصميم وحساب الأبعاد الأولية للمقطع العرضي للسد المقترح.

الكلمات الدالة: التحسس النائي، نظام المعلومات الجغرافية، نموذج الارتفاع الرقمي، اختيار مواقع السدود.

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Introduction:

Importance of water is increasing due to the high population growth and global warming in the World. Iraq is an agricultural country and the demand has been growing for more agricultural production to ensure food security. Thus, the need to construct dams has been growing vastly to meet the requirement of water supply, clean hydroelectric energy and irrigation. Dam construction in their various stages, namely reconnaissance, planning and design stages need up to date and complete information about terrain surface and relief. Delineation of terrain parameters, such as slope, drainage network, watershed boundaries etc., are often required in preparation of development and conservation plan for natural resources.

Recent advance in remote sensing and GIS are proving to be very valuable tools in many natural resources application such as hydrological modeling of terrain for water harvesting, visualization of different aspects of watershed. Remote sensing and GIS are widely used in terrain mapping purpose such as resource management, and engineering sectors in planning and developmental purpose. Considerable effort has been devoted in recent years about the capability of these techniques in assisting engineering dam design by allowing efficient, quick and economical in data collection, processing and analyzing terrain surface and relief comparing with the traditional design.

It is worth to mention some of the people investigations in this field, Uboldi and Chuvieco [1] used remote sensing and GIS to assess current land management in the valley of Colorado river. The remote sensing provides information on actual land use/cover, while GIS enables an integrated evaluation on land potentialities to be made. They demonstrated the value of spatial analysis in land use management is greatly enhanced by the use of GIS. Martinez and Stuiver [2] investigate the automated delineation of drainage networks and elementary catchments from digital elevation models. Based on their results, they concluded that automating the method for obtaining the spatial representation of drainage networks and elementary catchments is important since these entities are terrain objects connects different aggregation level of hydrographic information. Amarakul and Sanyong [3] study the GIS application for administration and management on the Huaisai Royal Development Study Center. GIS was used as tool for making decision on the location of check dams in this region. Based on their conclusion, the total of 150 check dams should be construct. Singh [4] calculate the water flow, storage and visualization of Belachiwadi and Gudwan dam site in India utilizing GIS. Furthermore, he discuss the various calculations regarding the construction of dam. Elsheikh and Zeinelabdein [5] investigate the proposed site for dam project on river Nile located in Sudan. Their study based on the use of the enhanced Landsat imageries and the structural analysis of the fractures in the investigated site. Their results show that the tensional fractures related to the UM Maraheik fault may affect the efficiency of the dam wall and the engineers should consider this in their design. Drainage analysis on a terrain model for Bekhma area Northern Iraq has been performed by Mudher [6] using GIS techniques. The Arc Hydro tools are used to derive several data sets that collectivity describe the drainage patterns of the catchments using the DEM data. Based on the results obtained in this study the author concluded that the automated derivation of the topography watershed data from DEMs is faster, less subjective and provides more reproducible measurements than traditional manual techniques applied to topographic maps. Furthermore, digital data generated can be readily imported and analyzed by GIS.

In this study, automated derivation of topography watershed data of catchments area was acquired to construct the database. Investigation about the suitable locations of the proposed dams was carried out. Furthermore, various calculation regarding the design of the dam, its parameters were performed.

Research significance:

Traditional manual techniques applied to the preliminary plans for proposed construction project like dam need a lot of time, cost and effort. The emergence of remote sensing techniques is a potential source of data of the hydrological processes, and the improved capabilities of generating and processing. GIS techniques have gained a prominent role in hydrological modeling. The automated derivation of topography watershed data and maps using remote sensing and GIS is rapid, less subjective and provide more reproducible measurement than traditional techniques applied to topographic maps. Considerable effort has been devoted in recent years to derived terrain maps directly from digital representation of the topography (DEM) for engineering planning. GIS Arc Hydro provides increased efficiency; a typical hydrographical analysis was performed. An attempt has been made in this study to investigate the application of remote sensing and GIS techniques for suitable sites selection of the proposed dams based on the construct of database. By using capability of remote sensing and GIS technology to prepare a detailed hydrological impact analysis of the proposed dams sites which play a vital role in analysis of any watersheds.

Statements of objectives:

The study has four major objective; those are:

1. To prepare a database to described the characteristics of the basin.
2. To integrate and analysis the digital data through utilizing the ERDAS, ARC GIS, Globle Mapper and Surfer 9 softwares.
3. To find the suitable locations of the proposed dams in the basin.
4. To design the selected dam cross-section.

Methodology:

The approach adopted in this study has illustrated in figure (1). The study area is located in the northwest of Iraq about (65Km) southwest from Mosul city as shown in figure (2). The geographic boundaries of the area are stretched from (35°30' - 36°30') N Latitude and from (41°55' - 43°06') E Longitude. The study area covers about (102146 km^2). This area is characterized as Mediterranean Sea climate conditions as the winter is cold with high precipitation and the summer is hot and dry. The average yearly rainfall ranges from 200 to 400 mm [7].

Geologically, the area under investigation is a part of the Cenozoic Era which include the Quaternary period and Tertiary period and Mesozoic Era consist of Cretaceous period. Tectonic formation of the study area consist of unstable shelf in the north of the high folded zone in Sinjar belt while, the northeast part was located in the foothill zone of the Makhul belt. The middle and south part of the basin were located in the stable shelf in the Salman-Hadhar Zone in the Anah-Baaj belt and Najaf- Abujir- Hadhar belt [7].

Geomrophologically, the basin was characterized by mountainlly-hilly terrain in the north and northwest of the basin with undulating to steep relief in the south and southwest. These

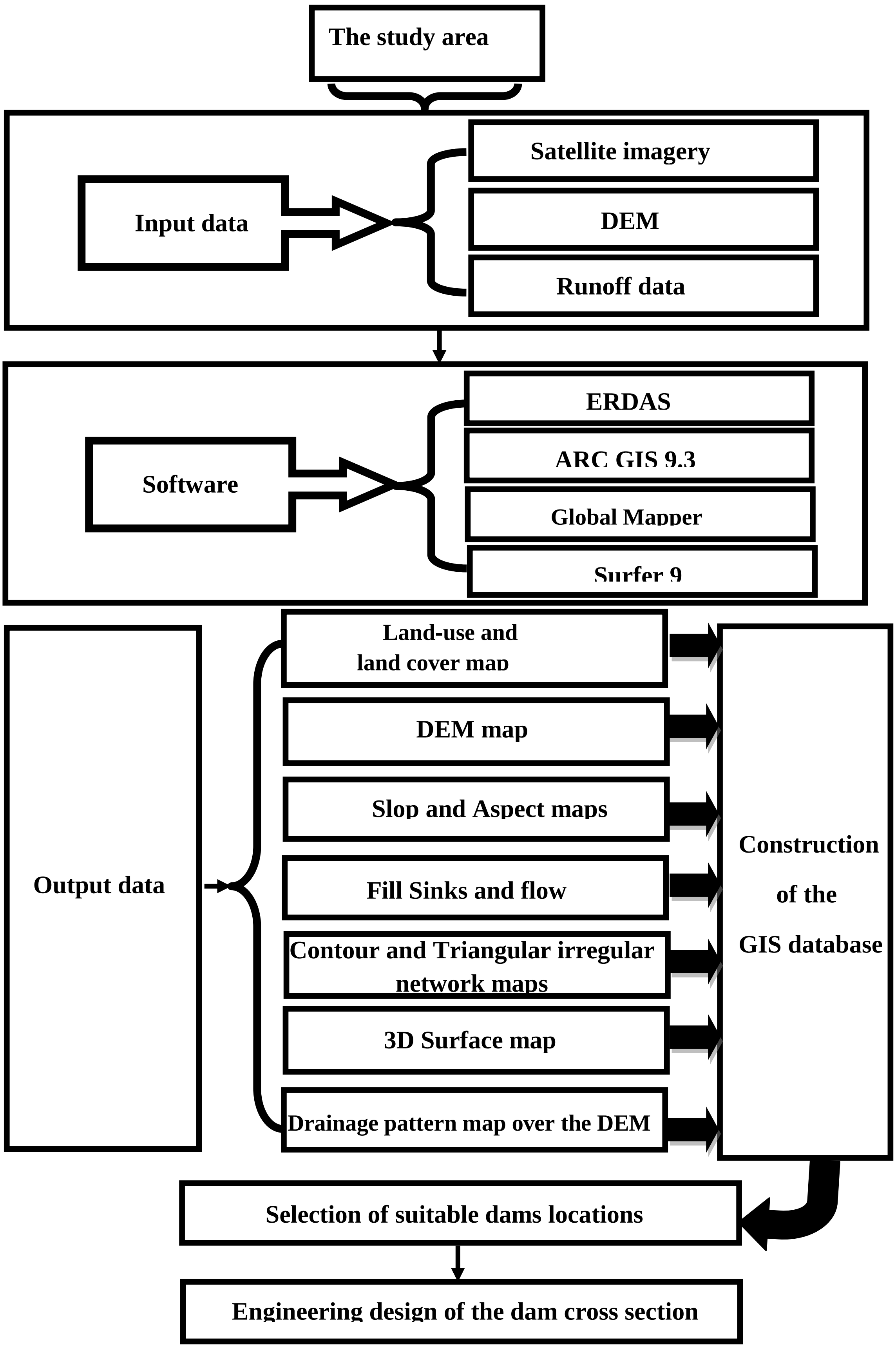

Figure (1): Flow chart illustrating methodology zones namely the high topography mountain zone, the foot- slope zone, the accumulation plains zone, the active erosional zone and depositional zone [7].

The application of remote sensing and GIS to locate dams sites and design cross section was effectively accomplished in three main stages. These stages are the reconnaissance stage, the preliminary design stage and final design.

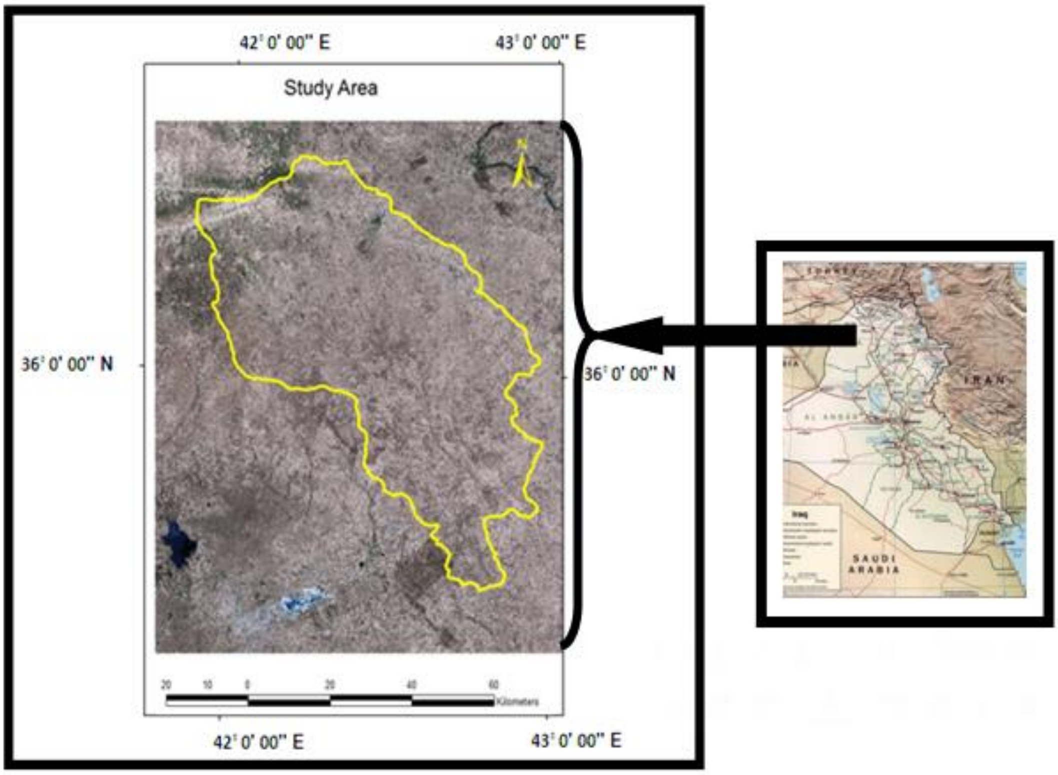

Figure 2: The Study area

In the reconnaissance stage, information about the site and the surrounding area was achieved. A Landsat Thematic Mapper (TM) images of 22 May 2007 with three band synthetic natural true color combinations of 2, 3 and 4 with spectral ranges wavelength of 0.52-0.59 µm, 0.63- 0.69µm and 0.76-0.90 µm, with 14.25 meters spatial resolution was interpreted using ERDAS software. In the preliminary design stage, a comprehensive topographical watershed database of the basin catchment was carried out. Satellite data was utilized in preparation of land-use and land-cover map based on the image characteristics. Detailed topographical watersheds were analyzed through the spatial analysis of geographical information system utilizing Arc Hydro tools to derive several data sets that collectivity describe the patterns of the catchments. The outcome of this study were visualized in a DEM map, relief slope and aspect maps, fill sinks and flow direction maps, contour and triangular irregular networks maps, 3D perspective view, drainage pattern over DEM map and soil map. The presentation of results based on the outcome with different sets of features was used to demarcate the suitable locations for dams. Three dams locations were chosen taking into account the data sets that performed to described the characteristics of the basin. Dam site one was chosen to be the best site since it is provide lesser length with more lake storage, lesser materials requirements and has substantial of foundation material for dam construction. The evidence suggested that the surrounding area from dam site will enjoy the benefits of the irrigation. The engineering design of dam cross section was performed in the in the final design stage.

Results:

Land- use and land- cover map was shown in Figure (3). The map was interpreted from a Landsat Thematic Mapper (TM) images captured in 22 May 2007 as mentioned in the reconnaissance stage using ERDAS software. The summary of the map is shown in table 1. As shown in this table, 48.7% of the basin is characteristic by fallow land. The vegetative farm is covered about 19% of the basin and the non-vegetative land was covered about 25.1%.The exposed rocks cover about 7.2% of the basin. From this land- use map, we can say that the basin characteristic by non-vegetative land and the fallow land. Thus, the need to construct dam in the middle and south part of the basin is necessary.

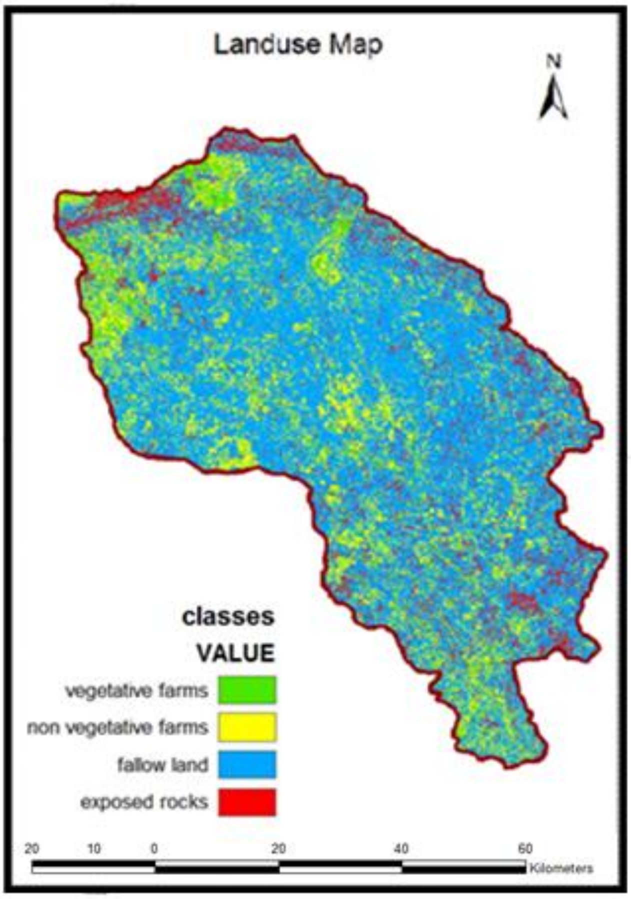

Figure 3: Land use and land cover map of the basin

Table (1): Land use types and their areas within the basin

Land use classes	Area (km²)	Area (%)
Vegetation farms	19407	**19**
Non vegetation farms	25648	**25.1**
Fallow land	49780	**48.7**
exposed rocks	7354.5	**7.2**
Total	102146	**100**

Digital elevation model for Mosul area used as elevation reference for study captured and generated from Shuttle Radar Topography Mission (SRTM) with 30m resolution from United states geological survey (USGS) in 2001. The north and northwest parts of the basin have the higher elevations than the middle and south parts as can be seen from the digital elevation model of the basin as illustrated in figure 4. The elevation of the basin varies from 101 to 1454 m with mean elevation about 777.5 m. The minimum elevation of the basin was about 101 m in the south, the maximum elevation was about 1454 m in the north. The deep valleys, originating from the south with almost parallel flowing streams starting up from the north parts of the basin are five major valleys shown clearly in the DEM, named as Methaha, Tharthar. Thareathar, Al-ahmar and Kubeera respectively from west to east in the basin. Those valleys connected together in end part of the basin and formed one main valley.

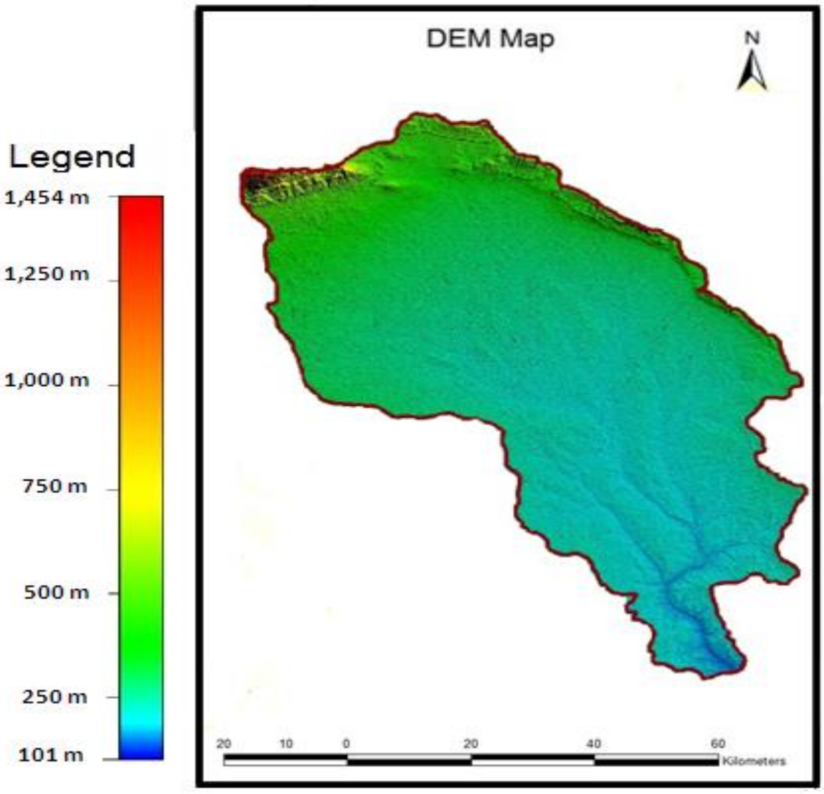

Figure 4: DEM of Tharthar basin.

Slope and aspect maps of the basin which are the two important characteristics of the basin are determined from the DEM and shown in figure (5). Slope map shows that the basin has been characterized by a low to moderate slope between 0 to 20 degrees and steep regions are generally in the north part of the basin within 40.569 degree. Aspect classes which is an important characteristic for the water flow in the basin shows that the basin mostly faces south, west and east.

The Derived DEM is used with Arc-Hydro tool of Arc-GIS for basin boundary delineation. The possible sinks in the derived DEM was sinked for eliminating the unreasonable low elevation cells with respect to the surrounding cells as shown in figure (6). In order to determine the flow directions, the relations between the neighboring cells are searched and its neighboring cells will determine the direction of water with the rule of water will flow to the neighboring cell which has the highest downward slope [6]. The flow direction map is illustrated in figure (6) shows that the drainage flow toward south and connected together in one main stream at south.

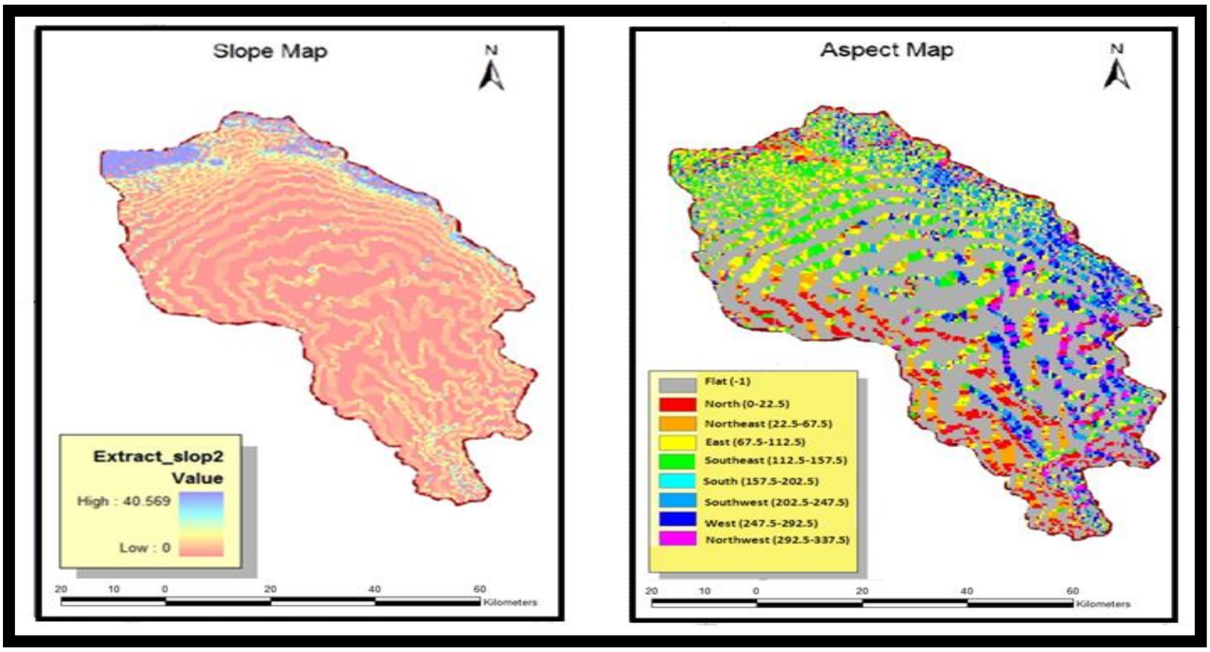

Figure 5: Slope map and aspect map of the basin.

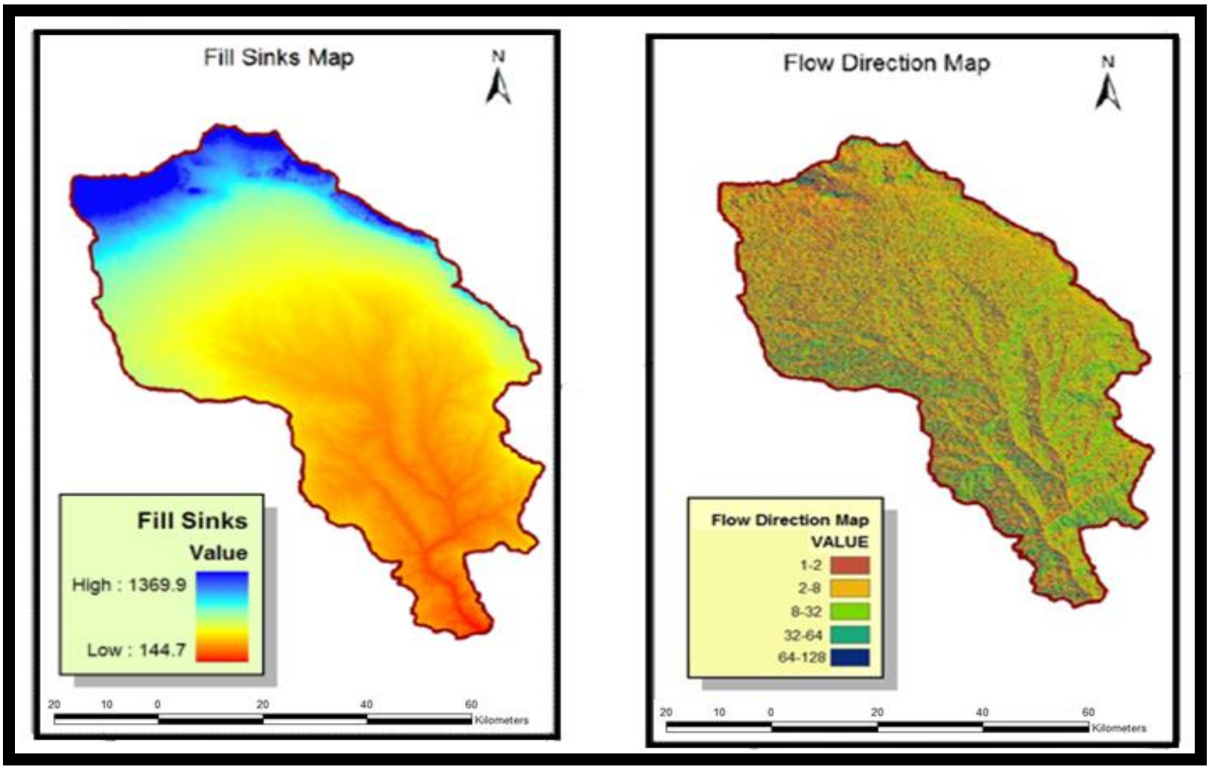

Figure 6: Fill Sinks and flow direction maps.

In order to observe the terrain elevation of the basin, the contour line map, the triangular irregular network were derived from the DEM using Arc-GIS as exhibited in figure (7). In order to explore further information about the drainage valley depth, a 3D surface map was drawn for the lower part of the basin using Surfer 9 program as shown in figure (8). Figure (9) shows the drainage network over DEM for the whole basin by utilizing the Arc-Hydro tool of Arc-GIS. The drainage network was characterized by dendritic and parallel patterns.

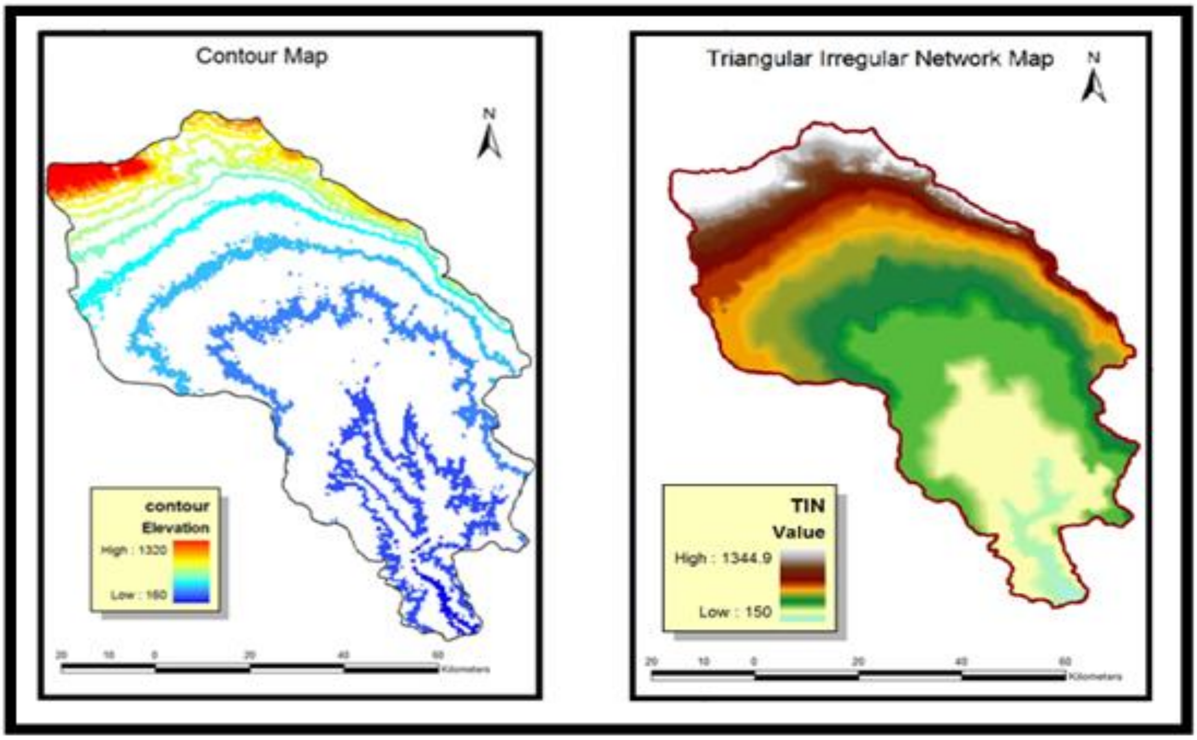

Figure 7: Contour and Triangular irregular network maps.

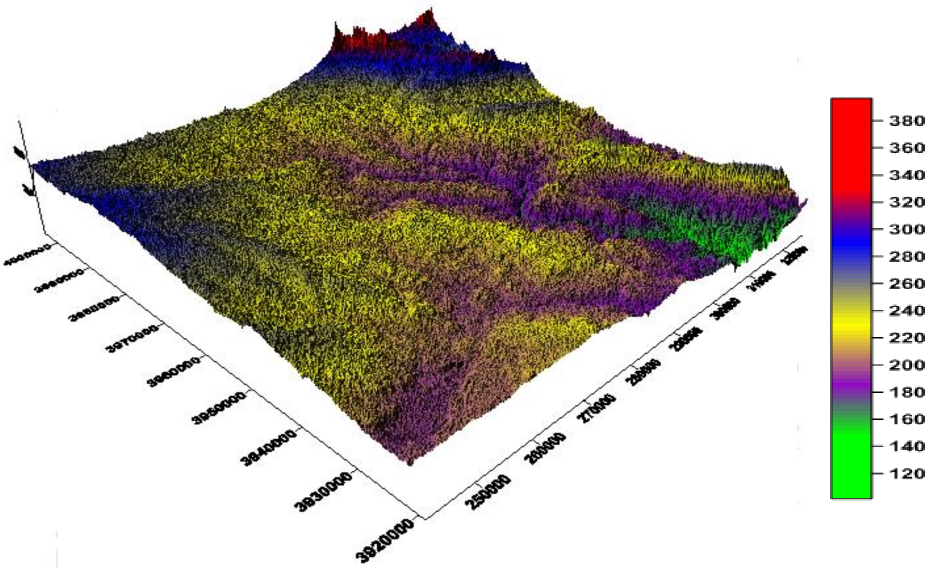

Figure 8: 3D Surface map of the basin.

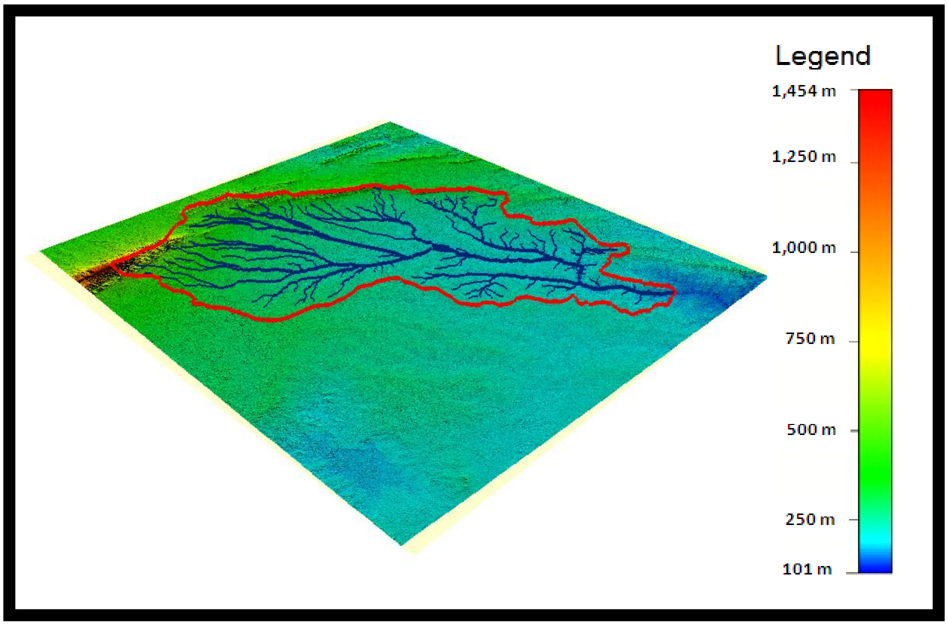

Figure 9: Drainage pattern map over the DEM of the basin.

Three locations were chosen in the south part of the basin. The dams locations had been decided by carefully considered the decision based on the land- use and land-cover map, geomorphology of the basin, contour map and 3D surface view, drainage networks, and length and abutment of the dams.

The three sites were overlay on soil map of the basin which was digitized by GIS depending on Buringh manuscript [8] (see figure 10). Site one was chosen in the end of Kubeera valley, site two was located at the end of Al-ahmar valley and site three was located at the end of Methaha valley on the main valley. Soil type of site one and two was reddish brown soils medium and shallow phase over gypsum, sand and mud stone. Site three was located over gypsum desert soil.

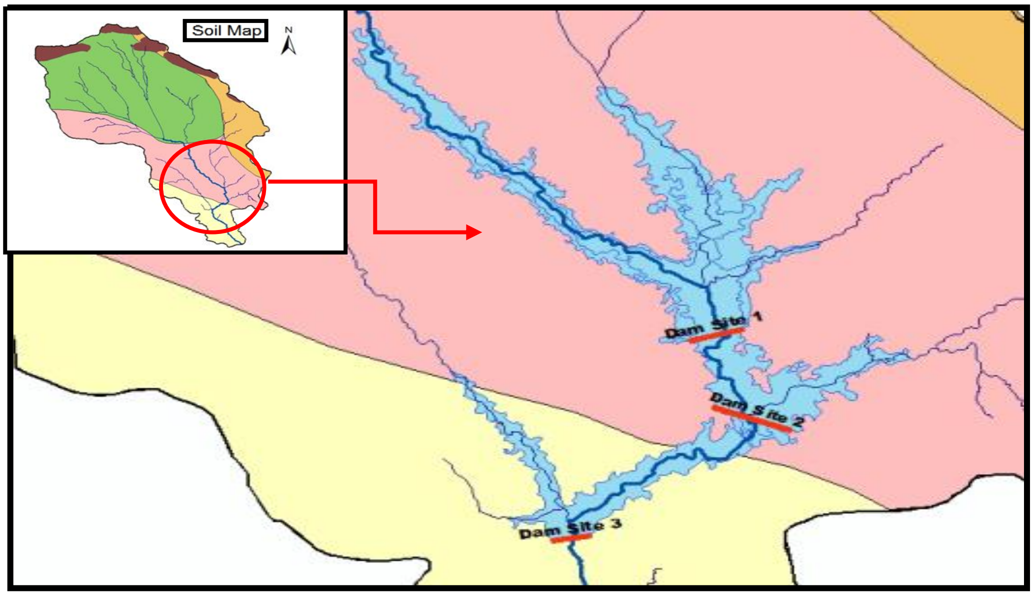

Figure 10: Map of the suitable location for dams over soil map.

The cross sections of the three locations (shown in figure 11) were plotted using Global Mapper software utilizing DEM data.

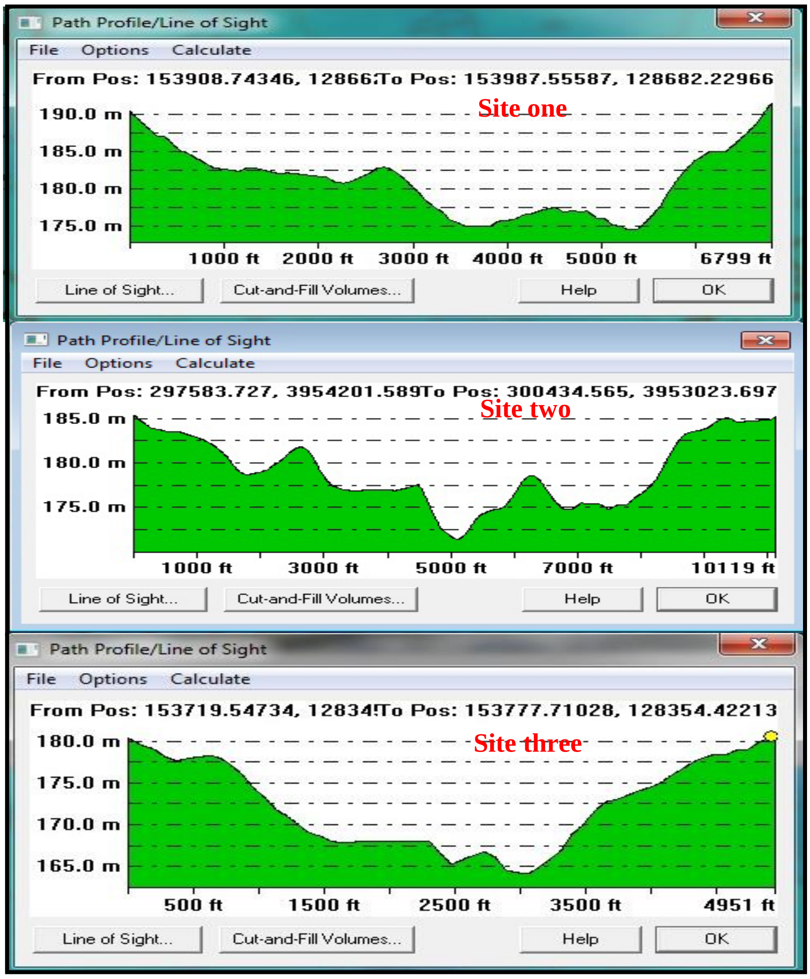

Figure 11: Cross sections of the three dams.

The hydrological information about the three sites were presented in table 2. The surface area, length and the height of the dams were utilizing from cross sections plotted by Global Mapper software. Actual storage was calculated depending on trapezoidal rule between each two contour lines utilizing Arc GIS software. The expected annual surface runoff was calculated based on the expected annual surface run off [7].

Table 2: Hydrological information about the three sites

Site No.	**Surface Area (Km^2)**	**Height of the Dam (m)**	**Length of the Dam(m)**	**Actual Storage MCM**	**Expected annual surface runoff MCM**
Site 1	38.385430	15	2.13	197.682613	183.3
Site 2	34.911679	15	3.09	179.332910	185.455
Site 3	15.948795	15	1.52	109.89571	188.68

Discussion:

Based on the presented results in the database, site three found not suitable to construct a dam due to the gypsum foundation. Now, the comparison between site one and two. Site one was chosen to be the best location to construct a dam since it was provided lesser length with more lake storage which can assimilate the expected annual surface runoff than site two. Furthermore, its required lesser materials for construction. In final stage the type and the design of dam cross section was performed. Rock-fill dam with clayey core was selected due to the availability of the material for construction and foundation strength. The dimensions in meters and side slopes upstream and downstream of the dam cross section were presented in figure (12) [9].

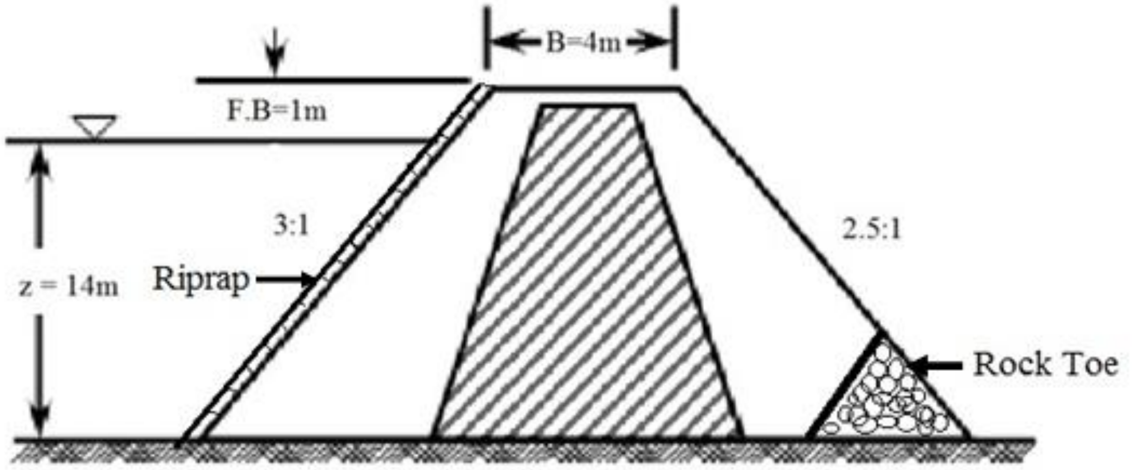

Figure 12: The design dam cross section.

Conclusions:

The results show the possibilities of integrating remote sensing, geographic information system (GIS) and digital elevation model (DEM) linked and imported with several softwares. This integration was provided wide range for creating thematic databases of the watershed and hydrological information of the catchment basin to locate dams sites.

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