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DAM Site Selection Using GIS Techniques and remote sensing to Minimize Flash Floods in East Nile Locality (Soba Valley)-Khartoum State

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ABSTRACT: *In the last few years devastating flash floods descending downstream through valleys had occurred in East Nile Locality-Sudan. A flash flood can be caused by intense rain, particularly when it takes place in a saturated area where rain has previously fallen. Under these conditions the additional rain runs off over the surface and accumulates in streams and channels at a much accelerated pace. The flooded water had caused a considerable damage in houses, roads and properties. Construction of earth dams is suggested to minimize the destructive effect of these flash floods and make use of stored water in agriculture and grazing. To determine the location of earth dams, multi criterion methods had been used. The best dam location had been achieved applying the selection criterion. The surface areas, volume of reservoirs, had been determined for every selected location Using ArcGIS. Major Landuse, landcover, stream order and location of water body had projected on the watershed area of the Soba valley to extract the residential areas, agricultural areas and grassland effected by suggested dams. Dam location selection model and volume model had been designed to repeat the steps and report the analysis results automatically.*
Keywords: *Flash flood, DAM and Model*

I. INTRODUCTION

Water is one of the main requirements for healthy plant growth. Most arid and semi-arid regions, suffer from insufficient and unreliable rainfall. A high rate of evaporation in the growing season is also common. When it rains in semiarid areas, the rain- storms are usually heavy. The prevailing soils generally cannot absorb the amount of the water which falls in such a short time. [3][4]

Most techniques for water collection make use of large water sources such as rivers and ground water (e.g. wells and irrigation systems), and require large-scale investments. But in many countries in the world small-scale, simple methods have been developed to collect surface runoff for productive purposes. Instead of runoff being left to cause hazards, it is harvested and utilized. Many types of water harvesting techniques with many different applications are available. [1]

Ground investigation is important before planning to construct an earth dam especially site selection and earthworks considerations. Generally, dams in arid regions, particularly, in Sudan, are built to guarantee water supply and reduce the negative impact of flood events. In fact, East Nile Locality is suffering surface water scarcity compensated by flash flooding, which has been affecting East Nile Locality for many years during the autumn season. The catchment experienced major floods during the years 1988, 2007, 2013 and 2014. Unexpected flash floods and strong population growth rates associated with high water needs for agriculture will increase pressure on water resources in Khartoum state especially Blue Nile. Water resources are limited and construction of new dams will be an important part of the solution.

II. METHODOLOGY

2.1. Study Area:

The study area consists of East-Nile and Bahri localities in Khartoum state. The catchments of the natural streams in the study area lay between latitudes (16°40'59"N-14°50'26"N) and Longitudes (34°38'52"E-32°05'23"E) (Figure 1)

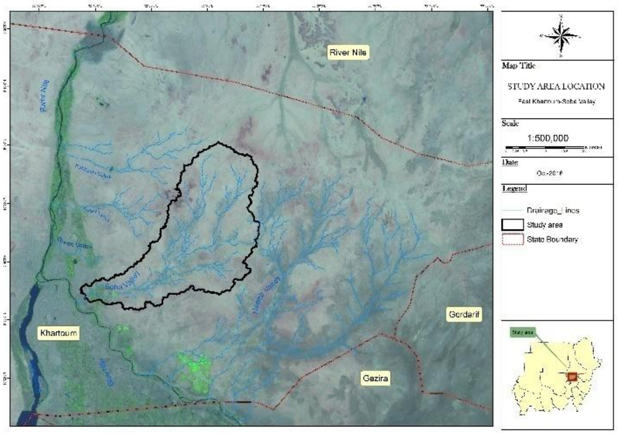

Figure 1 Study area

Several valleys dominate the area. Territory of the national capital is classified under the climatic category of the southern Sahara. Khartoum region is categorized within the zone of semi- arid, which is characterized by the high temperature degree during the day all over the year. The rainfalls fluctuate from year to year and the annual average ranges from 200 mm in the north to 250 mm in the south. Temperatures are highest at the end of the dry season due to cloudless skies. The warmest months are May and June, when the average temperature is 41°C and max temperatures can reach up to 48°c.[4]

2.2. Data Sources:

1- Digital Elevation Model:-
- Date of data: Aug. 2008
- Data Coverage (7490Km2 – 84*92Km) (East-Nile and part of Bahri localities in Khartoum state between latitudes (15°07'38.6"N-16°01'3.6"N) and Longitudes (33°8'48.8"E- 33°03'8.8"E)
- Produced by SRTM-USGS
- Resolution: 30*30 m
- Datum: WGS84
- Projection: UTM, Zone 36N.
- www.opentopography.com

2- Shape file of Soil data:-
- Date of Collected data: 2010 By Ministry of Water Resources and Electricity (DIU)
- Data Coverage (7490Km2 – 84*92Km) (East-Nile locality in Khartoum state latitudes (15°07'38.6"N-16°01'3.6"N) and Longitudes (33°8'48.8"E- 33°03'8.8"E)
- Datum: WGS84
- Projection: UTM, Zone 36N.

3- Shape file of landuse and Land cover data:-
- Date of Collected and prepared of data: 2010 By Ministry of Water Resources and Electricity (DIU)
- Data Coverage: Khartoum state
- Datum: WGS84
- Projection: UTM, Zone 36N.

4- Data from Google earth:-
- Villages in the study area
- All Agriculture projects in the study area
- Roads and their pipe culverts

2.3 Methodology:

2.3.1. Conditions for water harvesting:

- **Climates**

Water harvesting is particularly suitable for semi-arid regions (300-700 mm average annual rainfall). It is also practiced in some arid areas (100-300 mm average annual rainfall). These are mainly subtropical winter rainfall areas. In most tropical regions the main rainfall period occurs in the 'summer' period, when evaporation rates are high. In more arid tropical regions the risk of crop failure is considerably higher. The costs of the water harvesting structures here are also higher because these have to be made larger. [1]

- **Slopes**

Water harvesting is not recommended on slopes exceeding 5% because of the uneven distribution of runoff, soil erosion and high costs of the structure required.

- **Soils and soil fertility management**

Soils in the cultivated area should be deep enough to allow sufficient moisture storage capacity and be fertile. Soils in the catchment area should have a low infiltration rate. For most water harvesting systems soil fertility must be improved, or at least maintained, in order to be productive and sustainable. The improved water availability and higher yields derived from water harvesting lead to a greater exploitation of soil nutrients. Sandy soils do not benefit from extra water unless measures to Improve soil Fertility Are applied at the same time. [1]

- **Crops**

One of the main criteria for the selection of a water harvesting technique is its suitability for the type of plant one wants to grow. However, the Crop can Also be Adapted to the structure. The basic difference between perennial (e.g. trees) and annual crops is that trees require the concentration of water at points, whereas annual crops usually benefit most from an equal distribution of water over the cultivated area.[1]

- **Technical criteria**

When selecting a suitable water harvesting technique, two sets of criteria, of equal importance, should be taken into account [1]:-

- Water harvesting technique should function well from a technical point of view.
- Should 'fit' within the production system of the users. If the risk of production failure of the new technique is too high compared with proven techniques, or the labor requirements of the new technique are too high, your proposed water harvesting system, although designed well, will not be adopted because the priorities of the future users are different.

2.3.2. Selection water harvesting Techniques:

Figure2 provides an overview of preliminary selection of a water harvesting technique. The list of water harvesting techniques in Figure2 is far from complete. You will probably come across different traditional and/or non-traditional techniques. Water harvesting systems can be grouped into two categories: Systems in which the bunds follow the contour line are called contour systems. Systems in which bunds do not follow the contour line, but enclose a part of the slope are called *freestanding systems*. Water harvesting systems for trees usually have an infiltration pit because the harvested water has to be concentrated near the tree. On long slopes systems with an infiltration pit are not advisable, because these systems harvest a large quantity of runoff water, too much to be collected in an infiltration pit. On long slopes the water is collected in a larger, cultivated area and used for either fodder/rangelands or crops. All kinds of variation are possible within water harvesting systems. The bunds can be constructed using a variety of materials: earth, stones and living and/or dead vegetable material (living barriers or trash lines). The bunds may or may not have a provision for draining the excess harvested water. For the free- standing systems variations are also possible in the layout of the bunds. They can be semi-circular, V-shaped or rectangular [2].

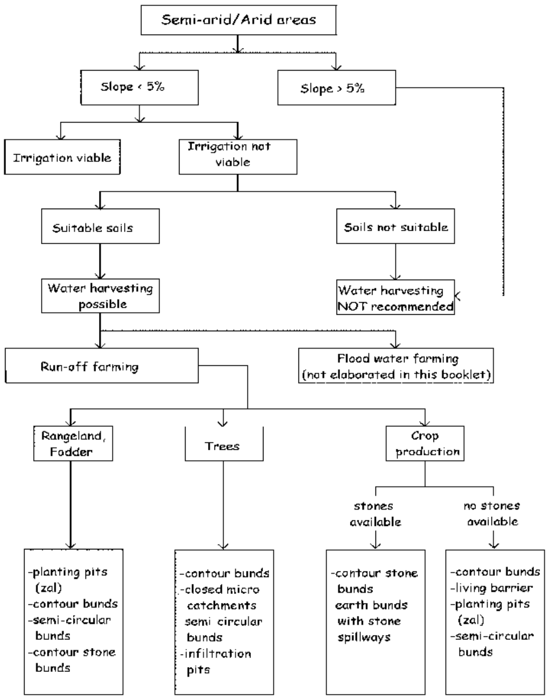

Figure 2 Selection of a water harvesting system [2]

2.3.3. Small Earth Dams

Small earth dams are water harvesting storage structures, constructed across narrow sections of valleys, to impound runoff generated from upstream catchment areas. Construction of the dam wall begins with excavation of a core trench along the length of the dam wall which is filled with clay and compacted to form a 'central core' that anchors the wall and prevents or minimizes seepage. The upstream and downstream embankments are also built using soil with 20-30% clay content. During construction – either by human labor, animal draught or machine (bulldozer, compacter, grader etc.) – it is critical to ensure good compaction for stability of the wall. The dam is fenced with barbed wire to prevent livestock from eroding the wall. Typical length of the embankment is 50-100 m with water depth ranging 4-8 m. An emergency spillway (vegetated or a concrete Shute) is provided on either, or both sides, of the wall for safe disposal of excess water above the full supply level. The dam water has a maximum throwback of 500 m, with a capacity ranging from 50,000 – 100,000 m. The dams are mainly used for domestic consumption, irrigation or for watering livestock. If the dams are located on communal lands, their establishment requires full consultation and involvement of the local community. The government provides technical and financial assistance for design, construction and management of these infrastructures. Community contribution includes land, labor and local resources. The community carries out periodic maintenance of the infrastructure – including vegetation management on embankment, desilting etc. – and of the catchment areas (through soil and water conservation practices). [8]

2.3.4. Selection of Suitable Site for Water Harvesting Projects:

After the boundary of the watershed derived from the DEM by software ARC hydro, the software ArcGIS had been used to derive the layers of different orders of valleys from the DEM According to the results of Slope and hydrology analysis, seven locations had been selected, To determine earth dam's locations multi criterion methods had been used after that the best dam location regarding the selection criterion had been achieved. The surface areas, volume of reservoirs, had been determined for the seven suggested locations Using ArcGIS. The path profiles had been prepared utilizing Global Mapper Software in the seven selected locations. Major Landuse, landcover, stream order and location of water body were projected on the watershed area of the Soba valley to extract the residential areas, agricultural areas and grassland that had been effected by suggested dams.

2.3.5. Calculation of the volume and surface of a reservoir using ArcGIS:

The surface areas, volume of reservoirs, had been determined for every suggested location. Using ArcGIS by converting contour into a Triangulated Irregular Network (TIN), then the contour that marks the reservoir maximum level had been selected and converted into a Polygon to calculate the total volume of the reservoir. The volume model had been designed and run to achieve the area and volume of reservoir.

III. PRIOR APPROACH

On the application of Remote Sensing in flood management noted that DEM model is the main part of flood hazard mapping. In particular, slopes data from DEM are useful for many hydrological studies and can be employed for dam location selection. Furthermore, a limited effort has been devoted in recent years to determine the capability of these techniques in assisting engineering dam design by allowing efficient, quick and economic data collection. However, the application of remote sensing in ephemeral streams is limited compared with permanent rivers.[6]

Used remote sensing and GIS techniques to assign the location of small water harvesting structures across streams/watersheds. Various thematic layers such as Landuse/Landcover, geomorphology and lineaments were used. These layers along with geology and drainage were integrated using GIS techniques to derive suitable water harvesting sites. In addition to the suitable site selection of the dams, they calculated the storage and transmittance of groundwater in the study area.[10]

Furthermore, proposed three dam site locations for Jeddah City in Saudi Arabia based on topographical analysis using different data sets such as topographic maps, remote sensing images, a digital elevation model with 90-m resolution (STRM 2000) and geological map. In addition, these selected locations were in the outlet areas where large tracts of land could be temporarily inundated by water as a result of water being held back by the proposed dam.[11]

IV. OUR APPROACH

Model Builder is very useful for constructing and executing simple workflows, it also provides advanced methods for extending ArcGIS functionality by allowing you to create and share your models as tool. Dam location selection and Volume models has been designed as shown below:-

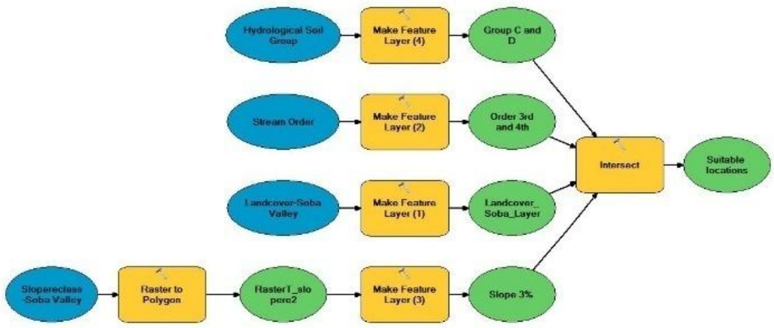

Figure 3 DAM selection Model

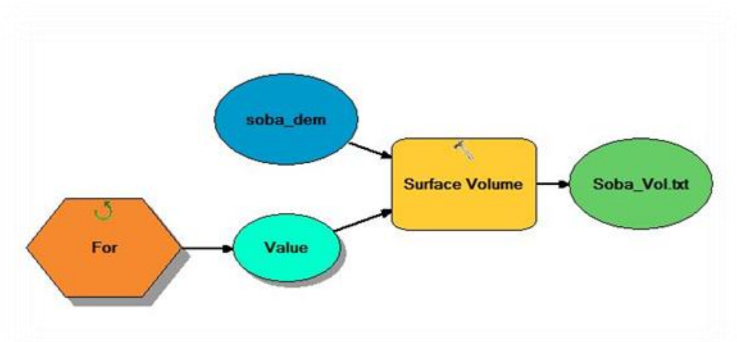

Figure 4 Volume Model

Volume model had been built and using to calculate reservoir volume for selected sites the following had been resulted:

Table 1 Reservoir Surface Area and Volume

Elevation (m)	Reservoir Surface Area(Km2)	Reservoir Volume (10^6 m3)
391	4.467	4.76
392	7.375	10.39
393	11.071	19.25
394	15.339	32.15
395	20.302	49.58
396	26.408	72.41
397	33.994	101.97
398	43.666	139.88
399	55.287	188.40
400	68.791	249.34
401	83.967	324.67
402	99.694	415.56
403	114.612	522.17
404	127.828	643.08
405	140.585	776.82
406	153.434	923.28
407	167.390	1082.83
408	183.062	1257.00
409	200.925	1447.70
410	219.975	1656.95
411	239.212	1885.49
412	257.766	2133.20
413	275.236	2399.06
414	291.542	2681.91
415	306.498	2980.50
416	320.568	3293.58
417	334.862	3620.66
418	350.828	3962.51
419	368.115	4320.90
420	384.397	4696.53

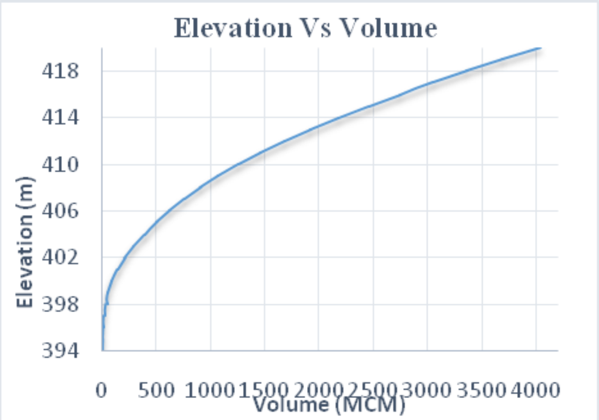

Figure 5 Elevation Vs Volume

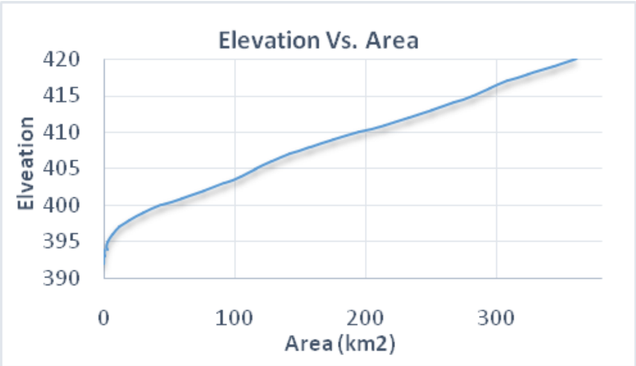

Figure 6 Elevation Vs Area

- Appling conditions of dam site selection in 3.3.1 and Figure 4 the following results had been achieved:

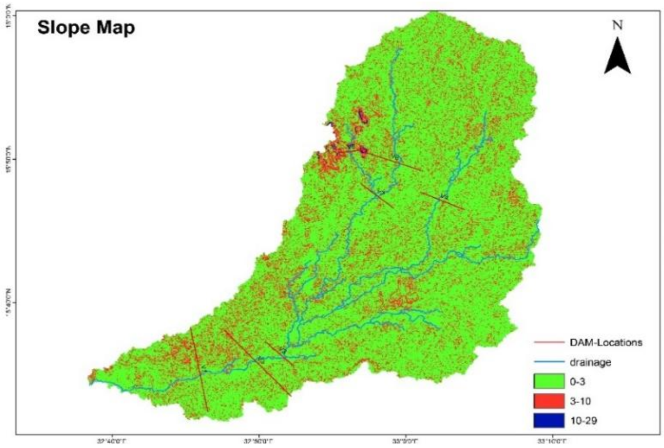

Figure 7 Slop Map

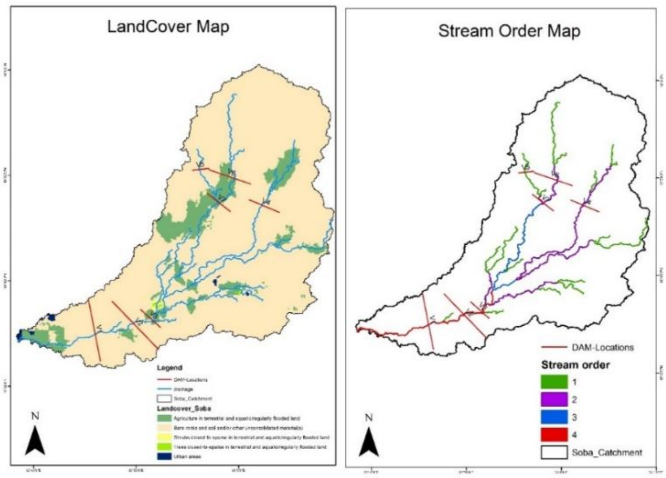

Figure 8 Land Cover and Stream Order Map

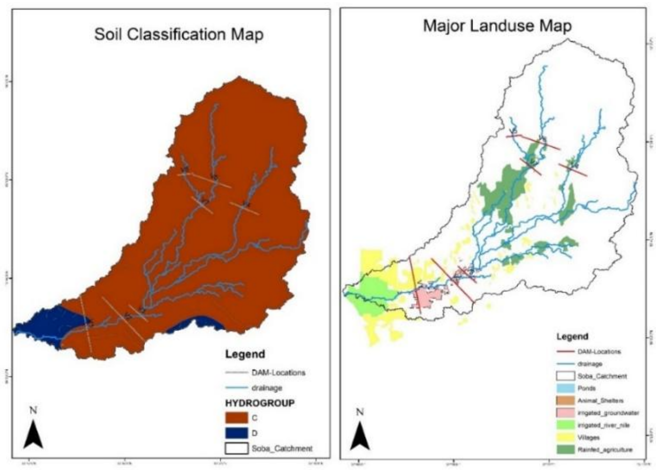

Figure 9 Soil and Landuse Map

- The cross-section had been prepared for each proposed dam site, then the layer of lakes had been exported to Google Earth to extract the affected areas of villages, agricultural lands and grasslands:-

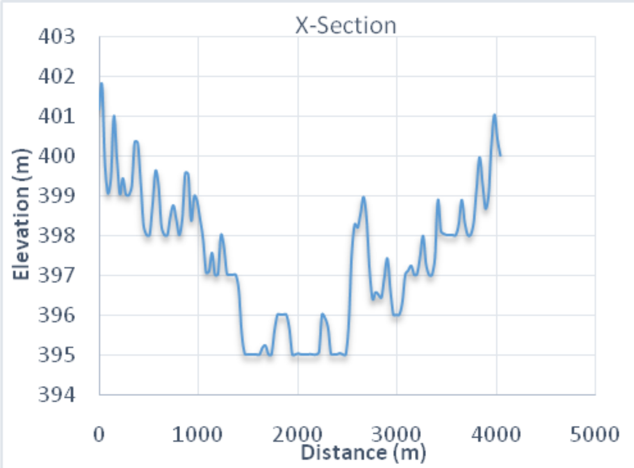

Figure 10 Cross Section of Proposed Location of DAM 1

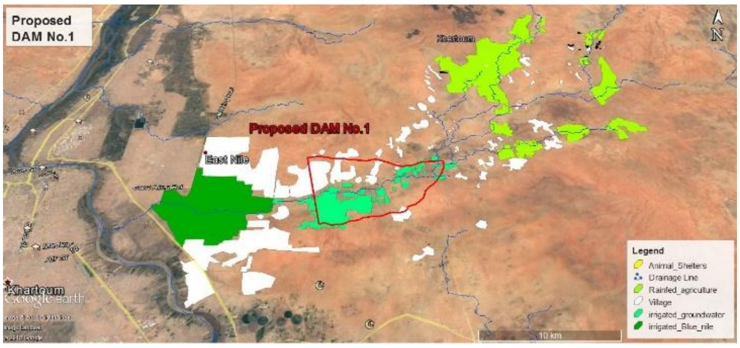

Figure 11 Location of DAM 1

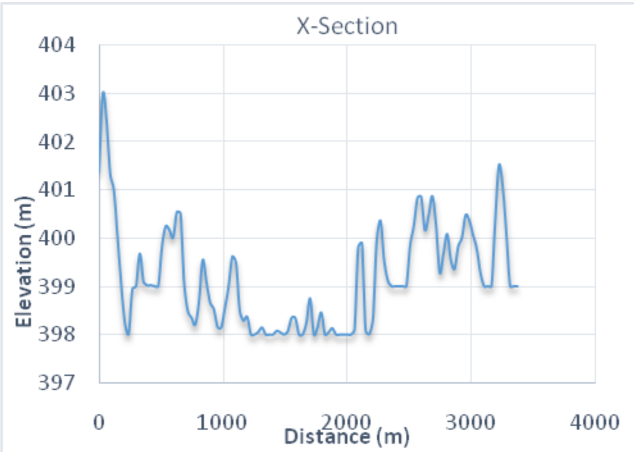

Figure 12 Cross Section of Proposed Location of DAM 2

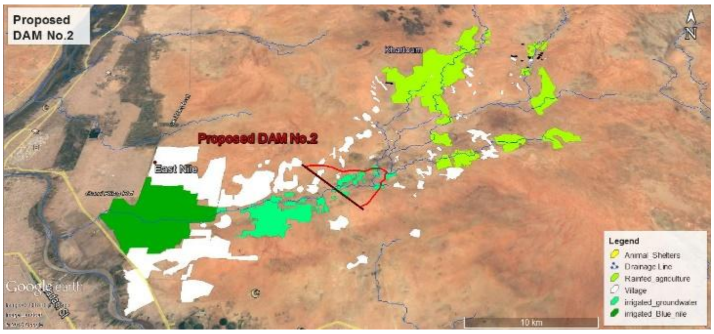

Figure 13 Location of DAM 2

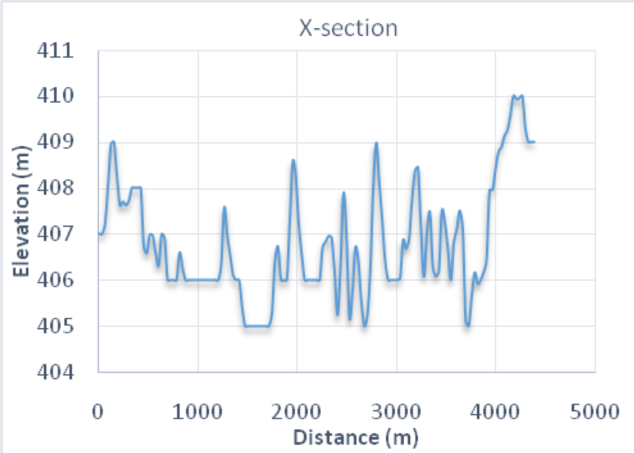

Figure 14 Cross Section of Proposed Location of DAM 3

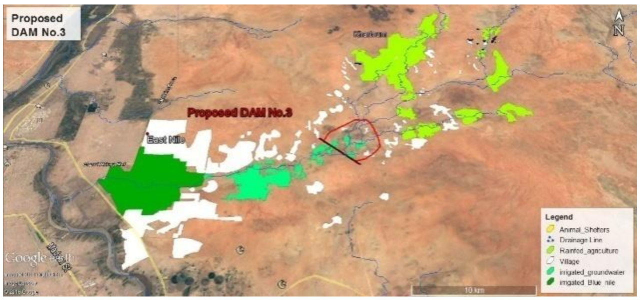

Figure 15 Location of DAM 3

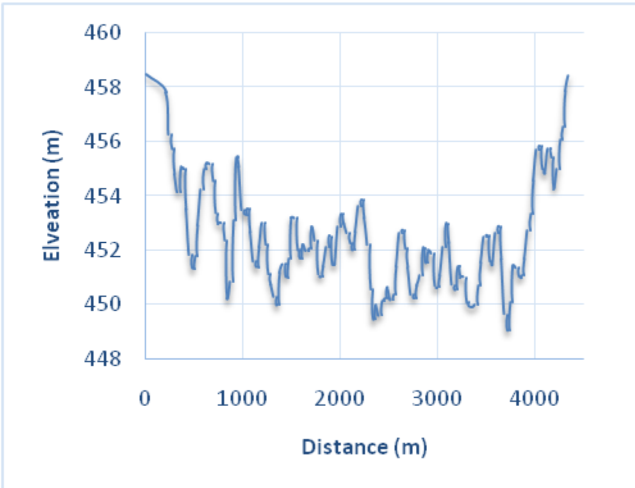

Figure 16 Cross Section of Proposed Location of DAM 4

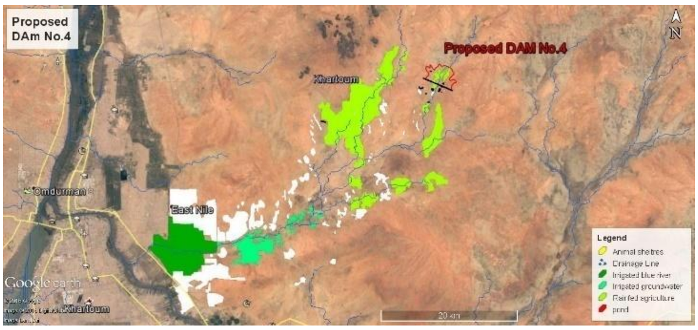

Figure 17 Location of DAM 4

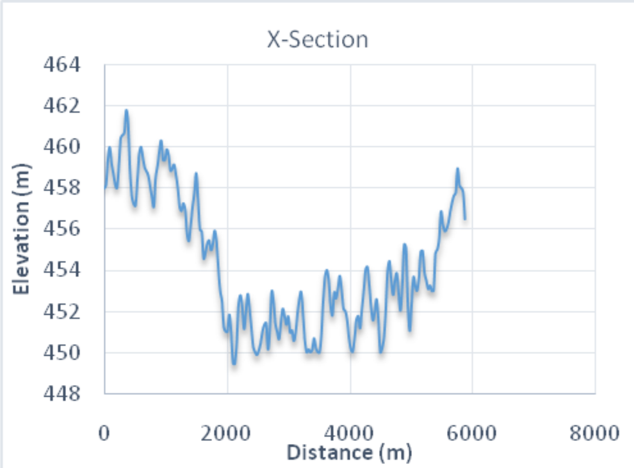

Figure 18 Cross Section of Proposed Location of DAM 5

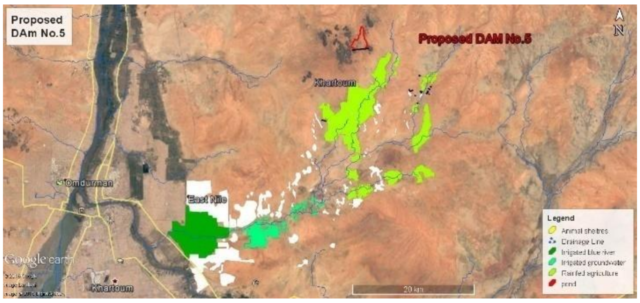

Figure 19 Location of DAM 5

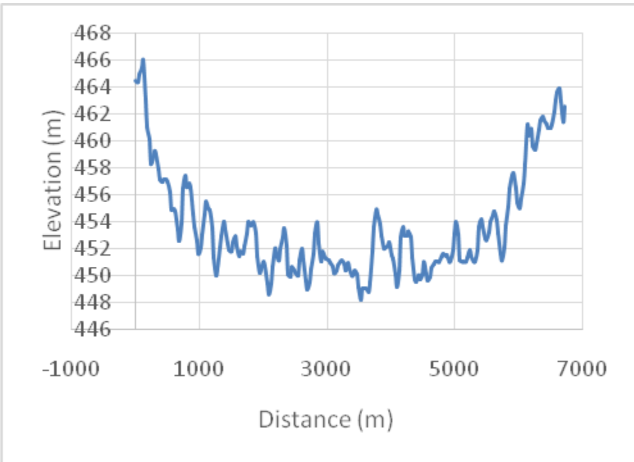

Figure 20 Cross Section of Proposed Location of DAM 6

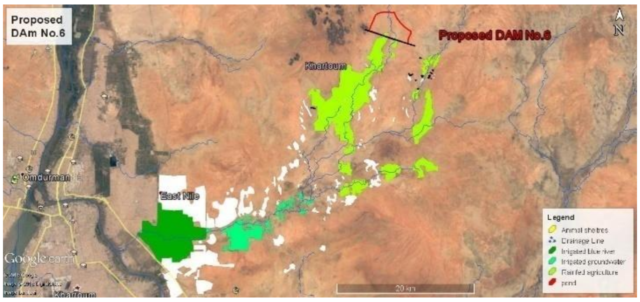

Figure 21 Location of DAM 6

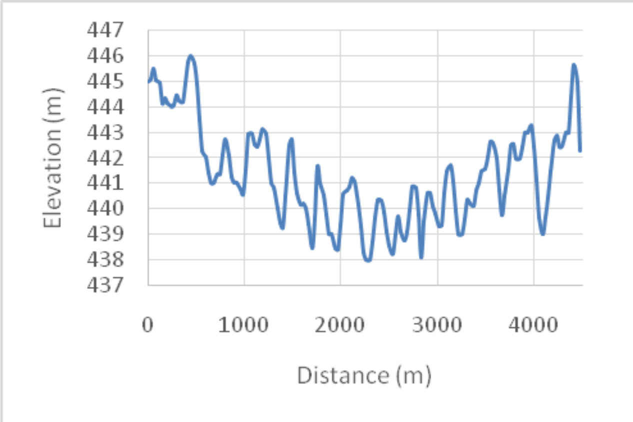

Figure 22 Cross Section of Proposed Location of DAM 7

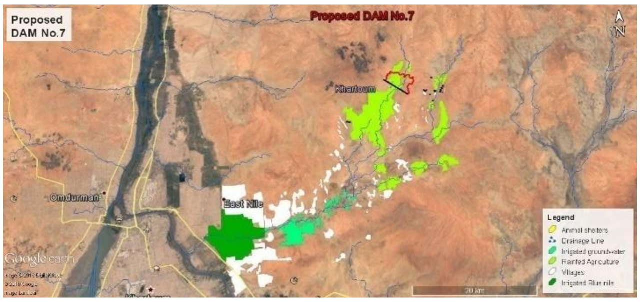

Figure 23 Location of DAM 7

- The following table shows the effects of each proposed dam location in the study area:-

Table 2 Impact of Selected site of DAMs

DAM	potential cultivated area to be covered by lake	potential residential areas to be covered by lake	Area of reservoir
No.	Km2	Km2	Km2
Location 1	11.44	54.479	65.919
Location 2	0.61	18.268	18.878
Location 3	0.79	21.713	22.503
Location 4	0.02	9.875	9.895
Location 5	0	4.783	4.783
Location 6	0	16.538	16.538
Location 7	0	14.071	14.071

- Location of DAM number has the following advantages and disadvantages. The main advantages of this location are: firstly the minimization of the effect of flash flood in Marabe-alshareef town and the agricultural projects near this town, secondly the lake of this dam can be used for irrigation purposes. Its disadvantages are: firstly it will cover large areas of the villages and areas that can be suitable for agriculture or grazing. Secondly the cost of the dam construction is high compared to the cost of settlement of the affected villages and compensation of agricultural lands that could be affected.
- Locations number two and three are the second best options, but they have the same disadvantages of the location of DAM one, with less affected areas, where the dam lake area is less than the first location.
- In location number four the amount of reserved water is not enough compared with the construction cost of the dam as well as the wide areas that will be negatively affected by the construction this dam.
- Location number five had been excluded because it is located in steep surface in the Valley of rank four as well as that the amount of reserved water is not feasible.
- Locations number six and seven can be considered as the third option because they can minimize the effect of flash flood with disadvantages of large area needed for the construction of the dam, which reduces agricultural and grazing lands as well as the high cost of the dam construction compared to the compensation cost of the affected agricultural lands.

- Location of DAM number one had been selected as the best choice regarding reservoir volume which enables the storage of large water quantity. This choice has the credit of minimization of the flash flood effect and the capability of irrigation of wide agricultural and grazing lands

V. CONCLUSION

After the boundary of the watershed had been derived from the DEM, the software ArcGIS had been used to derive the layers of different orders of valleys from the DEM. According to the results of slope and hydrology analysis, seven locations had been selected as suggested water reservoirs, To determine earth dam's locations multi criterion methods had been applied. The best dam locations satisfying the selection criterion had been achieved. The surface areas and volumes of reservoirs had been calculated for seven selected locations. The path profiles were produced in the seven selected locations. Major Landuse, landcover, stream order and location of water body were projected on the watershed area of the Soba valley to extract the residential areas, agricultural areas and grazing lands that had been affected by the dams. Dam location selection model and volume model had been designed to repeat the steps and report the analysis result automatically.

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