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Assessing the potential of floodwater harvesting in Seleit Area Wadis, Sudan - using remote sensing and GIS

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Abstract

This study focused on investigating the potential of floodwater harvesting from four ephemeral seasonal streams (wadis) in Seleit Area in the north of Khartoum State in Sudan. The area is subjected to severe flashfloods that resulted in huge damages in lives and properties. It aimed, in one hand, to estimate the potential runoff of the rainstorm events that could be impounded in some sites along the wadi course to prevent downstream population from the flash floods threats. And from the other hand, to site some locations that could be suitable to endue new environments for effective use of the floods water by practicing some kinds of irrigated agriculture or rangeland enhancement, as an example. GIS and Remote Sensing were used as assisting tools in calculating the watershed areas of the wadis and in assessing the potential sites for water harvesting systems.

Introduction

Water harvesting (WH), with its different types, is getting a new interest to be evaluated as a traditional water management especially in arid and semi-arid regions. The expectation of the acute water shortage in the coming decades brings the WH as an important and alternative water source. The existing resources, groundwater, streams and rivers, are declining and they are not sufficient to cover the ongoing increasing water demand.

Water harvesting for dry-land agriculture is a traditional water management technology to ease future water scarcity in many arid and semi-arid regions of the world (Prinz and Singh, 2000). In Sudan, where the major part of it falls within the arid and semi-arid zones, different traditional water harvesting techniques and systems are being practiced since long and are still referred to in the literature by their traditional names, e. g. Haffir and Teru (Oweis et al., 1999).

As a semi arid zone, the study area is subjected to the spatial variation in amount and duration of rainfall during the rainy season as well as rainstorms with high intensity and short duration causing flash floods.

The last decade showed a trend of rainfall increment. Furthermore, the heavy floods are with small interval. In 1988, 1994, 1998 and 2001, the area was subjected to flash floods, which most of them were severe and left huge loses of lives and houses. The occurrence of flash flood is due to the semi arid conditions, the sparse vegetation cover, the steep topography, and the heavy rainstorms. The broadness and shallowness at the delta or down stream of the wadis serve flooding and the heavy rainstorm serves flash flood.

Jeili town was the most susceptible area for floods in 1988, 1998 and 2001; it witnessed critical destruction for buildings and settlements. This was due to Wadi El Jeili crosses the town and farms from east to west.

The study aimed to asses the potential of Water Harvesting in Seleit area as sort of sustainable community development and water resources management. Reducing the amount of water reaching the wadis deltas, which are flood prone areas, could save the damages and environmental problems caused by the flash floods. The fertility and broadness of wadis courses and deltas could be devoted for housing and agriculture to meet the increasing expansion of population and food demand. In addition, in such semi-arid area, where rainfed agriculture is threatened due to the rainfall fluctuation in amount and distribution and high evaporation, water harvesting could serve the settlement of the nomads and the practice of irrigated agriculture.

The use of the spatial technique, GIS and Remote Sensing (RS), was to assess their capabilities in the planning and localization of sustainable water harvesting systems.

Materials and Methodology

The following data were used in conducting the investigations of the study area: a Landsat (TM) image with resolution of 30 m for the year 2000, two contour maps with scale (1:100 000), geological map with scale (1:250 000), and soil map with scale (1:250 000). In addition, rainfall and evaporation data for the years (1988-1999) were used for the drainage basins analysis.

ArcGIS 9.0, ArcView 3.2 and the Remote Sensing platform Erdas Imagine 8.5 were used for the spatial analysis of the study area. The Rainfall-Runoff (NAM) model was used for the stream flow calculations.

Seleit Area constitutes the northeastern part of Khartoum state in Sudan. It is located between 32° 31`- 33° 00` E and 15° 45`- 16° 00` N; and has an area of 1,150 km². The area is a flat plain with some scattered cropouts. It is of a semi arid climate (average annual rainfall 120 mm), with sparse vegetation. About 80% of the area is dominated by the rangeland with little cultivation near the Nile and in the courses of the wadis (ephemeral seasonal streams). The main wadis of the region are El Kangar, El Seleit, El Jaili, and El Kabbashi (Fig 1).

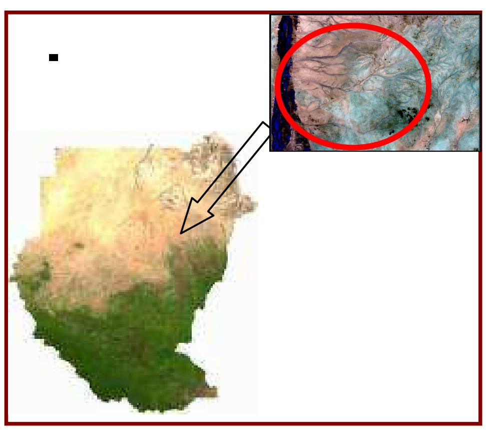


Figure 1: The Location of the Study Area

Water Volume Calculation

NAM[1], a rainfall-runoff model, was used to calculate the water volume carried by the wadis of the study. For the simulation, the model needed the catchment area of each wadi, which delineated using the GIS software, and the rainfall and evaporation data of the study area. The watershed and sub-watershed for each wadi together with the daily rainfall and evaporation data

[1] NAM forms part of the rainfall-runoff (RR) module of the MIKE 11 River modeling system. It was originally developed by the Department of hydrodynamics and Water Resources at the Technical University of Denmark.

for 12 years (1988-1999), were used to simulate the water volume of the maximum rainstorm for the wadis of the study area.

To define the terrain relief of the study area, a Digital Elevation Model (DEM) was developed. It was developed from two topographic maps covering the elevation of the study area. The mosaic of the contour maps was processed using Erdas Imagine 8.5. Then, the contour lines were digitized, where the coordinates X, Y, and Z represent the latitude, longitude and altitude, of a point, respectively. The elevation of the study area extends from 375 m (River Nile) to 520 m northeast of the River Nile.The interval between the contour lines is 20 m. The slope was interpolated using the Natural Neighbors method in ArcMap.

For the calculation of the wadis watersheds and sub-watershed, the ArcHydro[2] Tools in ArcGIS was used. For the terrain processing in ArcHydro, a DEM is the initial input to calculate the flow direction, which is the first requirement for catchment area delineation. The DEM that was derived from the contour maps was unable to represent the topographic feature of the study area (as will be discussed in the results and discussion section). Therefore, the SRTM 90m DEM provided by the International Centre for Tropical Agriculture (CIAT)[3], 90m resolution at the equator, was used.

The daily rainfall and evaporation data for the years (1988-1999) were used in the simulation. The years 1988, 1992, 1994, and 1996 are classified as years with heavy rain, annual rainfall more than 130 mm, and the year 1990 as a dry year with annual rainfall less than 10 mm. The evaporation data is of a high potential and exceeded most of the time the rainfall value.

Localization of Potential Water Harvesting Sites

For identifying areas for rain- and floodwater harvesting as well as designing water harvesting system, there are important parameters that should be considered: Rainfall, topography and terrain analysis, hydrological process and water resources, vegetation cover, and soil characteristics (Prinz et al., 2000).

The probability of occurrence P (%) for each rainfall was calculated using the method recommended by FAO, where the annual rainfall totals of the study area for 24 years (1981-2004) were used.

The time of concentration of a catchment is defined as the time needed for a drop of water to travel from the most distant point in the watershed to the design point downstream. It includes both time for overland flow and time for channel flow.

To estimate the time of concentration, the Kirpich equation (1940) , which is commonly used for rural areas and has been useful for many wadi systems (Al Weshah, 2002), was used in this study.

The geology and soil investigations for the study area were done using geological and soil maps for Khartoum State. Both maps were digitized in Erdas 8.5 and saved as vector layers. The process of cleaning and building of topology, for correction as well as building of the polygons, for both layers were done also in Erdas 8.5. Then, the conversion to a shape file together with the classification process was processed in ArcView 3.2. The shape files of the watershed polygon of the four wadis and the soil map were overlaid. The different soil regions and types for each wadi were specified. The same process was repeated for the geological map to define the geological characteristics of the region.

The investigation about the water resources in the study area was dependant on the investigation done by the ‘Sudanese German Exploration project, 1979, for Khartoum state’.

[2] ArcHydro is an ArcGIS-based system geared to support water resources applications

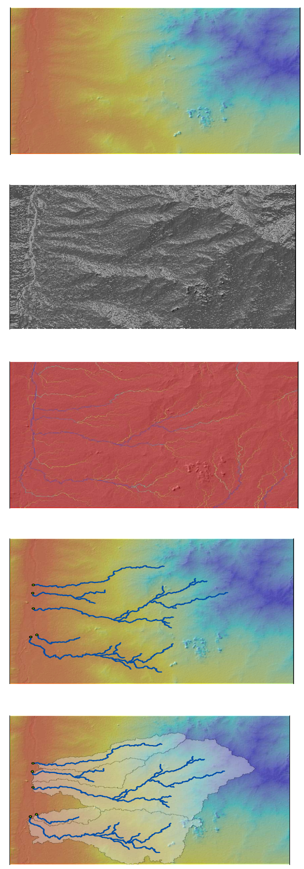
[3] Hole-filled seamless SRTM data V1, 2004, International Centre for Tropical Agriculture (CIAT). http://gisweb.ciat.cgiar.org/sig/90m_data_tropics.htm.

They have stated that the water resources are limited to the River Nile and to the water carried by the wadis during the rainy season. The groundwater occurrence is limited only to the areas adjacent to the River Nile. The groundwater recharge from the rain water is found to be negligible.

Results

Calculation of Water Volume of a Rainstorm

The watershed area for every wadi was calculated using the GIS environment facility. Using ArcHydro, the SRTM 90m DEM was used to delineate the streams, the drainage points, and finally the wadis watersheds. The watershed areas found to be 554.36, 398.247, 57.482, and 114.173 km² for wadi El Kangar, wadi El Seleit, wadi El Kabbashi, and wadi El Jaili respectively. Taking the same sequence, the longest path for each wadi found to be 92, 61.2, 20.2, and 31.5 km.



(a) (DEM).

(b) Flow Direction.

(c) Flow Accumulation.

(d) Streams and Outlet points.

(e) Watersheds Areas

Figure 2: Sketch explains the process of delineating the catchment area of the study area Wadis.

The average slope of the study area is found to be equal to 9.3% (Fig. 3). The spatial distribution for the data represented by the contours was not enough for the interpolation process. The SRTM 90m DEM showed a good quality of detecting the flow direction, stream path, and the wadis system; and this agrees with what Borgniet et. al. (2003) stated in this regard (Fig. 3).

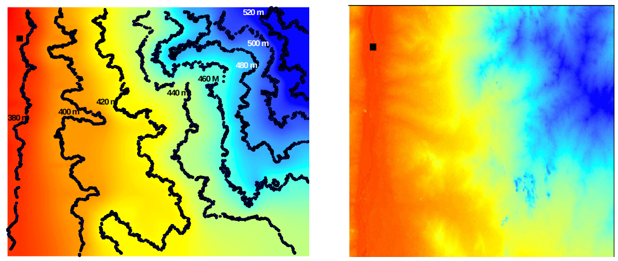


Figure 3: DEM derived from Isolines (left) and SRTM 90m DEM by CIAT.

The simulation results showed that the study area was subjected to flash floods in the years 1988, 1994, and 1996. In reality, the study area was subjected to severe floods during the same periods. However, there are some years were no runoff occurred and all month are with zero runoff. The dry months in every year (October – December) were represented with zero runoff with exception to the 3 years followed the year 1988; as this year showed a very intensive rains that is a unique record for more than 50 years. The simulated results prove the ability of the model to represent the hydrological process of the watershed. In the years 2002 and 2003 the annual rainfall amounted to 319.8 mm and 310.1 mm respectively. The corresponding runoff for each wadi was approximate in amount to that for the year 1994 where the annual rainfall was 197 mm. This means that the flash floods in the study area could happen in the future with less return period.

There is no discharge measurement station for the wadis of the study area. Therefore, no calibration for the simulated runoff has been processed. The values of the model parameters were given considering the topographic features, catchment size, and soil and vegetation cover characteristics of the study area, i.e. selection was depended on engineering judgment. Taking the ground surface characteristic as an example; it is of fine soil texture that turned to a crusted layer after a small time of the rainfall starting. This feature serves the runoff and gives little time for the infiltration process to be completed. However, the graph of the annual rainfall and the one that represents the simulated annual runoff are showing a promising similarity that can be taken, more or less, as a prove of model well representing simulation (Fig.4).

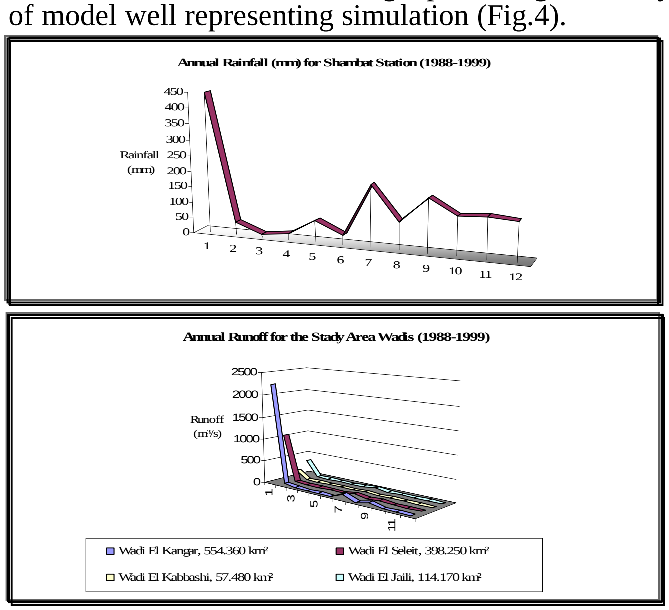


Figure 4: Annual Rainfall of the Study Area (above) and the simulated annual Runoff of the study Area Wadis (below).

Water Harvesting Potential Sites and Suggested Systems

According to the probability of annual rainfall totals subject to the study area, the return period of each event was calculated. The analysis shows that the rainfall events with probability 70-100%, annual rainfall 0-69 mm, can occur every year. Rainfall with probability 30-70%, amounts to 70-124 mm, could happen every 2-3 years. Those more than 124 mm and less than 200 mm annual rainfall have frequency of 4-6 years. But the rainfall more than 300 mm has 10-15 years of return period.

The potential annual runoff for each wadi for the different probabilities and frequencies is shown in Table 1.

Table 1: Probability and Return Periods of Rain Events and the Corresponding Runoff.

Probability (%)	Return Period (Year)	Runoff (m^3/s)			
		Kangar	Seleit	Jaili	Kabbashi
70-100	1	0-0.7	0-0.3	0	0
30-70	2-3	0-2	0-1	0-0.5	0-0.3
> 30	10-15	7-110	3-48	2-24	1-13

The time of concentration of each Wadi is found to be 19.6, 14.3, 5.5, and 7.7 hr for wadi El Kangar, wadi El Seleit, wadi El Kabbashi, and wadi El Jaili respectively. The results agree with the fact that flash floods in the study area lasts for a few hours to a few days depending on the rainstorm intensity and duration.

Wadi El Kangar

Two third of the drainage points lay within the wadi alluvial. These points could be of high potential for water harvesting systems due to the accumulated water from more than one sub-watershed (Fig. 5).

- ✓ Site 1 => earth dam
- ✓ Site 2 => an underground dam within the stream bed.
- ✓ Site 3 and 4 => Earth or underground dams.

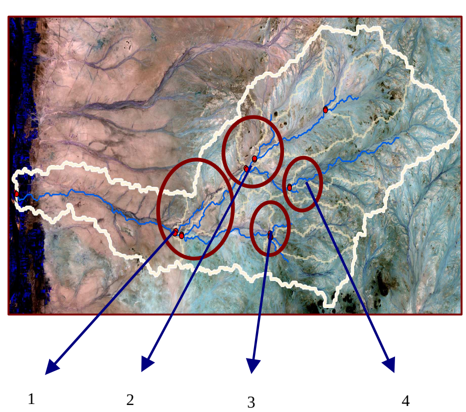


Figure 5: Wadi El Kangar

Wadi El Seleit

The soil map shows that all the drainage points are within the stream bed (wadi bed. Downstream of the sub-watersheds is suitable for holding water in the reservoirs that will give the chance to reduce the water velocity. The dashed shape is suitable for agriculture because of the existence of some settlement, or for groundwater recharge due to the wadi deposits and the proximity to the Nile (Fig 6).

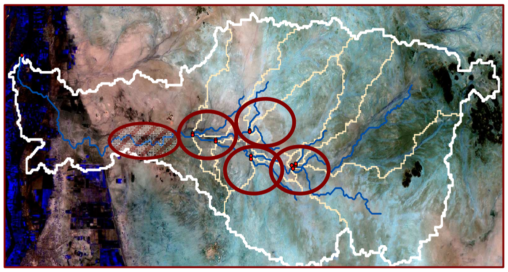


Figure 6: Wadi El Seleit

Wadi El Jaili

The wadi lies on the basement complex region, where no aquifers for groundwater exist.

- ✓ Site 1 => could be suitable for groundwater recharge to help to preventing the drying up of the wells within the area.
- ✓ Site 2 => A dam could serve both: hold the water for watering purposes and the flooded plain could be used later for agriculture as some settlements exist.

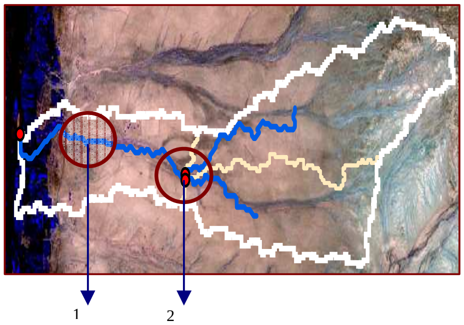


Figure 7: Wadi El Jaili

Wadi El Kabbashi

This wadi is of small watershed area. Therefore and in addition to the stream unity, water harvesting system at the downstream of the wadi will be appropriate for groundwater recharge, or for storing water in dam, or for cultivating the area adjacent to the wadi course (Fig. 8).

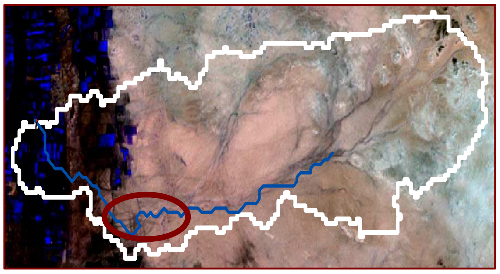


Figure 8: Wadi El Kabbashi

Conclusion

The watersheds of the four wadis were defined and calculated using ArcHydro. The areas of wadi El Kangar, El Seleit, El Jaili and El Kabbashi are found to be 554.36 km^2, 398.25 km^2, 114.17 km^2, and 57.48 km^2, respectively and sequentially, the corresponding runoff for the maximum annual rainfall are found to be 1530.213, 1048.119, 321.784, and 163.1(m^3/s).

The Remote Sensing and GIS were used to define the wadis of the study area downstream and to localize the WH sites. They found to be of great help for data preparations and for decision making. The study came to a conclusion that the potential of water harvesting in the study area exists. Implementing such systems could open new environments for permanent and better settlement conditions as well as new opportunities for sustainable development.

Acknowledgment

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