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. This old technology is gaining new popularity these days (Prinz 1996, Critchley and Siegert 1991, cited in Prinz et al., 2000). 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 (Seleit 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.

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. The fertility and broadness of Wadis courses and deltas could be devoted for housing and agriculture to meet the food demand increasing expansion of population. 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.

Remote sensing (RS) is defined as the measurement or acquisition of information of some property of an object or phenomenon by a transducer that is not in physical or intimate contact with the object or phenomenon under study (WCA, 2005). The digital image classification, including data manipulation pre-processing and enhancement, is used to process the satellite data (Cracknell and Hayes 1993, cited in Eiumnoh, 2000). The Geographical Information System (GIS) is a system designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information (Burrough 1986, cited in Eiumnoh, 2000), and to support decision making processes as well (WCA , 2005).

The use of the spatial technique, GIS and Remote Sensing (RS), aimed to assess the capabilities of such technologies in planning and localizing sustainable water harvesting systems in the study area..

MATERIALS AND METHODOLOGY

The following data and softwares 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 with average annual rainfall amounts to 120 mm and 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 this region are El Kangar, El Seleit, El Jaili, and El Kabbashi Fig (1).

Fig. 1: The Location of the Study Area

1. Water Volume Calculation

The ArcHydro Tools in the ArcGIS were used to define the terrain relief of the study area and in the calculation of the Wadis watershed and sub-watershed areas. For terrain processing in ArcHydro, a DEM is the initial input to calculate the flow direction. The DEM was developed from the 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. And the distance between the contour lines is 20 m. The slope was interpolated using the Natural Neighbors method in ArcMap. But, another DEM (SRTM 90m) provided by CIAT was used to prepare the spatial information for the watersheds and sub-watersheds area delineation and calculation. The flow direction was extracted from the DEM and then, the required areas were computed.

Then, NAM, the rainfall-runoff model, was used to calculate the water volume carried by the wadis of the study area. This model forms part of the rainfall-runoff (RR) module of the MIKE 11 River modeling system. It represents various components of the rainfall-runoff process by continuously accounting for the water content in four different and mutually interrelated storages. The model can be characterized as a deterministic, lumped, conceptual model with moderate input data requirements.

The input data were the watershed area, the daily rainfall and evaporation data for 12 years (1988-1999) of Shambat station, the nearest meteorological station to the study area. Among these years; 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 high potential and exceeded most of the time the rainfall value.

The initial conditions required by the NAM model consist of the initial water contents in the surface and root zone storages, together with initial values of overland flow, interflow, and baseflow. The estimation of the parameters depended on the catchment size, the soil and geological characteristics and the longest path of the watershed. Thereafter, the potential runoff of every Wadi watershed and sub-watershed was calculated.

2. Localization of Potential Water Harvesting Sites

For identifying areas for rain- and floodwater harvesting as well as designing water harvesting system, the following parameters were considered:

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

The time of concentration of the catchments areas of the Wadis was computed applying Kirpich equation (1940). It is commonly used for rural areas and has been useful for many wadi systems (Al Weshah, 2002).

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. Then, the classification was processed in ArcView 3.2. The shapefiles 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 with the geological map to define the geological characteristics of the region.

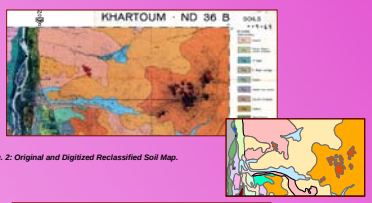


Fig. 2: Original and Digitized Reclassified Soil Map.

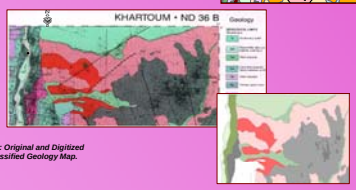


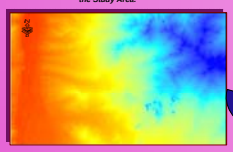
Fig. 3: Original and Digitized Reclassified Geology Map.

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'. 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

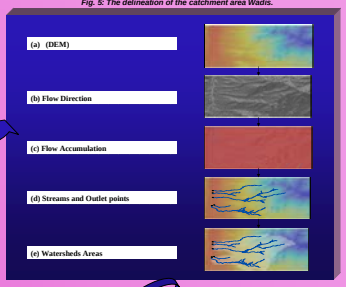
1. Water Volume Calculation

Fig. 4: The SRTM 90m DEM by CIAT representing the Study Area.



ArcHydro Tools

Fig. 5: The delineation of the catchment area Wadis.



Year	Runoff (m³/s)			
	Kangar (554.360 m²)	Seleit (398.25 m²)	Kabbashi (57.48 m²)	Jaili (114.17 m²)
1988	**1530.213**	**1048.119**	**163.1**	**321.784**
1989	36.563	20.924	1.627	4.012
1990	5.186	2.574	0.101	0.442
1991	6.743	0.306	0	0
1992	1.856	0.549	0.228	0.414
1993	0	0	0	0
1994	**110.85**	**48.567**	**12.914**	**24.459**
1995	0	0	0	0
1996	**62.591**	**25.414**	**7.109**	**13.703**
1997	0.308	0.277	0.055	0.091
1998	7.195	2.82	0.937	1.675
1999	1.939	0.924	0.281	0.486

Table 2: Potential Runoff for each wadi.

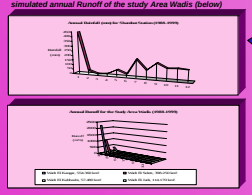
Runoff Simulation (NAM Model)

ID	Wadi Name	Area (km²)	Longest Path (km)
1	El Kangar	554.360	92.0
2	El Seleit	398.247	61.2
3	El Kabbashi	57.482	20.2
4	El Jaili	114.173	31.5

Table 1: figures of wadis watershed and the longest path

Model Calibration

Fig. 6 Annual Rainfall of the Study Area (above) and the simulated annual Runoff of the study Area Wadis (below)



There is no discharge measurement station for the wadis of the study area. Therefore, no calibration for the simulated runoff has been processed. However, the graph of the annual rainfall (Fig. 5) and the one that represents the simulated annual runoff (Fig.6) are showing a promising similarity that can be taken, more or less, as a prove of model well representing simulation.

2. Localization of Potential Water Harvesting Sites

Probability (%)	Return Period (Year)	Runoff (m³/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

Table 3: Prob. and Return Periods of Rain Events and the Corresponding Runoff.

Name	Longest Path (km)	Slope (m/m)	Time of Concentration (hr)
Kangar	92.0	0.003	19.6
Seleit	61.2	0.003	14.3
Jaili	31.5	0.004	7.7
Kabashi	20.2	0.004	5.5

Table 4: The longest Path, Slope and time of Concentration for each Wadi.

The probability and return periods of rainfall events together with the time of concentration make possible the analysis of siting the potential sites for water harvesting system. In addition, overlaying the soil, geological and the wadis watershed polygons facilitate determining the characteristics of the selected sites and accordingly suggest water harvesting systems.

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.

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

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 .

WADI EL JAILI

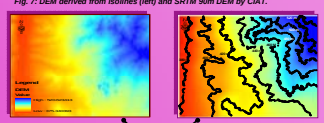
The wadi lies on the basement complex region, where no aquifers for groundwater exist

- ✓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.

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



The spatial distribution for the data represented by the contours was not enough for the interpolation process. Therefore, the SRTM DEM provided by CIAT was used in delineating the wadis watersheds.

Fig. 8: The Digitized Wadis and the Extracted Streams and Watersheds from the SRTM 90m DEM by CIAT

According to Borgniet et. al. (2003), the accuracy of DEM for hydrological network application must be defined through specific criteria that are being qualified as "hydrological criteria". These criteria could be slopes, azimuths, or, in a more concrete way, the stability and quality of detection of the drainage directions, water paths, and river system. The SRTM DEM showed a good quality of detecting the flow direction, stream path, and the wadis system (Fig. 8).

CONCLUSION

- The annual runoff of each wadi shows a potential of water volume that can be saved for later use during the dry season for the different water utilization in the region.
- There are potential WH sites, where water can be hold to first prevent the destructive impact of the flash floods at downstream areas and to give the scattered settlements in the middle and upstream areas the possibility of permanent and stable settlement around the new water points. A better environment could be introduced to the region.
- Remote Sensing and GIS found to be of great help for data preparations as well as for decision making, but never would they be decision tools. Field visits and taking benefits of the local people knowledge about the area will help in localizing the sites of the harvesting systems in a scientific but real way.
- Socio-economic studies for the region should be considered in the further studies. They are of high importance when assigning the beneficiaries of the water harvesting systems. Water harvesting for plant production or for domestic use and livestock watering depends mainly on such studies.

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