Remote Sensing Data based Rainwater Harvesting Approach for Remote Rural Areas - A case study, Blue Nile area, Sudan.

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Abstract:

The method of water harvesting is very crucial to the collection of the volume of water required for sustainable water supply. Most physical water scarcity remote rural areas worldwide are characterized by a reasonable amount of rainfall. These areas lack the suitable Surface Rainwater Harvesting System (SRHS) to collect the required water volume. To address this problem a remote sensing data based Surface Rainwater Harvesting Approach (SRHA) was proposed. The proposed approach was tested on existing surface rainwater harvesting systems (SRHS) in residential and agricultural areas inside the study area. The study area is bounded by latitudes 11^0-12^0 N and longitudes 33^0-34^0 E, with an approximate area of 11,000 km^2. The SRTM90 DEM data of the study area was processed using QGIS application program hydrological modules. The hydrological model of the area was created, the catchment areas were derived and draining capacities for the specific test sites were calculated. The results revealed that the remote sensing data based approach is capable of locating sites with draining capacities 82 and 8 times those of the traditional systems in the residential and agricultural areas respectively. These results demonstrated that the proposed approach can facilitate locating optimum surface rainwater harvesting sites that would provide sustainable water supply and mitigate physical water scarcity problem in remote rural areas.

Key words:

Rainwater, catchment area, draining capacity, remote sensing data, water scarcity.

1. Introduction.

“Life is not possible without water; it is essential for life in general and humans, plant and animals in particular.

“Water scarcity is, therefore, thought to be a serious problem throughout the world and mitigating this problem is one of the biggest challenges of the 21st century (J. Worm et al 2006)”.

Although millions of people are suffering from the water supply problems all over the world, water problems are quite different in different areas. However, most of these problems are related by a way or another to water source, quantity, quality and harvesting system.

The water source problems are mainly experienced in urban areas in general and in over populated urban areas in particular, where these water sources are put under growing pressure of very rapid urbanization that requires water for drinking, terrace cleaning, garden irrigation, laundry, cars washing and sanitation.

Urban areas are typically characterized by concentrated demand of water because of high population density and varied uses of water. As a result water supply problem became acute. In this circumstance there is a need of alternative water supply sources and thus rainwater harvesting comes into attention. Water crisis has become an acute problem faced by the inhabitants of Dhaka city. It is found that total water demand in Dhaka city is 2,240 million liter per day (MLD) whereas supply is 2,150 (MLD) (A. Tabassum. et al 2013).

The water quantity problems or physical water scarcity problems are mainly experienced in urban over populated areas and rural areas facing the problems of climate change that affect the rate of rainfall and the lack of integrated water management.

A recent study shows that there is acute crisis in the quantity and quality of water in Dhaka, the capital of Bangladesh. The problem is so severe in some areas that people do not get the minimum required quantity of water for drinking (Verma H.N. at al 1995).

The water quality problems depend on the available water sources and the standard of living in the specific area and are mainly experienced in urban areas. In urban areas water quality problems are usually, tackled by proper treatment methods which may include rigorous verification of both the source and storage. In rural areas the rainfall water represents the main water source which is relatively free from impurities. However, its quality may deteriorate during harvesting, storage and household.

Rainwater collection systems are commonly believed to provide safe drinking water without treatment because the collection surfaces (roofs) are isolated from many of the usual sources of contamination (e.g. sanitation systems) (Luke Mosley 2005).

However, the quality of the rainwater harvested should be verified before supplying it for domestic use. This can be achieved by checking the level of water turbidity, bad taste or smell, level of chemical substances, faecal origin present bacteria etc. Also, the catchment area and storage should be regularly checked for cleanness.

The water harvesting system depends on the geographical area, in most of the countries urban areas are provided with good/modern systems that consider quantity, quality and sustainability.

The literature clearly shows that the range of applications of RWH systems in urbanized areas is very large. (Alberto Campisano et al 2017). "Rainwater harvesting for supplying drinking water in urban areas has a long history especially in semi-arid areas (Duygunur Aslan et al 2018)".

In most of the remote rural areas all over the world very simple surface rainwater harvesting systems are adopted that only care about water quantity with no success [Fig.1, Fig.2]. This would be demonstrated in the study area under consideration which represents a very typical example of this. **Fig. 1** describes the typical remote rural areas water harvesting system. The sieve, slow sand filter and the tank are labeled by the letters a, b and c respectively.

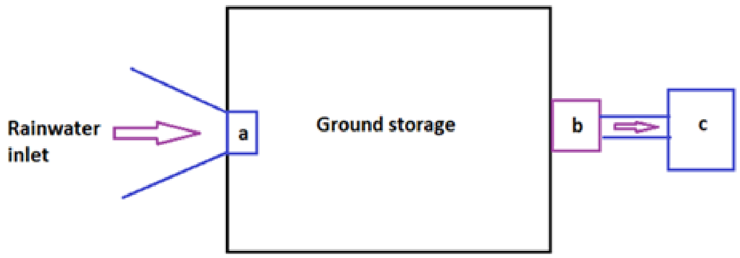

Fig. 1, Typical rural areas rainwater harvesting system, a is a sieve, b is a slow sand filter and c is a tank/concrete dock.

A Google Earth image derived by Google GIS on-line facilities shows a typical rainwater harvesting system in the study area figure 2 below.

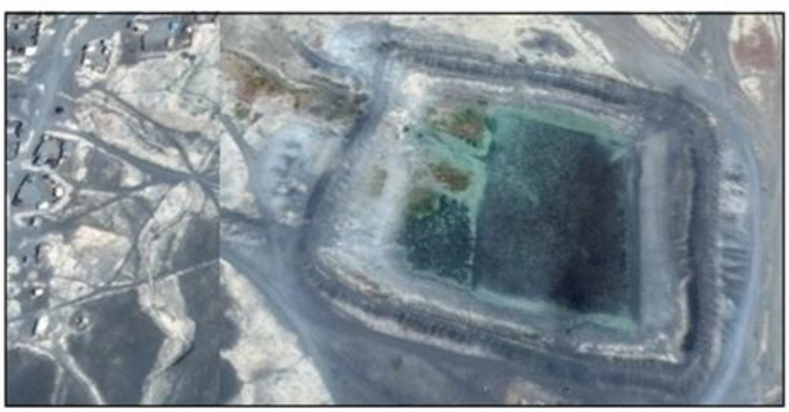

Fig. 2, Typical existing rainwater harvesting system (Hafeer), in the study area (dry season, empty).

This paper would focus on physical water scarcity in remote rural areas and the role of remote sensing data in mitigating this problem. This would be achieved by evaluating the (SRHA) proposed approach, using existing traditional surface rainwater harvesting systems in the study area.

2. Study area.

The study area is located in the savannah zone and represents parts of two states in the Sudan (Blue Nile and Sinar states), but the majority of it falls in the Blue Nile state. It is bounded by latitudes 11 to 12 N and longitudes 33 to 34 E [Fig. 3]. **Fig. 3** is a Google Earth image, showing the general location of the study. The mountains are bounded by black line, agricultural areas green, the Blue Nile blue. The general slope direction of the area is indicated by light blue arrows and sample villages are marked red.

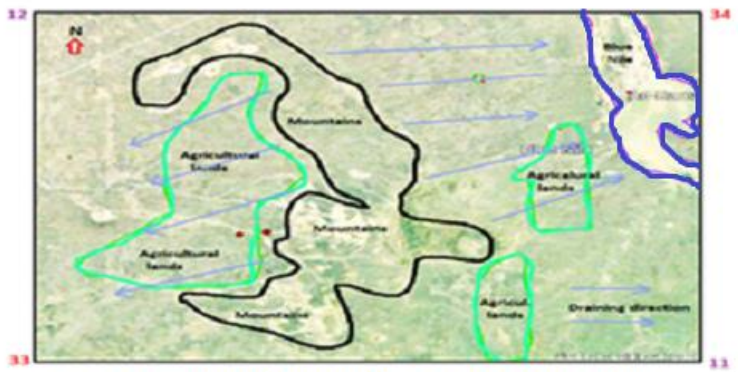

Fig. 3, Location of the study area, light blue arrows indicate the general slope of the area

The Blue Nile state has an area of 44,844 km^2 and a total population of 1,193,293. The economic activities in the area are based on agriculture, livestock plus increasing mineral exploration (WIKIPEDIA 2019). Crop production is practiced using traditional methods in small areas in the vicinities of residential areas. The rainfed semi-mechanical agricultural methods are practiced in large areas. “The rainy season extends from May to October with an annual rainfall rate of 300-900 mm (H. A. A. Hamdoun 2014).

The climate of the area is characterized by a hot rainfall season and a maximum rainfall that takes place during the period mid-July to mid-September. This is the period with sufficient rainfall to build up soil moisture and provide good contribution to ground water potential in the area. The topography of the area is characterized by a series of mountains in the center of the area running in the north south direction and represents a water divide zone dividing the area into east and west zones. These zones were occupied by the residential areas with their traditional small agricultural lands in their vicinities, the semi-mechanized rain fed agricultural areas and scattered rock out crops. The general slope of the eastern zone is in the north east direction and water drains in the Blue Nile River, while that of the western zone is in the south west direction and water drains in the White Nile River.

3. Drinking water problems in the study area.

The main sources of drinking water in the area are wells and surface rainwater such as rivers, lakes and even rainy season water ponds [Fig. 4]. However, surface rainwater represents the main source for drinking water in the area as wells are very expensive for local people to construct, may not be free from salinity and arsenic contamination and the ground water is very deep especially in the black cotton soil dominated area.

Fig. 4, Rainy season water ponds in the study area, (https://thewaterproject.org/water-crisis/water-in-crisis-sudan.

"Rainwater is free from salinity as well as arsenic contamination and is safe too if it is maintained hygienically. The physical, chemical, and bacteriological characteristics of harvested rainwater usually represent suitable and acceptable standard of potable water. Harvested rainwater can be used not only in drinking purposes but also in cooking, washing, and bathing" (B. K. Biswas et al 2014).

However, though the project area has a very dense drainage system [Fig. 5] and a high rate of rainfall but still suffers from a severe shortage of drinking water. **Fig. 5** is a typical drainage product of processing the SRTM90 digital elevation data of the study area using QGIS application program hydrological modules. Module r.fill.dir was applied to generate a depressionless elevation map and a flow direction map from the raster elevation map of the area. Module r.watershed was applied to calculate total drainage area for each stream reach. Module r.water.outlet was applied to create a watershed for each cross point.

Local people have enough drinking water during the rainy season only and when it is over they start suffering from water scarcity and stress. People travel tens of kilometers to bring water from the Blue Nile using Caros (barrel pulled by a donkey or horse) or trucks. However, water wells are available in some of the lucky villages, where water is pulled manually, but still they are not capable of providing people with enough drinking water [Fig. 6].

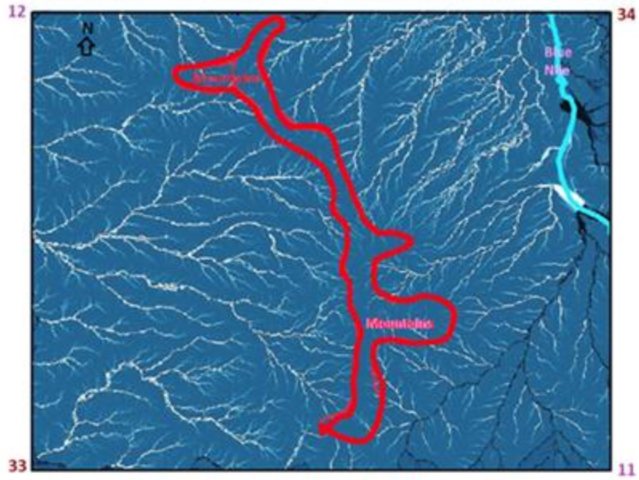

Fig. 5, The drainage network in the study area.

Fig. 6,Drinking water scarce in Sudan's Blue Nile, River Nile, (https://www.dabangasudan.org/en/all-news/article/drinking-water-scarce-in-sudan-s-blue-nile-ri).

Sudanese Members of Parliament have revealed that several people have died of thirst in the Red Sea and Blue Nile states, where the shortage of clean drinking water is acute. Kothar El Atta, one of the MPs from the Blue Nile constituencies has confirmed the death of people in state (DABANGA 2018).

Animals also, travel to and from the Blue Nile to drink water. This needs a great effort and causes a lot of suffering to the people. The major impacts of this are related to human's safety and health, kids' education and micro economy of individual family. The situation is even worse for the rain fed agricultural farmers especially in the crop harvesting season and raises the crop production cost in the area.

4. Surface rainfall water harvesting methods in the study area.

The storage medium (Hafeer) is usually located at the lowest point in the area. This is usually based on the experience of the local people and is not related to the topography of a large area. This results in wasting a lot of effort and money by building a large number of Hafeers in the same residential/agricultural area by moving the site from time to time due to the insufficient rain water supply [Fig. 7, Fig. 8]. These figures are Google Earth images derived using Google GIS on-line facilities to demonstrate the wasted effort in establishing a large number of Hafeers in the same residential/ agricultural area (numbered red). They also, show the proposed approach derived harvesting sites (red circles). The effort made in the proposed approach is aiming at integrating the water quantity, rainfall rate and size of draining catchment area. Other parameters such as precipitation and evaporation can be considered in designing the storage medium. This would no doubt facilitate selection of a site that would provide sustainable water supply for the area.

Fig. 7, A group of Hafeers established in the same residential area (numbered red, 1-8).

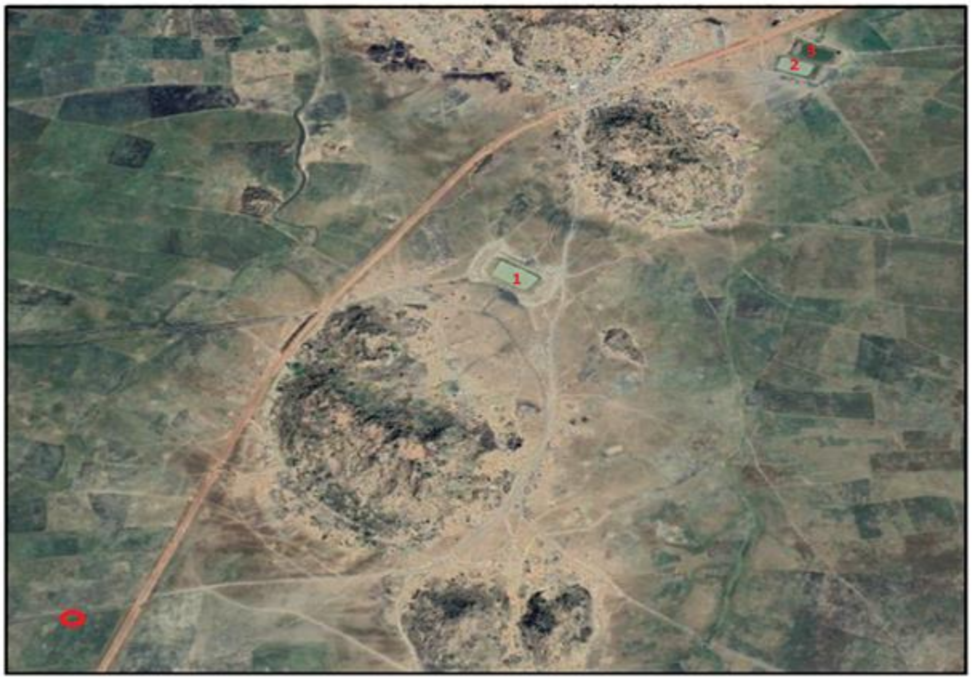

Fig. 8, A group of Hafeers established in the same agricultural area (numbered red, 1-3).

5. Methodology.

The methodology adopted in this investigation was based on data processing and analysis associated with a remote sensing data based SRHA. A digital elevation model of the study area was processed using suitable hydrological modules (r.fill.dir, r.watershed and r.water.outlet) to derive the basic hydrological layers such as flow accumulation raster, watershed basins, drainage network etc., for the study area. The processing steps followed are presented in the flow diagram shown in Fig. 9. **Fig. 9** is showing the data processing steps followed in the investigation. All the data processing operations were carried out using the hydrological modules available in QGIS open source application program.

The SRTM90 digital elevation model of the area was downloaded and processed to create a depression-less DEM. The latter was processed to derive the hydrological layers for the study area. The watershed basins layer was processed to derive the sub-basins for specific outlet sites in the study area. The sub-basins were factorized and their catchment areas were calculated. The catchment areas were used with the minimum rainfall rate in the study area to calculate the draining capacities for the specific study outlet sites. The proposed approach was tested on existing water harvesting systems in the residential and agricultural areas inside the study area and results are analyzed and reported.

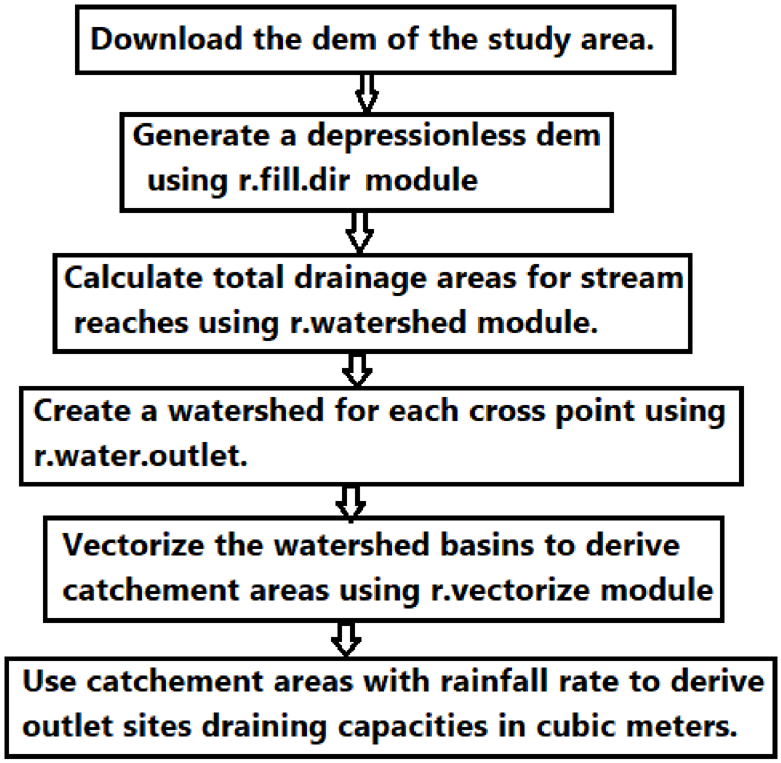

Figure 9, Flow diagram showing data processing steps.

6. Data capture and processing.

The free of charge SRTM90 digital elevation model was downloaded and processed to derive the hydrological model of the study area. Processing was made using the hydrological modules available in QGIS application program. The catchment areas for the eight Hafeers present in the residential area, Fig.7 (numbered red) and one proposed approach demonstration site (red circle) were derived. The same was done in the agricultural area with three Hafeers and one demonstration site. These existing Hafeers were used for demonstrating the waste effort made by the local authorities in establishing them with the lack of the basic data integration. The results are presented in tables 1 and 2. In these tables, the catchment area (km^2) was derived from the hydrological model. The site drainage capacity was calculated, using the minimum rainfall rate in the area (300 mm) by the following equation:

Drainage capacity (m^3) = catchment area (m^2) x minimum rainfall rate (m) ----------- (1)

Location	Catchment area (km^2)	Draining capacity in (m^3)
Hafeer 1	0.861	258,300
Hafeer 2	0.842	252,600
Hafeer 3	0.807	242,100
Hafeer 4	0.892	267,600
Hafeer 5	0.707	212,100

Hafeer 6	0.914	274,200
Hafeer 7	0.798	236,700
Hafeer 8	0.748	224,400
Demo-loction	67.5	20,250,000

Table 1, Catchment areas and minimum rainfall rate (300 mm) draining capacities of the eight (1-8) Hafeers and one demonstration site in the residential area, (Fig. 7, labeled red).

Location	Catchement area (km^2)	Draining capacity (m^3)
Hafeer 1	0.647	194,100
Hafeer 2	0.726	217,800
Hafeer 3	0.692	207,600
Demo-location	5.745	1,723,000

Table 2, Catchment areas and minimum rainfall rate (300 mm) draining capacities of the three Hafeers and one demonstration site in the agricultural area, (Fig. 8, labeled red).

7. Discussion.

The draining capacities presented in tables 1 and 2 demonstrated the clear difference between the water harvesting sites located by the traditional methods and those located by the proposed approach. In table 1 the capacity of the eight Hafeers in the residential area ranged between 212,100 and 274,600 cubic meters, with an average capacity of 246,000 cubic meters. The capacity of the proposed approach demonstration site (500 m from residential area) is 20,250.000 cubic meters. This is equivalent to 82 times the average capacity of the eight Hafeers. Similarly, in table 2, the capacity of the Hafeers in the agricultural area ranged between 194,100 and 217,800 cubic meters with an average capacity of 206,500 cubic meters. The capacity of the proposed approach demonstration site (1.5 km from existing Hafeers) is 1,723,000 cubic meters. This is equivalent to 8 times the average capacity of the three Hafeers. There is no doubt that the draining volume of water does not depend on the catchment area only. Other factors such as, rate, frequency and areal coverage of the rainfall in the catchment area, precipitation, evaporation, and topography and soil type have to be considered. However, still the difference in draining capacity between the traditional methods and proposed approach is very large.

These tests results clearly revealed that the proposed approach can facilitate optimum location of rainwater harvesting sits which can be related to the volume of required water. The method is very simple and easy to apply; the required remote sensing data is available and free of charge. To name but a few, SRTM Global DEM data, ASTER Global DEM, JAXA’s Global ALOS 3D World etc. Also, the remote sensing data processing application programs are available free of charge or of the shelf at reasonable commercial prices. Typical examples of these application programs are QGIS, ArcGIS, SAGA GIS, HEC RAS, HEC HMS, OPEN FOAM etc.

8. Conclusion.

The investigation focused on the role of open source remote sensing data in rural remote areas surface rainwater harvesting. A simple and straight forward remote sensing data based approach was proposed and tested. The results indicated that draining capacities obtained using the proposed approach are larger than those associated with the traditional methods (82 and 8 times in residential and agricultural areas respectively). The worldwide remote rural areas water physical scarcity problem is an acute problem that should be seriously considered using new approaches. It may get very sophisticated by time as the rate of increase in population is fast and these areas are frequently struck by droughts. This would seriously impact the large urban population centers. The consequences are immigration and creation of residential colonies around these centers, which are already experiencing water scarcity and stress. The demonstrated approach represents a reliable solution to the physical water scarcity problem in these areas. The approach is simple to apply, the required remote sensing data is available and free of charge and data processing programs are also, available free of charge or at reasonable prices. Importantly, the research results provided an evidence for the important role the proposed approach may play. Future research on the topic should include more study areas with a large number of traditional rainwater harvesting systems.

Acknowledgment.

This project was funded by the Deanship of Scientific Research (DSR), King Abdulaziz University, Jeddah, under grant no. G: 135-980-1439. The authors, therefore, acknowledge with thanks DSR technical and financial support.

9. References.

[1] J. Worm and T. vanHattum, Rainwater Harvesting for Domestic Use, Agromisa Foundation and CTA, Wageningen, The Netherlands, 1st edition, 2006.

[2] A. Tabassum et al 2013. Rainwater harvesting as an alternative option for sustainable water management of Dhaka city. Availabe: https://www.witpress.com/Secure/elibrary/papers/SC13/SC13028FU1.pdf.

[3] Verma, H.N., Tiwari, K.N., 1995. Current Status and Prospects of Rain water Harvesting. Indian National Committee on Hydrology, Roorkee, India.

[4] Luke Mosley 2005. Water Quality of Rainwater Harvesting Systems. Available: https://www.researchgate.net/publication/242143735_Water_Quality_of_Rainwater_Harvesting.

[5] Duygunur Aslan et al 2018. A Biomimetic Approach to Rainwater Harvesting Strategies Through the Use of Buildings . Euroacian Journal of Civil Engineering and Architecture.

Available:
https://www.researchgate.net/publication/311782273_Historical_development_of_rainwater_

[6] WIKIPEDIA 2019. The states of Sudan, Blue Nile State. Available: https://en.wikipedia.org/wiki/Blue_Nile_(state).

[7] H. A. A. Hamdoun 2014. WATER RESOURCES MANAGEMENT IN SUDAN, Challenges. Available:
https://sustainabledevelopment.un.org/content/documents/2141Country_intervention_on_drought_Sudan.pdf.

[8] B. K. Biswas et al 2014. Construction and Evaluation of Rainwater Harvesting System for Domestic Use in a Remote and Rural Area of Khulna, Bangladesh. Hindawi Publishing Corporation, International Scholarly Research Notices, Volume 2014, Article ID 751952, 6 pages, http://dx.doi.org/10.1155/2014/751952.

[9] DABANGA 2018. All news SUDAN. Available: https://www.dabangasudan.org/en/all-news/article/sudanese-mps-people-dying-of-thirst-in-re.