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The Economic and Environmental Effects of Water Harvesting in Arbaat Region Red Sea State

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Abstract

This research aims at assessing water harvesting and its economic and environmental impacts in the Arbaat Red Sea State area. The hydrological aspects of water resources namely rainfall groundwater and springs in this region were studied within the basin area of (23.040) Km^2. In addition, all the projects aimed at increasing water yield and its impact on agricultural production, pastoral life and forests were identified and studied. Geographic Information Systems (GIS) and Remote Sensing (RS) were used to map the water harvesting area in Arbaat. The data obtained were processed using statistical analytical methods. The results show that there is a correlation between water harvesting, agricultural and livestock production. This was clear in Khor Arbaat Reparation Program (KARP) from (1992-2004). Reports by engineering consultant for groundwater recharge between (1987-2011) expected the increasing of water harvesting from 0.1 m^3/ day in 2002 to 5205 m^3/day in 2011; the total production of 18000 Km^3/ day increased to 23205 Km^3/ day in 2011. Water potential can help achieve a comprehensive and sustainable development in the region concerning agriculture and livestock if it is well supported and financed. The agricultural land is about 4,600 acres, but 1500-2000 acres are cultivated covering 30 % of the Port Sudan market's needs.

Keywords: Khor Arbaat, Water harvesting, Khor Arbaat Reparation Program, Red Sea State.

1. Introduction

The Red Sea State is located between latitudes 17- 23.2° N and longitude 35- 38.5° E (Figure 1). Arbaat region is located in the north - east of the state, twenty kilometers from Port Sudan, with an area of 54.850 acres. Arbaat region consists of three areas, the first one is Arbaat Al Muwyh that lies between the upper and lower gates at the narrow entrance of khor Arbaat. This area is considered hilly with steep slopes of 1/120 meters degree with a limited agricultural potential (Bun, 1980). The second area is Arbaat Alziraa starting at the lower gate confined between the lower gate and the Red Sea coast with a steep slope of 1/200 meters degree. It is fan-shaped and the component delta covers an area of 25 km with stabilization in housing and agriculture, stretching up to the coast region, which represents the third area in the Arbaat region (Bailey, 1987).

As mentioned earlier, the average per capita daily water consumption in Port Sudan is less than ten liters per day. Water problems in the Red Sea State led to the flow of many investors and the migration of most of the productive sector to other locations inside or outside the country which left quite negative impacts on the economic activities of the rigion and led to the closure of about 70 % of the factories there.

2. Research Problem

Despite the efforts which had been made to tackle the issue of water harvesting in Khor Arbaat, the positive economic and the environmental impacts are still limited. This research shows that there are still natural hydrological, and biological problems, especially in farming, herding and in the forests, in addition to the lack of scientific and strategic plans which prevents projects from reaching the standards of sustainable development in the region.

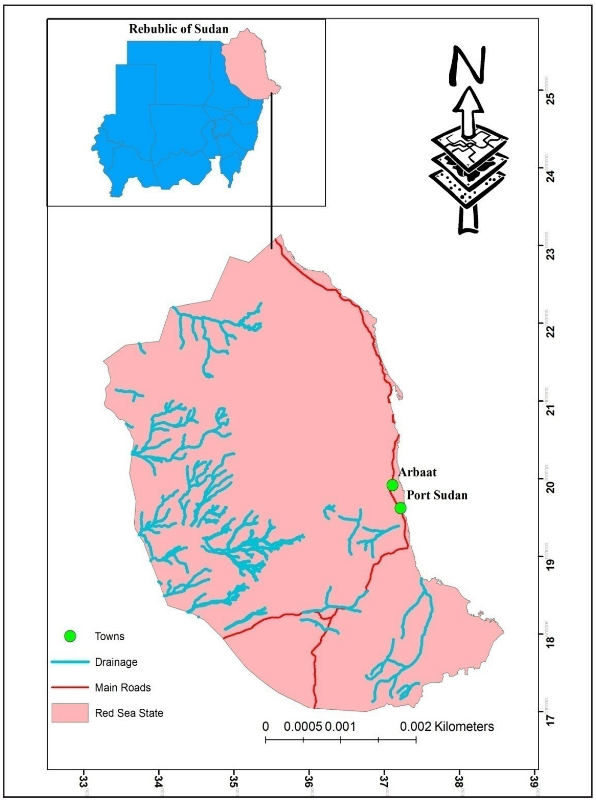

Figure 1. Red Sea State

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3. Research Objectives

The main objectives of this research include: (1) Assessing the strategic significance of Khor Arbaat as a main source of fresh water in the region, (2) Determining the water budget and how to manage it for various purposes, (3) Highlighting the obstacles and problems which reduce the optimum exploitation of Khor water, and (4) Submitting proposals and solutions for the sake of increasing the water yield in the region.

3.1. The Study Area

Arbaat region is classified as coastal arid and semi - arid regions, with the average annual rainfall in the northern part being 50 mm and increasing to the south to more than 200 mm in winter (Bashir, 1991). The wind is northwest. The climate of the region is affected by the Red Sea hills and the coast beside the orbital separator (Dabalob, 1999). The geology of the region is characterized by basement rocks, tertiary volcanic and surface sedimentary rocks, with barrier reefs at the coast (Musa,1989). The region has mixed soils, which consist of silt and sand, and a rough texture with limestone. Mangrove, that is naturally grown, dominates the area of the coastal plain, while Acacia sp dominates the area off the sea coast (Satter, 1989).

3.2. Drainage System

Khor Arbaat comes from the catchment area (Odroos) in the mountainous region, flowing from the west to the east towards the Red Sea. The storage capacity of Khor Odroos is about 2.7 million cubic meters (MCM) of water. The upper Khor reaches a distance of 90 km towards the north and 40 km towards the northeast and the width of the Khor is between 1500- 2000 meters forming a fan - shape delta following the upper gate. It has been divided into eleven branches (Dhrab, Aichenk, Ahgeor, Kspaa, Kmueb, Houphouet, Blonay, Balmiat, Kmoa, Waco). Figure 2 shows the drainage system of the Arbaat Basin.

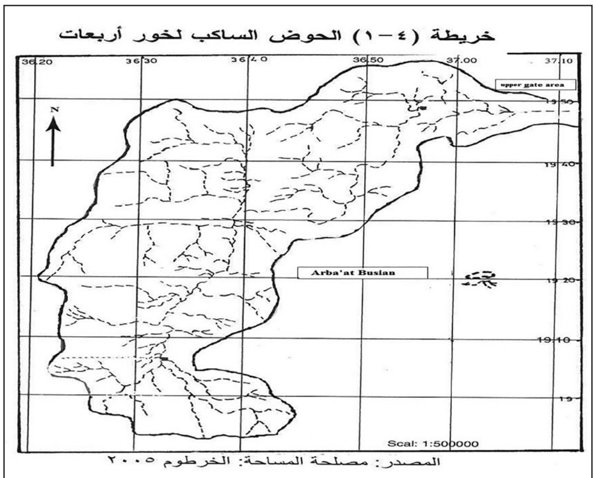

Figure 2. Drainage system of Arbaat Basin (Source: Remote Sensing Authority, 2007)

3.3. Khor Arbaat

Khor Arbaat is about 165 km long forming a fertile alluvial soil in the Arbaat Delta. The average annual discharge of Khor Arbaat is about 18.450.000 meter^3 (Baashr and ALmahey, 1998; Kabashy, 2002). It consists of a series of streams, which come from Odroos in the mountains. The total area is estimated to be about 50 thousand acres including forests, the housing area, and agricultural land. The estimated arable soil is approximately 33.000 acres, while the exploited area is between 2.000 -5.000 acres. Irrigation depends on spate irrigation and rain for the cultivation of maize, millet and some vegetables. (Kabbashi, 2002). Figure 3 shows Khor and the Arbaat's Delta location from Land sat 8 (2016).

3.4. Important Tributaries of Khor Arbaat

Following are the main important tributaries of Khor Arbaat:

- ***Khor Aychenk:*** This is the largest tributary of Khor Arbaat. It runs from west to east ending in the Arbaat Delta; its soil is characterized by sandy gravel. The flora of this Khor consists of Cappories deciduas and Prosopis chiliensis.
- ***Khor Oujor:*** This tributary covers a large area up to the position of the Delta; the soil is sandy gravel, the vegetation includes Prosopis chiliensis.
- ***Khor Hamshdow:*** is one of the important tributaries of Khor Arbaat.
- ***Khor Dhrab:*** This is the main branch of Khor Arbaat, running from the mountains towards the Delta, with a sandy soil, and arid-zone plants including Hyphaena thebaica, Salvadora persica, Capparis decidus (Dablob, 1998).

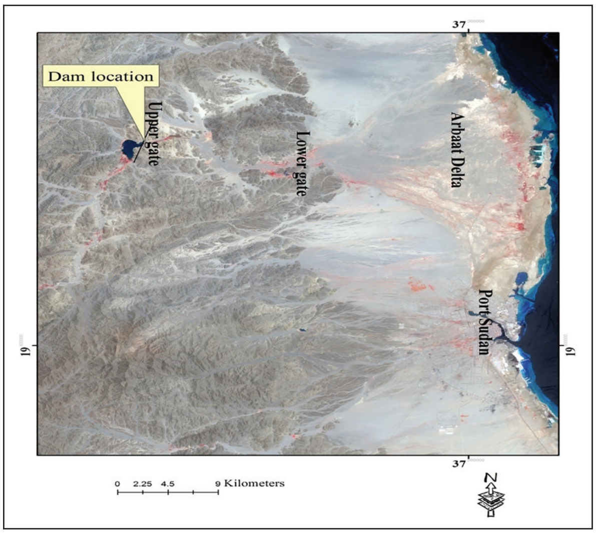

Figure 3. Khor and Arbaat Delta location from Landsat 8 (2016).

4. Materials and Methods

There are several difficulties encountered in the process of collecting information and conducting a field survey, including the lack of resources and studies on the region.. Moreover, the inhabitant local tribes are often found to be not cooperative enough to respond to researchers and their questions. The current research is based on personal interviews and research reviews to investigate the economic and environmental effects of water harvesting in that region. It also depends on a (KARP) project from 1992 – 2004. It studies the hydrological aspects of water sources from precipitation, groundwater and springs, based also on reports and some studies done by the Ministry of Irrigation and Water Resources and Metrology Department in the Red Sea

State. Geographic Information System (GIS) and Remote Sensing (RS) were used to map and locate the Arbaat basin and delta. The data obtained were processed using statistical analysis methods to analyze the available hydrological and metrological data for the detection of the impact of water harvesting on the environment and the economic activities in the Arbaat region.

5. Results and Discussion

5.1. Rainfall

Figure 4 shows the annual rainfall in the Arbaat basement from 1944 to 1990. The years 1950 and 1957 represent the highest rainfall records, while the period from 1958 to 1990 shows a lower rainfall representing the drought period in the state. Based on the temporal distribution, it is clear that the rainfall is scarce and irregular.

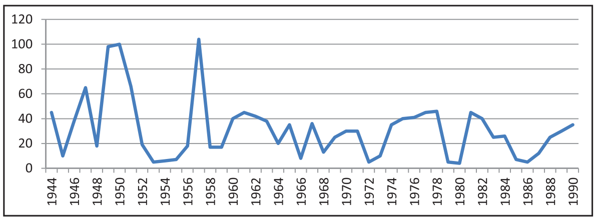

Figure 4. Annual rainfall/mm in Arbaat basement from (1944-1990).

Based on the seasonal distribution of rainfall, table 1 shows that most of the rainfall occurs in November, and thus most water recharge is derived from the winter season. According to the statistical analysis of annual rainfall moving average of 10 years, Table 2 shows that the arithmetic mean does not provide a clear explanation for the amount of precipitation due to the existence of huge variability in the annual precipitation.

Table 1. The seasonal distribution of rainfall

Rainy month (November)		Summer rain (July & September)		Winter rain (October & November)	
Rainfall (mm)	Annual rain%	Rainfall (mm)	Annual rain%	Rainfall (mm)	Annual rain%
20	47	9	21	26	60

Ministry of Irrigation and Water Resources (1999).

Table 2. Statistical Analysis of Rainfall / mm in 10 years

Years recorded	Arithmetic mean	standard deviation	Dry years 8 of 10	Average for the past (5 of 10)	Rainy years (2 of 10)
27	43mm	39mm	6mm	33mm	80mm

Source: Ministry of Irrigation and Water Resources (1999)

The maximum runoff, size of the flow and the duration of output have been analyzed and calculated using available hydrological data, metrological information and field work, which can be summarized as follows:

There is a lot of water entering the basin area and is dispersed in a large area used for agriculture and pastures which improved the Arbaat region environment. Table 3, shows the maximum surface runoff per cubic meter per second.

Table 3. The maximum runoff /m^3/sec.

Basement area (km2)	years	Maximum flow recorder	Flow (Return time)			
			2	10	50	100
4850	18	400 m^3	200 m^3/sec	450 m^3/sec	700 m^3/sec	800 m^3/sec

Source: Ministry of Irrigation and Water Resources (1999)

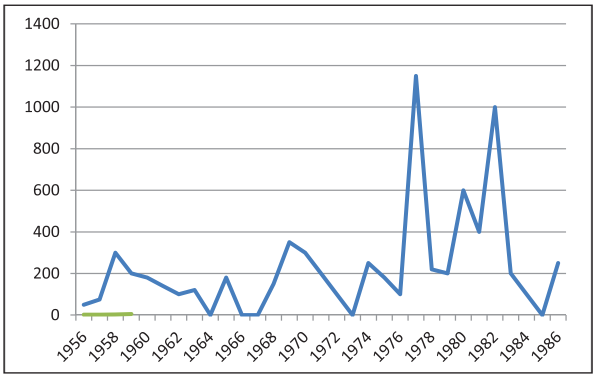

Figure 5. Annual floods rates/m^3 between 1956 – 1987.

From Tables 3 and 4, and Figure 5, it can be noted that there is a connection between the basin area and annual runoff. The duration of runoff increases the basin area. There is a relationship between the distribution of rainfall and the duration of runoff.

Table 4. Annual Runoff and Flood in the Basin.

Basin area	Years Surveillance	Maximum levels recorded	Dry years 8 of 10	Average for the years 5 of 10	Rainy years 2 of 10
Total annual runoff / MCM	18	67.8	4.5	11	26
Annual floods m^3 / year	17	990	250	430	820

Source: Ministry of Irrigation and Water Resources (1999)

5.2. Spring Water

The spring and seaport water is concentrated in the upper gate area which produces about 7,000 to 11,000 m^3 of water per day throughout the year. Winter rainfalls are the main source of the continuity of the spring water which reached 6.440 m^3. Figure 6 shows rates of monthly spring water.

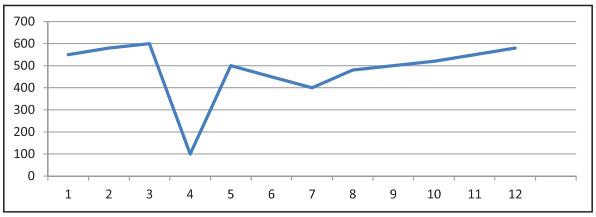

Figure 6. Rate of Monthly Spring Water Discharges/m^3.

5.3. Groundwater:

There are numerous studies of the groundwater wells in the region (e.g. Hussein, 1975; Musa, 1989) which explore the movements of the groundwater and identify the nature of the water rock features. From these studies, it is clear that the water stone rock for the well region extends to about 22 km, 12 km from the upper gate and 10 km from the lower gate. The variable depths of wells ranged between 3-15 meters or more depending on water strength and density This is associated with a high level of surface runoff and the extent of coverage of the rock layer; and the average of rock density and porosity coefficient is 0.2. The water storage capacity of the rocks of khor Arbaat is 48 MCM. The increasing of water and recharge in cubic meters per month was identified by studying the current annual runoff, and by analyzing the increasing level of water rock and natural water loss by evaporation, transpiration and drought, as shown in Table 5.

Table 5. Water increase per month in cubic meters

Month	Recharge /m^3
July	302 500
August	303 000
September	306 000
October	305000
November	405000
December	501 000

Source: Field work based on the Office of Engineering Consultants (2002)

According to the work done by researchers based on the information collected from Office of Engineering Consultants (2002), it is clear that groundwater rises in November and December on the basis of the flood compared with the rainfall. From Table 6, and according to the engineering consultant's studies in (2002), there was reserve water in the wells as a result of storage that can be exploited for various uses.

According to Hussein (1975), it is clear that in spite of the incomplete data, the application of various equations, there is no surplus water in the Khor due to the large quantities of water that flooded towards the sea and those are estimated at 359,000 m^3 / day. This water can be harvested and used in the development of that region.

5.4. Assessment of Traditional and Modern Water Harvesting:

1 / Diversion Dams:

These are earth dams built for agricultural purposes to divert water and irrigate farm land. Farmers built a number of dams, which take the form (U).They were traditionally weak and were destroyed by floods; therefore, they are considered less effective and have a negative impact on the soil texture due to flooding, siltation, escarpment in addition to the need for annual maintenance.

2 / Storage dams:

Three reservoirs exist in Arbaat area (the fourth tank, the entrance gate and upper gate tank). There has been a number of studies conducted to for the sake of constructing a storage dam in Arbaat (the upper gate dam). A study in 1987 recommended the constructing of a storage dam 20 km from the upper gate with a storage capacity of 5 million m^3 / hour. Another study in 1991 recommended that the dam must be constructed about 3.2 km from the upper gate with a storage capacity of 100 million m^3. According to a study conducted in 2002, a storage dame was constructed focusing on increasing the groundwater level. A report issued by some engineering consultants in 2002 stated that there will be an increasing in the groundwater recharge after the dam construction. Table 7, explains the increase in the groundwater recharge in different years.

Table 6. Assessment of wells recharge and the flow from 1972 to 2000

Year	Water Increase	Changes in storage ($10^6 m^3$ / sec)	The amount of water with drawn (10^6 m^3)	Recharge ($10^6 m^3$ / year)	The value of the budget ($10^6 m^3$ / year)
1972	3.6	8.64	5.480	14:48	9
1973	2.3	5.2	6.278	11.80	5.52
1988	7.0	16.80	6.57	23:37	16.8
1991	4.0	9.60	6.94	16:54	9.6
1993	8.5	20.4	7.3	27.3	20
2001	2.5	6.0	6.21	12:11	5.59
Average	**4.65**	**11:16**	**6.52**	**17.68**	

Source: Ministry of Irrigation and Water Resources (1999)

The area of the dam lake is about 5 km^2. It depends on the increase or decrease of seasonal water runoff and rainfall. It is one of the largest dams and is considered new because production began in 2004. Figure 7 shows the Arbaat basin and Delta location.

Table 7. Ground water recharge from (2002-2011) in m^3/day

years	No. Well	Expected production (m^3 / day)	Expected increase (m^3 / day)	Total production (km / day)
2002	10	18000	1.0	18000
2003	27	18000	7945	25,945
2004	27	18000	7123	25123
2005	27	18000	6849	24,849
2006	27	18000	6301	24301
2007	27	18000	6301	24301
2008	27	18000	6027	24027
2009	27	18000	5753	23,753
2010	27	18000	5479	23479
2011	27	18000	5205	23205

Source: Ministry of Irrigation and Water Resources (1999)

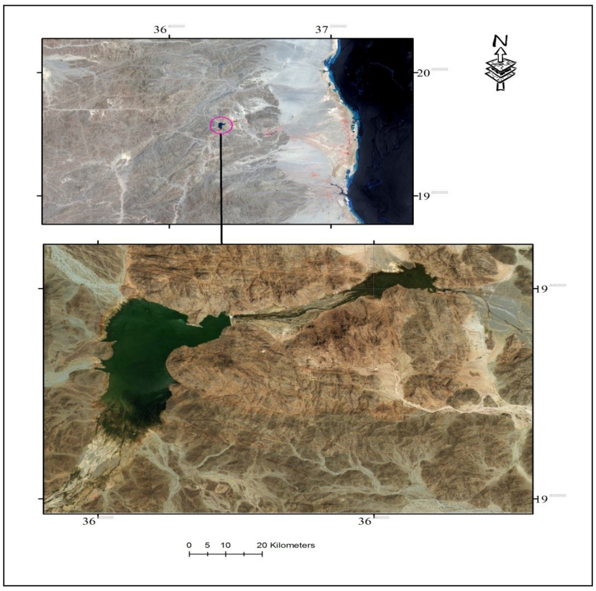

Figure 7. Khor and Arbaat Delta location from Land sat 8 (2016).

6. Arbaat Reservoir

6.1. Groundwater Levels

The fluctuation in the underground water level from one well to another has been different in a single season.

6.2. Feeding of the Reservoir

In the year 1971, the reservoir provided the city with about 12 million cubic meters, about with 9 million cubic meters in 1973.

Water-bearing Geological Formations

The presence of water in the composition of rocks occurs through the cracks, but it is relatively not much compared with the water found in sedimentary rocks.

The water-bearing rocks are mainly composed of homogeneous rock foundations such as stones and gravel deposited in Khor as result of weathering (Ahmedon, 2008).

6.3. Reservoirs Extension

The underground reservoir extends from the supreme gate to the lower gate over an area of approximately 10.177 $km^{2.}$ The average prone is between 1.310 km^{2} and 13.3 km^2 (Ahmedon, 2008).

6.4. Storage Capacity

The storage capacity of the reservoir ranges from 36 to 48 million cubic meters, with the highest amount of storage reaching about 54 million cubic meters during the flood season (winter. The lowest discharge is 3 million cubic meters in the summer season; however, the average storage capacity in summer is 10 million cubic meters. (Adam, 2006).

Water Harvesting and its Economic Dimensions in Arbaat Area

According to a report recorded by SOS (1995, 1996, 1997, 2001) the first economic agricultural project in Arbaat region was in 1918. It was a project about cotton and tobacco cultivation using flood irrigation. A report from Soil Conservation Management in (1944) recommended reforestation in the Arbaat Delta to produce fuelwood for Port Sudan city. Between 1950-1955, cotton production was increased and also exported. The project was developed with funding from the US for the years 1960- 1961 by constructing earth dams in the lower areas of delta toward the east direction in Khor Hmshdo and Khor Dhrab (SCE, 2004). Since the beginning of the eighties, agricultural production has deteriorated due to the lack of water, the poor conditions of the existing dams, and the unstable repairing and maintenance operations until the initiation of Khor Arbaat Reparation Program (KARP) in 1993 (SOS, 1997).

According to the (KARP) studies, it is clear that there is a positive connection between water harvesting and the agricultural production process, which can be clarified as follows:

The area of agricultural land is 4,600 acres, from which 1500-2000 acres were cultivated. This area covers about 30 % of the Port Sudan market's needs. According to a field study, there is a relationship between the increase in agricultural productions and the amounts of available water. Figure 8, shows the relationship between agricultural production and water harvesting in tons. The storage capacity of the reservoir ranges from 36 to 48 million cubic meters, with the highest amount of storage reaching about 54 million cubic meters during the flood season (winter. The lowest discharge is 3 million cubic meters in the summer season; however, the average storage capacity in summer is 10 million cubic meters. (Adam, 2006).

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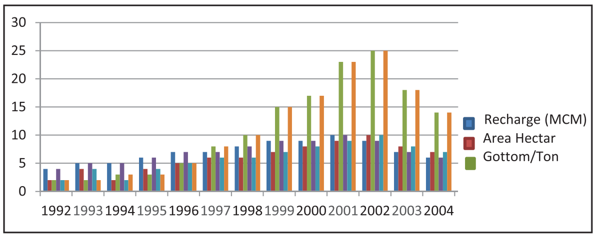

Source: Prepared according to a fieldwork research results (SOS, 2001)

Figure 8. The relationship between agricultural productions and water harvesting in tons

From figure 8, it is clear that the over the duration period of Khor Arbaat Reparation Program (KARP) (1996-2002) there was an increase in productivity per tons. During this time water has been harvested in eleven branches of khor Arbaat which feed the Delta.

When funding ended in 2002, the project began to decline gradually even at the present time as a result of lack of routine maintenance which led finally to the collapse of most of the dams.

6.5. Water Harvesting and Livestock

Khor Arbaat is a rich area where different varieties of livestock were found. Records from SOS (2001) show that 72 % of the population own goats and 13 % have sheep and 15 % own qualitative livestock. There are several problems faced by livestock owners and these can be summarized as follow:

- Mobility, where pastoralists move long distances seasonally with their families in the winter season to the coast; this is referred to as (gunap trip), and in summer they move to the mountains; this is called the (Alooulib trip) due to precipitation and its effects on the growth of the weeds in those seasons.These lead to a decline in specific plants including Panicum turgidum and Capparis deciduas and the increase of the invasive plants such as Prosopis chilensis.
- There is a clear shortage in water in this region. 66 % suffer from lack of water; 9 % rely on pipelines; 15 % rely on wells and 10 % on flood water (Cole, 1989). The technique of water harvesting can solve all these problems and may increase the cultivation of forests and rangelands in order to stabilize pastoralists and provide them with drinking water. This can increase animal livestock and production for the Port Sudan city market.
- The increasing of agricultural and livestock production in the region along with an improved chance of marketing in Port Sudan city can create jobs and intermediate trade. These local economic activities can raise the income of Arbaat communities, thus improving the living standards and health services in the region which suffers from poverty and lack of work opportunities. Water harvesting in the region is the perfect choice to achieve better and sustainable levels of development.

7. Conclusions

Through the evaluation of (KARP) projects for water harvesting in the Arbaat area over the period from 1992 to 2004, it becomes clear that the increasing of water output in the dams, led to a rise in the levels of well groundwater in the region This has enhanced the cultivated area and pastures. An open market for the livestock and agricultural products in Port Sudan city can create employment, intermediate trade, and transportation. This can in turn contribute to the per capita income of the Arbaat population and improve the living standards, health conditions, and health services in this region that has been suffering from poverty, very limited work opportunities and high unemployment rates for a long period of time. Water harvesting remains the best solution to achieve the best levels of sustainable development in the region.

In conclusion, this research paper offers the following set of recommendations that can hopefully help in the stability of this region in the future.

Recommendation

1- A sustainable maintenance and periodic monitoring of water harvesting projects.
2- Conducting geological and metrological studies continually on precipitation and runoff to reduce the risk of droughts.
3- A follow - up treatment of special problems of water reserve from sedimentation and silting and their impact on the soil types.
4- The cultivation of lands around valleys and dams is a source of benefit for the environment.
5- A follow-up evaluation of the agricultural expansion and the education of farmers to contribute to the production process.
6- Using modern irrigation techniques such as drip irrigation.
7- Protecting agricultural and livestock production to achieve attractive and stable prices.
8- Controlling the spread of Mesquite trees, especially in agricultural lands.
9- Developing the laws and legislation of water management.

References

Adam, E.T.B. (2006). Hydrology of Khor Arba'at - Faculty of Earth Sciences, Red Sea University (Port Sudan) (supplementary research for the degree of (BA).

Ahmedon, A.B.A. (2008). Chemical Characterization of Catchment Area and Water of Arbaat Region. Ph.D thesis in Environment and Resources. Red Sea University.

Bailey, K. (1987). Method of Social Research. ed. free press, New York .

Bashir, M.K.A. (1991). Rainfall in Red Sea Province.

Bun, (1980). Reconnaissance of groundwater and surface water Resources in coastal area of Sudan, Red Sea hills, Sudan, Report GRAS, Khartoum (1980).

Cole, R. (1989) Measuring Drought and Drought Impact in The Red Sea Province, Oxfam Publication, London.

Dablob, S.H. (1998). A working paper entitled: Program of priorities for combating drought and desertification in the Red Sea State, workshop.

Dabalob, S.H. (1999). Desertification in the Red Sea state.

Hussein, M.T. (1975). Hydrogelogical Investigation of Khor Arbaat Basin, Bull. No.28. Geological and Mineral Resources, Khartoum, Sudan.

Kabbashi, Mohamed El Amine, (2002). Red Sea State, Drinking Water Conference: Risks and Treatments - Khartoum - UNESCO Water Chair. Arab Organization for Agricultural Development.

Ministry of Irrigation and Water Resources (1999), Sudan.

Musa, M.M. (1989). Structural geological Study of the upper gate area (Arbaat ') for suggested dam site. GRAS. Port Sudan unpublished.

Satter, R.G. (1989). The Charcoal Producers of tambek: Integrated Study of Sea Hills, C and. Scient thesis, Oslo.

SOS, Sahel International Organization in Sudan. (1995). Soils and Use in Khor Arbaat Delta, Hunting Technical Services LTD.

SOS, Sahel International Organization in Sudan. (1996). Women of Khor Arbaat Delta.

SOS, Sahel International Organization in Sudan. (1997). Review of Khor Arbaat Rehabilitation Project.

SOS, Sahel International Organization in Sudan. (2001). Evaluation of Khor Arbaat. Rehabilitation Project.