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Assessment of Rainwater Harvesting Techniques and Practices for Domestic and Crop Production Purposes in Kassala State-Sudan

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Abstract: Managing water resources in a sustainable manner is utmost important, especially where water is scarce in arid and semi-arid zones. The main problems associated with water uses in Sudan are limited water storage capacity, evaporation from large water bodies (reservoirs, Hafirs, irrigation and drainage network), sedimentation accumulation in dams and irrigation canals, land degradation deforestation and repeated drought cycles, weeds infestation and bank erosion. Hence there is a need for efficient water management in Sudan. This study is conducted in Kassala state which lies in the arid region in Eastern Sudan where rainfall characterized by low annual amount. Rainwater harvesting techniques (RWHTs) are widely practiced in the state for two purposes; domestic water supply and crop production. The main objective of this study is the assessment the rainwater harvesting techniques practices for both domestic water and crop production purposes. The analysis of 30 years rain data shows that the dry years were dominant 54%, there were repetitive drought cycles with lengths of four years (2008-2011). The wettest cycles were four years (1987-1990), rainfall in the study area shows a decreasing trend. Rainfall in the area is variable in space and time and has a localized nature. Terraces are the dominant rainwater harvesting technique for crop production it increases the crop yield to five folds in some cases. The area experiences water soil erosion problems due to deterioration of vegetation cover. Transferring water from the wettest part (southern of the state) to the driest northern part is a viable solution. Hafir should be placed in the opposite direction of wind direction to decrease the wind erosion for embankment and evaporation. Increasing the hafir depth rather than width and length may minimize the evaporation losses.

Key words: Water harvesting techniques · Dry areas · Crop production

INTRODUCTION

Water is essential for life and it is vulnerable resource. Around 1.2 billion people live in areas of physical water scarcity and another 1.6 billion people encounter economic water shortage [1]. Therefore, managing water resources in a sustainable manner is utmost important, especially where water is scarce such as in arid and semi-arid zones. Water resources in Sudan consist of: rainfall, estimated at 1000 km^3; the Sudan's share in the Nile river that is 18.5 km^3, non-Nilotic rivers (5.5 km^3)and the renewable ground water which is estimated at 4.0 km^3 [2]. Based on the Ministry of Irrigation and Water Resources projection, the total annual demand of Sudan would be 48km^3 by the year 2027. The current total available water is 30 km^3, resulting in a deficit of 18 km^3. Accordingly, there is a need for efficient water management in Sudan. Ahmed (2006)[3] suggested that the main problems associated with water uses in Sudan as being: limited water storage capacity, evaporation from large water bodies (reservoirs, Hafirs, irrigation and drainage network), sedimentation accumulation in dams and irrigation canals, land degradation deforestation and repeated drought cycles, weeds infestation and bank erosion.Kassala state lies in the arid region where rainfall characterized by its low annual amount, high spatio-temporal variability coupled with high evaporation rates that is 7 – 10 times the annual rainfall for some periods, resulting in a large water deficit and low vegetation cover let alone the high degree of erosion and soils and the low water retention and absorption capacity of soils. The flat plain covers 80% of Kassala state where it lies beneath basement complex formations with poor ground water resources Therefore, groundwater sources in the state tend to be distributed along the cracks in the geological formation and the few

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areas where alluvial deposits accumulate. The largest state's aquifers is the Gash Basin which has an estimated strong capacity of 600 million cubic meters and runs North, from the Eritrean high land and through Kassala town.

A rural livelihood depends largely on rainfall and its management. Rainwater harvesting techniques (RWHTs) are widely practiced in the state for two purposes; domestic water supply and crop production. Few studies conducted on the evaluation of RWHTs for those two purposes. The main objective of this study is the assessment the rainwater harvesting techniques practices for both domestic water and crop production purposes. The specific objectives are to assess the hydro-climatic performance of Hafir water for domestic water supply and the performance of rainwater harvesting techniques in crop production.

MATERIALS AND METHODS

Kassala state (14.86 – 17.02 ^{0}N and 34.09– 37.55^{0}E) is composed of eleven localities (Fig.1), of which nine are primarily rural in composition while the two localities of Kassala and New Halfa are the urban localities.

The soil is varied from heavy dark clay soil formation in the southern area to the lighter, highly permeable clay soil in the northern part of Kassala state, supporting rain fed agricultural system (The climate is dry). Annual rainfall ranges from 83 mm in the northern part of the state to around 300 mm in the Southern part of the state. The evapotranspiration is very high estimated at 12mm/day. A decline trend of 2.6 mm in rainfall is observed since 1940 in the state, humidity is around 36% increases in the rainy season. Wind speed about 6.5m/h. The state slope is from South to North and Northwest with gradient 1m/1200m.

Data were collected using three approaches. Field survey trip, questionnaire and offices time series recorded data. A survey trip is carried out in order to obtain the coordinates of all hafirs and small dams using GPS. The collected data included Hafirs dimensions (top width, bottom width, bottom depth, top length, bottom length, top depth, Embankment heights, inlet and outlet dimensions). The collected data were used to estimate the storage capacity of studied Hafirs using the following equation:

$$V= (A+A1)* (½) *(h)$$

Where:
V= is the volume of hafir
A= is top area of hafir
A1= is bottom area of hafir
h = depth

A questionnaire was designed. The total sample size is 61 distributed on the villages shown in Table (1). The data were analyzed using SPSS package and excel sheets.

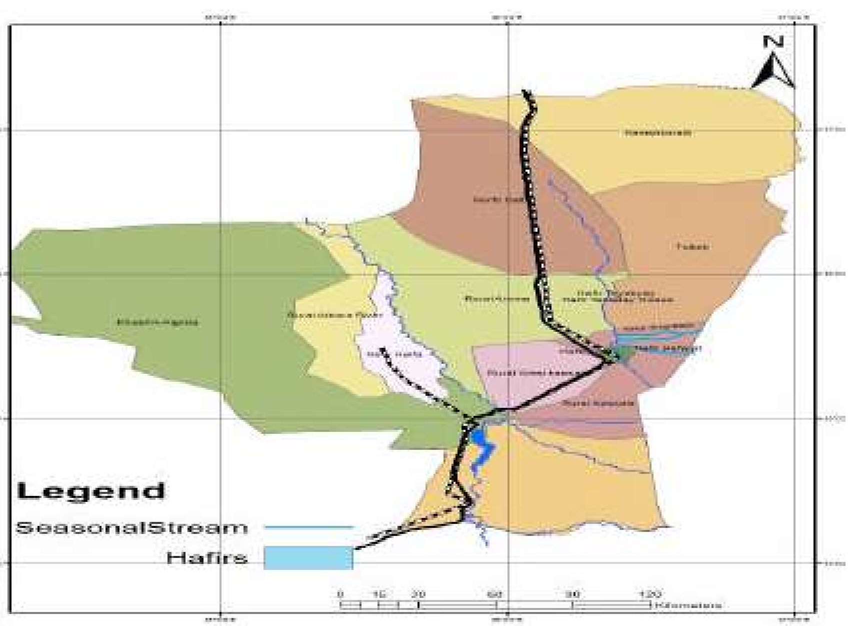

Fig. 1: The Study area (Kassala state map)

Table 1: Questionnaire's selected areas

Village	Locality	Population	Villages Co-ordinate	
Hafarat	Rural kassala	1302	15.480500N-	36.557810E
Umsafary	Rural kassala	1635	15.47294 0N	36.54428 oE
Kollil	Rural kassala	407	15.453600N	36.26870oE
Tyakyay	Tulkok	2500	15.8400000N	36.380000oE
Tahdayosses	Tulkok	4183	15.6300000N	36.420000oE

RESULTS AND DISCUSSIONS

Rainfall is variable in space and time, especially in arid and semi-arid climatic zones. Figure (2) shows the annual rainfall in Kassala state, it decreases from Southern parts to Northern regions. The average annual rainfall was estimated at 221 mm for the period 1980-2011. This is coupled with a standard deviation of 103 mm, giving a coefficient of variation of 46%.

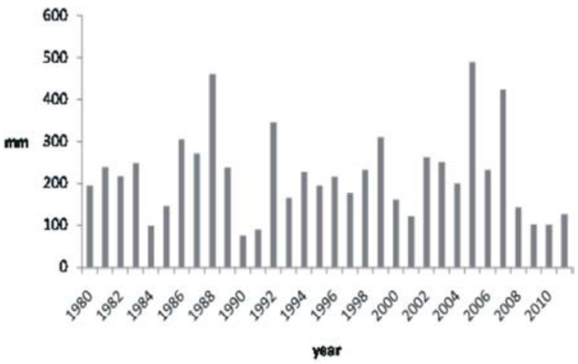

Fig. 2: Annual rainfall in Kassala state

The analysis of the last 30 years shows that the dry years (below normal) were dominant (54%). Also, there were repetitive drought cycles with lengths of four years (2008-2011), three years (1995-1997) and 2 years (2000-2001); whereas the wettest cycles were four years (1987-1990), three years as shown in Figure (3). Currently, rainfall shows a decreasing trend. Generally, this high rainfall variability should be well considered in managing water resources in Kassala state, especially hafir waters.

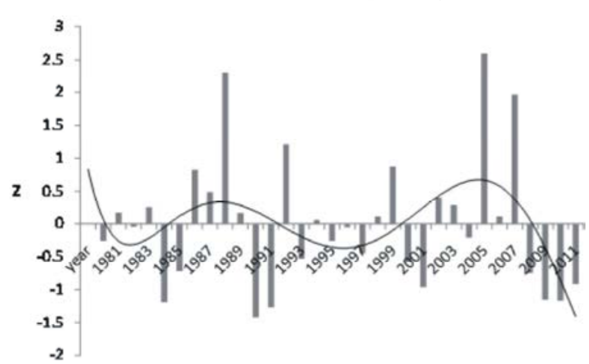

Fig. 3: Trend of annual rainfall in Kassala state

Rainwater Harvesting Techniques (RWHTs): Table (2) shows the livelihood generation at the studied locations. It is obvious that the majority practices are agriculture (86%).

Table 2: Livelihood generation options

Valid	Frequency	Percent	Cumulative %
Farming	51	83.6	83.6
Grazing	1	1.6	85.2
Farming& Grazing	6	9.8	95.1
Other	3	4.9	100.0
Total	61	100.0	

Therefore, managing rainwater using RWHTs is inevitable. According to the results and analysis of the questionnaire terraces and hafirs were found dominant RWHTs as 70.5% of the people are applying three RWHT (Figure 4), purposefully used for crop production (Terraces) and domestic water supply (Hafir) in Kassala state. The latter purpose appears to be slightly dominant. Most of the farmers indicated that the adoption of terraces resulted in increasing the crop production, averaging in 180 - 450 kg/feddan and it may reach 450 - 540 kg/feddan as shown in Figure (5).

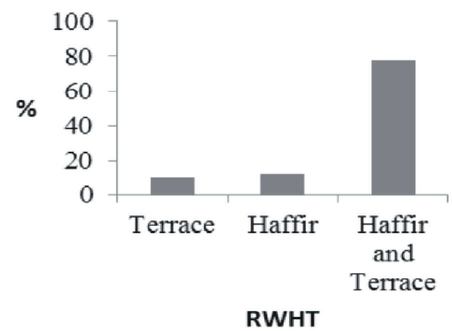

Fig. 4: Dominant RWHT in Kassala state

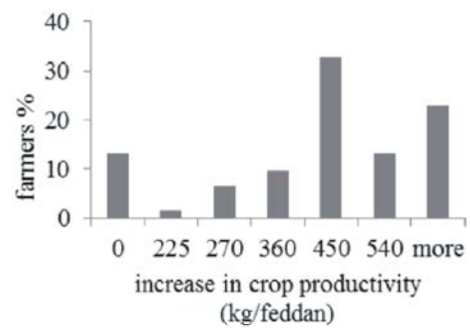

Fig. 5: Increase in crop yield using RWHT

On the other hand, about 33% stated that the crop production (sorghum, maize, sesame…etc) could be stable at 180 kg /feddan without the adoption of RWHTs (Table 3). The majority however stated that RWHTs increased the crop production five folds. Not with standing, about 13.1% of the questioned people indicated that the adoption of RWHTs resulted in a zero increase in crop yields. This may be attributed to natural causes (failure in the rainy season itself) and to man-made causes (lack of scientific concepts in the designed RWHTs).

Table 3: Crop yield (kg/feddan) without using RWHT in Kassala state

Yield kg/fed.	Percent	Cumulative percent	Yield kg/fed.
0	16.4	16.4	0
90	21.3	37.7	90
180	32.8	70.5	180
270	19.7	90.2	270
360	3.3	93.4	360

Among the factors that could affect crop yields, rainfall variability ranked first (50.8%); whereas 14% believed that the adoption of RWHTs could affect the crop yield as shown in Table (4).

Table 4 Factors affecting production increase

Factor	Percent	Cumulative percent
Rainfall	50.8	50.8
RWHT applied	14.8	65.6
Rainfall and RWHT applied	34.4	100.0
Total	100.0	

This is stating that rainfall and RWHTs are the main factors affecting crop yield, confirming that the sustainability of RWHTs depends largely on both amount and timing of rainfall as also stated by [4]. Hafir, shallow well and Borehole are the main sources for drinking water supply in Kassala state. The dominant Hafir, being (23%). However, in many places two sources may exist simultaneously as for example 42% was found using both hafir and shallow wells as presented in Table (5).

Table 5 Drinking water Sources

Valid	Percent	Cumulative %
Hafirs	23.0	23.0
Borehole	3.3	26.2
Shallow well	3.3	29.5
Hafir and water point	9.8	39.3
Hafirs & borehole	18.0	57.4
Hafir and shallow well	42.6	100.0
Total	100.0	

The hydro-climatic analysis revealed that the majority of hafirs start the filling process in July (59%), however considerable percentages start in June (27%) as depicted in Table (6).

Table 6: First inflows received at hafir

Period	Percent	Cumulative percent
July	59.0	59.0
August	9.8	68.9
June	27.9	96.7
May	3.3	100.0
Total	100.0	

It is found that the filling process follows the rainfall spatial distribution since those villages located at the south-eastern part of the state such as Hafarat, Kollil and Umsafary villages used to start the filling process in July, whereas the Northern-western villages (Tyakyay, Tahday Osses) used to start in June, i.e. the rainfall starts earlier in the Southern part. The differences found in the starting times of filling reflect the high spatio-temporal variability of the rainfall in Kassala state. The peak discharge is received in August as most of the hafirs are fully in August (57%). However, 27% are fully in September (Figure 6).

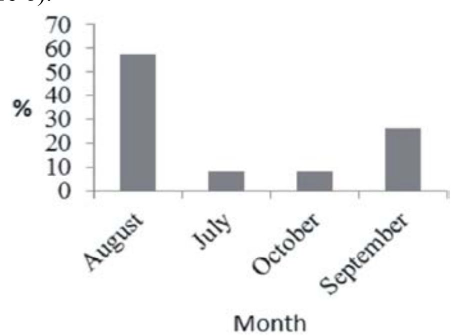

Fig. 6: Full capacity period at the hafir

These results indicated the localized nature of the rainfall, i.e. most of the hafir waters accumulated as a result of local rainfall. However, appreciated amount is received through minor streams/ khors, which are affected by the rainwater concentration time, catchment size, slope length, slope gradient, in particular and runoff coefficient in general. The storage capacity of the hafir ranged between 9 – 60 thousand cubic meters. This amount lasts for 3-6 months as observed by local people, depending on the location, hafir characteristics (soil type, physical and chemical characteristics) and hafir water management.

Table (7) shows the estimated water consumption (human beings and livestock) at selected villages. About 86% said they are satisfied with the current hafir capacity. The hafir water is mostly managed by local committees (93%), whereas the NGO's contribution does not exceed 5% and 1%.Thus, managing hafir water qualitatively and quantitatively depends largely on local experience. However, the education level is found very low since the majority (62%) is illiterate, 32.8% with primary education and both the high and secondary education and universities levels are limited to less than 5%.

Table 7: Populations and animals water consumption

location	Number of animals Camels	Cows	Goats	Sheep's	Population	TC* (m^3/month)
sHafarat	15	480	2600	1200	1302	4155
Umsafary	10	200	3400	1500	1635	3981
Kollil	16	180	3200	1200	407	3428
Tahdayosses	310	250	5300	680	4183	7165
Tyakyay	170	100	3700	2200	2500	5873

On one hand, the people are poor due to low income, in spite of this they buy water and consume their time looking for water. The lack of water affects their daily working hours which are spent looking for water on the expense of the family income. Shepherds take their animals far from town looking for water and this is reflected in increased cost of fresh milk in spite of large numbers of reared animals [5].

Table (8) indicated that the current and design dimensions of hafirs at the studied locations. It is clear that there is a mismatch between the actual and designed dimensions. For instance, the top and bottom lengths of hafirs were varies in average by ± 18% and ±13%, respectively. These changes affected the storage capacity of the hafirs. For example, the current storage capacity of the hafir at Tyakyay village is reduced by 10% due to silt accumulation, indicating the land degradation problem (soil water erosion), which may be attributed to deterioration of the vegetation cover.

Table 8: Comparison between design and actual dimensions of hafirs

Location	Length (m) Designed Top	Bottom	Actual Top	Bottom
Hafarat	130	114	197	159
Umsafary	130	114	162	118
Kollil	130	114	150	138
Tahdayosses	210	196	210	196
Tyakyay	100	76	100	76

On the other hand, the storage capacity of Hafarat hafir is increased by 30% due to the expansion in dimensions; however such increases are lacking design aspects leading to high evaporation losses due to the increase in exposed surface area of the hafirs. The relative high population and animal densities, variability of rainfall and mismanagement aspects are the main reasons behind such water deficit. The mismanagement aspect for example has increased the exposed surface area (Tahday Osses) and the small capacity of the hafir in Tyakyay. Moreover, Kollil, Umsafary and Hafarat hafirs have deteriorated due to lack of periodic silt clearance maintenance coupled with increasing in total consumptions. These management aspects reduced the seasonal functioning period of hafirs to an average period of five months. To avoid these problems (evaporation and infiltration) it is recommended restoring the standard dimension of hafir. These dimensions are appropriate where the thickness of the clay soil is more than 6m. It is always better to increase the depth of hafir rather than to increase

The smaller the surface area of hafir, the lower is the evaporation rate. Also growing trees surrounding the hafir to protect the hafir from gale (strong wind) and to decrease wind speed, evaporation and seepage control structure. These are provisions like lining of hafir that minimize or avoid seepage and infiltration through the body or floor of hafir.plastic or concrete lining can be applied as mitigation measures if affordable.

The relative high evaporation 34% and 25% respectively in Hafarat and Kolliland high infiltration (Tahdayosses, Kollil and Umsafary villages) with high percentage(44%, 33% and 32%) respectively are attributed to the expansion in length and width lead to increase in exposed surface area(Table 9). Such differences in northern and southern parts may encourage the idea of transferring water from wet parts (southern) to drier (northern) parts using for example pipes. Table (9) shows the monthly water balance of selected hafirs where most of 50% of the Hafirs water lost by evaporation (30%) and deep percolation (20%), indicating that better water management would double the residence period of water.

Table 9: Hafir monthly water balance

Location	A.W (m^3/season)	P_{re} (month)	Z%	E%
Hafarat	38949	4	26	34
Umsafary	29928	3.5	32	22
Kollil	32670	4	33	25
Tahdayosses	60000	3	44	18
Tyakyay	9071	1	16	1

It goes without saying that the silt accumulation in the hafirs indicates the soil erosion problems in the state. Thus, vegetation covers, i.e. forest should be restored and silt traps should be associated with hafir designs.

CONCLUSIONS

From previous results, following conclusions can be drawn:

- Rainfall of Kassala state is variable in space and time and has a localized nature. The drought cycles are found dominant (54%) with average length of 2 years.
- Terraces are the dominant rainwater harvesting technique for crop production in the state. Their adoption increased the crop yield to five folds at some cases.
- Most of the hafirs water storage capacity is deteriorated, basically due to silt accumulation and the expansions in length and width leaded to high evaporation losses.
- The majority of the hafir used to be managed by un educated people.
- The area experiences water soil erosion problems due to deterioration in the vegetation cover.
- Transferring water from the wettest part (Southern of the state) to the driest northern part is a viable solution.
- Hafir better to be placed in the opposite direction of the wind, this may decrease the wind erosion and evaporation.

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