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Full length Research Paper

Factors Affecting the Sustainability of Wateryards in Western Sudan

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Abstract

Wateryards are the most common water supply source in western Sudan. Components of a wateryard include: a borehole fitted with an engine-driven pump, an elevated tank, animal watering troughs and taps for human use. Despite efforts to rehabilitate and upgrade the functionality of wateryards, their sustainability- in terms of water productivity (quantity), quality, accessibility, reliability and the affordability of the water produced - was short-lived. Within a few years most wateryards had deteriorated to their pre-rehabilitation condition. Factors such as the quantity of livestock that rely on the wateryards, the extent of (excessive) use, the yield potential, the existence of nearby alternative water source(s), the degree of community participation in the management of the wateryard, the misuse of water revenues, and the ready availability of fuel and spare parts all had an impact on the sustainability of the rehabilitated wateryards in western Sudan. With due consideration to these factors, sustainable water supply sources cannot be achieved without considering technical, institutional, environmental, economic and social factors within the broader context of the key principles and good practices of Integrated Water Resources Management (IWRM).

Keywords: Kordofan State, Sudan, Water supply systems, Sustainability of wateryards.

INTRODUCTION

The majority of rural water supply systems, especially wateryards in Sudan (Figure 1) are facing the problem of sustainability (Ibrahim, 2017). There are numerous interpretations of what sustainability of a water supply system may mean. According to Durga et al. (2018) sustainability in community water supply schemes means “delivering service up to design life, proper mechanization of operation and maintenance, availability of spare parts, availability of maintenance personnel and active users’ committees with adequate funds”. They emphasize that support for social capital building, active communication by local leaders with community members regarding the planning and operation of water systems, social factors, and administrative, financial and technical aspects are important factors for the sustainability of rural water supply systems. Arabi (2019) also emphasizes the relationships between sustainable operation, maintenance and management of water supply facilities and socio-economic, cultural, technical and institutional elements such as the collection of water tariffs in East Darfur state (Sudan). Mugumya (2013) discusses the importance of community-based water management systems as a remedy for rural domestic water supply sustainability problems in Uganda. According to Smith et al. (2012) financing, transparency, accountability, capacity building, harmonization and coordination between different stakeholders are key factors for sustainable water supply systems and should be embedded at various institutional levels. Tafara (2013), Mwnagi and Daniel (2012) conclude that effective participation of stakeholders is critical to enhance the sustainability of rural community-based water supply

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Fig.1. Sudan location map showing its main States and towns.

projects. According to Beyene (2012) the involvement of women in decision making processes and the training of local communities contributed to decreasing the failure rate, while weak institutional support after construction increased the failure rate of the installed wells in Ethiopia. Haysom (2006) correlates non-functionality of distribution water points in 38 communities in Tanzania to poor financial management.Domngue**z** et al.(2019) address the sustainability problems of rural water supply systems by using multi-criteria analysis tools to identify indicators based on quantitative data from the household survey and water monitoring in Colombia, while Alejandro et al.(2017) analyze sustainability by using an operational framework based on identification of weaknesses/barriers, agreed priorities, regular monitoring, developed action plan and management response to provide feedback on water supply, sanitation and hygiene (WASH) services in eight African countries .

For the purposes of this paper, the author defines sustainability of a water system as its ability to continue (after construction or rehabilitation) providing services in terms of productive, accessible, reliable, and affordable good quality water in an equitable and environmentally responsible manner over time. This definition explicitly enshrines the ultimate objectives that sustainability should achieve, and can be assessed by some measurable indicators as shown in Table 1.

This article discusses sustainability of some rehabilitated wateryards in western Sudan (Kordofan and Darfur states) based on: (i) collation and analysis of secondary and primary data on performance of rehabilitated wateryards in Kordofan states, (ii) technical assessment of some rehabilitated wateryards, and (iii) interviews with water users to solicit their views on the functionality of their wateryards.

PROBLEMS OF WATERYARDS AND IMPACT IN SUDAN

In Sudan the term wateryard is applied to a water supply system composed of one or more boreholes, fitted with a diesel engine or an electric-driven pump, an elevated tank, animal watering troughs, stand pipes and taps for human water supply (Public Water Corporation, 2009). A borehole fitted with an electrically-operated submersible pump or a diesel-operated reciprocating pump can produce

Table 1. Indicators for assessing sustainability of wateryards, Sudan.

Sustainability objectives	Indicatorsfor assessingsustainability
Water quantity/productivity	Continuity of the system to produce water according to the designed capacity to meet the users' demand.
Accessibility	Reduced time spent fetching and obtaining water, and proximity of the wateryards to users.
Reliability	Functionality over time and low frequency of system breakdowns.
Affordability	Effective water pricing (compared to the family income) and its compatibility with operation and maintenance costs.
Water quality	Safe water (quality) meeting WHO and national standards.
Equity	Equitable water use (some for all forever).
Environmental conservation	Proper hydrologically-sited wateryards and non-destructive to the surrounding environment.

5 - 25 cubic meters of water per hour, however the specific capacity of the borehole can be higher. The total daily water production and the working hours of a wateryard largely depend on the time of the year, the number of livestock in the area and the availability of nearby water supply sources. During the dry months (January to June) wateryards often operate for as much as 20 hours per day while during the rainy season and the cold (winter) months they tend to operate for an average of between 4 and 8 hours respectively. In recent years the low-yield reciprocating pumps have been replaced by compatible submersible and/or turbine pumps. Field experience showed that turbine pumps suit a pump-setting depth of not more than 60 m, while submersible pumps should not be installed in wells with sand content greater than 50 grams/liter. The different components of the wateryards are protected by a fence to prohibit access by animals and unauthorized persons. In recently rehabilitated or constructed wateryards the compound has been sub-divided into two sections to separate human and livestock water users (Figure 2).

Presently (2020) there are more than 7000 wateryards (Figure 3), mainly for domestic water use, all over the country. The predominance of wateryards, which depend on groundwater from deep and/or shallow aquifers in western Sudan, can be attributed to the following (Ali and Hamaza, 1998):

- More than 70% of human and animal populations are located in rural areas that are generally far from the Nile and its tributaries. Thus groundwater and surface water from seasonal streams are the main sources of water.
- Over 70% of the country is within arid and semi-arid zones where rainfall is scarce, variable and where drought events are frequent; making groundwater from deep aquifers the most reliable source of water.
- Increased groundwater demand for agricultural production.

The basic guiding principles for construction of rural water supply sources (promulgated by the Land Use and Water Programming Department as early as 1967 in Sudan) emphasize that: (i) provision of water supply should be demand driven, and (ii) water should be provided for economic development, increased agricultural production, better utilization of rangelands, resolution of conflicts, and should also consider the carrying capacity of natural resources. These stated guidelines are rarely observed and consequently have little or no influence on the present trends of groundwater development and the construction of wateryards in the country (Shepherd et al., 1998). Currently (2020) wateryards abstract a total of about 2.5 km^3 of water annually which represents about 25% of the estimated total groundwater recharge and less than 0.5% of the total reserve in-storage of all groundwater basins in Sudan (Drinking Water and Sanitation Unit (DWSU), 2012). Exceptions are the alluvium basins, particularly the Gash and Wadi Nyala basins in eastern and western Sudan respectively, where annual abstraction exceeds recharge.

Problems underlying poor performance of wateryards in Sudan are plentiful and interrelated and include, but are not limited to, the following:

- Wearing out or aging of the wateryard facilities.
- Poor design and layout of the wateryards.
- Diversity of pumps and engines.
- Low yield of the pumps.
- Managerial and institutional problems.

Aging of the wateryard facilities

As shown in Figure 4, wateryards construction in Sudan began as early as the 1950s (or even before). According to the Drinking Water and Sanitation Unit (DWSU), 56% of wateryards in Sudan have exceeded their useful lifetime, estimated as 25 years for the borehole, 10 years for the pumping unit and 20 years for the buildings. About 70% of these aged wateryards work with efficiencies of less than 50% of their initial capacity; designed to provide 20 liters per person per day. Moreover, their oil consumption has increased by almost 33% due to the wear and tear of the engines. In effect, most of the water-

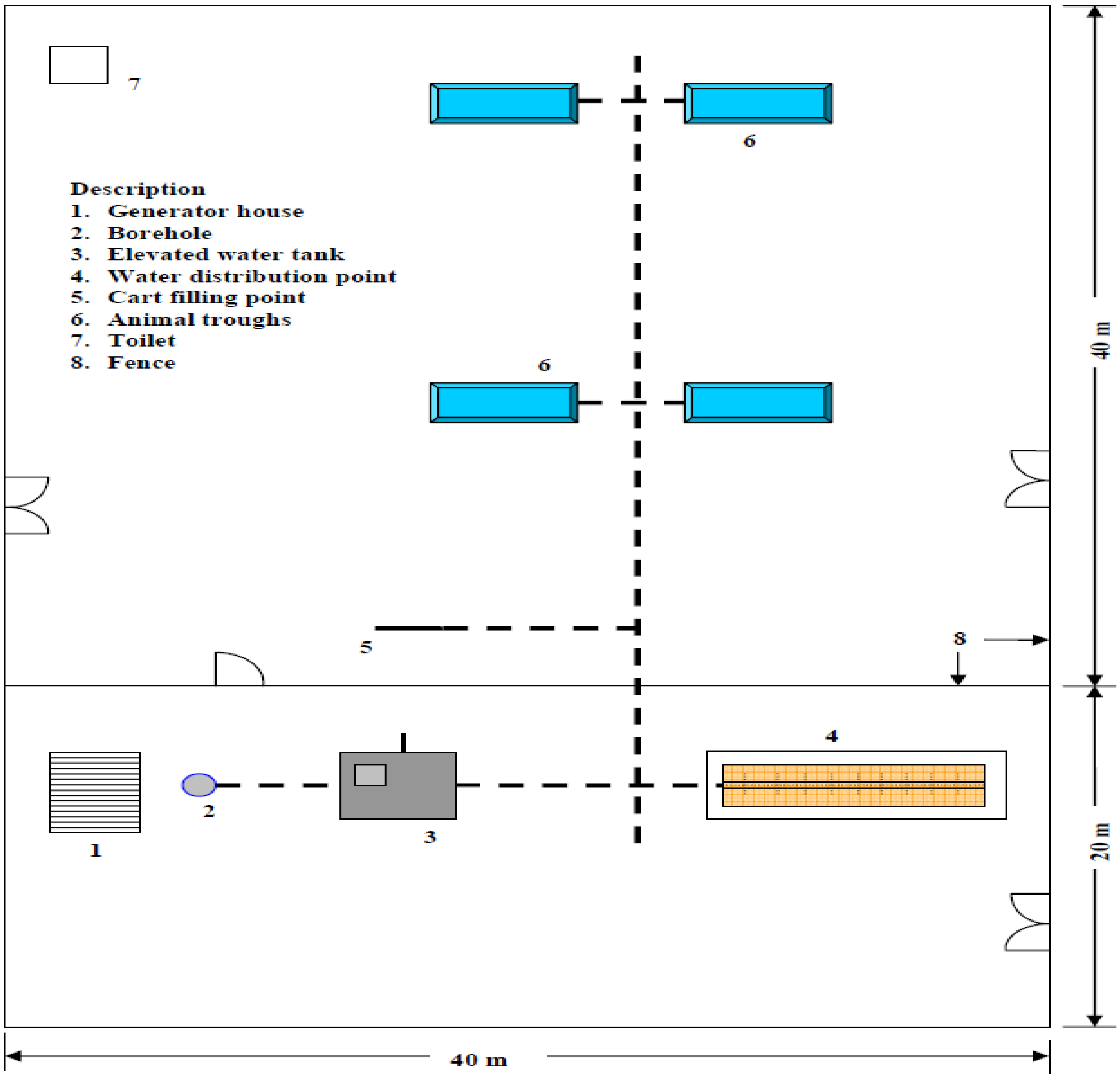

Fig. 2. Layout and components of a typical wateryard in Sudan.

yards, for example in Kordofan and Darfur states, work excessively for nearly 20 hours a day to meet human and animal water demand, especially during the dry months (January to June).

Poor design and layout of the wateryards

Boreholes constructed as early as 1976 were drilled with 212 mm-diameter drill bits, cased with 166 mm-diameter pipes and screened with 0.06 cm-slot width pipes. Most boreholes were constructed without gravel packs, which stop the aquifer's fine-grained materials from invading the boreholes. As a result, most of these boreholes need de-silting by bailing. In addition, the installed screens suffer from incrustation and deposition of salt layers on their surfaces. Finally, most wateryards are poorly fenced and designed without any separation between human and animal users inside the wateryard's compound. This means

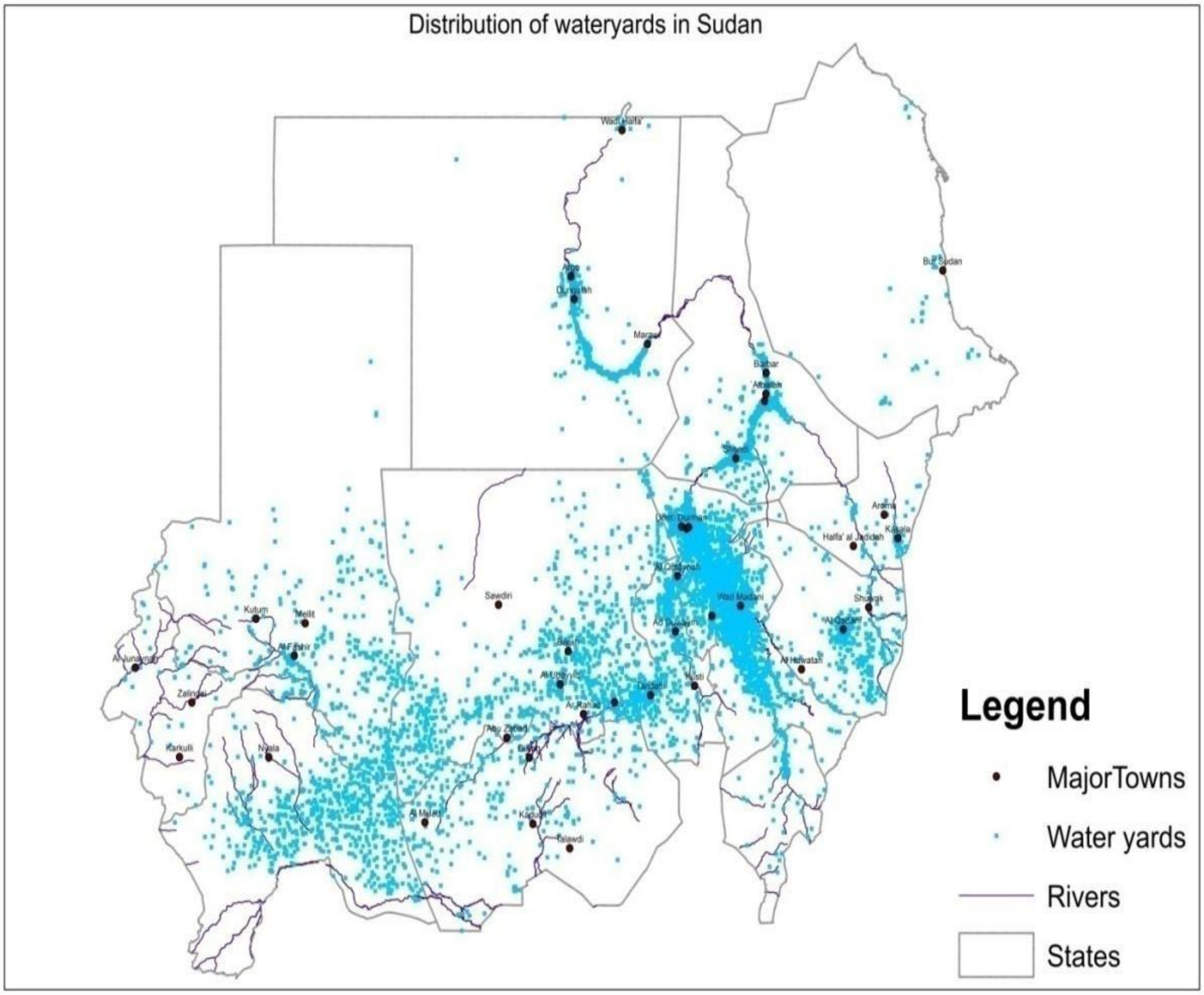

Fig. 3. Density distribution of wateryards in Sudan.

humans and animals take water from the same troughs.

Diversity of pumps and engines

The problem of wateryards is further complicated by the diversity of the installed pumping units (submersible pumps and generators). Presently (2020) there are more than four types of pumping units that operate boreholes in Sudan. This variation has led to a lack of standardization and has contributed to a shortage of spare parts and readily available trained technicians who can maintain these different pumping units.

Low yielding pumps

Most boreholes, especially in Darfur and Kordofan states, were installed with low yielding reciprocating pumps, though recently some of them have been replaced by higher yielding submersible pumps. From a design point of view, the reciprocating pumps were considered to provide about 7.0 m^3 per hour corresponding to 25 strokes per minute. However, at present, the pump yield varies between 3.5 – 5.0 m^3 per hour due to the aging of the pumping units which operate about 15-20 hours per day to meet the demand for water. Such excessive operation exposes pumps to recurrent breakdowns, exacerbated by the non-availability of spare parts in the local market.

Managerial and institutional problems

The majority of wateryards in western Sudan (Kordofan and Darfur states) are managed by the respective State Water Corporations (SWCs), which appoint the wateryard staff (operator, clerk and guard). The wateryard staff is responsible for the day-to-day operation, routine maintenance and collection of revenue from users of the wateryards. The maintenance center (SWC's sub-office) in the Locality is responsible for repairing majorbreakdowns and for maintenance work beyond the capacity of the wateryard's operator.

This operation and management system suffers from a duality in responsibility for the collection and disbursement of the wateryards' revenue. While the collection of revenue on a daily basis is the responsibility of the staff appointed by the SWC at the Locality level, the collected revenue is under the custody and management of the Director General of the SWC at its headquarters located in the capitals of the respective states.

The consumption and cost of the items used in operation and routine maintenance of the wateryard varies from one wateryard to another and depends, among other things, on the efficiency and capacity of the pumping unit, the working hours of the facility, as well as the integrity of the wateryard staff in the absence of enforced control measures. According to the SWC in the southern parts of Kordofan and Darfur states, where livestock are the predominant consumers, some wateryards work effectively for only six months a year (from early January to June) due to the presence of surface water during the rainy season (June to November). Consequently, revenue drops during the rainy months. It is interesting to note that during the peak working months (January to June) the average monthly revenue of a wateryard can reach 3,730 US Dollars/month of which operation costs account for 62% (Table 2).

Including the factors stated above, the operation, maintenance and management system of wateryards, as undertaken by the SWC, is constrained by the following institutional problems:

- Weak controls over revenue collection in the absence of any reliable measures of the amount of water produced by each wateryard. In reality, the actual amount of revenue on the basis of sold water is at least several times the remitted amount to the SWC offices at state level (Ali, 2015).
- A long vertical chain of communication extending from the wateryard staff at the village level to the maintenance center at the locality level, to the SWC's headquarters within the Ministry of Urban Planning and Public Utilities and/or the Ministry of Finance at state level. Furthermore, the water sector in the states lacks adequate technical, managerial and financial capacity to carry out the assigned responsibilities in an efficient and effective manner. This is further constrained by frequent staff changes in the hierarchy leading to overall instability in the management system.
- Poor community involvement in the operation and management of wateryards. Community involvement is constrained by a lack of clear policies on the establishment of community-based water management systems in the SWC structure. Communities therefore lack a sense of ownership of the wateryards and other water facilities in their localities.
- Slow movement and bureaucracy of the SWC maintenance crews in responding to community requests when wateryards maintenance and repairs are needed. The staff working in the maintenance centers in the localities are poorly motivated and in need of technical support and capacity building, mainly in the maintenance of submersible pumps and electrical generators.
- During the dry season, the users are excessively charged in order to keep their wateryards operational and quite often users are compelled to pay for the spare parts due to the slow response of the SWC which is responsible for undertaking the maintenance and repair of the wateryards.
- Absence or little integration of rural water supply provision with other natural resources in the area. In many places wateryards cause increased desertification in their near surroundings which is further exacerbated by the inappropriate spacing between the wateryards and other water points such as surface water harvesting structures, especially along the transhumant pastoralist routes that traverse Kordofan and Darfur states.

Pre-rehabilitation impact

As a result of the abovementioned problems, about 30% of wateryards, especially in Kordofan and Darfur states, are non-operational (Ali, 2008), while about 50% operate at less than 50% of their designed capacity, resulting in the following pre-rehabilitation impacts:

i. Poor accessibility and reliability.
ii. Poor sanitary conditions.
iii. High household expenditure on water.

i. Poor accessibility and reliability

The decline in the production of wateryards coupled with the growth in human and animal populations has resulted in low per capita water consumption barely exceeding 16 liters/person/day. This is exacerbated by variability and decline in rainfall, especially in the arid areas of western Sudan. To date only about 50% (Figure 5) of wateryard users have access to about 11-16 liters/person/day, which is less than the minimum consumption rate of 20 liters/person/day recommended by the water supply, sanitation and hygiene (WASH) national strategic plan (2012-2016) in Sudan (DWSU, 2012).

In terms of the accessibility of wateryards and water supply, only 20% of rural populations have access to wateryards within a walking distance of less than one km from their dwellings during the dry season, while during the rainy season about 40% of the same population access water within less than 0.5 km.This discrepancy (from 20% to 40%) in accessibility between dry and rainy seasons respectively implies that a great number of people use rainwater during the wet period. Many people in rural areas (in Kordofan and Darfur states) walk up to 6 km and more during the dry season months to fetch water. This falls to 2 km during the rainy season mainly

Table 2. Average revenue, operation and maintenance (O&M) cost (US Dollars) for a single wateryard during the dry months, West Kordofan State.

Item (in US Dollars)	Months (2018)						
	January	February	March	April	May	June	Average
Water revenue	2,814	3,336	4,571	4,781	4,482	2,398	3,730
O&M cost	1561	2010	2,595	3,347	2,689	1,727	2,312
Balance	1253	1353	1,975	1,434	1,820	672	1,418
O&M/revenue %	55.5%	59.8%	56.8%	70%	60%	72%	62%

(Source: State Water Corporation, West Kordofan).

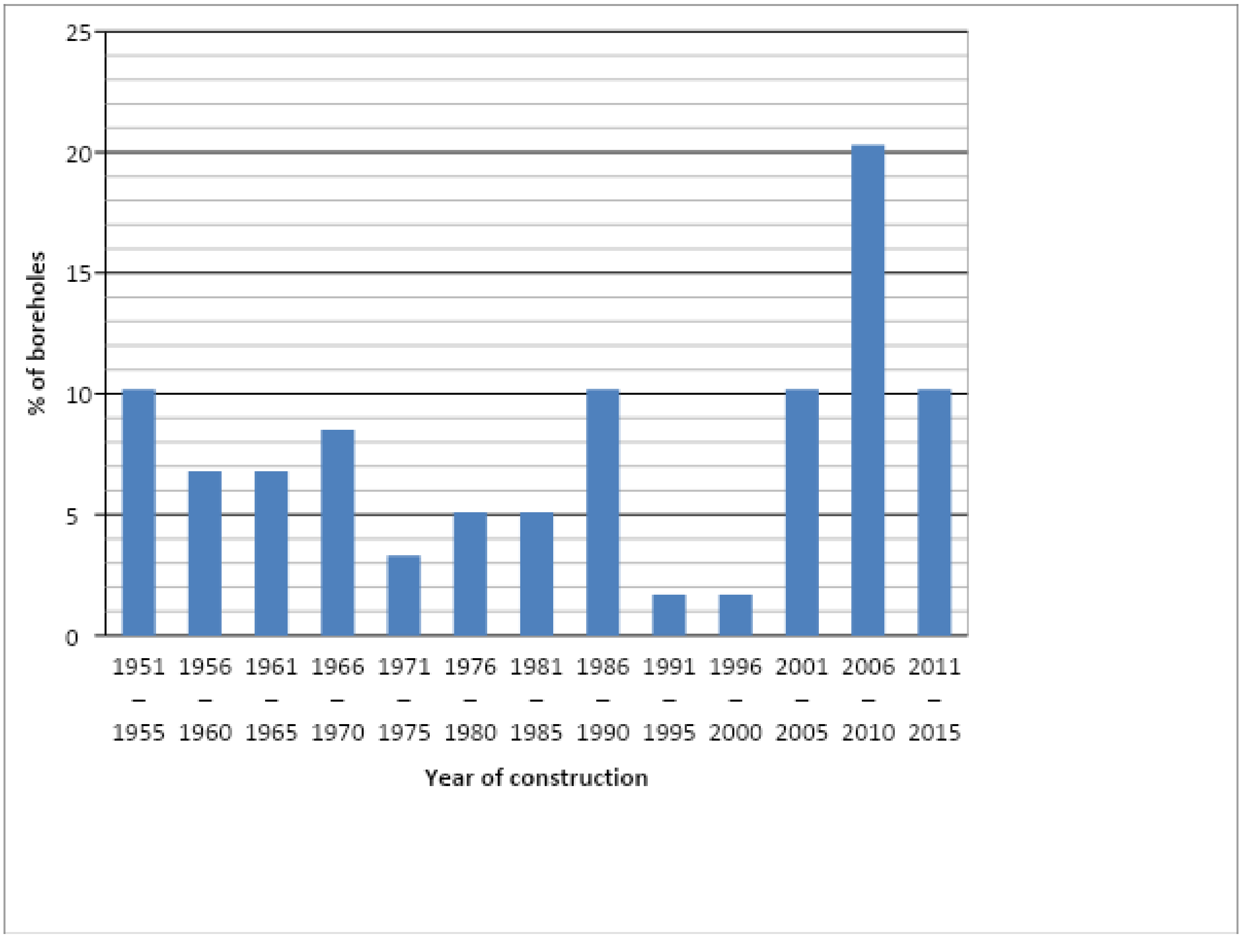

Fig. 4. Age distribution of wateryards in Sudan.

due to the availability of rainwater in natural ponds and clay depressions (Figure 6). Also Figure 6 is comparable with Figure 7, which clearly shows an increase in water borne diseases during the rainy months. In terms of time, at least 140 person days per year per family (in Kordofan and Darfur states) are lost in fetching and collecting water from wateryards for domestic consumption (Ali, 2015); a burden mostly borne by women and girls.

The reliability of wateryards is also compromised since they are susceptible to recurrent breakdowns and stoppages which impede users' access to clean water. In Kordofan and Darfur states, where wateryards are the main water supply source during the dry months, the frequency of wateryard breakdowns varied between 1 to more than 5 times per month depending on the condition and age of the wateryard.

ii. Poor sanitary conditions

To further add to the problems above, most wateryards are poorly designed, lacking drainage channels and failing to separate between animal and human users. In some wateryards animals and people access water from the same trough resulting in poor overall sanitary conditions. This can lead to the transmission of diseases from animals to people. In addition, the risk of water

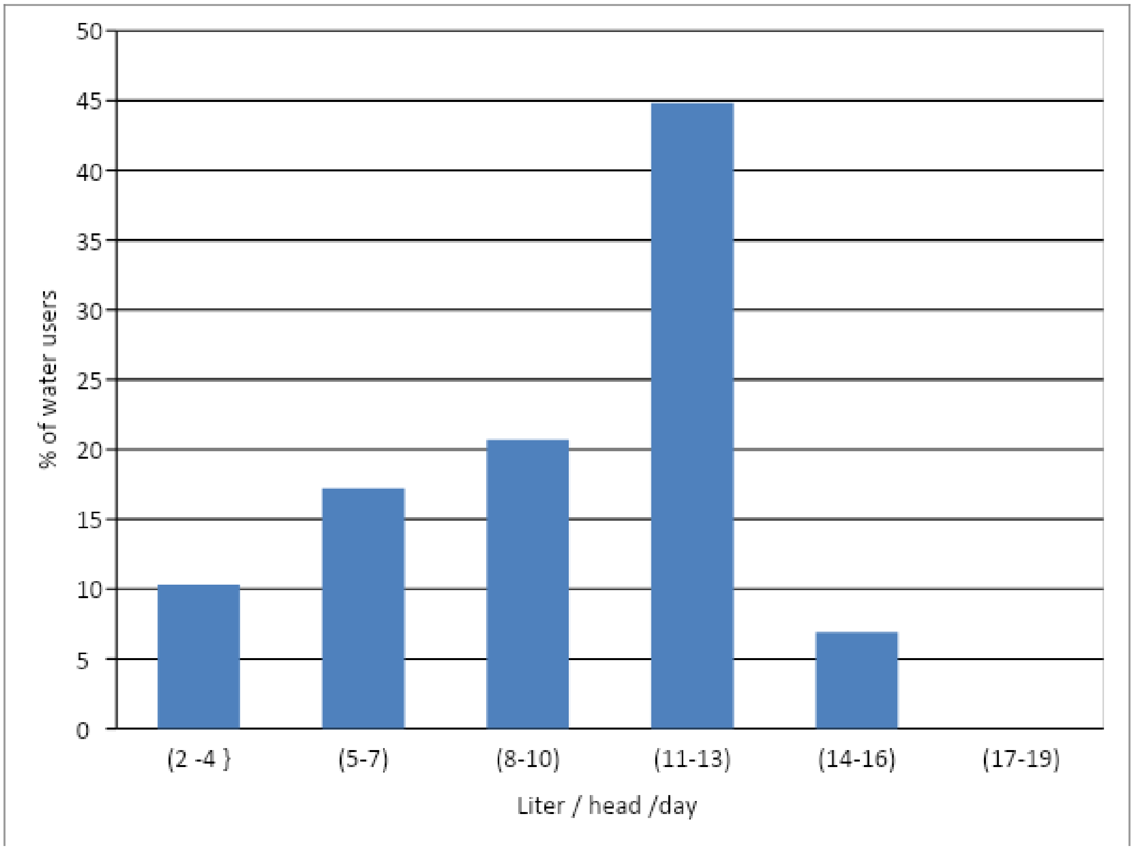

Fig. 5. Human water consumption rate from wateryards, Kordofan and Darfur states.

contamination in wateryards is very high due to the lack of hygiene education among communities.

iii. High household expenditure on water

The cost of water from wateryards is officially priced by the SWC. These water fees are designed to be affordable to the local population. However, due to the frequent breakdown of wateryards, users pay extra water charges (up to 200% of the official water prices) to cover their high operation and repair costs, particularly during the dry season months. As shown in Figure 8, about 65% of wateryard users spend between 10-30% of their annual income on water, with a little under 5% of families spending more than 60% of their income to obtain water from wateryards (Takana et al., 2009). This percentage (60%) is 12 times above the water supply affordability threshold, as defined by the African Development Bank (Hutton, 2015).

REHABILITATION OF THE WATERYARDS

Sudanese government and Non-Government Organizations (NGOs) have rehabilitated a number of wateryards in the country with a view to upgrading and increasing their yields in a sustainable manner. This rehabilitation work entailed the following:

- De-silting of the boreholes.
- Replacement/rehabilitation of the pumping units (diesel engines and pumps).
- Replacement of the piping and distribution systems.
- Rehabilitation of the storage tanks.
- Re-fencing of the wateryards.

The technical viability and effectiveness of this rehabilitation work, in terms of water supply sustainability, were assessed and evaluated at a number of wateryards in North and West Kordofan States. The assessment (conducted by the author) was based on a technical review of wateryards data, field visits to some of the rehabilitated water yards, and interviews with wateryard users.

De-silting of boreholes

Boreholes which utilize groundwater from the Um Ruwaba Formation aquifer (Gadelmula et al., 2018), mostly drilled as early as the 1970s, suffer from the invasion of fine-grained sands - aggravated by the lack of gravel packs between the drilled hole and the casing of the borehole - and possibly the incrustation of the screens. Rehabilitation of these boreholes was confined to de-silting (removal of fine-grained sands) by mechanical bailing and did not include any acid treatment

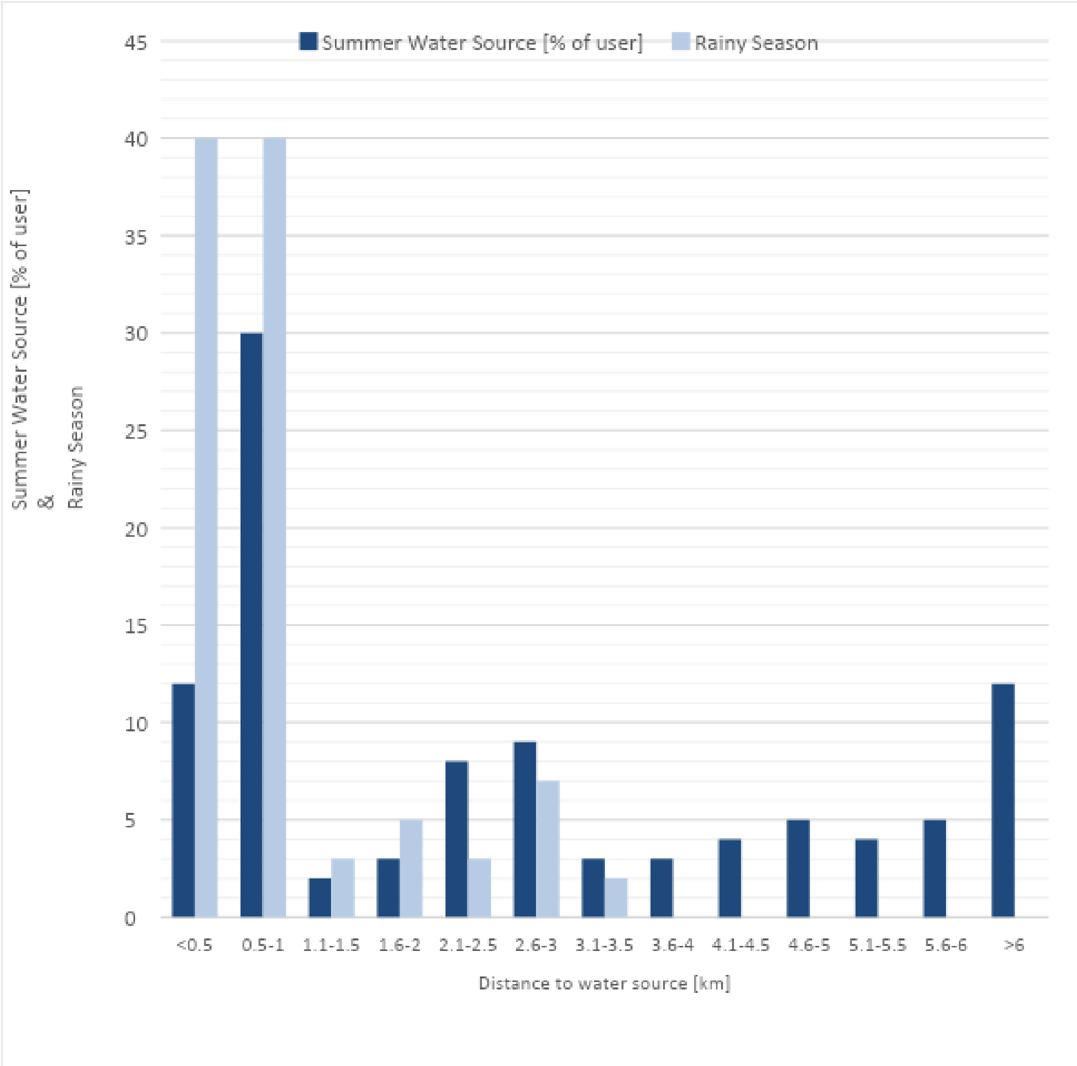

Fig. 6. Distance to water sources during the dry season and rainy months, West Kordofan state.

for any of the boreholes. Acid treatment could have been an effective treatment to restore borehole filters affected by incrustation due to the relatively high salinity and iron content of the Um Ruwaba and Nubian sandstone aquifers respectively (Salama, 1976). De-silting, therefore, resulted in a very small average increase of less than 20% in borehole's yield and in limited cases caused a drop of water level and/or complete damage of the borehole due to aging and incrustation of the screens over time.

Replacement/rehabilitation of the diesel engines and pumps

Earlier rehabilitation projects (before 2000) implemented by NGOs in Kordofan and Darfur states focused on the complete overhauling and/or replacement of the diesel engines and the reciprocating pumps, despite their high cost. However, in subsequent years, the rehabilitation of reciprocating pumps was replaced by installation of 5.0 cm submersible pumps, increasing yield by three-fold. Generally, for all rehabilitated wateryards, one liter of fuel produces about 4-7 cubic meters of water, notwithstanding efficiency of the pump. In the absence of installed meters to measure daily water production of the boreholes, this rate of oil consumption against water production (one liter of fuel versus water produced) is frequently used as a basis for estimating the volume of the produced water and hence the estimated water revenue.

Replacement of the distribution system

A wateryard distribution system starts with a storage tank and a 75 mm steel pipe which carries water from the tank to taps on two filling platforms and to the animal watering

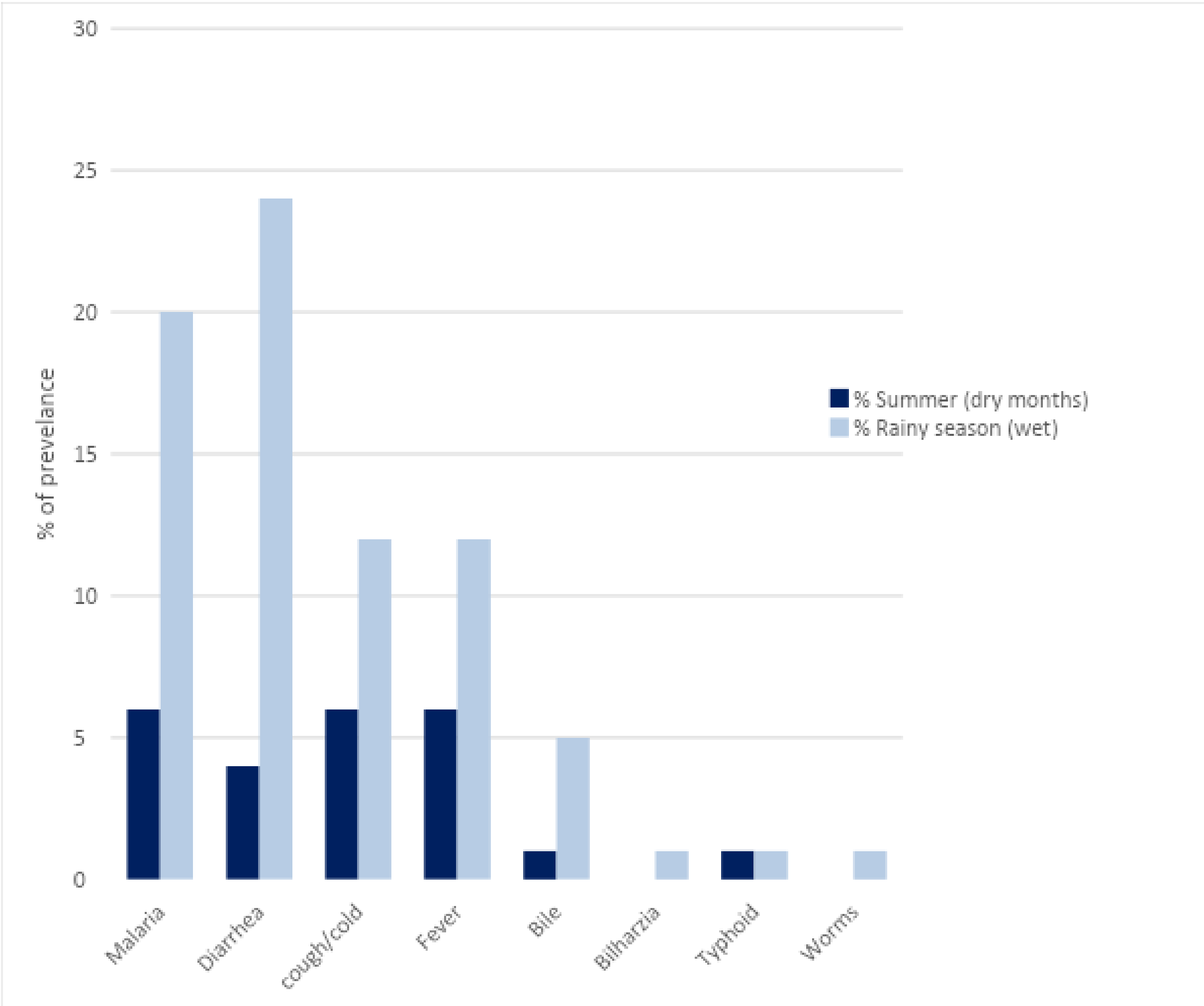

Fig. 7. Prevalence of water-related diseases during the dry and rainy seasons among wateryard users in Kordofan states.

troughs. In the rehabilitated wateryards at least one of the filling platforms was re-constructed at a height of one meter. This was purposefully designed for women users to make it easier for them to place and remove their water containers. On each filling platform six taps were usually fitted. These were often damaged soon after being installed, especially in wateryards where human water demand during the peak summer period is high. In a limited number of sites, standpipes for filling water tanks and donkey-drawn water-carts were installed.

Fencing of the wateryards

Wateryard rehabilitation included sub-dividing the wateryard's compound into two sections, with the aim of separating human and animal water users. The objective was to improve accessibility, preserve water hygiene and prevent people from taking water from animal watering troughs. In most of the rehabilitated wateryards, this separation could not withstand peak dry season pressure and fences were completely damaged as a result. This was especially the case at wateryards where livestock were dominant.

IMPACT OF THE REHABILITATED WATERYARDS

The results of the rehabilitated wateryards assessment - in terms of water quality, reliability, accessibility, quantity and affordability (QARQA) - are exemplified by the sampled wateryards shown in Table 3.

Impact on water quality

The rehabilitated boreholes which tap water from the deep aquifers of the Nubian and/or Um Ruwaba Formations (Gadelmula et al., 2018), naturally have a total dissolved solids content varying from 250 – 500 mg/liter which is fit for human and animal consumption.

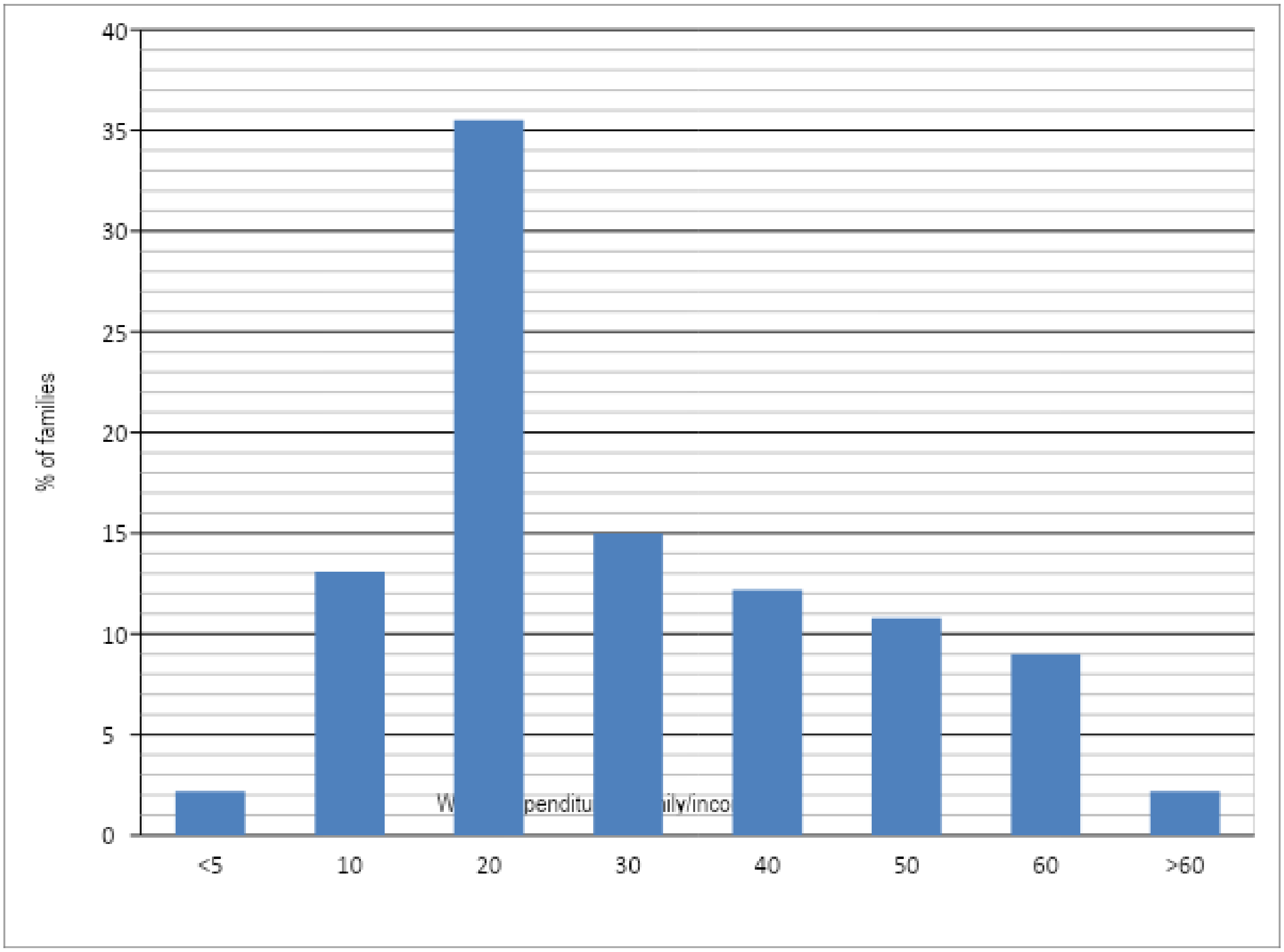

Fig. 8. Expenditure on water supply compared to family incomes in Kordofan and Darfur, Sudan.

However, at a number of rehabilitated wateryards (such as those in Kedadda, Dodaya and Um Jako villages shown in Table 3), the poor and/or damaged condition of the taps forced people to take their water from the animal troughs, thus increasing the risk of water contamination.

Water accessibility

The impact of the rehabilitation work on water accessibility was assessed in terms of the time spent by the users to fetch water from the rehabilitated wateryards. Figure 9 shows water accessibility before and after rehabilitation. It is evident that there was a marked increase in time saved in obtaining water, amounting up to 75% time saved immediately after rehabilitation. However, this was short-lived in most places as time spent fetching water (including waiting time at the wateryard) gradually increased to reach pre-rehabilitation levels. For instance, at Kedadda wateryard (Table 3) villagers spent on average two hours to obtain water from the wateryard before rehabilitation. Immediately after rehabilitation, time spent fetching water dropped to 0.75 hours. However, this reduction only sustained for around six months, thereafter increasing to pre-rehabilitation levels (Figure 9). Such gradual increases in water collection times are directly related to the gradual deterioration of the wateryard's condition. In Shaboulla wateryard, on the other hand, notwithstanding other reasons, the time for obtaining water was reduced by between 50% and 75% and sustained for at least six years, mainly due to the effective management of the wateryard by a trained village water committee (Figure 9).

Reliability

Reliability of the rehabilitated wateryards was assessed in terms of the frequency of breakdowns and the length of stoppage periods awaiting repairs. The reliability of the rehabilitated wateryards was improved as all sampled sites worked well without experiencing major breakdowns for a period ranging between half a year (e.g. inKedadda)

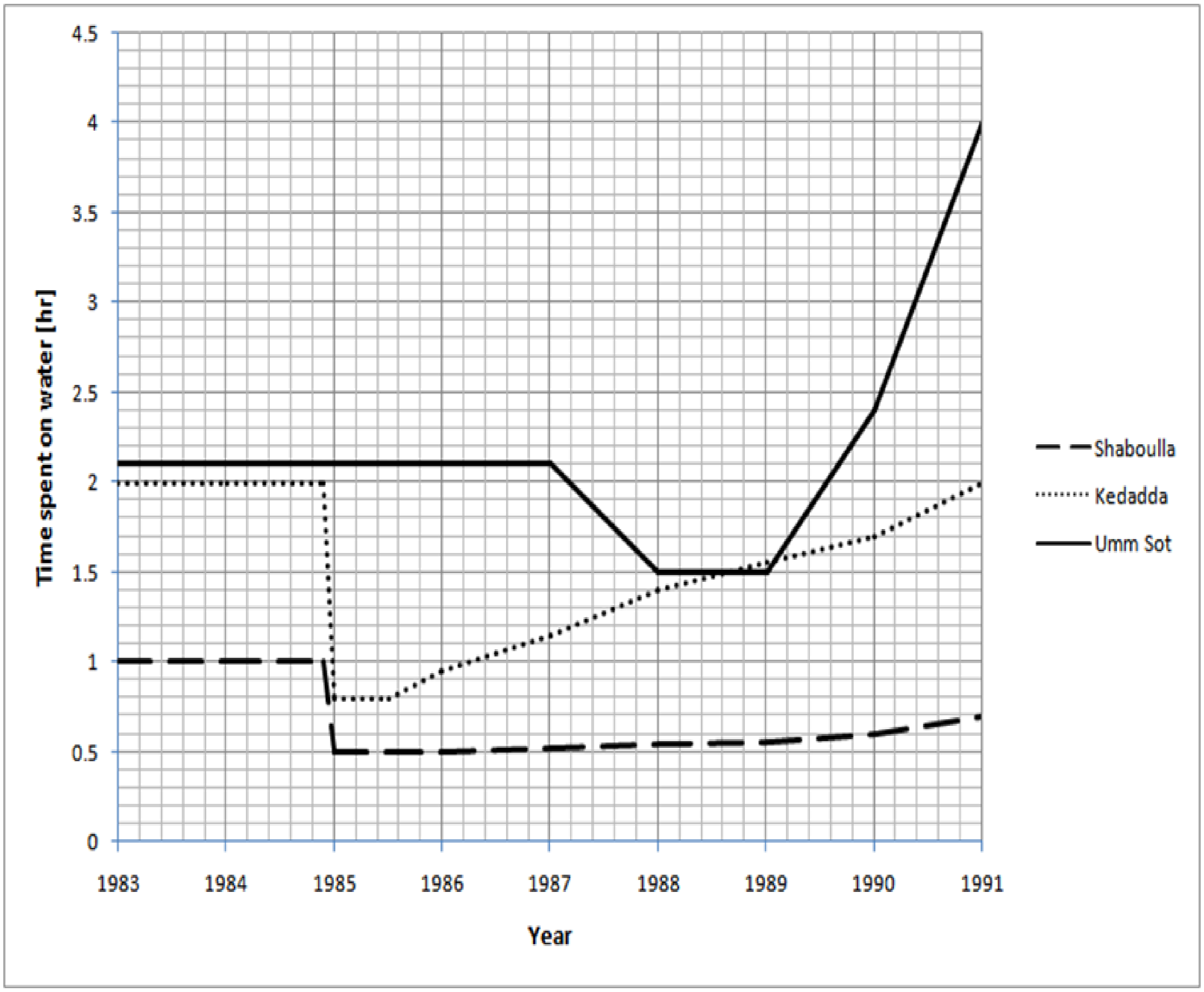

Fig 9. Time spent in obtaining water from rehabilitated wateryards, Kordofan states.

to three years (e.g. in Shaboulla) while the frequency of minor breakdowns ranged from 1-3 times/month compared to more than 5 times/month at non-rehabilitated wateryards (e.g. Um Jako in Table 3).

Water quantity

The impact of wateryard rehabilitation on the amount of water pumped can be viewed in terms of per capita consumption before and after rehabilitation. Based on the results of user interviews, per capita consumption increased to between 9 and 18 liters/person/day (l/p/d) immediately after rehabilitation, constituting a 40 – 150% rise as compared to the pre-rehabilitation period (Figure 10). However, this increase was only sustained for a short duration (6 months after rehabilitation), with the exception of a few sites such as Shaboulla (Figure 10) where the increase in per capita consumption persevered for more than five years.

FACTORS AFFECTING THE SUSTAINABILITY OF THE REHABILITATED WATERYARDS

Sustainability versus deterioration of the rehabilitated wateryards could be attributed to a set of inter-related factors including, but are not limited to the following:

- Ratio of people to animal users.
- Frequency of breakdowns.
- Distance to the nearest alternative water source(s).
- Community participation and effective management.
- Number of years since rehabilitation.

Ratio of people to animal users

A strong relationship was observed between the people to animal ratio and wateryard condition, particularly during peak demand (March - May). When animals outnumbered people, wateryard conditions were found to

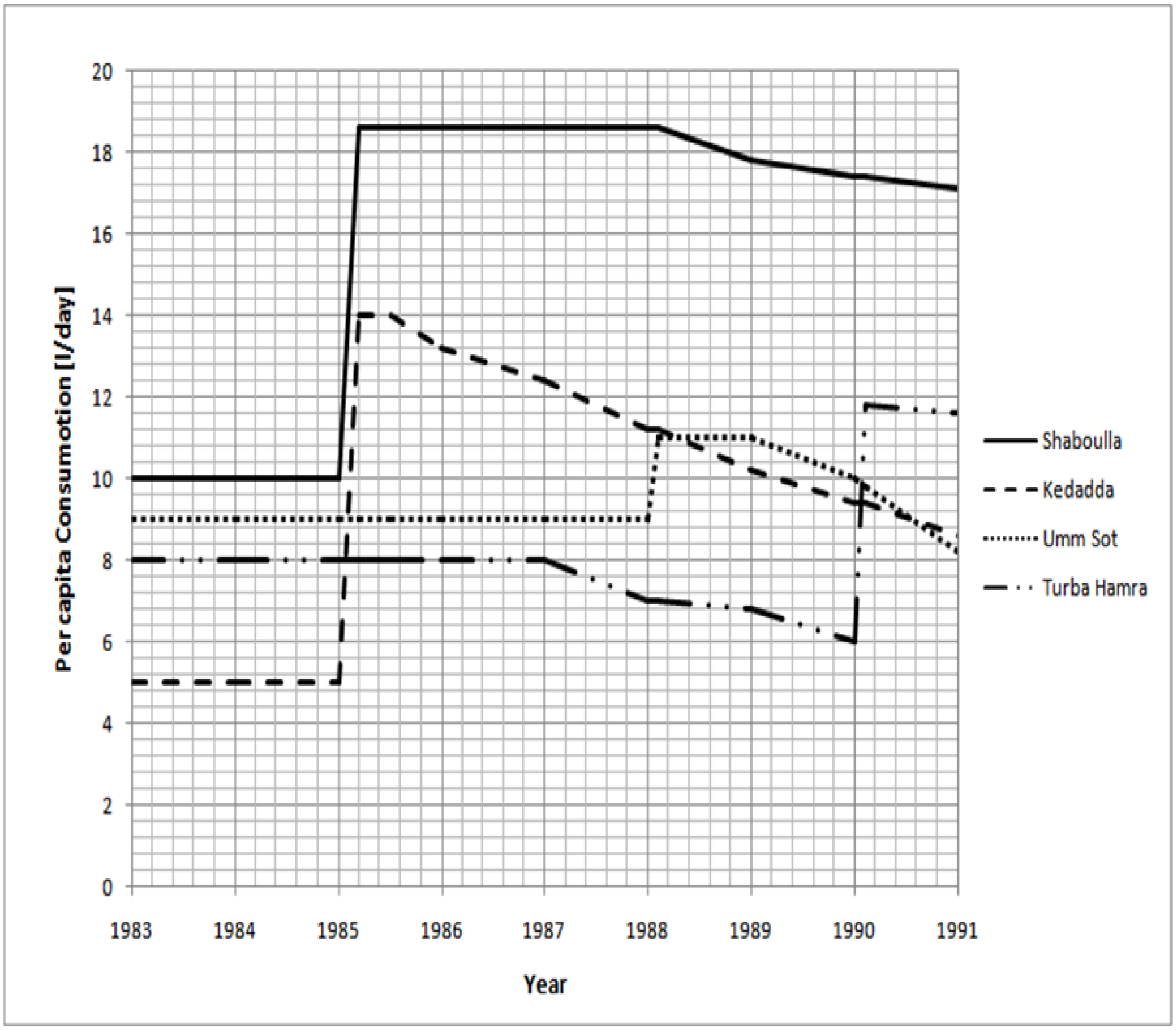

Fig. 10. Changes in water consumption at some rehabilitated wateryards, Kordofan states.

be generally poor. In wateryards which deteriorated rapidly (see Table 3), the people to animal ratio varied between 5:7 (Kedadda) to 2: 6 (Umm Sot). On the other hand, for better rated wateryards this ratio varied between 1: 1 (Shaboulla) and 5: 3 (Wad El Wali). Once again in the case of Shaboulla wateryard, community members exercised regulatory control over the number of animals allowed to use the wateryard on a quota basis which did not exceed 50 camels per day. The condition of the wateryards was also clearly time dependent (Table 3) as they all gradually deteriorated with the exception of Shaboulla wateryard where other inter-related factors might have counterbalanced the effect of time and age on the wateryard.

Frequency of breakdowns

The history and/or frequency of breakdowns is associated mainly with the pumping systems (engines and/or pumps) which can be regarded as a good indicator of a wateryard's condition. The number of breakdowns per month varied from 1-2, 4 and more than 5 indicating good, fair/poor to very poor wateryards respectively. Wateryard breakdown periods (i.e. where they continue to be idle before being repaired) due to mechanical faults varied in length from a minimum of 3 to a maximum of 60 days. The shortest breakdown period was caused by faults in the pistons and/or sucker rods, while the longest breakdown period of 60 days was primarily due to the complete breakdown of the pumping unit inside the borehole. Intermediate breakdowns of 7-12 days were typically caused by a faulty crankshaft, pistons and/or sucker rods. Stoppages due to fuel shortages were often very short not exceeding 1 to 3 days due to quick community action securing fuel even at higher market prices.

Distance to alternative water source(s)

The presence of an alternative water source nearby to the wateryard was found to be an asset. Other factors withstanding, wateryards located at distances greater

Table 3. Status of some rehabilitated wateryards and sustainability affecting factors, North and West Kordofan states.

Wateryards	Rehabilitation date	Assessment date	Status of wateryards	Affecting factors					
				Peak working hours/day	Breaks/month (number)	Human: animal Ratio	Distance to alternative source (Km)	Consumption (liter/capita/day)	Yield m^3/hr
Shaboulla	1985	1991	Good	20	2	1 : 1	5	18	7.5
Medasis	1983	1991	Poor	24	4	5 : 8	15	12	4
Kedadda	1985	1991	Poor	24	4	5 : 7	18	9	5
Um Dakoka	1985	1991	Fair	24	4	6 : 4	12	13	15
UmmSot	1987	1991	Poor	18	5	2 : 6	6	9	3
Dodaya	1986	1991	Poor	24	4		25	9	4
Turba Hamra	1990	1991	Good	24	1	5 : 4	10	12	7.5
Wad El Wali	1990	1991	Good	24	1	5 : 3	10	12	7.5
Um Jako	?	1991	Very poor	24	5	3 : 7	0.5	9	3
Um Guraa	2004	2005	Good	20	1	2:3	12	7	10
Um Zour	2004	2005	Poor	22	3	1:3	7	10	5
Shagaleb	2003	2005	Good	20	2	1:3	11	9	10

than 12 km to an alternative water supply source were generally in poor condition. Shaboulla, for example, is less than 5 km from an alternative wateryard (Wafaa), and remained in good condition long after rehabilitation. Not only does the distance to other alternative water supply systems appear to matter, but also the geological and the geographical position of the wateryard could adversely affect the wateryard's condition. For example, Umm Sot and Dodaya wateryards lie respectively on the marginal boundaries of Bara and El Nuhud sedimentary basins with the basement rock formation which is non-groundwater bearing. Beyond Umm Sot southwest and Dodaya northeast to Obeid at 25 km and 80 km respectively, no wateryards exist. Both wateryards (Umm Sot and Dodoya) were rated poor and their surrounding areas showed clear effects of environmental degradation driven mainly by overgrazing, demand for wood and agricultural expansion.

Community involvement and effective management

The involvement of communities in wateryards management was found to be critical in keeping the wateryards operational, particularly where wateryards were rehabilitated after 2000 in Kordofan states (Table 3). Sustainability at these sites was greatly enhanced by the establishment and training of the village water committees (VWCs). Each VWC was composed of 15 to 18 members of whom at least 3 were women. VWCs maintained regular meetings, discussed specific water related issues and implemented regulations limiting the number of livestock, particularly camels, attending the wateryard per day. Generally, these VWCs were empowered and aware of their rights and roles regarding the daily management of the wateryards. Community involvement and participation attributed positively to the sustainability of the wateryards offsetting other negative factors (Ali, 2005).

CONCLUSION

Despite the efforts exerted by the water supply sector and its partners to solve the water supply problems in Sudan through the rehabilitation and/or construction of wateryards, the demand for sustainable and improved water supply sources, mainly from wateryards, continues to rise especially in Kordofan and Darfur states. Besides the technical aspects, the sustainability of these water supply sources needs to be considered at all stages of planning, project design and implementation. This requires the full involvement of WASH partners and requires that due consideration is given to social and cultural factors such as population diversity/homogeneity, the spirit of cooperation among the community, education and knowledge in technical aspects, the willingness of the community to participate in rehabilitation/construction activities, and community willingness to pay the water tariff to cover wateryard operation and maintenance costs (El Sammani, 2004). Though there is currently no endorsed national water resources management policy concerning water supply, sustainability of wateryards must be linked with Integrated Water Resources Management (IWRM) principles and good practices (Bashar, 2020). These principles and good practices emphasize the creation of enabling institutional frameworks and policies which promote community participation in the management of water supply sources, linking water supply delivery with the sustainable use of local natural resources, highlighting the role of women in water management, and realizing the economic and social values and benefits of water. The role of women requires special emphasis, since women are the main managers and fetchers of water for domestic use in western Sudan.

The selection of those wateryards that require rehabilitation must be made after comprehensive screening and review of each wateryard's technical information and previous performance, including the causes of failure and the willingness of the local community to participate in rehabilitation activities. Without real community motivation, improvements in working conditions of the maintenance crews and changes in water supply and sanitation policies at federal and state levels in Sudan, the sustainability of community-based systems for management of water sources cannot be achieved. As most of the wateryards in Sudan have exceeded their useful lifetime (more than 25 years), a national rehabilitation programme is required to ensure sustainable water supply with a view to achieving the Sustainable Development Goals (SDGs), particularly SDG 6 which aims to 'ensure availability and sustainable management of water and sanitation *FOR ALL*' by 2030.

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