Environmental and Socio-economic Impact of Wadi Abu Soueid Water Harvesting and Spreading Project in Khartoum State, Sudan

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ABSTRACT

This study was conducted to assess the ecological and socio-economic impacts of Wadi Abu Soueid rainwater harvesting and spreading dam - a project located in an agro-pastoral rural area on the eastern bank of the Blue Nile River in Khartoum State. Wadi Abu Soueid dam was established in 1997 by the State's Ministry of Agriculture for improving rain-fed agriculture and rangeland in the area. A stratified random sample of five villages, located in the areas commanded by the water spreading dam, was chosen on the basis of distance from Khartoum. A proportional convenience sampling method was then used to select 50 respondents for interviewing. Primary data were collected through use of structured interview schedules, and secondary data were obtained from various relevant sources. The Statistical Package for the Social Sciences (SPSS) was used for data analysis. Comparative analysis for the periods prior to and after the establishment of Wadi Abu Soueid dam revealed significant differences in terms of sorghum productivity, size of livestock herds and production and marketing of milk and live animals. The analysis also revealed improvement in the density of natural grass and tree cover in the rangelands following the construction of the dam. However, some negative impacts of the water spreading dam were evident. These included a significant increase in the densities of the noxious *Adar* (*Sorghum* sp.) weed and semi-parasitic *Buda* (*Striga hermonthica*) plant, security problems (including trespassing on farmland and rangeland by nomadic groups from neighboring areas and animal thefts), and uncontrolled flooding of potentially productive farmland due to neglect of dam maintenance. Technical defects, relating to dam maintenance, and lack of follow-up activities resulted in loss of land due to uncontrolled flooding also became evident. Based on the findings of the study, a set of recommendations was put forward, including the scheduling of regular maintenance of the Wadi Abu Soueid and the other water harvesting dams, ensuring adequate follow up of pasture and crop land improvement programs, the introduction of improved crop varieties, and the intensification of technically coordinated extension programs for achieving sustainable use of the natural resources in the area.

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Key words: Wadi-Abu Soueid; rainwater harvesting; environment; socio-economic impact

INTRODUCTION

Water harvesting is defined as "a process of inducing, capturing and storing rainwater or stream flow to improve soil moisture for subsequent uses." (Ali *et al.*. 2007, citing Boers, 1994; Boers and Ben-Asger, 1982; Critchley and Siegert, 1991; Oweis *et al.*, 1999). Interest in rainwater harvesting has been growing steadily during the past two decades, and the use of water harvesting techniques has been declared as a solution to the growing water needs in developing countries (Nijhof *et al.*, 2010, cited in Banclark, 2010). As emphasized by Barron (2009), "rainwater harvesting can serve as an opportunity to enhance ecosystem productivity, thereby improving livelihoods, human well-being and economies." In other words, as viewed by FAO (2003), "Water and food security are closely related. If water is a key ingredient in food security, lack of it can be a major cause of famine and undernourishment, particularly in food-insecure rural areas where people depend on local rain-fed agriculture for food and income generation."

Rainwater spreading is one of the water harvesting techniques that have been in use in dryland areas. Ahmed (2000) classified rainwater spreading practices into three types, as follows:

1. Controlled water spreading which involves diversion of water via artificial or natural channels which are usually located near the *wadi* channel.
2. Controlled water spreading by building a check dam as a diverting canal to direct water towards the land to be cultivated.
3. Collecting runoff in check dams – a traditional system where small earth-fill dams are constructed in the beds of ephemeral *wadis* to collect water and sediment. In addition to slowing down runoff, soils suitable for crop production are accumulated

Rainfall is a decisive climatic factor from an agronomic point of view and for the natural vegetation as well. The success of water spreading projects depends on the amount of the rainfall received in the targeted area. According to Critchley and Siegert (1991):

Water harvesting (WH) can be considered as a rudimentary form of irrigation. The difference is that with WH the farmer (or more usually, the agro-pastoralist) has no control over timing. Runoff can only be harvested when it rains. In regions where crops are entirely rain-fed, a reduction of 50% in the seasonal rainfall, for example, may result in a total crop failure. If, however, the available rain can be concentrated on a smaller area, reasonable yields will still be received.

According to Darag (1999), dams or diversion dikes, built to spread water over depleted rangeland, are the most important water spreading techniques for rangeland improvement and rehabilitation, through the application of adequate management system. Water spreading provides quantity and quality vegetation which is used as forage by both livestock and wildlife species. But, as Oweis *et al*. (1999) noted, "many water harvesting techniques have failed despite good techniques and design; because the social, economic and management factors were inadequately integrated into the development of the system. On the other hand, the environmental impacts have been overlooked."

In Sudan, three main water harvesting techniques are used; namely building of dams, channeling run-off water to fill natural and manmade *hafirs* (water reservoirs) in low-lying lands, and the slowing of water flow in sloping lands through use of contour terracing systems. In Khartoum State (one of the states of Sudan which are affected by desertification), several environmental conservation and natural resource management projects were formulated and implemented by the State's Ministry of Agriculture, Animal Resources and Irrigation to combat desertification. Among these are water harvesting and spreading projects in lands used for rain-fed crop production and grazing by agro-pastoral population groups. Water harvesting is considered to be the most effective means for utilizing and conserving the rainwater that is carried to the Blue Nile by seasonal streams. The numerous beds of seasonal water courses or *wadis* of Khartoum State (such as Wadi Abu Soueid, Wadi Elmugaddam and Wadi Soba) are assumed to constitute suitable sites for the implementation of feasible water harvesting projects to rehabilitate and improve the grazing and rain-fed farming systems of the local population. However, no systematic studies have been conducted to assess the effectiveness of the water harvesting and spreading techniques that were employed or their environmental and socio-economic impacts.

The present study is designed to focus on assessment of the environmental and socio-economic impacts of one of the water harvesting and spreading projects of Khartoum State, namely the Abu Soueid Water Spreading Dam. The study was intended to achieve the following main objectives:

1. To assess the contribution of Wadi Abu Soueid water spreading project to desertification control in the area in terms of improvements in the natural vegetation cover.
2. To assess the impact of Wadi Abu Soueid water spreading project on arable farming and the socio-economic conditions of the target population.

MATERIALS AND METHODS

The site of the study was Wadi Abu Soueid Water Spreading Dam area which is part of the dryland areas of Khartoum State. It is located between latitudes 15˚ 35″ and 15˚ 41″ N, and longitudes 33˚ 32″ and 33˚ 36″ E, about 125 Kilometers due East and South-East from the junction of Blue and White Nile Rivers at Khartoum, the capital of the State. The project, which was established by the State's Ministry of Agriculture in 1997, involved the construction of two earthen embankments (each of about 4 kilometers in length) to intercept the waters of Wadi Abu Soueid. with the aim of spreading rain water over a land area of about 64 square Kilometers or about 15,220 feddans (one feddan = 4200 $m^{2)}$.

The physical features of the area commanded by Abu Soueid Dam are typical of the Butana landscape. Land is generally flat with a gentle slope towards the Blue Nile River. It constitutes a watershed characterized by the presence of a main water course (Wadi Abu Soueid) which flows from Abu Delaig hills in the north east toward the Blue Nile. There are no hills in the waterbed, except for some scattered sand hummocks and dunes. Small streamlets during the rainy (Kharif) season join to form the Wadi Abu Soueid watercourse or *wadi*. The flow of this *wadi* lasts for up to 6 months, depending upon the amount and duration of rainfall. The mean annual rainfall in the area ranges between 139 and 159 mm, and the rainfall distribution is rather erratic.

In Wadi Abu Soueid, the prevalent soil is clay loam. Its moisture retention capacity is comparatively high, and that is why it is considered to be suitable for successful application of water spreading systems. The vegetation cover is dominated by woody species, namely *Acacia mellifera* (Kitir), *Merua crassifolia* (Sarih), *Acacia tortilis* (Seyal), *Acacia ehrenbergiana* (Salam), and *Ziziphus spina christi* (Sidir). These are dominant in low-lying sites of the *wadis* (the beds of seasonal water courses). *Calotropis procera* and *Acacia nubica* (indicators of vegetation degradation) are prevalent in certain areas. The ground flora of the area is dominated by the perennial drought-tolerant *Pamicum turgidum*, *Cenchrus ciliaris* (Huskanit), and *Euphoris aegyptica*. These provide valuable grazing material for camels and small ruminants. *Aristids spp* are dominant on clay soil.

The population is composed of Arab tribes, mainly Batahin (the dominant tribe), Hassania, Ahamda, Kababish, Massalamia and Bedderia. These tribes have never experienced conflicts over land or pasture use. The community members are leading a very peaceful life and living together in harmony. Livelihoods are based on use of natural-resources. Most of the tribes in the study area practice dryland farming and livestock rearing. Animal production is the main occupation, but the successive years of drought have resulted into significant reduction in the number of reared animals in the area, particularly those grazing on natural pastures. The reared animals in the area are cattle, camels, sheep, goats and donkeys, in addition to poultry, the production of which is regarded as women's business.

Crop production is subsistence-oriented. Two indigenous varieties of low yielding dura (sorghum), the staple food grain, are cultivated with low level of mechanization and no or little use of chemical fertilizers. However, the soil gets fertilized naturally from animal droppings because grazing of crop residues is practiced following dura harvest. The dura stalks are conserved to feed livestock in the dry season. Minor crops, such as watermelon, cucumber, okra, and *karkadeh* are sometimes grown. The land is officially owned by the government, but community members have locally recognized land use rights.

The conceptual model of the study is composed of a set of hypotheses on the environmental and socio-economic impacts of the water harvesting and spreading project under investigation. Each of the stated hypotheses relates to a number of variables.

Four principal hypotheses were formulated for testing as follows:

1. The water spreading project of Wadi Abu Soueid has brought about both quantitative and qualitative improvements in the natural tree, bush, and grass cover in the area.
2. The water spreading project has increased the areas under crops, and encouraged greater engagement in commercial animal production activities.
3. The water spreading project has resulted in reduction of the rate of out migration from the area.
4. Water harvesting and spreading can have both positive and negative environmental and security impacts

The selection of a representative sample of the agro-pastoralists residing in area commanded by Wadi Abu Soueid rainwater harvesting and spreading project, for interviewing, involved use of a stratified random sampling procedure for selection of 5 representative villages. The stratification of the villages was based on distance from Khartoum city – the capital of Khartoum State. Following that, a proportional convenience sampling procedure was employed for selection of a 50-member sample to represent the heads of households residing in the randomly chosen villages of Salamat Wad Nile, Al Hidaibab, Seyal Alfaki Saad, Al Ahamda and Al Nikhaira.

The methods used in data collection included a reconnaissance survey of the study site, individual information gathering interviews with the study respondents involving use of a structured schedule, photography, and compilation of secondary data from available records. A reconnaissance survey was carried out first to delineate the study area and then to collect some basic data for preparing the data collection schedules. The main instrument used for obtaining primary data was a structured interview schedule which was designed in consultation with experts in the field. The interviews for collection of primary data were conducted with the selected heads of households, but information about all family members was recorded. Relevant secondary data were obtained from local departmental records, including reports on the area, including estimates of human and livestock populations, cultivated areas, and crop yields (Ministry of Agriculture, Khartoum State, 2000; Ministry of Agriculture and Forestry (MAF), 2001).

The data were closely examined to assess the effect of water spreading on socio-economic and environmental conditions of the area. The electronic statistical package for the social sciences (SPSS) was used for data analysis to generate descriptive statistics, frequencies, t-test statistics and correlation coefficients.

RESULTS AND DISCUSSION

The impact of rainwater spreading on natural vegetation was assessed from the perceptions of the study respondents. Table 1 (a) shows the percentage distribution of the sample members by perceived densities of the different species of the natural vegetation of Wadi Abu Soueid area in the periods prior and after erection of the water spreading dam. The responses indicated that the lands commanded by Abu Soueid Dam contain rich stands of Tumam grass (*Panicum turgdum*), Dambalab (*Schoenefeldia gracilis*) and Saha (*Blepharis edulis*). All these are palatable plant species desired for grazing by livestock.

Table 1 (a) also indicates that the densities of Talih (*Acacia seyal var. fistula*), Seyal (*Acacia tortilis* var. *raddiana*), Kitir (*Acacia mellifera*), Sider (*Ziziphus spina-christi*) and Salam (*Acacia ehrenbergiana*) have increased substantially following the establishment of the rainwater spreading project. The densities of some of the less desirable plant species, like La-oat (*Acacia nubica* Benth) and Usher (*Calotropis procera*), both of which are undesirable plant species, have declined following the construction of the water spreading dam. Land cover by *Cassina senna* (Senna Mecca or Sanamakka), a medicinal plant, has also declined after the introduction of water spreading techniques, seemingly because of expansion of cultivated crops.

The perceived density levels of the plant species in the pre-dam and post- dam periods were measured in terms of an ordinal scale (a score of 1 for perceived low density, a score of 2 for perceived medium density, and a score of 3 for perceived high density. Thus, the computed arithmetic mean scores ranged between 1 and 3. Differences in the perceived densities of the different plant species in the rangelands of the area in the pre and Post-dam periods were found by t-test analysis to be significant at the .01 level.

The analysis, thus, has indicated an overall improvement in the natural grass vegetation cover in Wadi Abu Soueid area. This is partly attributed to the construction of the water spreading dam, and partly to the rangeland development activities of the Range and Pasture Administration of Khartoum

State’s Ministry of Agriculture, Animal resources and Irrigation (including regular broadcasting of seeds of desirable indigenous plant species on degraded range sites and the opening of networks of fire-lines after the rainy season to help confine uncontrolled bush fire). However, the observed increase in the density of Adar weed (*Sorghum* *sudanensis*) and Buda (*Straiga hermonthica*) - a parasite plant affecting the growth of dura - constitutes a negative effect of the water spreading project.

The t-test analysis results in Table 1 (b) also reveal significant differences in the densities of the natural woody plant species in Abu Soueid area between the pre- and post-dam construction periods. The introduction of the water spreading technique has resulted into a significant increase in the density of woody species, including ones that provide feed for livestock, especially camels and goats. The relatively dense tree cover is expected to lead to decrease of wind velocity and, thus, protection of soil from wind erosion.

Land in Wadi Abu Soueid area is predominantly registered as government property. Customary land tenure arrangements, however, have provided for access to land by members of the local tribal groups. Members of the population enjoy communally recognized rights to use of land resources that are not officially registered to individuals or other private entities. Pasture lands are regarded as open-access resources. However, access to farmland is rather limited, and most of the farmland parcels possessed by the respondents were found to be of small size. Only few of the residents of the area have access to larger land holdings.

The impact of rainwater spreading on crop production was significant. From the results of the data analysis conducted, there were indications that the rainwater spreading project had lead to expansion of the cultivated areas and to introduction of new crops shows an increase in both minimum and maximum areas under dura (sorghum) in the seasons following the operation of the rainwater spreading dam. Areas cultivated with dura increased by an average of 1.76 feddans per household in the after-dam-construction period. Table 2 (a) also reveals that the areas under vegetable crops have increased following the construction of the water spreading dam. The cultivation of vegetable crops, including watermelon, is an innovation whose adoption was facilitated by the water spreading project. No vegetable crops were cultivated by the respondents in the period before construction of the rainwater spreading dam. However, the maximum area under vegetables per household was found to be two feddans, seemingly because of the limited experience of farmers in cultivation of these crops.

The t-test analysis results displayed in Table 2 (b) indicate the presence of a significant difference between the mean areas under vegetable crops in the periods before and after the construction of Wadi Abu Soueid water harvesting and spreading dam. The water spreading project has provided for introduction of vegetable crops, which before the construction of the dam were rarely cultivated.

As shown in Table 2 (b), the mean difference between areas under dura for the periods before and after the erection of Wadi Abu Soueid dam is significant at the 0.1 level. While the areas under dura cultivated by the respondents used to range between 3 and 35 feddans before the dam was erected, the areas under dura ranged between 4 and 50 feddans in the seasons following the establishment of the water spreading project.

The yields of crops, as indicated by the statistics in Table 3 (a), have also increased in the periods following the application of the rainwater spreading technique. Dura production was found to range between 12 and 250 sacks per farm among the respondents (with a mean of 43.28). Dura productivity per feddan ranged between 1.5 and 5 sacks (with a mean of 2.73).

In the period before construction of the water spreading dam, the minimum and maximum sacks of dura produced by the respondents were found to be 7 and 150 sacks respectively (with a mean of 29.46 sacks). Dura productivity per feddan ranged between 1.17 and 4.29 sacks (with a mean of 2.17 sacks). In the period after construction of the dam, dura productivity ranged between 1.5 and 5 sacks (with a mean of 2.73 sacks). Thus, from the foregoing figures, the mean production of dura has increased by 46.9%, and productivity has risen by 25.8%.

Table 3 (a) also shows that the minimum and maximum production of vegetables in sacks were 0 and 30 respectively, and the minimum and maximum watermelon production were 0 and 4 (lorries) respectively in the period following the use of rainwater spreading. It is notable that the production of these minor crops was modest, seemingly because of lack of experience among farmers concerning the management of these new crops.

The t-test analysis results in Table 3 (b) indicate the presence of a significant difference in dura production in the periods before and after construction of Wadi Abu Soueid dam. Dura productivity per feddan has increased slightly on average after-operation of the dam. The modest increase in dura productivity can be attributed partly to the substantial increases in the levels of infestation of the irrigated farmland by the nocuous Adar weed (*Sorghum sudanensis*) and the parasitic Buda plant (*Straiga hermonthica*).

Table 4 (a) shows the number of animals which were kept by the families of the respondents. It was found very difficult to get information from the respondents concerning the exact sizes of the herds owned by their families. That was because some superstitious livestock owners, among them, were reluctant to give precise information about the number of animal they are keeping because they were fearful of "*the evil eye*" and they were also fearful of imposition of more taxes on them by the government.

Analysis of the data obtained revealed that the impact of rainwater spreading on animal production was positive. Table 4 (a) indicate that the numbers of the different animals kept by the respondents' families have increased substantially in the period following the construction of Abu Soueid Water Spreading Dam relative to the period before the construction of the dam. The mean number of heads of goats kept by the family has increased from 12 to 17 (46.3%), the mean number of sheep increased from 41 to 64 (57.1%), that of cattle increased from 9 to 16 (76.7%), that of camels increased from 1 to 2 (43.4%) and that of donkeys increased from 1 to 2 (34.1%). In Table 4 (b), t-test analysis shows that the increases in the numbers of camels and donkeys after dam construction are statistically significant at the 0.05 level, while the increase in the number of goats is significant at the 0.1 level.[1]

Data analysis also reflected improvement in the animal feeding practices used by the respondents in the period following construction of the dam. As shown in Table 5, 100% of the respondents used natural pasture for feeding their animals before construction of the dam. Camels depended exclusively on natural grazing. Fodders were fed only to goats, sheep, cattle and donkeys. Concentrates were used in the feeding of cattle and goats mainly, and to a lesser degree in the feeding of sheep.

Because of shortage in natural pastures during the dry-season, the herders use supplementary feeds to nourish their animals, such as dura stalks (or residues) left in the field after harvest of dura grains for human use. The amount of fodder fed this way depends on the crop density. As indicated earlier, dura production has increased after construction of the dam, compared with the before-dam period. This means that the amount of dura stalks available for feeding the animals has increased in the after-dam period. As reflected in Table 5, most of the respondents (96%) use dura crop residues as fodder for goats, 98% use dura crop residues for supplementary feeding of sheep, 88% use dura residues for feeding donkeys, and 84% of them use dura stalks for supplementary feeding of cattle.

Based on the results of the present study, it is worth mentioning that the feeding of camels depends exclusively on the natural vegetation within Wadi Abu Soueid area and the neighboring vicinities. Goats, sheep and cattle are fed on pasture grasses and fodders, with supplemental feeding involving use of concentrates (especially for cattle and goats). The donkeys are fed on pasture grasses and dura crop residues.

Sometimes the respondents use irrigated fodder crops, such as Clover (*Medicago sativa*) and Abu Saba'een (*Sorghum bicolor*) to provide supplementary feeding for their livestock. The production of these irrigated fodder crops has been facilitated by the rainwater spreading technique.

The above-mentioned findings suggest that people in the study area do not depend exclusively on natural pasture grasses throughout the year. They supplement pasturing with feeding their livestock on fodders (mainly the dura crop residues) and on concentrates. This suggests that the rangelands in the area are not degraded by overgrazing, which indicates a significant positive impact on natural vegetation and animal production resulting from the water spreading project under study.

The respondents feed concentrates to their lactating animals in order to meet their nutritional requirements. Concentrates, including wheat barn and oil-seed cakes, are used by 60% of the respondents in cattle feeding, by 30% in goats feeding, and only by 4% in sheep feeding. Concentrates are not given to camels and donkeys. The respondents use concentrates to feed only animals that produce milk for household consumption and for sale.

The data analysis results in Table 6 indicate that 40% of respondents were not involved in milk production for sale in the period before the construction of the dam, compared to 20% in the after-dam construction period. In other words, now 80 percent of the respondents are involved in individual and group commercial milk production (a 33.33% increase in the number of producers of milk for sale is indicated by this figure). A 50% increase in engagement of the respondents in breeding and selling of live animals also occurred following the establishment of the dam.

Also shown in Table 6 is that engagement in sale of live animals increased from 20% in the pre-dam period to 40% in the post-dam period. This indicates a positive impact on quantity and quality of livestock from the water spreading projects, seemingly because of improved nutrition practices. To be noticed is the finding that sale of live animals is practiced through individual channels.

The foregoing results indicate that the economic status of the target population of Abu Soueid Water Spreading Dam has improved. Data analysis revealed that income from both milk and live animal sales has increased significantly after use of rainwater spreading practices in the areas. The mean income from milk production increased from 40850 SDDs in the pre-dam period to 94480 SDDs in the post dam period; with a mean difference of 5362 SDDs (significant at the 0.05 level). On the other hand, the mean income from live animal sales increased from 31280 SDDs in the period before construction of the dam to 87020 SDDs in the post-dam period; with a mean difference of 55740 SDDs (significant at 0.05 level). Thus, incomes from both of milk and live animal sale activities have increased significantly after the establishment of Abu Soueid dam. Plant crop production was found to be mainly for household consumption and feeding of livestock. The contribution of crop production to household income is indirect through provision of feeding material in commercial animal production activities: Only few farmers were found to have been engaging in production of plant crops for sale.

The impact of Wadi Abu Soueid Water Harvesting and Spreading Project on environmental and community security proved to be significant. Table 7 suggests that trespassing on rangeland and farmland by nomadic herds from neighboring areas was perceived by the 16% of the respondents to have increased in the period following the construction of the dam. Only 6% of the respondents perceived that problematic trespassing of crop land by animals used to occur in the period prior to operation of the rainwater spreading project. The trespassing on pasture lands became more problematic following the construction of the dam. While 42% of the respondents perceive of trespassing on rangeland as has become more problematic following the use of rainwater spreading, only 12% of the respondents indicated that trespassing on pastures in the area was a problem prior to erection of Wadi Abu Soueid dam. Fire breakouts in the period following the construction of the dam were also perceived to be substantial by 48% of the respondents. Nowever, fire breakouts in the area prior to establishment of the dam were more prevalent (as perceived by 80% 0f the respondents).

The most serious problem facing the residents of the area was the increased occurrence of animal thefts following the establishment of the water spreading dam. Tree cutting is perceived as a problem, but the practice of excessive tree cutting has declined - an indication of increased environmental protection awareness among community residents. However, over flooding of farmland caused by repeated breakages of the dam embankments and lack of maintenance of the dam structures, has constituted a new serious problem that needs to be addressed by the concerned agencies.

The analysis that was conducted to assess the impact of the water spreading project on seasonal out migration indicated a positive effect. Data analysis reveal that the maximum length of the seasonal out migration of the respondents' family members in the per-dam-period was about 6 months, compared to a much lower maximum of 3 months in the post-dam period. The t-test analysis indicated presence of a significant difference between the mean length of seasonal out migration of family members in the pre-dam period (2.56 months per year) and that for the post-dam-period (0.72 month/year). This result indicates that the water spreading project has increased the engagement of community members in local economic activities, and thereby has facilitated greater involvement in local community development.

The results of correlation analysis (Table 8) have contributed meaningful insights. Correlation analysis was carried out to determine the magnitude and significant of the associations among variables relating to the environmental and socio-economic impacts Wadi Abu Soueid water spreading project. The analysis revealed that farmland size correlates positively and significantly at 0.01 with area under crops. The computed coefficient (r=1.000) indicates a cropping intensity of 100%, that is all farmland in possession of the respondents had been cultivated with different crops (mainly dura). Farm size was also found to correlate significantly with size of livestock herds kept, and with income from animal production (more significantly with number of camels in possession and with income from sale of milk). The associations between sizes of the different livestock herds kept by the families in the study area were found to be positive, meaning that, on the average, family members who own more goats also own more sheep, cattle, camels and donkeys. Ownership of livestock herds was also found to correlate positively and significantly with the number of months of out migration. Family size was found to correlate positively with the number of animals kept and negatively with perceived presence of problematic land use, environmental and security hazards. Members of large families in the area feel more secure than those belonging to the small resource-poor households.

CONCLUSIONS AND RECOMMENDATIONS

The results of the present study revealed that the establishment of Wadi Abu Soueid water spreading dam has brought about significant environmental and socio-economic improvements in the targeted area. However the water harvesting dam has also resulted in some negative environmental impacts that need to be redressed.

The field survey revealed that the ecological and socio-economic conditions in the area before and after the establishment of the water spreading dam are significantly different in terms of the density of natural vegetation cover, farming scale, crop and animal production practices, the number of animals owned by the pastoralist and agro-pastoralist household members, incomes from crop and animal production, community security, and the extent of annual temporary out migration of community residents.

The impact of water spreading on the natural vegetation was positive. The tree and grass species have flourished to the advantage of community residents. Crop areas and yields have increased significantly relative to the period before the project was established. Community residents became more involved in commercial animal production. The sizes of the different livestock herds kept by families in the project area have increased substantially, relative to the period before the construction of the dam.

The negative impacts of Wadi Abu Soueid dam include the observed wide-spread infestations with *Buda* and *Adar* weeds that have led to reductions in dura (sorghum) yields. Trespassing on pasture and farmlands, as well as animal thefts, has increased. Some farmers have also lost the opportunity to farm more land due to land over-flooding by waters from the dam as a result of negligence of maintenance operations and follow-up activities. These problems need to be addressed by all the concerned stakeholders.

Based on the above-mentioned conclusion, the study recommends regular maintenance of Wadi Abu Soueid dam and the other water harvesting structures in the rural areas of Khartoum State by the concerned authorities. Also recommended by the study is the adoption of participatory planning, implementation and follow up programs for ensuring sustainable improvement of rangelands and crop and animal production activities in the rain-fed areas of the State. The intensification of technically coordinated and supported extension programs based on participatory approaches is suggested as a means for achieving sustainable development and efficient use of the natural resources of the rural areas.

REFERENCES

Ahmed, S. E. (2000). Keynote Address: Desertification – its Causes and its Impact on Water Resources Management in Arid Regions. International Seminar on Combating Desertification, N'Djamena, Chad 30 October to 4 November 2000/ UNESCU-MAB Drylands Series No. 1, 11-19.

Ali, A., Oweis, T., Rashid, M., El-Naggar, S., and Abdul Aal, A. (2007). Water harvesting options in the drylands at different spatial scales. *Land Use and Water Resources Research* **1**: 1-13.

Banclark, L. (2010). Rainwater Harvesting: A Suitable Poverty Reduction Strategy for Small-Scale Farmers in Developing Countries? MA Dissertation, University of East Anglia (http://www.ewb - uk.org / file store / Lisa % 20 Bunclark_Rainwater%20Harvesting_2010.pdf).

Barron, J. (2009). Rainwater harvesting: a lifeline to human well-being. *POLICY BRIEF*, Stockholm Environment Institute (SEI). (http://www.sei-international.org/mediamanager/documents/Publications/Water-sanitation/rainwaterharvestingpb-090330.pdf).

Boers, Th. M. (1994). Rainwater Harvesting in Arid and Semi-Arid Zones. Ph.D. Dissertation, Wageningen Agricultural University, the Netherlands.

Boers, Th. M., and Ben-Asher, J., 1982. A review of rainwater harvesting. Agric. Water Manage **5**: 145-158.

Critchley, W., and Siegert K. (1991). Water Harvesting: A manual for the Design and Construction of Water Harvesting Schemes for Plant Production.

Darag, A. (1999). Elodaya Desertification Control Project, Western Kordofan. World Forum of Mayors on Cities and Desertification. Bonn, 11-12 June 1999.

FAO, (2003). *Unlocking the Water Potential of Agriculture*. Food and Agriculture Organization of the United Nations, Rome, Italy. (http://www.fao.org/docrep/U3160E/U3160E00.htm).

Ministry of Agriculture and Forestry (MAF) (2001). Forum on Water Harvesting and Spreading in Sudan – Present and Future. June 26, 2000. Khartoum, Sudan.

Ministry of Agriculture, Khartoum State (2000). Annual Report

Nijhof, S., Jantowski, B., Meerman, R., and Schoemaker, A. (2010). Rainwaterb Harvesting in Challenging Environments: Towards Institutional Frameworks for Sustainable Domestic Supply. Waterlines, 29 (3): 209-219.

Oweis, T., Hachum, A., and Kijne, J. (1999). Water harvesting and supplemental irrigation for improved water use efficiency in dry areas. System-wide Initiative on Water Management (SWIM) Paper No. 7. International Water Management Institute. P. O. Box 2075, Sri Lanka.

Table 1 (a). Percentage distribution of respondents by perception of density levels of the different natural vegetation species before and after construction of Wadi Abu Soueid Dam.

Natural vegetation species	Time period	Percentage distribution of respondents by Perceived density level of the plant species			Total
		Low	Medium	High	
Tumam grass	Pre-dam	8	92	0	100
	Post-dam	0	6	94	100
Dambalab	Pre-dam	0	72	28	100
	Post-dam	0	8	92	100
Saha	Pre-dam	100	0	0	100
	Post-dam	0	92	8	100
Adar	Pre-dam	100	0	0	100
	Post-dam	0	92	8	100
Buda	Pre-dam	100	0	0	100
	Post-dam	8	86	6	100
Senna Mecca/ Sanamakka	Pre-dam	0	78	22	100
	Post-dam	98	2	0	100
Usher	Pre-dam	0	92	8	100
	Post-dam	100	0	0	100
Salam	Pre-dam	12	84	4	100
	Post-dam	0	76	24	100
Sidir	Pre-dam	72	28	0	100
	Post-dam	2	98	0	100
La-oat	Pre-dam	22	78	0	100
	Post-dam	100	0	0	100
Talih	Pre-dam	0	96	4	100
	Post-dam	0	30	70	100
Seyal	Pre-dam	10	88	2	100
	Post-dam	2	32	66	100
Kitir	Pre-dam	0	72	28	100
	Post-dam	0	0	100	100

Table 1 (b). Results of t-test of differences in perceived density levels of natural vegetation species before and after construction of Abu Soueid Dam

Plant Species	Time Period	t Test Statistics		Sig.
		Mean score	Mean score Difference	
Tumam Grass	Pre-dam	1.92	1.02	.01
	Post-dam	2.94		
Dambalab	Pre-dam	2.28	0.64	.01
	Post-dam	2.92		
Saha	Pre-dam	1.00	1.04	.01
	Post-dam	2.04		
Adar	Pre-dam	1.00	1.08	.01
	Post-dam	2.08		
Buda	Pre-dam	1.00	0.98	.01
	Post-dam	1.98		
Senna Mecca/ Sanamakka	Pre-dam	2.22	-1.20	.01
	Post-dam	1.02		
Usher	Pre-dam	2.08	-1.08	.01
	Post-dam	1.00		
Salam	Pre-dam	1.92	0.32	.01
	Post-dam	2.24		
Sidir	Pre-dam	1.28	0.70	.01
	Post-dam	1.98		
Laoat	Pre-dam	1.78	-0.78	.01
	Post-dam	1.00		
Talih	Pre-dam	2.04	0.66	.01
	Post-dam	2.70		
Seyal	Pre-dam	1.92	0.72	.01
	Post-dam	2.64		
Kitir	Pre-dam	2.28	0.72	.01
	Post-dam	3.00		

Table 2 (a). Crop areas before and after the erection of Wadi Abu Soueid dam

Crops grown	Areas (in feddans) under crops *before* establishment of Abu Soueid dam			Areas (in feddans) under crops *after* the establishment of Abu Soueid dam		
	Minimum	Maxi-mum	Mean	Minimum	Maxi-mum	Mean
Dura	3.0	35.0	12.92	4.0	50.0	14.88
Watermelon	0.0	0.0	0.0	0.0	2.0	0.13
Other Vegetables	0.0	0.0	0.0	0.0	2.0	0.15

Table 2 (b). Results of t-test analysis of the differences in areas under crops cultivated by the respondents in the periods prior to and after construction of Wadi Abu Soueid dam

Crop grown	Period	Mean Area (feddans)	Mean areas difference (feddans)	Sig
Dura	Pre-dam	12.92	1.96	0.1
	Post-dam	14.88		
Watermelon	Pre-dam	0.00	0.13	0.05
	Post-dam	0.13		
Other vegetables	Pre-dam	0.00	0.15	0.05
	Post-dam	0.15		

Table 3 (a). Crop production statistics for the periods before and after construction of Abu Soueid rainwater spreading dam

Crop and unit of production	Period	Minimum	Maximum	Mean
Total dura production (sacks)	Pre-dam Post-dam	7 12	150 250	29.46 43.28
Dura productivity (sacks per feddan)	Pre-dam Post-dam	1.17 1.50	4.29 5.00	2.17 2.73
Watermelon production (lorries)	Pre-dam Post-dam	0.0 00.0	0.0 4.0	0.0 .28
Other Vegetables production (sacks)	Pre-dam Post-dam	0.0 0.0	0.0 30.0	0.0 2.82

Table 3 (b). Results of t-test of mean differences in production of crops before and after the construction of Wadi Abu Soueid rainwater spreading dam

Crop and unit of production	Period	Mean Production	Mean difference	Sig.
Dura (Sacks)	Pre-dam	29.46	13.82	0.05
	Post-dam	43.28		
Watermelon (Lorries)	Pre-dam	0.00	0.28	0.05
	Post-dam	0.28		
Other vegetables (Sacks)	Pre-dam	0.00	2.82	0.01
	Post-dam	2.82		

Table 4 (a). Sizes of livestock herds kept by respondents before and after construction of Wadi Abu Soueid dam

Type of Animals kept by respondents	Numbers of animals kept in the period before construction of Wadi Abu Soueid dam			Numbers of animals kept in the period after construction of Wadi Abu Soueid dam		
	Mini-mum	Maxi-mum	Rounded Mean	Mini-mum	Maxi-mum	Rounded Mean
Goats	0	80	12	0	100	17
Sheep	0	350	41	0	500	64
Cattle	0	100	9	0	150	16
Camels	0	6	1	0	8	2
Donkeys	0	5	1	0	7	2

Table 4 (b). Results of t-test of differences in livestock herd sizes before and after the construction of Wadi Abu Soueid dam

Type of animals kept	Period	Unrounded mean number	Unrounded mean difference	Sig.
Goats	Pre-dam	11.62	5.38	0.1
	Post-dam	17.00		
Sheep	Pre-dam	40.52	23.12	0.1
	Post-dam	63.64		
Cattle	Pre-dam	9.00	6.90	0.1
	Post-dam	15.90		
Camels	Pre-dam	0.94	1.72	0.05
	Post-dam	1.66		
Donkeys	Pre-dam	1.08	0.56	0.05
	Post-dam	1.64		

The computation of the percentage values are based on the unrounded mean number of animals owned by the families before and after construction of Abu Soueid dam.

Table 5. Use of different sources of animal feeds in Wadi Abu Soueid area

Type of animal reared	Percentage distribution of respondents by use/ non-use of different feeds in the feeding of different animals					
	Natural pasture grass		Fodders (mainly dura stalks)		Concentrates	
	Used (%)	Not used (%)	Used (%)	Not used (%)	Used (%)	Not used (%)
Goats	96	4	96	4	30	70
Sheep	98	2	98	2	4	96
Cattle	84	16	84	16	60	40
Camels	58	42	0	100	0	100
Donkeys	88	12	88	12	0	100

Table 6. Percentage distribution of the respondents by involvement in milk and live animal marketing activities

Period	Distribution of respondents by types of Engagement in milk production for sale			Distribution of respondents by types of Engagement in live animal production for sale		
	No engage-ment (%)	Individual engage-ment (%)	Group engage-ment (%)	No engage-ment (%)	Individual engage-ment (%)	Group engage-ment (%)
Pre-	40	16	44	80	20	0

dam						
Post-dam	20	22	58	60	40	0

Table 7. Percentage distribution of respondents by perceptions concerning security hazards in the pre- and post-dam periods

Types of security hazards	**Pre-dam period**		**Post-dam period**	
	Hazard perceived as not problematic (%)	**Hazard perceived as problematic** (%)	Hazard perceived as not problematic (%)	**Hazard perceived as problematic (%)**
Trespassing on farmland	94	**6**	84	**16**
Trespassing on rangeland	88	**12**	58	**42**
Fire breakouts	20	**80**	52	**48**
Animal thefts	68	**32**	42	**58**
Cutting of trees	20	**80**	70	**30**

Table 8. Matrix of inter-correlations for selected variables

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
X_1	1.00	.31*	.273	.244	.31*	.38*	.26*	.24	.45*	.06	.06	.32*
X_2		1.00	.80*	.75*	.36*	.39*	.27	.77*	.39*	.17	.17	-.06
X_3			1.00	.75*	.28*	.49*	.32*	.89*	.54*	.14	.14	-.12
X_4				1.00	.37*	.11	.66*	.86	.38	.20	.20	-.08
X_5					1.00	.07	.47*	.30*	.30*	.45*	.45*	-.12
X_6						1.00	-.02	.25	.49*	-.06	-.06	-.12
X_7							1.00	.49*	.43*	.32*	.32*	-.07
X_8								1.00	.44*	.22	.22	-.04
X_9									1.00	.25	.25	-.03
X_{10}										1.00	1.00*	.21
X_{11}											1.00	.21
X_{12}												1.00

*= Significant correlation

Key:

X_1 = Family size

X_2 = Number of goats kept

X_3 = Number of sheep kept

X_4 = Number of cattle kept

X_5 = Number of camels kept

X_6 = Number of donkeys kept

X_7 = Income from sale of milk

X_8 = Income from sale of live animals

X_9 = Out migration (months)

X_{10} = Farmland size

X_{11} = Area under crops

X_{12} = Perception of land use hazards