Evaluation of the Sand Abstraction Systems for Rural Water Supply: the case of Lupane District, Zimbabwe.

Oniward Svubure[1], Tapiwanashe Gumbo, Gabriel Soropa, Farirai Rusere, Annah Ndeketeya and Desire Moyo

Department of Irrigation and Water Engineering, Chinhoyi University of Technology, Off Harare-Chirundu Highway, P. Bag 7724, Chinhoyi, Zimbabwe.

Abstract
Modern sand abstraction systems, an improvement of the traditional river bed sand wells have been used for over a decade in semi-arid rural Lupane District in Zimbabwe as a drinking water source. The study investigated the water quality from the sand abstraction system, its contribution to the communities' water needs, the constraints and the perception of the community on the sand abstraction system. Water samples were collected for quality assessment and a mixture of qualitative data collection techniques were used. Data was analyzed by chi-square tests. Overaly, modern sand abstraction systems have a potential to supply adequate and safe drinking water to the rural communities. However, there is need for protection of the sandy aquifer from erosion, bacterial and chemical contamination. A piped water distribution network coupled with electrically driven pumping was recommended for sand abstraction systems in Lupane to alleviate challenges that come with use of the systems.

Key words: traditional river bed sand wells, sand abstraction water supply system, rural water supply, rural Lupane District, Zimbabwe.

1.0 Introduction

The world faces severe and growing challenges to sustain water quality and to meet the rapidly growing demand for water resources, particularly among rural communities in Africa and Zimbabwe. Reasonable access to water is the availability of at least fifty litres of water per person per day from a source within one kilometre of the homestead (WHO, 2000). The water supply and sanitation coverage for Africa remains the lowest at 62% and 60% respectively (WHO, 2000). This contrasts the coverage in Zimbabwe, which has declined to 30% in the last decade owing to a host of factors (Manyanhaire *et al.,* 2009). These include the destruction of infrastructure by cyclone Eline, frequent droughts, and the socio-economic problems which the country faced at the turn of the millennium.

Women pay the heaviest price for poor water supply and sanitation (WHO, 2000) as they are forced to walk long distances to fetch water. Contamination risks exist during the transportation of water to the homestead if the source is located too far away. Other hygienic aspects such hand washing become less common when a water source is greater than one kilometre from the home, but more frequent when the water is more accessible (Manyanhaire, 2009). Another dimension is the time and energy spent collecting water. Water must be available when required, and those who travel longer distances to the water point tend to use less negatively affecting consumption and hygiene practices.

Potable water is one that is safe to drink, pleasant in taste, and suitable for domestic purposes whereas contaminated water contains suspended or dissolved material making it unsuitable for drinking (Clark, 1971). Practically, the quality requirements for drinking water can be expressed in tables giving the 'highest desirable' and 'maximum permissible' levels for each parameter (IRC, 1981). But at the same time, improvements giving

[1]Corresponding author. Present address: Department of Irrigation and Water Engineering, Chinhoyi University of Technology, Off Harare-Chirundu Highway, P. Bag 772, Chinhoyi, Zimbabwe. Tel.: +263 67 2203-5 or 29053-5; fax: +263 67 28957.
E-mail addresses: osvub@yahoo.com, osvubure@cut.ac.zw (Oniward Svubure), tgumbo@gmail.com (Tapiwanashe Gumbo), gsoropa@yahoo.co.uk, gsoropa@cut.ac.zw (Gabriel Soropa), frusere@cut.ac.zw (Farai Rusere), zuluannah@gmail.com , andeketeya@cut.ac.zw (Annah Ndeketeya), dmoyo@cut.ac.zw (Desire Moyo).

people water for their basic hygiene needs should not be inhibited by rigid adherence to 'ideal' standards. Water quality guidelines are divided into four main aspects: bacteriological, physical, chemical, and radiological. Consumer attitude towards their drinking-water supply is mainly affected by the quality aspects that they perceive with their own senses (WHO, 2004). In Zimbabwe, no standards applicable to potable water have been developed and the country uses the World Health Organisation (WHO) standards for portable water.

People in rural areas of Zimbabwe traditionally obtained water from unprotected sources such as from sand wells in rivers for generations before the introduction of alternative sources like hand pumped boreholes and dams (Hussey, 1999). Soil erosion in many cases leads to large quantities of sand deposits into waterways and rivers. These unconsolidated sediments in rivers retain water in the pore spaces. In long stretches of a river where the sand builds up to two metres or more, large volumes of water are retained. This water retained within sand riverbeds has traditionally been utilized by arid-land dwellers and has been an established and accepted practice, probably throughout history. Temporary sand wells are dug in the riverbeds and are regularly deepened as the water level drops. This water abstraction method is low cost, practical and easily constructed which makes it popular with resource-poor communities. However the sand wells last only for one season and also causes environmental degradation. This occurs when branches, leaves, seeds and other organic matter from bush wood fences used to protect the sand wells were buried in the sand during rains. The seeds would germinate forming islands of vegetation on river beds in the process, thereby threatening the river lifespan. The community members had to continuously shift the position of the sand wells on a yearly basis looking for a river section holding water. The present technology of sand-abstraction is the result of a progression from the traditional open sand well to the installation of sub-surface abstraction equipment that effectively separate water from sand (Nyoni, 2009).

A previous study on the water situation in rural Lupane District by Hussey (1991) reveled that the villagers did not favour groundwater for their water needs. Borehole water was unpalatable because of the high salt content. The small earth dams dry up quickly and the villagers ended up drawing water from shallow wells dug into the dry silt of the dam basin but the water was found to be completely inadequate and unsafe. While the traditional sand wells provided better quality water than shallow wells in the dam basins, their depth is increased as water continues to recede posing a danger to the users (Hussey, 1991). In addition, when the river flow begins, the protective thorn fences are washed into the wells and trap the silt and finer sediment. This in turn clogs up the river and makes it difficult for people to dig wells at optimum sites in the following season (Hussey, 1999). Also, excessively used river sites, however, can become fouled from clay and/or livestock droppings. From this study, the need for a water source that countered most of the short comings posed by previous water sources was eminent. A new water supply system was introduced in the villages by several Non-Governmental Organizations (NGOs). It is an infiltration gallery based system, commonly referred to as Sand Abstraction in Zimbabwe and in Southern Africa at large (Hussey, 1997). It is a system of abstracting water from the underlying water bearing sand of surface dry river beds. The picture below (*Figure 1*) shows the layout of a typical small-scale sand abstraction system as developed by Dabane Water Trust (Nyoni, 2009) with a single home-made well-point and a flexible connecting pipe to a Rower pump on the riverbank. The Rower pump is situated no more than 5 metres above the saturated river sediment level and discharges water into a sump. Water is then transferred a greater distance and height by a Joma pump to a water supply point such as a water storage tank in a garden which can be located several hundred metres away and some 8 metres higher.

2.0 Objectives of the study

There is no comprehensive knowledge on the accomplishment of contemporary 'Sand Abstraction Systems' (SASs) in meeting its objectives of providing an adequate, safe, palatable and environmentally non-degrading rural water supply in rural Lupane district**.** The NGOs promoting SASs have only carried out internal evaluations and monitoring of the rural water supply projects. A comprehensive study which includes engaging the beneficiaries, studying their different water uses and respective quantities, the water quality and the system performance itself has not been done. Besides, research emphasis on SASs mainly focused on the quantification of storage capacity (Clanahan, 1997; Chiteku and Mutsvangwa, 1999), with less emphasis on water quality. The overall objective of this study therefore was to determine the potential of the contemporary sand abstraction systems to supply rural populations with water.

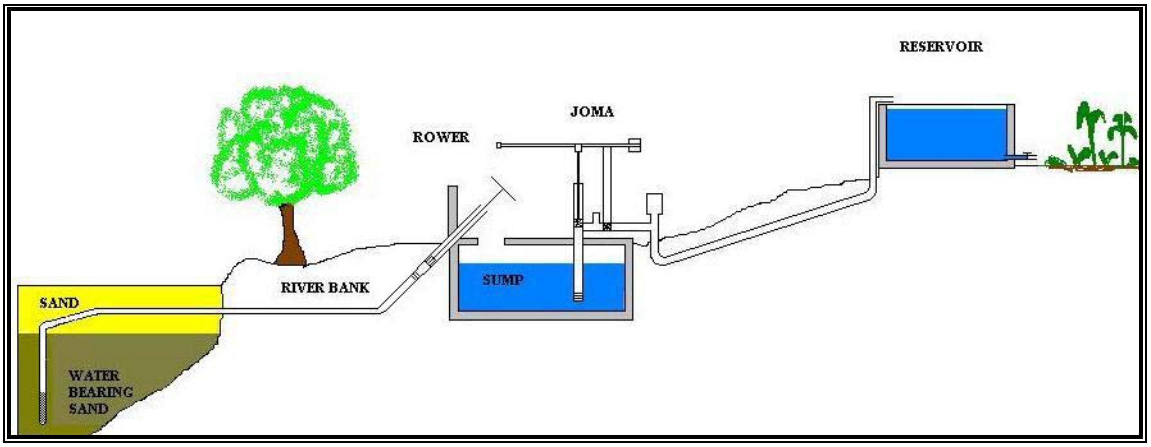

Fig. 1 Typical sand abstraction water supply system. **Source:** Nyoni, (2009).

Specifically, the study sought to establish the following: (i) the water quality of modern sand abstraction systems in the area, (ii) the contribution of the systems to the community water needs, (iii) the constraints associated with the systems and finally (iv) the community perception of the modern sand abstraction systems.

A case study method research strategy was adopted in this paper. Yin (2003, 21) defined the case study as "an empirical enquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". A mixture of qualitative data collection techniques were used which include key informant interviews, semi-structured interviews and observations; and in the process benefit from the inherent multiple sources of evidence. Water samples were also collected for laboratory analysis. We also engaged three research assistants, all residents of Dongamuzi ward in rural Lupane District, who were familiar with the local people and customs. This made it easier for the people to open up to us and we could interact and converse with them more freely. The data collection exercise for this study was quite intensive and was conducted during the period August to November 2009.

3.0 Materials and methods

3.1 Study area

The study area covered three villages in Dongamuzi ward, a rural area in Lupane District, namely Nhlangano, Emsehleni, and Mkhayeni in which sand abstraction systems have been operating for at least 15 years (Dabane Water Trust, 2009). Lupane is situated in Matabeleland North, an area which is semi-arid and prone to droughts and acute water shortages. Lupane district falls in geographical regions IV and V, characterised by low to medium rainfall, averaging 400 - 600mm annually.

3.2 Water quality assessment

Water samples were collected from all the selected three SASs for quality analysis. The water quality analysis included the main chemical, physical and biological parameters which were used to determine whether the water met the WHO bench marks for potable domestic water. At each SAS water point, three point samples using 120ml plastic bottles were taken for bacterial analysis, and a further three samples of 500ml plastic bottles were also collected for pH determination and other laboratory tests. Prior to sample collection, the well was pumped for approximately 30 minutes. This exercise ensured that the sample was representative of the sandy aquifer and not the water bearing sand in close proximity to the well points. The bottles were capped, labeled, and stored in a cooler box after collecting the water samples from the pumps of the sand abstraction systems. The samples were taken to Datlabs Laboratory[2] in Bulawayo City for tests soon after collection.

Significant difference tests between the expected WHO bench marks for potable domestic water and the observed levels for each parameter measured were carried out using the Chi-Square (χ^2) test.

3.3 Field survey

3.3.1 Semi-structured interviews

A field survey was conducted in the three selected villages using a semi-structured interview guide. The sample size comprised of thirty (30) households per village. The village population in the study area ranged from about eighty (80) to one hundred (100) households. Sampling frames were in the form of a numbered household lists

[2] Datlabs Laboratory is a commercially run private laboratory and is well equipped to perform a whole range of water analyses and other. It is located in Zimbabwe's second largest city, Bulawayo.

obtained from the Village Heads[3] of the selected villages in the study area. The household list was divided into ten equal groups and from each group, a total of three households were randomly picked to give a sample size of thirty households from each village. In each household, the household head was the targeted respondent, but in instances where the household heads were not immediately available, other adult members of the household were used as proxies and interviewed. In situations where any household member volunteered information during the survey, such information was promptly recorded. The survey sought to establish, among other things, the water uses in the community and their respective water quantities. This was done to estimate the current community water demand which was then compared against the demand the water supply systems were originally designed for. If the quantity of water from the SAS was adequate to entirely meet the community's daily water requirements, then this contributed to the evaluation of the SAS as a sufficient rural water supply option. Another objective of the survey was to establish the most preferred water source by the communities among the water supply sources in the study area. In this regard, the villagers were asked their perceptions of the SAS in comparison with other common water sources within the study area. The villagers were also asked about the constraints associated with the SASs.

3.3.2 Interview of key informants

Key informant interviews were conducted in all the selected villages as a triangulation to check out the data gathered through the other data collection techniques. A checklist of questions drawn was used to conduct the key informant interviews. The interviewees were asked on the general water situation in the communities. For example, the respondents were asked on the water sources and uses in the community, perceptions on the SAS, preferred water sources and constraints encountered with the SAS. The key informants comprised of the Village Heads, local schools heads, local clinic staff, the Ward Councillor and some elderly villagers. All these people were considered to be very knowledgeable on such issues by virtue of their secular and social positions in society.

3.3.3 Observations

Observations were also used to back the interviews especially in circumstances where technical or numerical information was required and the respondents were illiterate or incapacitated to appropriately respond. The accuracy of data collected through the interviews was also validated through field observations on available water sources, the conditions of the water sources, the size of containers used and the number of trips women made to the water source.

4.0 Results and discussion

4.1 Water quality assessment

The table 1 below shows the laboratory results of selected chemical, physical and biological parameters in the water samples collected from the Nhlangano, Emsehleni and Mkhayeni villages sand abstraction water points.

Table 1 *Water Quality Analysis of water samples from Sand Abstraction Water Points from Lupane District, Zimbabwe (n = 90).*

Parameter	Recommended Limit	Maximum allowable limit	Sand abstraction water point		
			Nhlangano	Emsehleni	Mkhayeni
Conductivity (mS/m)	70	300	36	42	40
pH	6-9	5.5-9.5	7.0	7.3	7.1
Turbidity- (NTU)	1.0	5.0	6.3	6.5	6.5
Total hardness (mg/l)	20-230	650	118	119	121
Calcium (mg/l)	Not Specified	200	1.3	1.2	1.6
Magnesium (mg/l)	100	150	52	54	50
Sodium (mg/l)	100	400	10	9.5	9.7
Potassium (mg/l)	20	100	1.3	1.2	1.6
Iron (mg/l)	0.1	1.0	1.1	1.2	1.3
Manganese (mg/l)	0.05	0.1	2.4	2.6	2.8
Alkalinity	Not Specified	500	196	202	199
Chloride (mg/l)	250	600	<0.01	<0.01	<0.01
Sulphate (mg/l)	200	600	<0.01	<0.01	<0.01
Phosphate (mg/l)	Not Specified	Not Specified	<0.01	<0.01	<0.01
Fluoride (mg/l)	1.0	1.5	<0.01	<0.01	<0.01
Ammonia nitrate mg/l)	6.0	10.0	<0.01	<0.01	<0.01

[3] Village Heads are commonly referred to as Kraal Heads and they keep an updated list of households in their area of jurisdiction.

Approx Dissolved Salts (mg/l)	500	1500	210	190	220
Coli form per 100ml (Bacteria)	Negative	Negative	Negative	Negative	Positive

The values of *Conductivity, pH, Total Hardness, Magnesium, Sodium, Chloride, Sulphate, Ammonium Nitrate*, and *Fluoride* (table 1) from all the sand abstraction water points analyzed fell within the WHO recommended limits. However, values of *Turbidity*, *Iron* and *Manganese* from all the sand abstraction systems sampled and those of the *48-hour bacteria plate count* from Mkhayeni SAS were found above the recommended limits.

4.1.1 Turbidity

The observed turbidity values of water samples from all the villages were higher than those recommended for drinking water. Statistical[4] analysis results showed that there was a significant difference between the recommended and observed turbidity values of water samples from Nhlangano, Emsehleni and Mkhayeni villages. In drinking water, the higher the turbidity level, the higher the risk that people may develop gastrointestinal diseases (Anon, 2009). This is especially problematic for immune-compromised people, because contaminants like viruses and bacteria can become attached to the suspended solid. The suspended solids interfere with water disinfectants such as chlorine because the particles act as shields for the virus and bacteria. According to Adams (1999), human activities that disturb land, such as construction, can lead to high sediment levels entering water bodies during rain storms, storm water runoff, and create turbid conditions. Similarly, land degradation culminating from poor farming methods in the nearby gardens, soil erosion coupled by lack of soil erosion control structures near the sand aquifers could have led to the problem of the relatively high turbidity values. Consequently attention is now needed on these anthropogenic activities around the sampled sand abstraction water points to prevent the turbidity levels from rising further.

4.1.2 Iron and Manganese

The observed iron values of water samples from Nhlangano, Emsehleni and Mkhayeni and villages were higher than the recommended values for drinking water. The statistical analysis indicated that there was a significant difference between the observed iron[5] values and the recommended. Similarly the observed manganese[6] values of water samples from Nhlangano, Emsehleni and Mkhayeni sand abstraction systems were higher and significantly different than those recommended for drinking water. Iron is more common than manganese, but they often occur together (McFarland, 2001). Iron and manganese are considered secondary contaminants. Secondary standards apply to substances in water that cause offensive taste, odour, colour, corrosion, foaming, or staining but have no direct effect on health (Herman, 1996). Iron pipes can corrode and leach iron into a household water supply and it is suspected that this could have been the cause of the excess iron content in the sand abstraction water samples. The steel pipes have been in use as manifolds for more than 15 years in these sand abstraction systems.

4.1.3 The 48-hour bacteria plate count

The water samples from Mkhayeni sand abstraction point tested positive to the presence of *Escherichia coli (E. coli).* Statistical analysis indicated that there was a significant difference between the recommended and the observed 48-hour bacteria[7] plate count values of water samples from Mkhayeni village. The observed 48-hour bacteria plate count is an indication of the presence of high numbers of microbial organisms and that this water supply needs to be monitored closely on a seasonal basis. Coliforms are several different types of bacteria that exist in the intestines of warm blooded animals and are found in bodily waste, animal droppings, and naturally in soil (Anon, 2002). Coliform bacteria are described and grouped, based on their common origin or characteristics, as either total or faecal coliforms. The group of total coliforms includes faecal coliform bacteria, such as *E. coli*, as well as other types of coliform bacteria that can survive in soil and vegetation. The presence of faecal coliforms usually indicates recent contamination of groundwater by human sewage or animal droppings, which could contain other bacteria, viruses, or disease causing micro-organisms (Anon, 2002). Livestock which drink water from troughs located near the sand abstraction pumping units could be responsible for the droppings that directly contaminate the water in the sand aquifer and might also have been washed in

[4] χ^2_{cal} **(3.714)** < χ^2_{tables} **(15.507)**, at 5% level of significance, we reject H_o and conclude that there is a significant difference between the recommended and observed turbidity values.

[5] Since χ^2_{cal} **(117.6)** > χ^2_{tables} **(15.507)**, at 5% level of significance, we reject H_o and conclude that there is a significant difference between the recommended and observed iron values.

[6] χ^2_{cal} **(1177.15)** > χ^2_{tables} **(15.507)**, at 5% level of significance, we reject H_o and conclude that there is a significant difference between the recommended and observed *manganese* values.

[7] Since χ^2_{cal} **(5)** < χ^2_{tables} **(5.991)**, at 5% level of significance, we fail to reject H_o

from upper laying lands through storm run-offs during the rainy seasons. The small gardens within the vicinity of the sand aquifers use animal droppings as manure which could have been washed in the river bed through run off or through leaching subsequently causing bacterial contamination of the water supply.

Overally, considering all the parameters analyzed, it can be concluded that the water quality from the sand abstraction water points was reasonably acceptable in view of that the water was not subjected to any form of treatment. However, bio-fouling and the other elements found in excess of the recommended were witnessed.

4.2 Contribution of SAS to the community water needs

4.2.1 Water uses in the communities

Table 2 below shows the different daily water uses in rural Lupane and the respective quantities for each use. The data was compiled mainly from the semi-structured interview guide developed to among other things estimate the current water demand pattern in the study area. In addition, some data was obtained from the key informant interviews particularly the village heads. The average human daily water consumption in the villages were compared to the lifeline daily water consumption of 50 litres per capita per day (l/c/d), a daily water use considered by Gleick (1996) to be the basic minimum water needed to support human life. In all the three villages studied, the average human daily per capita water consumption was found to be well above the 50 l/c/d lifeline human daily consumption. The statistical[8] analysis also indicated that there was a significant difference between the average per capita human daily water consumption in all the villages and the lifeline per capita daily human water consumption. Consequently, in terms of meeting the per capita human daily water requirements, the sand abstraction systems in all the three villages were adequate.

Table 2 Amount of water used in each activity in litres per capita per day (l/c/d) in the selected villages in Lupane district, Zimbabwe (n=90)

Water activity	Average amount of water used in each village (l/c/d)		
	Nhlangano	Emsehleni	Mkhayeni
Cooking	6	5	5
Drinking	5	4	5
Sanitary purposes	16	13	14
Bathing	10	10	10
Laundry	30	34	40
Sub-total *(average domestic consumption)*	**67**	**66**	**74**
Gardening	14	14	16
Livestock	28	27	31
Grant total *(average household consumption)*	**109**	**107**	**121**
Life-line (*average household consumption*)	**50**	**50**	**50**

(At $\alpha = 0.05$, 2 degrees of freedom (k-1), $\chi^2 = 5.991$, reject $\mathbf{H_o}$ when $\chi^2_{tables} > 5.991$)

4.2.2 Water quantity adequacy

The villagers were also asked whether the quantity of water from the sand abstraction water supply systems were adequate and sufficient to meet their daily water requirements or not through the semi-structured interview guide. This was important to triangulate their response with the estimated total daily water requirement from their different daily water uses. Of the 90 respondents interviewed, 77% responded yes, and the remainder (23%) responded, no (see Fig. 2). This implies that the majority of the respondents find the quantity of water from the sand abstraction supply systems adequate. The few to whom water is inadequate mentioned some constraints associated with the sand abstraction systems and these are discussed later in this paper**.** In the preceding section, each person from the study area consumes on average water which was more than enough to meet the basic human requirements courtesy of the sand abstraction systems. This was also amplified by 77% of the respondents who said the quantity of water from the sand abstraction water supply was adequate for their daily needs.

[8] *At $\alpha = 0.05$, 2 degrees of freedom (k-1), $\chi^2 = 5.991$, reject $\mathbf{H_o}$ when $\chi^2_{tables} > 5.991$*

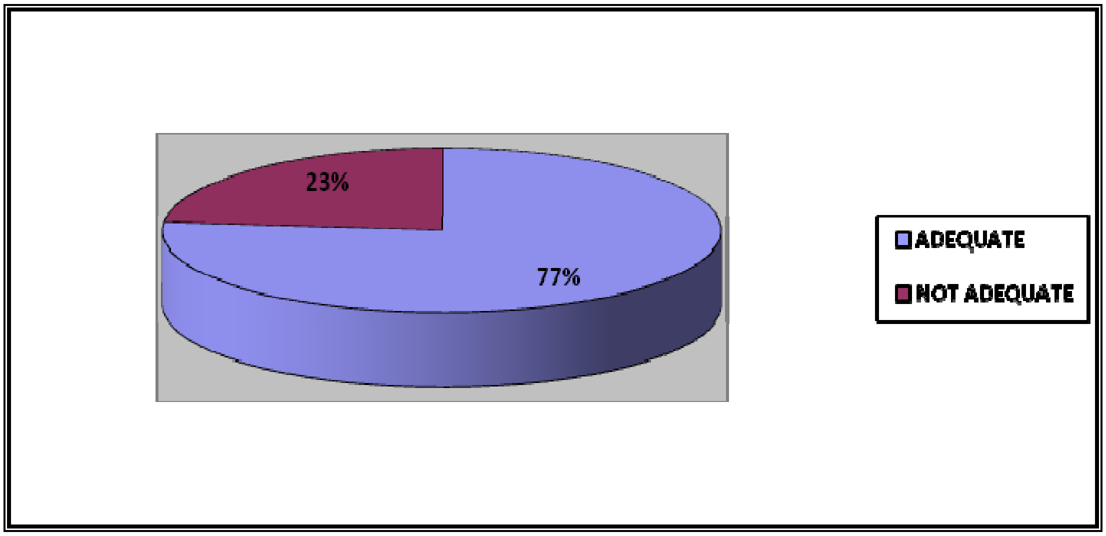

Fig. 2. Response of the households to the question of water quantity adequacy

4.3 Constraints associated with sand abstraction systems

Survey results from the 90 villagers indicated a total of seven constraints associated with the use of the sand abstraction system. These include the distance to the water point, inaccessibility by the disabled; low water yields in summer, frequent system breakdowns, costly maintenance, water point sited around infertile soils and the laborious ferrying of the water from the supply point back to the homestead (see Fig. 3 below). A substantial 10% of the respondents travel more than 1km to fetch water from the sand abstraction water point, a distance which was alluded to as too long. This is attributed to the fact that sand abstraction well points are sited at locations with the greatest water yield potential and not at the most central and convenient point of the village. Related to this constraint, 47% of the respondents cited the problem of transportation of water from the water source to their households. Rural African women use 40% of their daily nutritional intake traveling to collect water according to a World Bank (2000) study. This tends to limit the amount of water used by the villager household. Women carry containers of water weighing up to 20 kilograms when filled with water. According to an observation by Manyanhaire *et al*. (2009), carrying such burdens can cause damage to the spine and pelvis creating future problems in pregnancy. On average, the female member of the household make two to three trips everyday of the week, and this consumes most of their productive time. This constraint is attributed also to the reason that sand abstraction well points are cited at locations with the greatest potential of water yield and not at the most central and convenient point of the village.

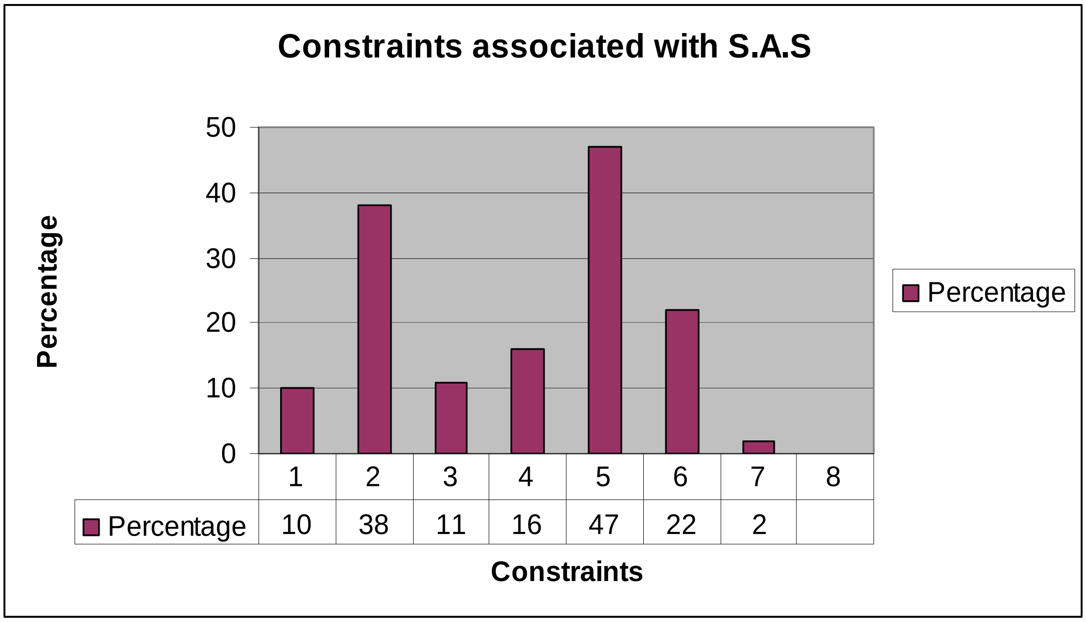

Fig. 3. Constraints associated with the sand abstraction water systems in rural Lupane district, Zimbabwe (n = 90)

Key: 1= Water Source too far from house hold; 2=Decrease in Water output in summer; 3=Water source sited on infertile soils; 4=Frequent pump break downs; 5=Transportation of Water from source to households; 6=Maintenance of system labour intensive; 7=Hand pump inaccessible.

Another constraint mentioned by 38% of the respondents was the decrease in water output in summer. The low water output was mostly experienced between August and October, a period with the highest temperatures and evaporation rates. Another concern raised by 11% of the respondents was the siting of the sand abstraction points surrounded by infertile soils for their crops and vegetables. This complaint arises because sand abstraction well points are cited at locations with the greatest water yield potential and not near good soils for establishment of irrigation gardens. A substantial 16% of the respondents found the hand pumps fitted to the sand abstraction system to be breaking down frequently. This augment the limitation cited by 22% of the respondents that of sand abstraction systems maintenance work being labour intensive and time consuming. Through water management committees, the villagers organize themselves to maintain the water supply systems and fix broken pumps. These villagers feel that this process sometimes take much of their valuable time which could alternatively been have used in their gardens or other productive uses. According to Nyoni (2009), if SASs are not properly designed, sand abstraction equipment can be vulnerable to flooding and clogging. Such a system will always keep villagers busy with the maintenance woks. It's possible that poor design may have attributed to the SASs breaking down frequently leading to the maintenance work being labour intensive and time consuming. Finally 2 % of the respondents found the water pumps to be inaccessible. These respondents were handicapped people who were not able to use the pump to draw water. It is a regrettable oversight that such basic technologies fail to take into account the needs of the disabled members of the community regarding a basic need for life such as water.

The limitations raised by the respondents associated with the use of sand abstraction systems demonstrate that this water supply system has some grey areas that need to be addressed to enhance its utility as a rural water supply system.

4.4 Community perception on sand abstraction systems

Table 3 below summarises the preferred water sources by the interviewed rural community members of Lupane district. Modern sand abstraction systems were the most preferred with 87% of the respondents, followed by dams with 7%, then boreholes with 5% and lastly the traditional sand abstraction (sand wells) with 1% of the respondents. The higher proportion of the respondents favoured the modern sand abstraction systems for their water supply indicating that these water supply systems are perceived as the most suitable water source in meeting the daily water requirements of the rural Lupane community. According to Butterworth *et al* (1999), sources of water receive relatively less preference from consumers due to their inherent shortcomings and this could have been the case in rural Lupane district.

Table 3. Preferred water sources by interviewed villagers in rural Lupane district, Zimbabwe (n=90)

Most preferred water source	**Percent respondents (%)**
Boreholes	5
Traditional sand abstraction systems (*river bed sand wells*)	1
Dams	7
Modern sand abstraction systems	87
Total	**100**

It can be concluded therefore that the overwhelming proportion of respondents opting for modern sand abstraction water supply systems indicate the acceptance of the technology by the rural community of Lupane.

5.0 Conclusions and recommendations

The sand abstraction water supply systems has water of reasonable quality and can adequately meet the per capita human daily water requirements of the rural communities. However there are some grey areas that need to be addressed to enhance its utility as a rural water supply system. It is recommended that an inter-sectoral approach should be adopted to improve the protection of the sandy aquifer from soil erosion, bacterial and chemical contamination. In addition, a piped water distribution network coupled with electrically driven pumping is recommended to bring water closer to the people.

Acknowledgements

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