# Storage capacity, basic water chemistry and impact of sand dams in Kenya: the sand dams of Utooni Development Organization

## Abstract

## Introduction: Purpose, placement and construction of sand dams

In three Kenyan Counties, Kitui, Machakos and Makueni, water scarcity is a major problem, where erratic seasonal rainfall and long dry seasons make it a limiting factor in local development. Sand dams designed and built locally have become a major source of water. The region is home to the Kamba people and is sometimes referred to as Ukambani, or the land of the Kamba. Two Kenyan non-government organizations (NGOs), SASOL in Kitui and the Utooni Development Organization (UDO) in Machakos and Makueni, organize and participate in building these dams, which serve from 10 to 600 families each depending on their size. The two NGOs combined have now helped build over 2500 dams and the number continues to grow.

Sand dams are structurally quite simple. The key to successful construction is correctly locating them in the seasonally flowing streams common in the region. The process of site selection works like this. The two NGOs work with people living along a stream who either have formed or are in the process of forming a community group. These groups must be formally structured and recognized by the government. Sand dams are regulated and require a permit before the community group is allowed to build one. Once the group is formed, then a survey is performed by the NGO with members of the community group to find the best location on the stream for the dam.

Most of the Ukambani region is very old geologically. The region was at one time a high plateau that eroded unevenly leaving behind groups of hills especially in parts of Machakos and northwestern Makueni. The Athii River, which begins in the Southern Aberdares and divides Machakos and Makueni from Kitui, drains most of Machakos and Makueni, but only a narrow strip along the SW edge of Kitui. Kitui drains north and east to the Tana River. Kitui has less pronounced geographic features, with low rolling hills sloping to the east. The underlying rock in the region is primarily metamorphic of igneous origin. The basic rocks are biotite gneiss and migmatite with some schist[1]. All are ancient metamorphic forms of granite and other igneous intrusions with quartz, feldspar, biotite, hornblende and other types of rock crystals that are squeezed and distorted under pressure to make layered structures. The rock is very dense with low porosity of about 1.5% in an unweathered state. Water can move through the rock slowly parallel with the layers of the structure, but is blocked moving perpendicular to the layers especially in unweathered rock. This factor makes them able to hold water impounded by the sand dams.

Engineers of SASOL and UDO look for specific sites in the selected streams where bedrock is either exposed or very shallow in the bed and extends upward on each side for 1.5 to 5 meters. They also look for pinch points where the rock narrows the stream channel enabling a smaller structure.

[1] Geological Survey of Southern Machakos, Mines and Geological Department, Kenya Colony, 1954

Once these places are identified the engineers do a site survey to determine the height, width and thickness of the proposed dam. In addition they look at the slope of the stream bed to determine the water holding capacity of the structure at the proposed height. Once the site is approved the community self help group is then required to build terraces that will protect the proposed dam from erosion. The engineers survey the terraces for the community group and the group then does the work with guidance from the NGO.

When terraces are complete and approved by the NGO a dam supervisor from the NGO is assigned to the site to supervise the process of building the dam. The stream bed is cleared of all sand and loose material and if necessary the soil on both stream banks is removed to the width of the dam exposing the bedrock on the sides of the stream. At this point the dam supervisor shows the community how to set rebar in the bedrock using a chisel and a rock hammer. The rebar is usually a 16mm diameter and the pieces reach nearly to the top of the dam. They are set from one to two meters apart across the width of the dam. Only a limited amount of rebar is needed for the wings of the dam as the total height shrinks.

At the same time the rebar is set, other community members begin collecting rock and piling sand for the main construction phase. Often loose rock is unavailable and rocks between 0.5 and 25kgs in size must be broken off exposed bedrock near the dam using sledge hammers. The rock is then piled as near to the construction site as possible. Most streams in the region have a good supply of sand, though sometimes it has to be carried to the dam site. This job is commonly performed by women while men do the work with the rock. In general more women are involved with construction than men and they often have important leadership roles in the process. The final ingredient supplied by community group members is water. Dams must be built in the dry season when there is limited below surface flow in the streams, or sometimes none at all. In the later case water must be brought to the site in jerry cans on people's backs, on donkey back, or in donkey carts. This can prove the most tedious job of all, further emphasizing the need for the dam.

Once all the materials are in place, UDO and SASOL then bring in cement and forms for actual construction. Dam supervisors assemble the forms. Dams are normally between 1.5 and 2.0 meters wide at the base, depending on dam height, tapering to 1 meter wide at the spillway and narrower in the higher parts of the wings. The upstream side of the dam is vertical, while the downstream side has a slight slope. The spillway width is generally determined by the width of the stream bed before construction and the wings are built one to two meters higher than the spillway on either side. Once the forms are ready the community begins construction by mixing 1 part cement with three parts sand and water. This slurry is then shoveled into the forms and rocks are added as appropriate. If sufficient people are on hand a substantial portion of the dam can be completed in one day. Normally most construction takes less than a week. Anywhere from 30 to 300 people can work on a dam in a day, again depending on size. Once the dam reaches its full height it is topped with a layer of cement and small stones, usually between 2 and 5 cm in diameter, to create a rough, non-slip surface that resists erosion. The community group is also responsible for curing the concrete of the dam. For four weeks following construction water is poured, splashed or thrown on the dam, wetting all surfaces to help the cement harden and resist erosion. Once this is done all the community can do is wait for the dam to fill with sand.

## Sand storage and water volume

Most of the streams in Ukambani have sandy beds. This bed load is continuously on the move, though its speed depends on the intensity of the rain and the volume that flows downstream during each rainy season (Hamilton 1983). The answer to the question of how long it takes for a dam to fill with sand is highly variable. The UDO engineers have witnessed dams fill in one intense rain event, a heavy one at the beginning of the rainy season when soils were dry and less prone to absorb water. Other dams have

Figure 1: Nzaaya Muisyo Dam #67 located at 01 41.215 S latitude and 37 24.581 E longitude. The dam is 2 meters high above bedrock, has a 21 meter wide spillway, backs up sand for 230 meters, holding approximately 5000 cubic meters of sand and 1750 cubic meters of water in the pore space at full capacity. Note that behind the dam are abundant, flourishing stands of Napier grass used for cattle fodder and bananas, which would not thrive in the area without the sand dam. The picture was taken in July 2013 about 2 months after the last of the long rains in May.

taken 4 years or more.  New dams seen by the author in June 2011 built by the Kitandi Fruit Tree Growers Self Help Group that were filled with open water, were completely filled with sand in 2013.

The primary use of most dams is for household water, though the volume stored allows for far more use than just that.  Local people come to the sand behind the dam and dig a temporary hole in the sand to reach the water.  These scoop holes are commonly wider than they are deep and water is scooped out using a calabash, a local gourd cut in half that serves as a scoop, to fill a 20 liter jerry can.  The water behind a dam commonly has uneven quality related to salinity and people experiment to find the best sites for drinking water and these are protected by a ring of thorny acacia branches.  Animals also get water from the streams.  Farmers bring their cattle, sheep, goats and donkeys down to the water to drink once daily.  The holes for animals are normally bigger and less rigorously protected, generally located a distance away from points used by people.

Another use for water is to wash clothing.  This is not a daily task, but it is one made much easier by the presence of the sand dam.  People in the area prefer locations of open water for this task.  In dams observed by the author, sites just below an existing dam were preferred.  At this point, as seen in Figure 1, the sand is not backed up, rather it is washed clean by the energy of water flowing over the dam during rains.  Slow leaks under or around the dam, usually of less than a liter per minute, keep pools of surface water present.  Water users questioned claim that these pools seldom disappear and since they are continuously renewed they become washing sites.

The final significant use of the sand dam water is irrigation.  Farmers who have land near the stream dig deeper, and more protected holes to fetch the volume of water needed to irrigate their tree nurseries and vegetable gardens.  One of the requirements for having UDO and SASOL assist a community group in dam construction is that each group must have a tree nursery to provide seedlings for group members and for sale.  These require daily watering.  At the same time, and often in the same place, self help group members grow vegetable seedlings for transplanting, either at the home compound or on land near the stream.  Though involving tremendous effort, many women will carry 20 to 40 liters a water a day from the dam to their compounds to water vegetables for home consumption and sale.  This involves carrying water uphill on their backs for 5 to 20 minutes for each jerry can every day.  Those who have land closer to the dam grow larger irrigated gardens.

A few more financially secure farmers have purchased gasoline powered pumps to move larger volumes uphill to provide for larger farms.  In 2013 these pumps cost around 62,000/= (Kenyan shillings) or $730 US at the exchange rate in July 2013.  The volume pumped varies according to the head height and is estimated to be between 20 and 200 liters per minute.  On farms seen by the author the water was pumped to storage tanks at the top of the farms.  Water was distributed from these tanks by jerry can, bucket, long hoses, or in one case, through a drip irrigation system.  One characteristic of farms with pumping systems stood out; the men worked at home.  Usually the irrigation system was used for cash crops and in most cases seen the male head of household was the person who described and managed the system.  Women were seen doing the labor and these were often women hired by the farmer.

The use of water in the sand dams for irrigation gives rise to the question of volume. How much irrigation could a sand dam support without compromising the need for household water and water for animals? The question is not an easy one to answer. While it is relatively easy to measure the surface area of sand behind a dam, the volume is more difficult. Stream beds are not flat with even widths at the top and the bottom. Unless detailed measurements are done before a dam is built and fills with sand, any measure of sand volume is going to be an estimate unless sophisticated equipment is available, which is generally not the case. In our work in July 2013 we measured a number of dams to estimate volume.

We used a simple formula. We first estimated that the depth of sand equaled the dam height times a fraction related to its increased distance from the dam, growing shallower as you get further away. Surface width at specific distance from the dam was measured, usually in 30 to 50 meter increments from the dam. This surface width was multiplied by 0.7 to get a value for width of the pre-dam stream bed. This value was based on observations and measurements in undammed portions of streams and is conservative. While stream shapes are variable, the intermittent flow and intensity of the runoff has produced stream beds that are wide and flat, especially in larger streams. The variability comes from intruding rock. The width and height measurement produced a cross sectional trapezoid which when multiplied by the distance between measurements provides an approximate volume. Most dams were measured every 30 meters moving upstream from the dam site, so a dam backing up 300 meters of sand would have 10 trapezoids added together to get a final measurement.

Table 1 below shows the final data of total sand volume for each of the dams measured. These are divided according to the self-help group (SHG) that built the dam. Kitandi Fruit Tree Growers SHG has the largest number of dams, while we only measured one from the Uvaani SHG, but it is a large dam and the group was actively involved in building a second dam during our visit. Sand volume is given in the adjacent column. Water volume is based on soil science literature showing that pure sand has porosity between 30% and 40% depending on sand granularity. We used the median value of 35% to make this calculation. The water volume given represents a completely filled pore space after a rainfall event or the immediate end of the rainy season. For most dams the actual volume observed was something less than this. Usually the holes observed, or that we dug, had water between 3 and 60 cm below the surface. In two cases water was flowing slowly on the surface so the dams could be considered saturated. It was rare that we did not find water in a hole dug to 60 cm. Dam 583 of the Kitandi SHG proved an exception; no water was found in the lower and middle reaches of the dam, but water was found between 350 and 700 meters from the dam. No explanation for this was identified.

Table 1 also shows an average of measurements taken for salinity and pH behind each dam. These measurements were taken either in holes we dug on the width transect line measured, or in existing holes dug by the community within 5 meters of the transect line. A Hach _______ was used to make the measurements. In most cases salinity values were below 500 ppm (or mg/liter), which is the level at which humans begin to taste salt. A few measurements rise above this level in the higher elevation dams measured, most notable is Mkuta-Mwea dam number 532. This dam was not used for drinking water and in fact was little used by the community at all. We found very few holes already dug

Table 1: A list of dams with date of construction that were measured for size, sand volume, salinity and pH. Complete data on GPS location, width versus length, Individual pH and salinity measurements are available from the author.

| Dam # | Year built | Dam height meters | Spillway width meters | Distance meters | Sand volume m3 | Water storage m3 | Average pH | Average salinity ppm |
|---|---|---|---|---|---|---|---|---|
| Kitandi Fruit Tree Growers Self Help Group | | | | | | | | |
| 548 | Jan-09 | 4 | 9.15 | 210 | none | none | 8.03 | 350 |
| 544 | | 3.2 | 12.2 | 467 | 7954 | 2658 | 7.38 | 484 |
| 545 | Feb-09 | 1.72 | 14.8 | 150 | 1621 | 567 | 7.69 | 499 |
| 546 | Mar-09 | 3.6 | 21.7 | 250 | 8530 | 2986 | 7.37 | 358 |
| 528 | Oct-08 | 1.5 | 14.3 | 240 | 4306 | 1507 | 7.72 | 334 |
| | | 3.15 | 20.3 | 180 | 6998 | 2449 | 7.53 | 418 |
| 566 | Aug-09 | 2.8 | 17.9 | 300 | 10887 | 3810 | 7.43 | 313 |
| 573 | Dec-09 | 1.4 | 11.6 | 225 | 2515 | 880 | 7.45 | 406 |
| 583 | Oct-09 | 2 | 11.5 | 777 | 4318 | 1511 | 7.67 | 339 |
| 587 | Nov-09 | 2.45 | 14.2 | 216 | 6357 | 2223 | 7.62 | 556 |
| 624 | | 2.2 | 16.8 | 240 | 5785 | 2025 | 7.54 | 279 |
| Uvaani Self Help Group | | | | | | | | |
| 581 | Oct-09 | 3.7 | 20 | 722 | 41704 | 14421 | 7.83 | 303 |
| Mkuta Mwea SHG | | | | | | | | |
| 532 | Jan-09 | 3 | 22.5 | 239 | 7708 | 2698 | 7.33 | 1459 |
| 64 | Jun-06 | 1.35 | 12.6 | 404 | 2649 | 927 | 7.67 | 892 |
| 63 | | 3.5 | 10.8 | 253 | 9307 | 2357 | 7.41 | 914 |
| Matondoni SHG | | | | | | | | |
| 1 | | 3.1 | 15.15 | 163 | 2506 | 877 | 7.59 | 1290 |
| 2 | Sep-08 | 3 | 10.4 | 181 | 4211 | 1474 | 7.28 | 374 |
| 3 | | 1.4 | 14 | 227 | 2859 | 1001 | 7.18 | 369 |
| Nzaaya Muisyo SHG | | | | | | | | |
| 70 | Jun-05 | 4.5 | 22.9 | 240 | 18377 | 6432 | 7.08 | 397 |
| 67 | May-05 | 2 | 21 | 230 | 5062 | 1772 | 7.34 | 492 |
| Kithito kya Atumia na Iveti SHG | | | | | | | | |
| | Jul-09 | 2.1 | 22.3 | 297 | 9064 | 3173 | 7.95 | 2990 |
| | Jan-08 | 1.5 | 27.7 | 660 | 16600 | 5810 | 7.87 | 2624 |
| Ilikoni Beekeepers SHG | | | | | | | | |
| | Jul-06 | 2.9 | 37.9 | 600 | 21120 | 7392 | 7.81 | 3460 |
| | Apr-07 | 1 | 15.1 | 180 | 3299 | 1155 | 7.97 | 2345 |

in the sand and UDOs local field officer stated that he had not seen people using the dam during his visits to the site.

The other dams where salinity is a definite issue are located in the southeastern portion of Makueni District not far from the town of Mtito Andei. This area has the lowest annual average rainfall of any area we visited, around 400mm/year, being located in the semi-arid agroclimatic zone 6, meaning that its potential evapotranspiration rate exceeds annual rainfall by at least a factor of 4. The two self help groups, Illikoni Beekeepers and Kithito kya Atumia na Iveti (meaning in Kamba; Efforts of Women and Men) are on the same wide river and all salinity measurements exceeded one part per thousand, reaching as high as 5 parts per thousand in one place. People prefer not drinking the water from the river if they have a choice, but do use the river regularly for watering their animals, washing clothes and other non-consumptive uses. No attempt was made to use the water for irrigation even though there were numerous failed attempts at dry land agriculture in the local area.

Salinity is not consistent behind most of the dams. There is considerable variability in a few. Most notable of these is dam 67 of the Nzaaya Muisyo SHG on a dam completed in May 2005. The dam is only 2 meters high, one of the shortest in the series of dams on the Mwea River, and backs up sand for 230 meters, holding just over 5000 cubic meters of sand and 1750 cubic meters of water. At 210 meters from the dam a small seasonal stream enters from the left as you walk upstream. At the point the main stream has a salinity of 175 ppm, but water at the mouth of the small tributary has a salinity of 2440 ppm. The salinity was measured 20 meters further up the tributary and it climbed to 2560 ppm. The UDO field officer with us at the dam connected this salinity measurement with a particular rock formation within the watershed of the tributary that goats like to go and lick to get salt. He said it was a unique geological feature in the area with a course structure that weeps during rainy seasons.

Other anomalous measurements in salinity were found as well, but none so glaring as this particular measurement. These variations are probably due to underground geologic features with rock, probably sandstone of some type, which contains salt. As water backed up by the dam raising the water table saturates this rock, salt leaches into the water. This water then returns to the stream when withdrawals from behind the sand dam lower the water table. In most cases the amount of water is not sufficient to change the salinity in the main stream by a significant amount. The importance of this measurement is its indication that water is fed into the main stem of the stream continuously from side and not just backed up in the channel.[2]

Sand volume behind the dam is only a part of the picture of water storage impacted by the dam. In many cases there is underground, in stream flow during the dry season, though it is often quite deep and difficult to access. The dam captures even this minimal flow. The real benefit of the dam is its impact on the entire water table. To understand this requires some historical information. Dr. Gideon Mutiso, founder of SASOL and native of this part of Kenya, both witnessed personally and interviewed

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[2] Acidity proved a very consistent variable. We saw no pH reading below 7.0 and the measurements higher than 8.0 were rare except in the Mtito Andei area dams. Acidity is not a major concern in the Machakos and Makueni area.

others about water availability in the area. Some older residents of all three counties have stated that springs were used as water sources in their youth, but these dried up as they grew older, in some cases producing water only seasonally, and in other cases drying up completely (Mutiso 2002). [3]

A significant study by L. Borst and S.A de Haas for a Master's thesis in hydrology in 2006 looked at the impact of sand dams on groundwater along the sides of the dam (Borst et al 2006). A major factor in this is the complex geomorphology of granitoid gneiss, hornblende dominated biotite and migmatite that dominate the geology of the region. [4] While the type of rock is fairly similar across the three counties, the depth of soil, amount of weathered material and degree of fracturing is not (SASOL 2003). Generally unweathered gneiss and biotite are impermeable with very low porosity. In conditions of weathering they flake and open for more water penetration from above. In some case the unweathered rock is fractured from tectonic forces, perhaps related to the formation of the Rift Valley over the last few million years. This makes it difficult to assess the actual ability of the sand dams to impact water supply beyond what is stored in the sand itself. However the study by Borst et al (2006) and a subsequent study by Hoogmoed (2007) of a dam in the Kiindu watershed near Kitui city suggests that as water levels are raised behind a sand dam a corresponding rise in the water tables near the dam occurs. This amount of water could match or exceed the water stored by the dam itself, depending on local conditions. At the same time it is very difficult to make accurate assessments of water availability without doing the needed assessment of near surface geology above the unweathered bed rock.

Studies sponsored by SASOL, including the two above, indicate that the water table behind a sand dam rises significantly along the sides of the dam. Borst et al (2006) measured significant increases in water head height at 50 meters from the stream bank using piezometers. These measurements have a slower response time to precipitation and river flow than piezometers closer to the stream, but do show an increase in head height due to the presence of the sand dam according to models developed by Hoogmoed (2007). While a great uncertainty remains in determining storage volume from the increased water table alongside the stream, that the storage volume is increased is certain.

A modeling effort done by advisors to the two masters theses referred to above, (Hut et al 2008) the authors take data from the Kitui dam and one in Voi and show the impact on groundwater storage. They show a slow and intermittent rise in groundwater in the Voi case where high irrigation withdrawals are the norm. The Kitui situation has lower withdrawal rates since no pumping systems are involved and higher rainfall amount provide a correspondingly more rapid increase in groundwater in the area behind the dam. They looked at land up to 400 meters from the middle of the stream perpendicular to the flow. Their conclusion is that the water level elevated by the dam will increase the height of the water table at approximately one hundredth the rate of water infiltrating the sand in the river due to low hydraulic conductivity, but after 10 years the head height of groundwater will rise equivalent to the rise behind the dam. How much water is stored depends on the porosity of the phreatic, or saturated, zone on both sides of the stream. This could vary from 1.5% of the bedrock to 30% in deep sandy soils. By

[3] Personal communication August 2009. The author went with Dr. Mutiso to Kitui and visited 4 dams in Kitui County built in cooperation with SASOL.
[4] Refer to the 1954 geology map of Machakos.

their model, the water stored by the sand dam may represent only 2% of the total stored volume in the surrounding groundwater (Hut et al 2008).

Going back to Dr. Mutiso's field observations mentioned above. He noted that springs identified as having disappeared in the lifetime of residents interviewed in the 1990's have now reappeared in valleys where a series of sand dams have been built in a cascade. The multiple dams have increased the water table enough to allow underground flow to reach these natural output points. The dams built in combination with efforts to increase infiltration rates and slow runoff, through terrace construction, tree planting and perennial grass growth on the contour have reestablished the hydrology natural to the region prior to the rapid population growth between 1950 and 1990 (Mutiso 2002, personal communication 2009, and Pauw 2008).

So how much water will a series of sand dam actually store? In terms of total precipitation through most of the region the amount of water stored behind a series of sand dam is quite a small percentage compared to total runoff, between 1% and 3% (Hut 2008). This volume substantially increases available groundwater for extraction by the local population either through withdrawal from the stream itself or from the discharge of springs resupplied with water by the cascade of sand dams. In addition, the water in the sand dam will be continuously fed from flow from groundwater alongside the dam. Table 2 is based on the model developed by Hut and his team, in turn derived from field measurement by Borst and de Haas (2006). It calculates a total storage volume based on a rise in ground water up to 100 meters from the stream bank equivalent to the rise in height of sand in the river backed up by the dam using 3 potential porosities: 1.5% for bedrock dominated groundwater storage, 5% for mixed bedrock, weathered rock and soil storage, and 10% for soil dominated groundwater storage. These numbers are very conservative compared to the model and even at the 10% levels are likely to underestimate the total hydrological impact. Until such time as accurate field data are determined it is best to use a conservative estimate. Even so this volume of water is highly beneficial to most communities in relation to their daily household, animal, and irrigation needs. They only become problematic if pump irrigation use becomes widespread.

Table 2: Estimated water storage for 5 dams with three different levels of available groundwater for recharge.

| Self Help Group | Dam # | Sand Volume* | Water Volume | Ground water 1.5% | Ground water 5% | Ground water 10% | Total water WV+GW10% |
|---|---|---|---|---|---|---|---|
| Kitandi | 528 | 4306 | 1507 | 540 | 1800 | 3600 | 5100 |
| Kitandi | 587 | 6357 | 2223 | 792 | 2640 | 5280 | 7500 |
| Mkuta Mwea | 63 | 9307 | 2357 | 1328 | 4428 | 8855 | 11,200 |
| Mkuta Mwea | 532 | 7708 | 2688 | 1076 | 3585 | 7170 | 9860 |
| Nzaaya Muisyo | 67 | 5062 | 1772 | 690 | 2300 | 4600 | 6372 |

*All numbers are volumes in meters cubed.

## Conclusion

Sand dams in Kitui, Machakos and Makueni have contributed greatly to the availability of water throughout the three counties where they are found. The total volume stored in the sand behind the dams is significant, but represents only part of the story. Using conservative estimates water storage in the ground beside the dams is at least three times as great as water stored in the sand, and this water contributes to extractable water in the dam throughout the season. The exact measurement of this groundwater storage is difficult to determine and requires more field work and a better understanding of the weathered bedrock and soil profiles alongside the rivers where sand dams are built.

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