Sand Dams for Semi-Arid lands: Development in Kenya of a locally resilient and appropriate water supply[1]

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Abstract

Water is one of the key limiting factors in arid, semi-arid and sub-humid lands throughout Africa. Reducing the labor demand involved in the daily efforts to find and haul water releases available time to women to pursue productive agricultural activities and care for their families. This in turns improves resilience at the household and community level. Sand dams have proven an excellent way to do this in the semi-arid areas of Kitui, Machakos, and Makueni Counties in Kenya and is spreading further inside and outside the country. The key to building a sand dam is community involvement from the earliest stage in the process. Locally controlled and organized NGOs are the primary promoters of this activity. The community development groups, called self-help groups, site the dam, prepare the supporting infrastructure, build the dam and coordinate local control of the new resource. This then drops the water collection time from more than 3 hours per day to as little as 15 minutes. The work then continues with promotion of drought resistant crops, better fodder supply, and income security.

Defining the water problem

Semi-arid land is defined as regions with low and highly variable rainfall with correspondingly high-risk agriculture. In many cases, the historic land use was pastoralism, but as population grew, agriculture spread to marginal landscapes capable of producing crops only in above-average rainfall years. The potential for failure is always high and risks are great. Resilience in these situations comes if the supply of landscape stored water resources are readily available. There are two critical types of stored water; soil water captured near the surface and readily available for crops and deeper groundwater or vadose water that moves underground to springs, supplying water in the dry seasons. Both are dependent on capturing rainfall at the surface and allowing it to percolate into the soil and deeper strata.

The problem across sub-humid and semi-arid lands in both Kenya and many regions of Africa is that population growth combined with political instability and poor agricultural practices have contributed to a denuding of landscapes (Teel 1994). This often means that rain, especially early season rains, falls on nearly bare soils capped with dry clays. Instead of penetrating, this water runs off the surface to the nearest stream carrying some of that soil and organic matter with it. The loss of organic

[1] Most of this article is based on my work with two non-government organization, SASOL and the Utooni Development Organization in 2009, 2011 and 2013, spending time building dams, visiting even more sites and conversing with their leaders, field workers and area farmers. All the pictures are mine.

material is critical as it has primary responsibility for storing soil water. This lowers landscape resilience especially in lower rainfall seasons, making it even more difficult for farmers to get a crop. At the same time the increased flush of runoff contributes to a slow and steady lowering of the water table, resulting in dry springs and greater labor requirements to fetch water (Tiffen et al 1994, and Mutiso, personal communication).

Resilience in any system depends on the ability to address the major limiting factors in a system. In semi-arid lands water is often the most important limiting factor, but the reasons for that shortfall are not always immediately apparent. A spring no longer supplying water year-round may have shrunk because of actions far higher in the watershed. Conversion of a higher elevation forest to agricultural land is a common cause and this could be exacerbated by grazing pressure from cattle, sheep and goats and subsequent loss of groundcover. Ironically the ability to address these problems is compromised by a lack of labor. Women are normally tasked with fetching water in rural areas. If the local spring is dry, this entails carrying water much further, decreasing labor needed for agricultural or household tasks. In the semi-arid agricultural lands of Kenya it is not uncommon for this task to take more than 3 hours per day (Utooni Development Organization, personal communication). Any effort to improve resilience of an area has to start with reducing this labor demand or they will founder.

Expansion of the water resource has happened locally in unexpected and highly creative ways in the land of the Kamba-speaking people in the counties of Machakos, Makueni and Kitui in Kenya. Here the landscape is hilly, with the highest points reaching nearly 2000 meters. This region lies between 0 and 3 degrees south latitude and 37 and 39 degrees east longitude, and rainfall patterns are complex, and often insufficient to produce crops. The intertropical convergence zone, the equatorial phenomenon that produces weather in the tropics, passes over the region twice a year, giving it two rainy seasons. The long rains occur in March, April and into May. The short rains last from October to early December. However, these two 60-day periods of rain are inconsistent, occasionally fail completely, and sometimes do not last long enough to allow a crop to complete its growth cycle. As a result, the region has a chronic food deficit, broken only in the rare good season when rains permit growth of maize.

In order to paint an accurate picture of this region's rain profile, it is important to take into account the rainfall variation across the region's geography. The topography slopes from high points in Machakos and north-western Makueni, lowers toward Kitui to the north and gradually drops in elevation and gets correspondingly drier as you move south and east toward Kenya's Indian Ocean coast (See Figure 1). The upper regions receive 800 to 1200mm of rainfall per year on average while the lowest areas of Kitui and Makueni receive less than 500mm annually. Generally, maize requires 600mm of rainfall in one season to guarantee a crop. Only in the hilltops of the upper region in normal or above-average seasons are rainfalls sufficient. Yet every year, the Kamba people persist in planting maize in the hope that they will catch a good rainy season.

Catching water

Like the rest of Kenya, population growth among the Kamba exploded in the period just before and following independence in 1964, reaching a high point in the early 1980s above 4 percent. This put a lot of pressure on the landscape. Even prior to the British departure erosion was named as one of the most severe problems. Yet because labor intensive terracing was mandated by the colonial government, many Kamba abandoned the practice following independence. The problem persisted and many resumed terracing and pursued tree planting by the 1980s, a fact noted in some detail in Mary Tiffen's book, *More People, Less Erosion* (Tiffen 1994). Yet this effort did not address what was a deeper and some recognized as more pressing problem, the availability of water. Water is the key limiting factor throughout this region. Resilience, defined as the ability to recover after periods of high environmental stress often caused by drought, depends on a steady supply of locally available water for a variety of reasons.

In the 1970's, Joshua Mukusya, working with the National Christian Council of Kenya (NCCK), was very aware of the dual problems of erratic rainfall and poor supply systems. Mukusya grew up near Kola, a town not far from the present border between Machakos and Makueni Counties. As a young boy, he was often sent down the hill to fetch water in whatever container he could find and then carry it back uphill to his mother. If he spilled a drop on the way, he received a sharp verbal or physical reminder of why he should be careful. As he grew, he wondered why it is that rain falls on his house and runs off downhill, then later he has to run downhill to fetch it. Why not catch it before it runs away?[2]

In 1978 Joshua and his wife Rhoda joined with five other families and founded a self-help group (SHG) they called the Utooni SHG. They wanted to work on issues related to water, agriculture, firewood, trees, and local economic development, including housing. The fundamental importance of water, primarily pushed by the women as they did most of the fetching, kept them focused, as did the lessons from development failures that Joshua witnessed during his time with NCCK. The self-help group is still functioning today, and has grown into the Utooni Development Organization (UDO), which works throughout Machakos and Makueni Counties and has even expanded into Kajiado County among the Maasai. They primarily build sand dams, but they never lost focus on Joshua's original vision of not having to chase water downhill. One look at their compound in Kola tells the story (Figure 2).

[2] Joshua Mukusya, personal communication July 2011.

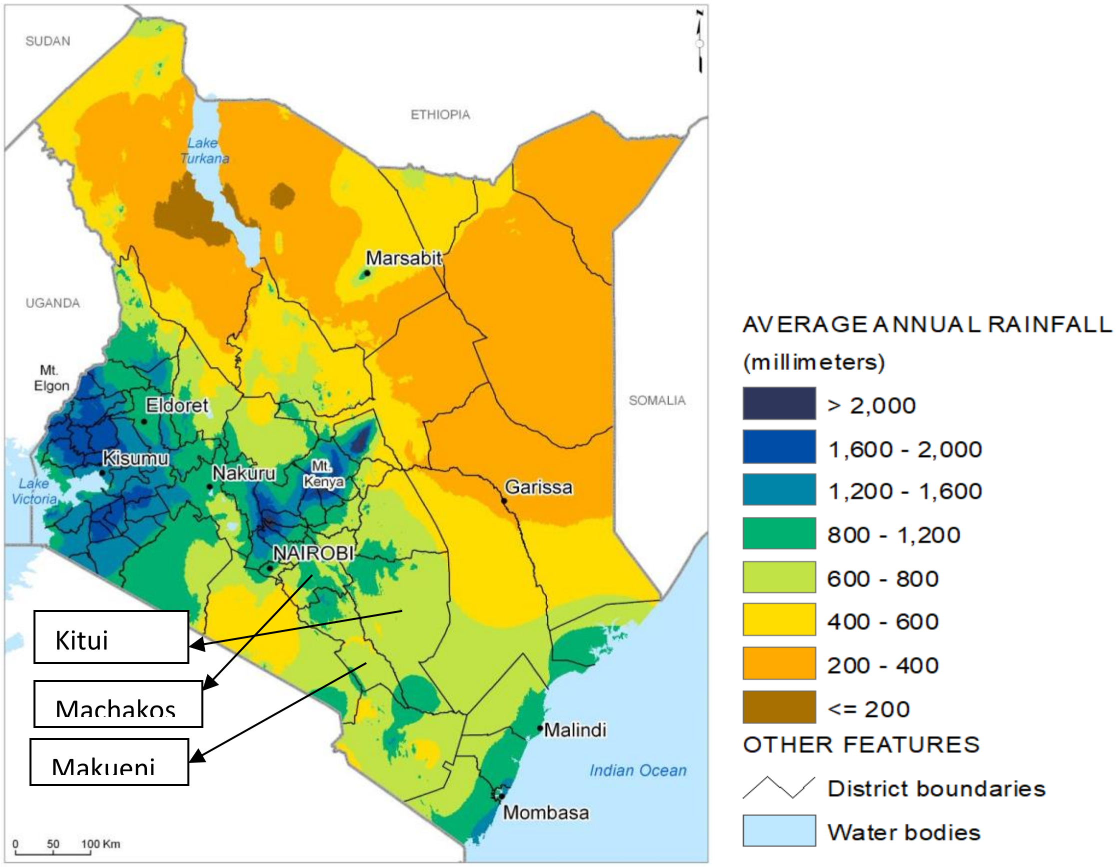

Figure 1: Rainfall map of Kenya. World Resources Institute (No date)

The UDO compound consists of four large buildings made of rock and cement, and a covered parking area. It stands on a slope that is now terraced gardens with lots of trees, which is somewhat unusual for the area. All the buildings have metal roofs and every roof has gutters to collect water. Hardly a drop of rain landing on the roof ever hits the ground; instead, water is channeled to a number of water tanks. Five of these tanks are the large black plastic variety: three holding 10,000 liters and two of 5,000 liters. These, however, are dwarfed by the 220,000 liter capacity large cement tank that holds nearly all the runoff from the office building, the covered parking area, and two ends of the long, narrow buildings where guests stay (Figure 2). A smaller cement tank next to it holds an additional 60,000 liters. Joshua calculated that the 320,000 liters of water storage would only be completely filled during a heavy rainy season, but he wanted to catch all possible water, and it does. UDO seldom has to buy water, nor do they need to expend extra energy to fetch it. UDO models its own philosophy through example: resilience means making the best use of the resources close to home.

Figure 2: The UDO compound's main water storage, which holds 220,000 liters. The square tank on the left holds 60,000 liters. The main office building is on the right (photo by author 2011).

UDO has taken this philosophy to the field. A self-help group near the town of Mtito Andei built a catchment system on a large rock outcropping. These rocky outcroppings are primarily hunks of granitic rock very resistant to erosion that were remaining after the surrounding plain eroded. It is impossible to know if the barren nature of these slopes is natural or a result of past overgrazing, but to UDO they became a resource. The Miamba Mitamboni SHG and UDO designed a catchment on the rock face, outlined by a low rock-and-cement wall ranging between 15 and 30 cm high, depending on the slope and location (See Figure 3 below). The wall channels rainfall to an outlet pipe at the lowest section of the approximately 3500m^2 catchment. This water flows to two 150,000 liter storage tanks. Because there is no forage on the catchment rock, for the most part animals stay away and the resulting captured water is quite clean and much lower in salt compared with the water found in nearby streams or wells. In fact, it is the preferred water supply for all the families within donkey cart distance of the storage tanks (Figure 4).

Figure 3: Catchment area of the Miamba Mitamboni SHG. The low cement and rock walls converge at a point behind the shrub in the lower left and feed into a pipe leading to the storage tanks (photo by author 2013).

The members of Miamba Mitamboni SHG sell the water for 3 Kenya Shillings per 20 liter jerry can. This money goes into a group fund to finance group projects like their community garden, which is irrigated by catchment water, as well as a revolving microloan fund available to SHG members.

Figure 4: Miamba Mitamboni water storage tanks with the native acacia bush land in the background (photo by author 2013).

The role of sand dams

Though the catchment system is impressive, the available rock required for their creation is relatively rare, and so most of UDO's energy is focused on building sand dams. The idea of the sand dam arose from work that Joshua Mukusya did with a man named Ndunda who had built dams with the British in the 1950s. Joshua visited some of these dams with Ndunda and saw that many were filled with sediment, primarily sand. When he dug in the sand behind the dam, there was water even in the driest of seasons. The thought came to him, "why not build dams intentionally to capture the sand?" During his work with NCCK he had seen literature about sub-surface dams that slowed the flow of underground water and allowed pastoralists to water their animals without the need to dig deeply and lift the water to the animal. Instead, the sub-surface dams enabled the animals to drink the water directly without additional human labor. Mukusya knew that a sub-surface dam like this one would not work in Machakos very well since the river had too steep a slope and the amount of sand trapped would be minimal. However, by constructing a dam between 1 and 3 meters high, they could capture more sand and therefore more water in the pore space between the sand grains. Joshua and the Utooni Development Self Help Group built their first trial dam in 1978 and it worked.

Figure 5: This sand dam was built in 2009 by the Kitandi Fruit Tree Growers SHG on the Kaiti River in Makuieni County. It was extended one year later to reach its present height. It has a 17.9 meter spillway and holds nearly 11,000 cubic meters of sand and 4,000 cubic meters of water when saturated. Note the strong stand of napier grass on the right stream bank. It is also planted as cuttings on the left bank (photo by the author, July 2013).

Sand dams are of necessity bulky structures like the one seen in Figure 5. They stand across a stream, and hold a considerable volume of water and sand that varies depending on the height of the dam and the degree of slope in the stream. In order to hold fast, they must anchor to the bedrock of the stream. Across the entire width of the stream, loose bedding material, including sand, is cleared all the way to the bedrock. This involves digging through a lot of soil to anchor the wings of the dam. Most dams measure between 1 and 4 meters in height above bedrock and are highly variable in width. Figure 5 shows a typical dam, this one built by the Kitandi Fruit Tree Growers SHG. In general the dams are just less than 2 meters thick at their base and slope inward on their downstream side until they narrow to just one meter of thickness at the top. The upstream side is vertical and straight. The dam in Figure 6 contains approximately 85 cubic meters of cement, sand, water and rock. These materials are anchored to bedrock using 18mm rebar that extends from the rock to just below the top of the dam. Forms for the cement are made after the rebar is secured and the process of building the dam begins.

Figure 6: A newly constructed sand dam by the Kitito Self Help Group, finished in June 2013. The dam has a 17.5 meter spillway. The 1.4 meter high left wing adds an additional 7.7 meters and the right wing another 6.0 meters. It stands 2.8 meters above bedrock, is 1.8 meters thick at the base, 1.0 meter at the top of the spillway, and 0.68meters at the top of each wing. The entire structure has a volume of approximately 85 cubic meters. The dam was built by hand with more than 100 community members involved in the process (photo by author 2013).

The sand in the dam, seen in Figure 5, builds up naturally from the bed of the stream. Natural erosion moves sand as water flows every rainy season. The dam slows the movement of water, and the sand particles, larger than silt or clay and unable to float in slow moving water, drop out rather quickly. Each time it rains, more sand moves downstream and the dam fills up in consecutive layers. According to UDO field officers, this takes between 1 and 3 years. Early in the process, the sand dam will have some clay and silt, most of which concentrates on the surface of the sand, but this is flushed over the dam in the next rainy season. When fully mature, the dam fill is primarily sand. The dam shown in Figure 5 was measured in July of 2013 and found to contain nearly 11,000 cubic meters of sand. Since sand has a porosity of between 35 and 42%, this means it contains 3800 cubic meters of water at full capacity. Moreover, this does not include the elevated water levels in the natural water table on both sides of stored sand. The total amount of water available for extraction from this dam could potentially be greater than 10 million liters (Hut et al 2008).

Perhaps the most impressive aspect of the Kitito SHG dam in Figure 6 was the community involvement in building it. UDO stresses the importance of community action in any dam they help build. First any community group must be officially recognized as a SHG by the government, and this requires the raising and paying of a fee that is often taxing to a poor community. Once this is done UDO will come to survey the area for appropriate areas for a sand dam and select a site. At this point the community is required to do two more things. First they must build two terraces on each side of the potential sand dam's sand catchment area, which in Kitito SHG's case meant 4, 250 meter long terraces.

These require about 1 person day of labor for every 2 meters of terrace. Second they must collect all locally required materials for the dam, primarily sand and rock. These make up over 90% of the volume of the dam, so between 75 and 80 cubic meters of material, all collected by hand. These two activities do a great deal to build community relationships in a common task, contributing overall to community resilience. At this point they can build the dam, which in many ways is a celebratory act, the culmination of community building activities.

The water newly available from these dams has transformative effects, even if they are not immediately visible. UDO has documented a number of these changes, as has Sahelian Solutions (SASOL)—another NGO working on sand dams in the neighboring county of Kitui. The first impact is felt by women, since they are normally the ones who fetch water for their households. It is not unusual for a woman to cut the time used to fetch water by three hours a day, though the average used by UDO is between one and two hours per day. The shortened distance to water can also allow women to transfer the job of fetching water to other family members, increasing time available to work on the farm, cook, care for children, and participate in community activities. Additionally, since the water is cleaner, instances of diarrheal disease drop. SASOL has documented an increase in school attendance after sand dams are fully functional (Mutiso et al, 2008) primarily because illness drops and nutrition improves. These immediate benefits lead to longer-term gains. The decrease in labor required to manage water means the household is able to more easily handle stresses that arise in other areas such as job loss.

When water is available, opportunities change for the entire household. The general pattern in rural Kenya is for women to manage household activities and for men to seek work for cash. Income from farming in semi-arid areas is minimal and highly inconsistent across seasons, so many men seek work in cities. Having water changes local employment prospects. This is especially true for households that have land a short distance from a sand dam. When walking and measuring sand dams in July of 2013, a number of farmers were seen in close proximity to the stream: men and women were preparing and planting vegetable gardens in small terraced plots. Their primary crops were sukuma wiki (a vegetable related to collards and kale), tomatoes, onions, and Swiss chard (which they call “spinach” when translating from Kamba). These vegetables are all highly marketable, and are often sold in the early morning and taken to local cities like Wote and Machakos. In these smaller gardens the farmers carry 20 liter jerry cans of water from the sand dam to their plots and water the vegetables, which they grow in shallow depressions. Though I did not see this personally, the UDO field officers said that a number of households, as far as half a kilometer uphill from the dam, plant similar gardens around their houses. They often use a donkey to carry up to four jerry cans of water per load from the sand dam with children between 8 and 14 years of age leading the donkey.

Also observed in July of 2013 were farmers who had installed pumps, although these were less common since level land near the streams is rare. For instance, Justin, chair of the Mkuta Mwea SHG, has a diesel-powered pump at the base of a dam in an enhanced natural depression in the river. He pumps to a garden where he raises tomatoes, French beans, Swiss chard, green peppers, Sukuma wiki, maize and green gram (an Indian legume sometimes called mung beans). Though he uses some to feed his family, most of his product is sold. However, he does not have to take the crop to market himself.

His reputation as a quality farmer is high and those who sell his goods in Wote come to him to get their produce. His pump was paid off completely in the first year of his operation.

Another farmer, chair of the Kitandi Fruit Tree Growers SHG, has a large farm adjacent to the stream that is connected with a pump. True to the name, he has planted a lot of fruit trees. When asked if other members also plant fruit trees, he said yes, but most grow them near their homes and bring water from the dams to get them started. All of these other farmers were using the large nursery on his property to grow the seedling trees for their farms. The species grown include avocado, citrus, mango, guava, papaya, banana, and even macadamia nut. Most of the trees are young and haven't reached their primary production years, but despite this, the avocado production was impressive. Also impressive was the quantity of vegetables growing on the farm. The vegetables are watered by gravity from two 1000-liter tanks that are filled by the pump. These serve as a reservoir for the water and help conserve fuel. The chair had hired a woman who had no land of her own to water and weed the vegetables. Most of his product was sold in nearby towns.

While the number of vegetables and fruit trees generally appearing around sand dams is significant, the most common plant grown near the dams is Napier grass (Figure 5 on the right of the dam), or *Pennisetum purpureum*.[3] This is a very deeply-rooted fodder grass with an ability to spread slowly via rhizomes and stolons, but mostly planted through root cuttings. When established it can stabilize the steep banks of terraces and it does very well on stream banks as well, but its primary purpose is as a fodder grass. It is not uncommon to bring the animals to the sand dam to drink, then load them with fodder cut along the edge of the sand to carry back to their stalls. Keeping the animals in stalls enables farmers to collect and store manure for use in their rainy season agriculture. It also avoids the overgrazing problem common in the region. The chair of Kitandi Fruit Tree Growers explained that the grass provides cut and carry fodder for lactating cows and goats, extending the milking periods and improving the health of calves, kids, and people, especially children. This otherwise unavailable protein supply is one of the most important benefits of the sand dams. When combined with its erosion control qualities, Napier grass is arguably the most important sand dam crop.

Another important long-term benefit of the sand dams is trees. No one has done more than Patrick Musyimi of the Makuta Mwea SHG, who has planted over 10,000 trees and is still working on his forest. Other than fruit trees, the most commonly planted species in the higher-elevation areas of Machakos and Makueni are *Eucalyptus camaldulensis*, *Croton megalocarpus, Grevillea robusta, Warburgia ugandensis* and *Prunus africanum*.[4] The last two are Kenyan native plants with medicinal properties. In lower, drier areas, *Melia volkensii* and *Azadirachta indica* are more important. Most trees need little or no supplemental water after they are established. The trick is getting them started and the sand dam provides the water to enable them to thrive. Through time this promotes reforestation of the region, a trend that is already visible in satellite data (Ryan 2012).

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[3] *FAOPennisetum purpureum*: http://www.fao.org/ag/agp/AGPC/doc/gbase/data/Pf000301.HTM

[4] Eucalyptus and Grevillea are both Australian imports used for firewood. Grevillea does well when close to crops as it does not compete for nutrients and its shade is light. *Croton megalocarpus* is a favorite native shade tree whose leave make good mulch.

As UDO helps communities build sand dams, other communities both inside and outside the country have expressed interest, including the Maasai in neighboring Kajiado. The Maasai primarily want to improve available water for their animals, and sand dams have distinct advantages over boreholes. First, sand dams provide water over a long area, not just at one distinct point, so the damage to the landscape is reduced. One Maasai made a very simple comment to Arnold, the field officer for Kajiado, which illustrates this point: "At our sand dam, there is no need to queue." Second they are far cheaper than a borehole and are built using primarily local resources. An average sand dam costs around $15,000, excluding labor, sand, and rock, all of which are provided by the community SHG doing the building. A borehole, on the other hand, costs an average of $75,000. Most local communities can afford neither, so outside assistance is required, but since communities participate in building a sand dam, the sense of local ownership is much higher and therefore the sense of responsibility for the outcome is higher as well. Third, sand dams have no running costs and rarely need repairs. Since starting construction of sand dams in 1978, UDO has built nearly 1500, of which only four have failed. Perhaps the greatest advantage for the Maasai is the impact that the higher water table near seasonally dry streams has on nearby vegetation. Over time, this causes riparian vegetation to improve and this becomes an important source of dry season fodder. Since the Maasai are almost entirely dependent on milk for sustenance, any improvement in cattle, goat, and sheep production results in significant increase in community resilience.

Thinking big by thinking small

A question almost always asked by people new to sand dams and the idea of catching water at high points in a watershed is this: what about the people downstream? Don't they have less water available because the people upstream are keeping their water? This is a good question and deserves a solid answer. SASOL and UDO have started sorting this out. The starting point is the ecosystem; what does the watershed, the entire area that drains water to the dam or series of dams in a stream, really look like? How does water move across this landscape? What did the natural system look like before humans altered the landscape? How did the flow patterns of water change in the altered landscape? Historical information is difficult to find in this region of Kenya, and what we do know is contained in the memories of the oldest community members, some of which is documented (Tiffen 1994). Dr. Gideon Mutiso, a co-founder of SASOL and longtime development consultant and academic, interviewed many of the old farmers in Machakos and Kitui, his home area, and captured pieces of this lost information.

The Kitui, Machakos and Makueni region has always been dry, specifically sub-humid to semi-arid. What has changed is the number of trees. Previously, it was a near continuous deciduous tropical forest in its higher regions and savanna woodland in the lower regions. These lower reaches were the home of large mammals like elephant, black and white rhinoceros, and numerous antelopes from eland to dik-dik, Cape buffalo, giraffe, lions, and leopards. Stream flow throughout the region was low, but continuous. Rainfall did not rush off the landscape when it fell; instead it hit a vegetated surface, slowed, and flowed through the soil and in the water table. Springs were common, still existing in much of the region even to the end of the 1940s. That is when the dramatic changes really hit. The local population expanded rapidly. The big game was almost entirely wiped out and confined to newly created parks by the colonial administration and then the new Kenya government. The highlands were deforested and converted to agriculture. The lowlands changed with the loss of browsing game like black rhinos, and acacia/commiphora scrub took over from savanna grasses. Rainfall more commonly hit bare soil in the highlands and ran off quickly, carrying soil with it, and failed to reach the water table at all. The water table lowered, springs dried up or became ephemeral and streams widened, with an increased bed load of sand, silt and clay.

The renewed landscape promoted by UDO, SASOL, and others seeks to restore a modified original ecology while maintaining a productive agriculture for people. They recognize the need to supply water as a first step, thus the sand dams. They also see the loss of perennial vegetation as a key aspect of degradation, so they promote tree planting and the growing of grasses. They also know that people have to grow crops in a way that reduces or eliminates further damage to the soil. Thus they promote terraces, advocate no-till and no burn agriculture, and push for drought-tolerant crops. These changes capture more rainfall and put it back in the ground. In fact, a dam captures only a tiny fraction of the water flowing off the landscape: researchers from Vrije University, Amsterdam, studied this in a watershed south of Kitui town and calculated a capture of 1-3% of seasonal flow by the dams (Borst et al 2006 and Hut et al 2008). However, this water is not lost; it is merely slowed and stored for more controlled release. As the sand dams rise and groundwater begins to swell, the dams raise the stream level. This rising water level combines with the terraces and trees, which slow surface runoff and allow more water to enter the soil, and eventually the water reaches the spring outlet points. The total amount of water flowing down the river does not change; what really changes is the timing of the flow. Instead of rushing in quick, energetic, and damaging bursts, water flows more gently over a longer period both on the surface and underground. When the original underground water profile is restored, the amount of water available downstream at any given time goes up, not down. The most significant change is that the size of the flood flow drops, while the base flow is restored. Whenever soil water supply rises, overall ecological resilience improves as well.

Conclusion

Sand dams are a locally conceived, low maintenance method of capturing runoff on a landscape. The captured water improves local ecosystem functions and at the same time enables local residents to collect water more conveniently throughout the year. In some cases the dams also provide water for dry season gardening and the growing of fruit trees and other multipurpose tree species. The fact that the sand dams and other forms of water catchment were locally developed and are locally owned improved the rate of adoption and made this a success story that has high potential to expand to other similar regions in East Africa and beyond.

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