An Assessment of the Social and Economic Effects of the Kitui Sand Dams

Community based Adaptation to Climate Change

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Abstract

In the semi-arid Kitui District (Kenya), two rainy seasons provide approximately 90% of the annual rainfall. The two dry seasons in between are characterized by large water deficits. Whilst the population is growing, more extreme climate variability is expected for East Africa in the future. Agricultural production and food security are at stake.

SASOL, a local NGO, designs sand dams to increase water availability and accessibility. Sand dams are small concrete structures in ephemeral riverbeds that store water from the rainy seasons under a layer of sand. So far over 500 sand dams have been build. The ADAPTS[1] project studies the hydrological and socioeconomic effects of sand dams to find out whether they provide a sustainable technique to cope with climate change and climate variability in highly rain-depended areas like Kitui District.

Hydrological studies carried out by ACACIA Institute proved that sand dams have a positive effect on water availability. They increase the volume of accessible groundwater and prolong the period in which groundwater is available for abstraction. The sand behind the dam enables the fast response of the groundwater table on precipitation and protects groundwater from excessive evaporation and contamination. The dams hardly influence downstream areas since they only retain 1.8-3.8% of the local precipitation.

This report shows the social and economic effects of the sand dams. In 2006, 106 dams were checked and a survey was conducted among 98 households with dams and 39 households without dams. In addition to the hydrologic data of ACACIA Institute, we found that 30% of the households with dam stated that the water table rose since dam construction -even though a GIS analysis pointed out that they had less rainfall than the other 108 households for 2004, 2005 and 2006. They did have a significantly higher dam density. Second, in addition to the conclusion of Hoogmoed (2006), the dams prolonged the water availability of primary water sources significantly with 2.5 months.

The sand dams cause a disparity in water accessibility between the two groups (farmers with and farmers without having a sand dam). Households with dams now live 1700 meters closer to their primary water source and daily save 100 minutes on fetching water whilst increasing their water use from 194 to 668 L/day. The situation of households without dams deteriorated. They walk an extra 90 meters each day and spend 6.4 minutes more on fetching water, while their water use decreased from 343 to 328 L/day.

In its turn, the increased water use and the saved time bring about tremendous positive social and economical changes, most of which are agricultural. The households without dams all saw their harvest of rain-fed crops decrease; many had no harvest at all in the dry year of 2005. At the same time, the households with dam increased their harvest and diversified their income: they increased the number of different crops they grow and many also started irrigating. The percentage of households with dam growing irrigated crops increased from 12% to 44%; the percentage of the households without dams stagnated at 18%. Furthermore, households with dam planted more different species and a larger amount of fruit trees.

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1 ADAPTS is a collaborative project by the Institute for Environment Studies, ACACIA Institute and Both Ends.

Many households also started non-agricultural (group) activities to boost their income. Brick making is most popular: it is responsible for the highest increase in water use and the biggest supplement to many incomes of households with dams.

Overall, whilst the income of households without dams decreased significantly with -38.056 KSh/year, the households with dam managed to maintain or even increase their income with +27.241 KSh/year. This means a sand dam can make a difference of 65.297 KSh (+/- €650) in a dry year like 2005[2], clearly demonstrating that the investment of less than € 30 per household for such a long-lasting construction is extremely low.

The dams also caused an unexpected and not yet fully understand difference in suffering on diseases. They suffer the same diseases, but the majority of the households with dam cite their suffering decreased since dam construction, while a majority of the households without dam say the exact opposite.

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2 The GDP per capita in Kenya was US$ 1240 in 2005 (http://hdrstats.undp.org/countries/ country_fact_sheets/cty_fs_KEN.html); or 93899 KSh (http://www.oanda.com).

1. Introduction

Climate in general exerts a major role in day-to-day economic development. With one-third of the people living in drought-prone areas in Africa, the continent is very vulnerable for the impacts of drought (Boko *et al.*, 2007). Poor communities have restricted choice for their livelihoods and limited capacity to cope with climate variability and natural disasters (COM, 2007). The IPCC expects more extreme climate variability in East Africa in the future. Annual precipitation is expected to increase, but as temperatures will rise potential evaporation will increase as well ad hence net water availability is projected to decrease (Aerts *et al*, 2006). Agricultural production and food security in many African regions are likely to be severely compromised by climate change and climate variability. At the present, there is already a high mortality risk because of water related natural hazards in many African regions including Kitui District (Boko et al, 2007; 438).

Policy makers and water managers face the task of ensuring water availability and food security, while taking into account the possible impacts of climate change. Local storage of water is increasingly seen as an important adaptation for ensuring water availability and food security to rural and urban populations, especially in developing countries (Kashyap, 2004). This is particular the case in semi-arid and arid regions outside the reach of perennial rivers and where there is no (or little) groundwater available. The need for increased storage capacity (and thereby an increase in water security) is underpinned by the Millennium Development Goals that specifically address storage needs to adapt to global changes such as sharply growing populations, climate change and catchment degradation (UN, 2000, 2002). It is, therefore, important to evaluate potential adaptation strategies on their efficiency and sustainability.

This research concerns a case study in Kitui District, Kenya, on the construction of sand dams in seasonal rivers. Large parts of Kenya suffer from water shortage. The annual rainfall (500 to 1050 mm/y) is considerable but limited to two rainy seasons. Rains fall in short events and hardly infiltrate the ground. Between these rainy seasons people in the rural areas encounter drought as a big problem; during prolonged dry periods they even depend on relief food[3]. In Kitui District the rain disappears as runoff into ephemeral rivers that stand dry for the rest of the year. Given the expected increase in climate variability (Huntingford et al, 2005; Aerts *et al*, 2006; Boko *et al*, 2007) and the massive potential of rainwater harvesting in Africa (UNEP, 2006), studying techniques of small-scale water storage becomes increasingly important.

This case study is part of the research program (ADAPTS) which aims: “to increase developing countries’ adaptive capacities by achieving the inclusion of climate change and adaptation considerations in water policies, local planning and investment decisions”. The main research-subject of this report is the social and economic impact of water-storing sand dams on the local community of Kitui District in Kenya.

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[3] In 2004 and spring 2005, for example, 25-49 % of the inhabitants of Kitui District received food aid (FEWS NET).

1.1 ADAPTS

The ADAPTS program is an initiative of the Institute for Environmental Studies (IVM) at the Vrije Universiteit, Amsterdam. The main aim of the program is to increase developing countries' adaptive capacities by including climate change and adaptation considerations in water management at the local scale. The program first identifies successful local water management activities and evaluates the robustness of these activities under current and future conditions. It will stimulate additional adaptations to make these local actions more sustainable and less vulnerable to climate change impacts.

The Kitui Sand Dam project and the involved NGO (Sahelian Solutions Foundation, abbreviated as SASOL) in Kenya is selected as one of the pilot areas for the ADAPTS program.

1.2 SASOL

The Sahelian Solutions Foundation (SASOL), a local NGO in Kitui, helps local communities with the design and construction of small-scale sand dams to increase the water-storing capacity of seasonal (ephemeral) rivers. SASOL's main goal is to reduce the distance to water sources for the entire Kitui District to less than 2 km and improve the overall water availability.

The dams are constructed using raw material (e.g. stone, water, sand) collected from the surrounding area. The local community offers labour to gather these materials and build the dam. Material costs per dam are US$ 8.000 on average, at an investment of US$ 35-50 per capita. This might seem like a lot, but according to Renpel (2005) the time saved on fetching water represents a level of payoff that justifies the large investment by a community. During the last 10 years, SASOL has developed around 500 dams in Kitui District and succeeded to reach their goal for large parts of the District.

In the dry season these dams offer water to an average of 150 people per dam. This adds up to a total of 67.500 people with potentially improved access to water during the dry season (Aerts & Lasage, 2005).

1.3 Sand dams

A majority of the population of Kitui District depend on ephemeral rivers for water supply. In the dry periods the water level is very low and water can only be found in scoop holes (holes dug in the riverbed). During prolonged dry periods there is no water left in the river at all in some catchments (like Kiindu and Koma), forcing people to walk long distances to larger rivers that still contain sub-surface water, making harvest fail and causing famine.

Sand dams are one way to deal with these problems. The dams, alternatively called sand storage dams, trap dams, sponge dams, or desert water tanks, have a very long history in Africa and the Middle East. In the eighteenth century sand storage dams were built in the United States of America's and Mexican borderland (van Haveren, 2004). The colonial Kenyan government built the first dams in Kitui District in the 1950s and '60s. They are however not as widely applied as surface water dams, and there are some major differences between the two.

Normal surface water has high evaporation rates and gets contaminated easily. Moreover, mosquitoes breed in it, causing malaria. Water stored in subsurface aquifers does not or hardly suffer from these problems (Hoogmoed, 2007)[4]. Sand dams enlarge the sub-surface aquifer of an ephemeral riverbed (see Figure 1.1). The dam is found on the underlying bedrock and its sides either also extent to bedrock material, or into the riverbank. Behind this dam, provided local conditions are suitable, sand will accumulate (hence the name 'sand dam'). The dam obstructs the flow of groundwater and the water percolates in the pores of the sand. These pores make up around 35% of the volume of sand, resulting in a specific yield of 27% (Borst en de Haas, 2006)[5]. The dam should not only act as a barrier but also as a spillway. This way it is ensured that the erosion will not affect the riverbanks. A mature dam (filled with sand) stores around 1.8-3.8% of the annual local rainfall (Aerts *et al*, 2006). Scoop holes, a well or a pump can be used to fetch water; the latter two are sometimes provided by SASOL.

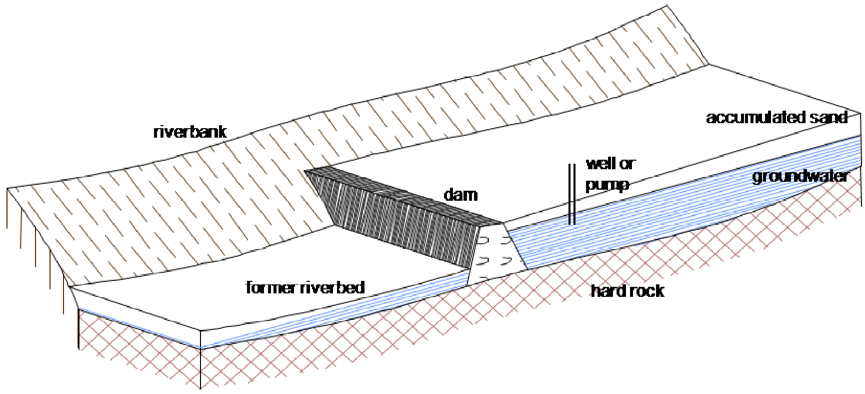

Figure 1.1 schematic drawing of a sand dam (Borst en de Haas, 2006).

1.3.1 Construction

Site selection for sand dam construction is based on physical and social aspects. Physical suitability of a location *inter alia* depends on the depth of the hard rock layer, the strength of the riverbanks, and the presence of sand in the riverbed[6]. The input and commitment of a community form the social aspect. When the community and SASOL agree to construct a dam, a dam committee is found to coordinate community involvement in the building process. The committee has to make a site selection, and set up rules and a division of work. The members are selected by the community. On average some 20 families are involved in dam construction. SASOL facilitates the site selection and the engineering of construction works as they have technical expertise and experience with dam construction. During the process of dam construction an artisan of

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4 Hellwig (1973) found that for coarse sand (comparable to the sand found at the Kitui sand dams) the rate of evaporation decreases to about 30% of the open water evaporation when the water table is 30 cm below the sand surface, and to around 10% when the water table is 60 cm below the sand service.

5 Specific yield is the available volume of water that can freely drain from a saturated rock or soil under the influence of gravity, and it is normally expressed as a percentage of the total volume of the aquifer (not just the pore space).

6 Clay is not suitable, because it has very limited water-extraction possibilities.

SASOL is present to support the community with technical knowledge. After the community has chosen a location that meets SASOL's technical standards, construction starts with digging a ditch in the river bed to reach the bedrock. This ditch is filled with mortar and rocks and the construction will rise 1–4 m above the surface, depending on the local circumstances. The work is done by about 15 persons from the community. The construction takes approximately 3 months and material costs are around US$ 5000. The number of dams constructed by a community depends on the length of the river, the number of suitable locations and the availability of funding. Whenever possible, dams are build in cascade, increasing the effect of the dams by slowing the water down and increasing base flow during the dry periods (Lasage *et al*, 2007; Borst en de Haas, 2006).

Figure 1.2 Two dams in an ephemeral river. The bright colour is accumulated sand (source of satellite image: Google Earth).

1.3.2 Ownership & Maintenance

Households that both invest in the construction of the dam and help to build it become owners and are allowed to fetch water from the dam[7]. A majority of the people (93%) is aware of this, although some people think that SASOL or the Kenyan government owns the dam.

Though the dams are robust concrete structures, they need some maintenance, especially on the riverbanks. However, only 69% of the households take the responsibility to act and protect the dam. Measures often include bank protection, not to let children play or the animals drink at the dam and locking the water pump. Many people however say to protect the dam but forget the bank. The concrete can last, but the connection to the riverbank is vulnerable for erosion. This process makes water flow around the dam,

[7] One man built three dams himself and is the only owner.

degrading its function. Some people even cultivate land on the riverbed, thereby changing the watercourse and jeopardizing the utility of the dam[8].

Figure 1.3 A new build dam without any sand accumulated behind it yet. The spillway is in the middle of the dam.

1.3.3 Dam robustness

For this research, 119 dams were evaluated in the field. Six of them completely broke down and five had such a weak connection to their banks that they probably broke down the next rainy season. Water was probably already flowing around these dams and they became useless. Two more dams were in a critical stage; they can still be saved but the banks need to be improved. Altogether, that means that 9-11% of the constructed dams do not last very long, mainly because the banks were not well protected.

1.4 Previous studies on the socio-economic effects

Rempel *et al* intensively studied the Kitui Sand-dam project in 2005. At 30 dam sites, six people or more were interviewed. This study shows many for example increased agricultural production, planting of new crops and saved time on fetching water. The outcome is interesting, but because only dam sites were studied, the study is not complete.

De Bruijn and Rhebergen studied both households with dams and households without a dam in 2005. They measured changes in social and economic standards in two catchments: one with a dam (Kiindu) and one without (Koma). The results were reported in 2006 (De Bruijn & Rhebergen, 2006). Again the main conclusion was that the dams have positive social and economic effects on the local people. However, the number of interviews -19 households with a dam and 18 without one- was too small to be reliable.

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8 The data about the ownership and the maintenance of the dam is derived from the interviews conducted for this research.

1.5 Research project

1.5.1 Goal

An important reason for conducting this study is to see whether upscaling of the sand dam technique to other parts of Kenya and other countries is feasible. For this, it is important to assess the current effectives of the sand dams in terms of their hydrological properties (water storage) and their socio economic impacts on communities (welfare of people).

The hydrological aspects are examined by Borst and De Haas (2006) and Hoogmoed (2007), as part of ACACIA Institutes' project "Recharge techniques and water conservation in East Africa". In this research a set of measurements is carried out to determine the functioning and effectiveness of the sand dams in the Kiindu River in Kitui District. The construction of sand dams turns out to be very successful in increasing groundwater storage capacity, prolonging the period of groundwater availability (bridging dry seasons) and improving water quality (Hoogmoed, 2007; 5).

The goal of this research is on the social-economic impacts of sand dams. It is expected that sand dams have a positive effect on the involved communities because of:

- Increased water availability, and higher reliability of water availability throughout the year;
- Saved time on fetching water because the primary water sources are now closer to homes.

Together these factors are expected to increase welfare of people, which will be measured in this research. For this, a large questionnaire has been developed and used in the field among farmers with a dam and among farmers in the same area that do not have a dam.

1.5.2 Research Questions

The socio-economic benefits will be examined using the following research questions:

1. Primary benefits: Changes in water accessibility:
    - Does the construction of sand dams lead to increased water use?
    - Do people save time on fetching water?
2. Secondary benefits
    1. Education:
        - Do the children of households get a better education?
    2. Agriculture
        - Is more irrigation applied since dam construction?
        - What is the effect of sand dams on the harvest of rain-fed crops?
        - What is the overall effect on crop performance and the number of crops grown?
        - What is the effect on livestock keeping
        - What is the effect on the number of trees planted

3. Ownership of assets:

   - Are there any changes in the matter households own?

4. Income

   - Is there a change in group-activities?
   - Is there a difference in number of households using micro credits?
   - What is the effect of sand dams on a households purchase power?
   - What is the effect on a households' income?
   - Health
   - Is there a change in the health situation of the sand-dam users?
   - Coping mechanisms
   - Does the construction of sand dams have an impact on drought-coping mechanisms used by the sand-dam users?

2. Study area

2.1 In general

Kitui District is located in the central south of Kenya (See Figure 2.1), between latitude 0º 3.7' and 3º 0' South and longitude 37º 45' and 39º 0' East. The total surface area is 30124 km^2, of which more than 20% is part of the largely uninhabited Tsavo National Park. The District is divided into 10 administrative divisions. The District-capital is Kitui Town, located in the west of the District, 135 km East of Nairobi.

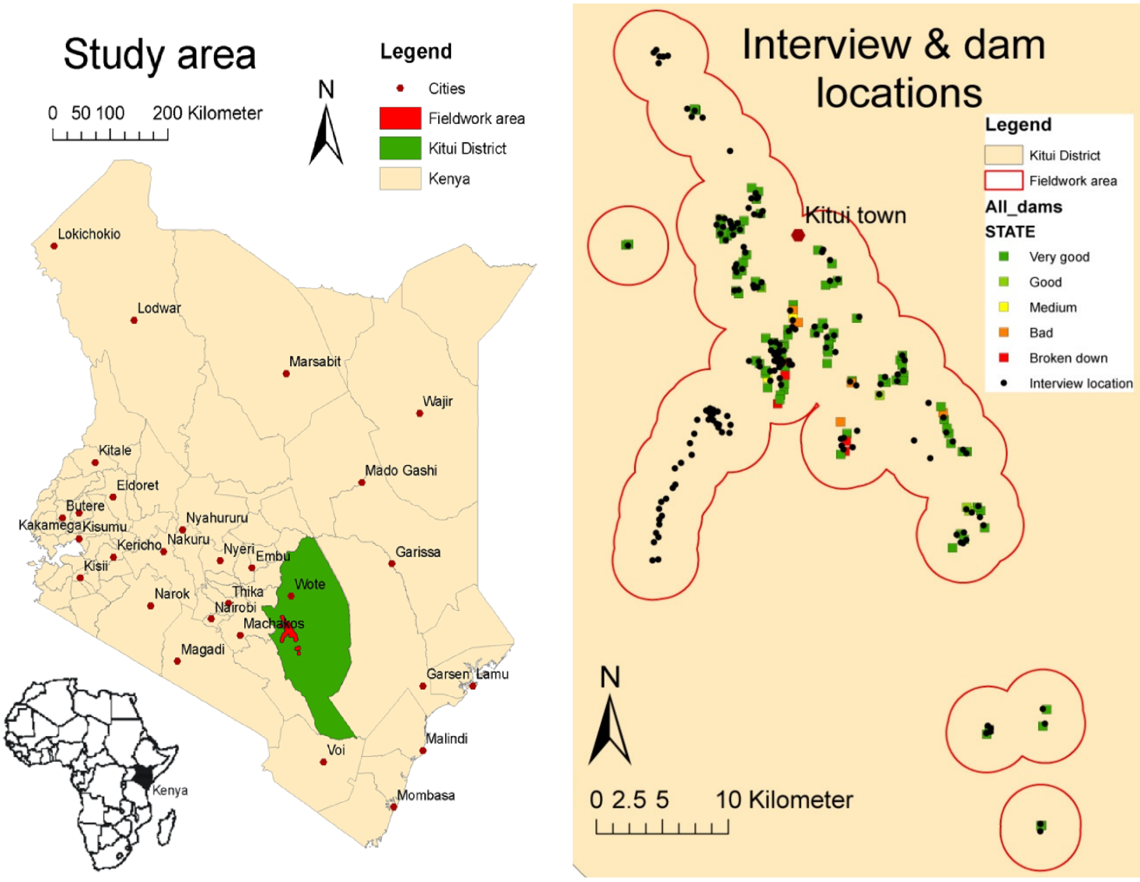

Figure 2.1 Left: study area in Kitui District, Kenya. Right: locations of the interviews and dams. The colours represent the state of the dams.

The District has approximately 550,000 inhabitants according to the 2002 population consensus. The average population density is 18.3 persons/km^2, ranging from 6 persons/km^2 in the division including the Tsavo National Park, to 153 persons/km^2 in the Central Division (including Kitui Town and the research area). The population growth rate was 2.2% in 2002 (District Commissioner Kitui, 2002).

SASOL has already build the sand dams over a large area of the district, but since time was limited and most roads are of bad quality in Kitui District, the research area is located within a radius of 50 km from Kitui Town. Interview locations depended on the location of catchment and the density of the sand dams. A higher sand dam density was intuitively translated in a higher interviews density; the same accounts for a higher household density.

2.2 Topography and Climate

The Kitui District has a gently eastward-facing slope. The higher, upland area in the West covers the Yatta plateau with elevations varying between 600m and 1800m above mean sea level. The research area is also located on this plateau at elevations between 750 and 1250m. The central part of the District is made up of hilly ridges separated by wide low-lying areas with altitudes between 600m and 900m. The lower area consists of an Eastward sloping plain, with some Inselbergs[9]. The elevation in these lowlands varies between 400m to 600m (See Figure 2.2).

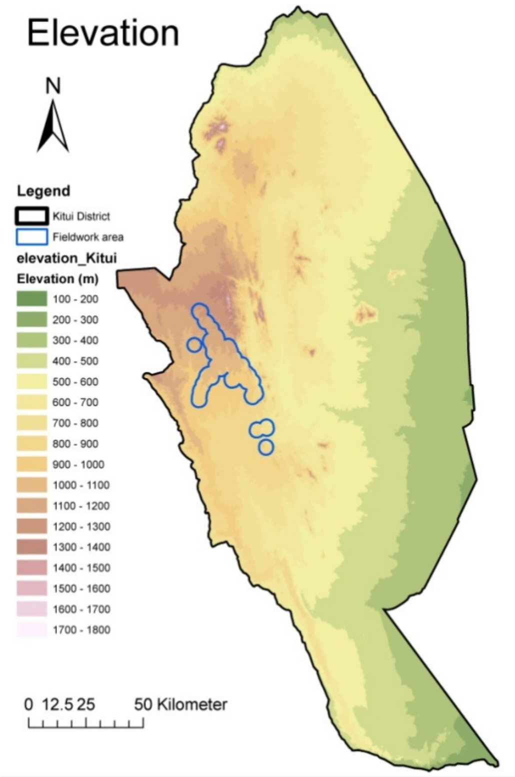

Figure 2.2 Elevation of Kitui District. The study area is highlighted with a blue line.

Because of the difference in altitude, the climate can be divided into two climatic zones (Louis Berger International Inc., 1983). The Western part of the District has a semi-arid climate. The Eastern and Southern parts of the District have lower average rainfall and higher temperatures (approximately 4°C higher compared to the western parts); and fall within the arid climatic zone. Temperatures in the Kitui District are high throughout the year, ranging from 16°C to 34°C (District Commissioner Kitui, 2002). The warmest periods are between June and September and January and February. These overall high temperatures in combination with the low and erratic rainfall, result in high rates of

[9] An Inselberg is steep ridge or hill left when a mountain has eroded and found in an otherwise flat, typically desert plain.

evaporation estimated around 1552 mm/yr (Borst en de Haas, 2006) to 1800 mm/yr (District Commissioner Kitui, 2002).

The rainfall pattern is bimodal. The 'long rains' fall in April-May; the 'short rains' last from October to December, and are more reliable. Annual precipitation ranges from 500 to 1050 mm/yr, but is highly erratic and unreliable, both spatially and temporally[10]. Overall, approximately 90% of the annual precipitation falls during the rain seasons (Hoogmoed, 2007)

Elevation and topographical features of the landscape strongly influence the amount of rainfall at a regional scale: the higher areas and hill masses in the West receive most rainfall (700-1050 mm/yr), these amounts decline to the South and East where the annual rainfall is less than 500 mm (District Commissioner Kitui, 2002). See Appendix II for precipitation maps of Kitui District.

It is not uncommon for rains to fail, causing long periods of drought that often result in crop failure and food shortage. Local lore states that rains completely fail at least one year in four (Thomas, 1999).

2.3 Geology and Soil types

2.3.1 Regional Geology

Like the whole of Eastern Kenya, metamorphic and igneous rocks (also known as the basement complex system) characterize the geology of the Kitui District. This basement system consists of various types of Precambrian sediments metamorphosed into gneisses, schists, quartzites and marbles. The Inselbergs found in the District comprise of alkaline rocks and other intrusive rocks, which are more resistant to erosion than the surrounding deposits. The Southern side of the District is primarily composed of Permian deposits, while in the Western part tertiary volcanic rocks are dominant, extending into the Machakos District.

Continuous processes of erosion have eroded and shaped the landscape, creating the hills, ridges and Inselbergs. These morphological features have a considerable influence on the distribution of deposits. The Tertiary and Quaternary deposits can be found on top of the hard rock, especially on the hill slopes and in the riverbed. (Borst en de Haas, 2006)

2.3.2 Local Geology

The geology of the Kiindu catchment consists mainly of gneisses, intersected with pegmatite veins and locally some quartzites. The bandwidth of the gneisses differs from half a meter to tens of meters, with a general structural trend of 0° to 35° (Borst & De Haas, 2006).

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10 Using historical data, Borst en de Haas (2006) found an average rainfall of 920 mm/yr for the Kindu Catchment.

Riverbeds are mostly filled with coarse sand (ca. 600 μm). This product of erosion of local lithological units forms phreatic aquifers with a thickness varying from several centimetres to over 2 meters (de Bruijn and Rhebergen, 2006).

2.3.3 Soil types

Red soils (Lixisols) are the most common in Kitui District. They derive from metamorphic rocks of the basement complex system. Red sandy loams cover the Eastern and Central parts of the District. The soils in the East are relatively low in natural fertility but rich in sodium, making them highly suitable for grazing. The soils in the Central parts of the District are usually high in fertility, but not intensively used for agricultural production due to the lack of water.

Alluvial deposits (Fluvisols) occur in isolated patches along rivers and on hill slopes. These so-called 'black cotton soils' mainly consist of clays (silty to silty-clayey loam). The soils are found in the Western part of the District. In the South shallow stony soils exist, with rock outcrops alternated with the black cotton soils and light brown sandy loams.

The drainage of all soils is very poor and most are easy erodible. This results in high run-off and erosion: big parts of the soils are highly degraded and eroded, with gullies through the soils to the bedrock. It also results in low infiltration of rainwater on the valley sides and the banks of rivers (Borst & De Haas, 2006).

2.4 Hydrology

Erratic rainfall in combination with poor drainage of the soil results in scarce surface-water- and groundwater resources. The district has two perennial rivers, Athi and Tana. The latter is the largest river in Kenya, draining most of the Kitui land area. Athi River forms the Western boundary of the district; both rivers discharge to the Indian Ocean (District Commissioner Kitui, 2002).

For the majority of the population in the Kitui District the ephemeral rivers are more important. The discharge of the rivers is characterized by high flows in April-May and November-December, and extremely low or no discharge in the dry periods. This strong seasonal character, in combination with immediate run-off from the hills caused by the poor drainage of the soil, often results in flash floods, transporting large amounts of sand and silt. Most of the ephemeral rivers are generally dried up within a month after the rainy season (Borst & De Haas, 2006).

The Metamorphosed Precambrian rocks (underlying most of the Kitui District) form poor aquifers. The Quaternary superficial deposits on top of this consist of alluvium and Quaternary deposits. Both form very good aquifers as they consist of usually coarse material with lot of pore space[11]. The aquifers are only recharged by rainfall.

The underground water sources often supplement scarce surface water sources through drilling boreholes (De Bruijn & Rhebergen, 2006).

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[11] Sand dams only work with coarse material (sand). In some catchments (like Koma) it is impossible to build functioning sand dams because only clay will accumulate behind the dam.

2.5 Vegetation

The vegetation in the District is drought resistant, consisting predominantly of semi-arid deciduous thicket and bush land. In the driest areas (below 900 mm/year) the thorn bushes grade into semi-desert vegetation. The vegetation consists mainly of Acacia's and other thorny bushes (for example Acacia spp., *Terminalia combretum* and *Commiphora spp*.) in grassland (Borst & De Haas, 2006). These trees and bushes are also the main vegetation in the study area. Close to the river more types of vegetation occur.

Forestland covers little less than 18.000 ha, serving mainly as water catchment areas Most of the hills used to be forested, but have been cleared for agricultural purposes and charcoal burning. Only patches, corridors of forest and dry forest in vast grazing lands remain. (District Commissioner Kitui, 2002).

At present, local people are still cutting down trees and shrubs for firewood, charcoal burning and building material. This results in large areas of bare land, which are more vulnerable to erosion.

2.6 Agricultural Potential and Poverty

The biophysical agricultural potential is mainly a function of soil characteristics and moisture availability, both being largely controlled by elevation and topography (Kasperson et al, 1995). In Kitui District only 2% of the land has a high agricultural potential, and 32% is of medium potential (Ministry of finance and planning, 2001).

With 65% of the inhabitants of Kitui Districts living beneath the poverty line of 2 dollars a day, Kitui District is one of the poorest regions in Kenya (District Commissioner Kitui, 2002). According to a 1992 study the average annual income in Kitui District was around 15000 Kenyan Shillings (International Development Studies Roskilde, 1992). Agriculture is the main economic source of income for 80% of the population. Most of the agriculture is rain fed, so a majority of the people in Kitui District depends on rainfall for their income. The major food crops are maize, beans, pigeon peas, cowpeas, sorghum, cassava, green grams and millet. Maize and beans are mostly grown in the higher and central parts of the District, with relatively high rainfall. In the lower areas, millet and cowpeas are the major food crops (De Bruijn & Rhebergen, 2006).

Due to the low availability of water sources, the production of irrigated crops (tomatoes, onions, kale and spinach) is relatively low. This activity is mostly done on small isolated plots along the river. Part of the production is sold on the local markets, while the rest is grown to supplement the diet of maize and beans.

Another form of agriculture is a tree nursery, in which tree seedlings are grown on an irrigated plot until they are large enough to grow without being irrigated at set times (See 2.3). The trees are sold or used for fuel (firewood or charcoal), construction, windbreaks, shade on the homesteads, and for fruits, which can be sold or consumed to supplement diets. The leaves of the trees can also be used as fodder for livestock.

Keeping livestock is the second major economic activity. The majority of the households in the Kitui District keep cattle, goats and donkeys. Cattle and goats are mainly kept for selling in the dry period, rather than for consumption. Milk production is generally minimal, but it can be consumed or sold at the local market. Donkeys are kept for transport of goods, mainly water. Bee keeping, basket weaving and charcoal burning are other important economic activities practiced in the area (Ministry of finance and planning, 2001).

Figure 2.3 Tree nursery (picture by W. Rhebergen).

Due to the recurring drought in vast parts of the District, food deficit and food poverty are experienced most of the year. During the dry periods the harvest of the farmers is supplemented by relief food from government and donor agencies (Lasage, 2007).

3. Method

3.1 Introduction

In order to measure the socio-economic effects of the sand dams, we followed the recommendations of a pilot study carried out by De Bruijn and Rhebergen (2006) who developed a questionnaire and tested it in the Kitui District on 37 households. This questionnaire was set up according to the guidelines in the report 'Designing Household Survey Questionnaires for Developing Countries' (World Bank Group, 2000).

For this research, the questionnaire by De Bruijn and Rhebergen (2006) was improved in May 2006 and another 137 households were interviewed in the following months.

The 2006 questionnaire is based on seven categories; raising both integer and nominal data on the question whether there is a difference in socio-economic standards between households with a dam and households without dams. The following socio economic categories were addressed: (See Figure 3.2):

- Family situation and education;
- Agriculture: irrigated crops, fruit trees and non-irrigated crops;
- Property: livestock, assets, sources of energy;
- Income: sources of income, micro credits;
- Water: amount used, travelled distance and time spend on fetching water, crisis management;
- Health: diseases;
- Dam: ownership and maintenance.

The 2006 questionnaire is added as Appendix 1.

Figure 3.1 Interview, with interpreter and co-author Hilda Manzi on the left.

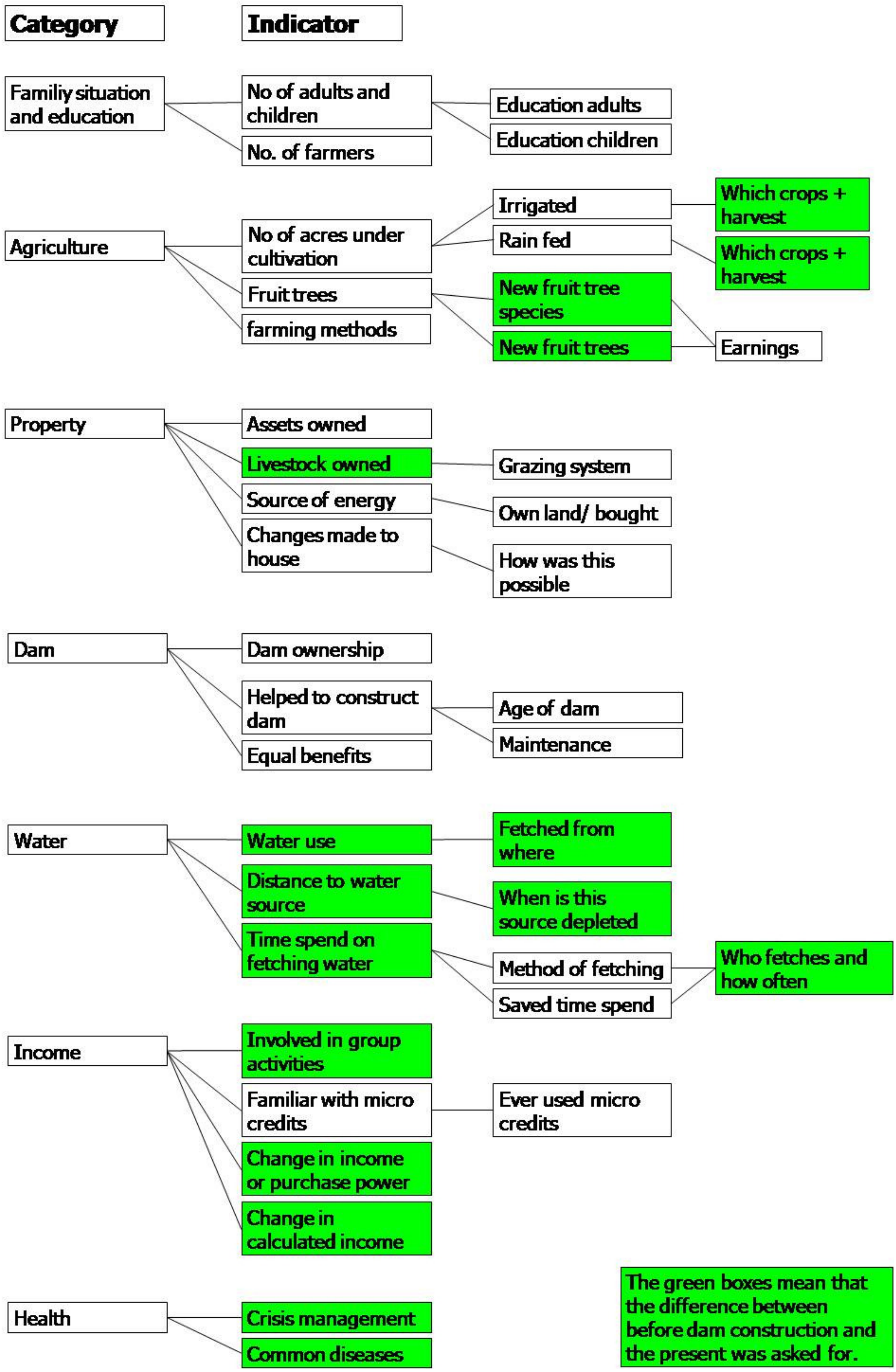

Figure 3.2 Flowchart of the categories and indicators of the 2006 questionnaire.

3.2 Selection of the interview locations for this study

De Bruijn & Rhebergen (2006) explicitly focused on the development of the questionnaire and conducted 37 interviews, equally spread over households with dam and households without a dam. Unlike the method of De Bruijn & Rhebergen, interviews were primarily conducted at households with a dam (N=98). 39 interviews were conducted with households were people did not use the dam, where it was broken or where no dams were build. For a feasible spatial analysis, the intended result was a map with clustered interview locations with a maximum distance of 6000 meters between two interviews[12]. Furthermore, a higher dam density was intuitively translated in a higher interview density; the same accounts for a higher household density.

Dams near interview locations (107 in total) were observed and checked on name, state, size and year of construction. A distinction was made between dams still functioning dams and those where water just flow around in the rainy season. Seven of the 107 dams (< 7%) fit the latter description; they were either in bad state or completely broken down. The coordinates of all interviews and dams were accurately taken by hand-GPS to make a spatial analysis possible.

3.3 Statistical analysis

All questionnaires are analyzed using Microsoft Excel. Whenever possible, the data from the 2005 interviews was added to the 2006 data. However, in many occasions it proved to be impossible because of slight differences in the questions asked, or lack of detail.

Households with dam and the households without dam were compared using F-tests. An F-test returns the one- or two-tailed probability that the variances of two groups of data are significantly different. The tests were always started with the households with a dam, so a negative z-value means that the households without a dam have a higher average. The z-value must be $-1.96 < z < 1.96$ to be significant, the accompanying p-value should be lower than 0.05.

Regression was performed to check whether two indicators were related. Some indicators were categorized using histograms.

3.3.1 Value of Kenyan Shillings

For this research, values are expressed in Kenyan Shillings (KSh). During the collection of data, June and July 2006, one Shilling was on average 0.0108 euro[13], meaning the amounts given in the coming chapters can roughly be divided by a hundred to convert them to Euros. If an amount is derived from another period of time, the value is converted to Euros for that specific period.

[12] It appeared that indeed the average walking distance to the primary water source before dam construction was 3012m.

[13] http://www.oanda.com/convert/fxhistory.

3.4 Spatial analysis

The intention was to perform a geo-statistical analysis. Geo-statistical analysis determines the probability of certain variables occurring over an area where not every location is identified (ESRI, 2001). The analysis interpolates areas and incorporated tools to extract useful information from the data. Unfortunately most of the interview-data proved to be unsuitable for interpolation, making spatial analysis either impossible or bounded by too many assumptions. See for example Figure 3.3 A. Household A en B are located near two different rivers, C is imaginary and located in between. Both A and B have a high water availability (for irrigation), whereas C is far away from any dam and water availability is low. Interpolation would however give household C a high value for irrigation as well.

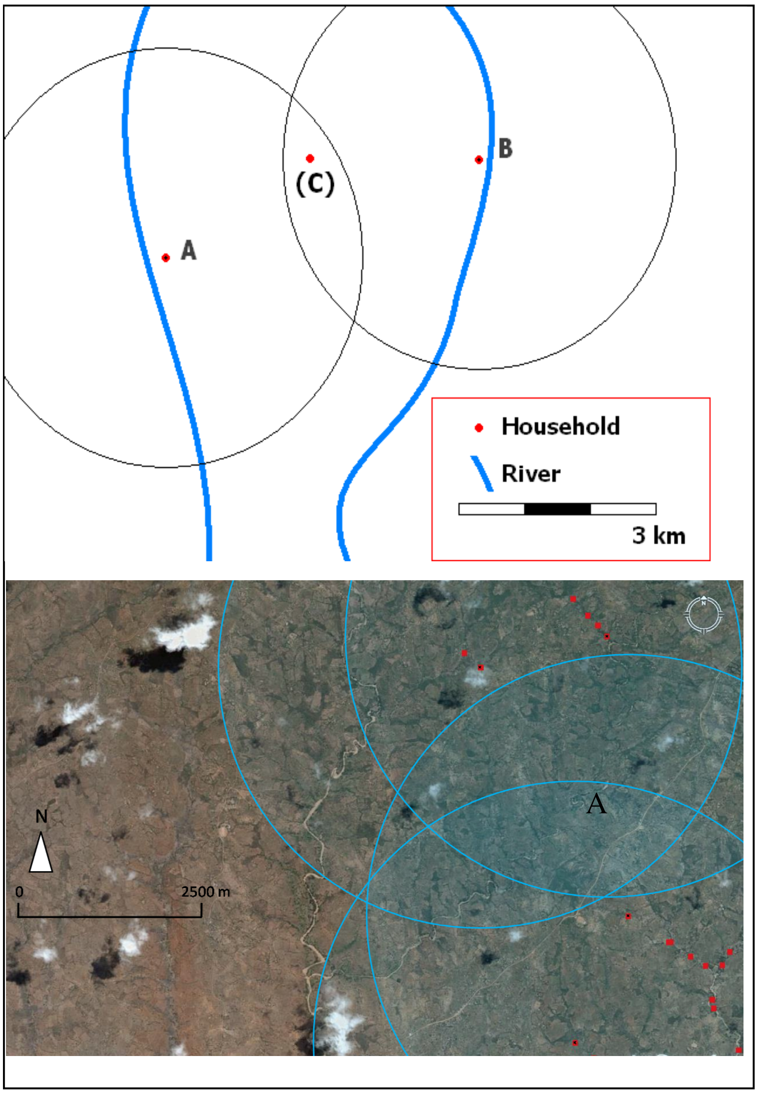

Figure 3.3

A. Schematic drawing to illustrate the data's unsuitability for interpolation. In this example, interpolation suggests that the imaginary household C irrigates crops if both A and B do so, yet the imaginary household is located too far from any river to successfully irrigate on a large scale.

B. Example of the situation in the fieldwork area. Households are indicated by red dots. Around four of them a circle is drawn with a radius of 3 km. The dark red colour near imaginary household A suggests there are many dams around creating many opportunities, whilst in reality the closest dam is located still two kilometres away (source satellite image: Google Earth).

The dam data proved to be more suitable for spatial analysis. This data was first used to calculate euclidian distances[14] from dams and dam densities with radii of 500- and 800

[14] The euclidian distance is the direct distance between two locations.

meter[15]. Second, it was compared to the 29 locations (=21% of total number of interviews) were interviewed people mentioned the water table has gone up. The 'water table' is a collection noun for e.g. a raised water level in a well, a greener environment since dam construction, increased soil moisture content or the area that became less dry. People were not directly asked if this was the case, but it was often given as an explanation for higher crop yield and as a major benefit of the dam. Furthermore, Tropical Rainfall Measuring Mission (TRMM) monthly satellite rainfall-data was collected and used to produce raster maps of rainfall in 2004, 2005, Jan-June 2006 and entire 2006[16]. The rainfall data is believed to be fairly accurate (Bowman *et al*, 2003) and was analyzed to find precipitation disparities between dam vs. no dam interviews and no change in water table vs. change in water table. An F-test for comparing two means was used to calculate differences between dam vs. no dam households and water table change vs. no water table change households.

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[15] According to Hoogmoed (2007) dams hold water not only in the riverbed, but also in the riverbanks. A distance of 500m is a guesstimation of the average distance up to where a dam has influence on groundwater levels. The distance of 800m is chosen because it is the average distance from households with a dam to their primary source.

[16] Fieldwork was done in June and July 2006, so the period of January-June was processed separately.

4. Results

4.1 Introduction

First, the households with dams and those without access to dams will be compared as two groups to see whether possible differences are really caused by the dam. After that the results of the socio-economic indicators will be shown.

These results can initially be divided into two sets. The *primary effects* are extra water available and time saved on fetching water. *Secondary effects* describe what people might actually do as a result of the primary effects of the dams: possible changes in farming practices, water use, economic activities, etc. A change in diseases is partly primary and partly secondary, but hard to understand and classified as secondary.

4.2 Comparing groups

It is important to know whether the outcome of parameters showing differences between households with dams and those without is truly caused by dams. Therefore, households with dams and households without dams are first examined on their dam density, to see whether the households can really be distinguished as two separate groups. Next, the two groups will be compared on annual rainfall, the amount of cultivated land per household, the number of people working on it (the manpower), and applied farming methods.

4.2.1 Dam density

As mentioned before, 98 interviews were conducted at households using a dam, and 39 interviews were conducted at households were people did not use the dam, where it was broken or where no dams were build. It might look abundantly clear, but because a dam can have a positive effect on its surroundings (see §4.2.2), and thus on households not marked as dam-users, the dam density of both groups was examined. No remarkable results emerged: the dam density for the households with dam was significantly higher for both radii of 500m and 800m (see Table 4 1)[17].

4.2.2 Rainfall

As stated in the introduction, rainfall in Kitui District varies greatly on a year-to-year basis. As far as the fieldwork area concerns, there is a great difference between 2004 and 2006. The year 2005, having only 563 mm of rainfall on average[18], is important for this research because it is the last entire year prior to the fieldwork and therefore many people used it as a reference for answering the questions. The latter, 2006, was more wet and brought 1064 mm of rainfall on average[18].

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[17] The dam density was examined for both radii of 500 and 800 meters. It is impossible to state that a sand dam has an influence up to a certain perfectly rounded euclidian distance, neither physically nor socially. The distance of 500m is only indicative; 800m is the average walking distance for households with a dam.

[18] Average of the 137 households.

As can be seen in Table 4 1, the households with dam on average had less rainfall than the households without dams, both for 2005 and 2006. For 2005, this difference was significant. In 2004, the households with sand dam had significantly more rainfall. The differences in rainfall are small (1.2-9.4%) and indicate that the differences in social and economical welfare of households with and without dams are presumably not caused by a disparity in rainfall.

Table 4 1 Average rainfall and dam density for households with dam and those without. Z must be larger than 1.96; p should then be smaller than 0.05.

		Rainfall 2006	Rainfall Jan-June 2006	Rainfall 2005	Rainfall 2004	Dam density (r=500m)	Dam density (r=800m)
Dam	Average	1058,91	375,21	553,11	677.05	2,14	1,40
	St dev.	92,75	57,83	22,41	31.79	1,45	0,88
No dam	Average	1077,2	399,31	586,56	657.52	0,26	0,22
	St dev.	49,14	38,51	18,22	28.95	0,88	0,45
Significance	Significant	no	yes	yes	yes	yes	yes
	z	-1.49	-2.84	-9.06	3.46	9.25	10.21
	p	0.13	$4.6*10^{-3}$	0	$2.7*10^{-4}$	0	0

4.2.3 Farmers per acre

The households without dams have more farmers and cultivate more land, yet the households with a dam have more farmers per acre of land[19]. This is interesting to see, however none of the differences are significant (see Table 4.2).

The households with dam and those without dams on average have the same number of children.

Table 4.2 Number of farmers per household and amount of land.

	No. of farmers per household (N=137)	Acres of land per household (N=174)	Average no. of farmers per acre (N=137)	No. of children
Dam	1.8563	3.0282	0.8865	4.43
No dam	1.9295	3.3974	0.6602	4.46
Sign. diff.	No	No	No	No
z	-0.2567	-0.69	1.69	-0.08
p	0.798	0.490	0.091	0.939

19 A little part of the land is rented. 4.9% of the cultivated land of households without dams is rented and 6.1% of the land of households with dam is rented.

4.2.4 Farming methods

Terracing is the most applied farming method: 83% of the households with a dam and 68% of the households without a dam apply it (See Figure 4.1 and Figure 4.2). Animal manure is the second most used: 59% of the households with a dam and 69% of the people without a dam use dung as fertilizer. Other often-applied farming methods are compost manure (19 households), grass lines (17), bunds (14) and fertilizers (6). It is interesting to see that most households using grass lines and bunds all have a dam (28 of the total 31). Of these 28, 50% started using bunds since dam construction but only 17% of the grass lines started after dam construction.

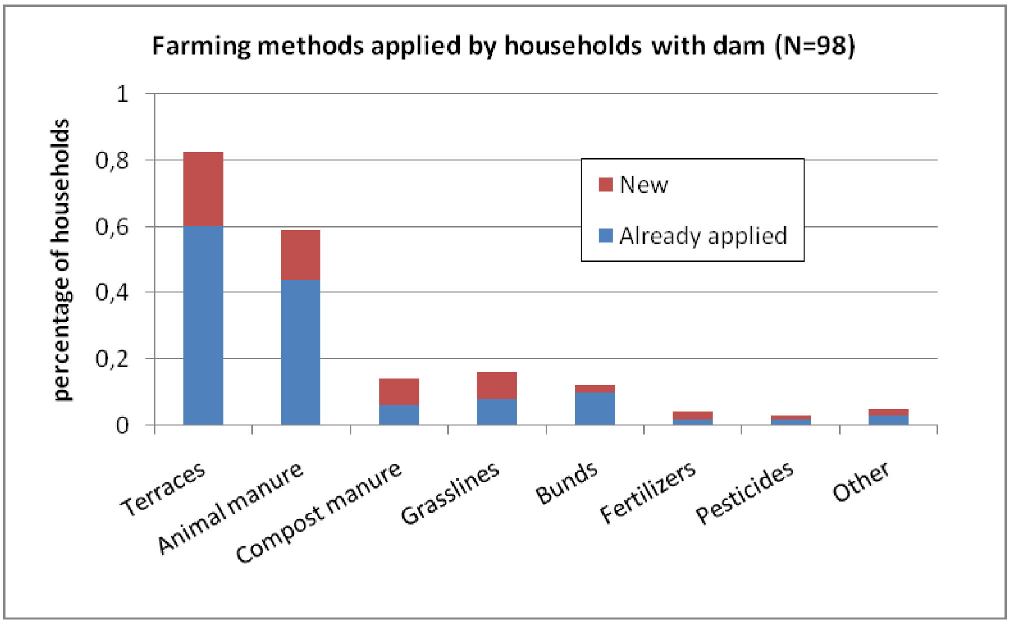

Figure 4.1 Applied farming methods now and before dam construction.

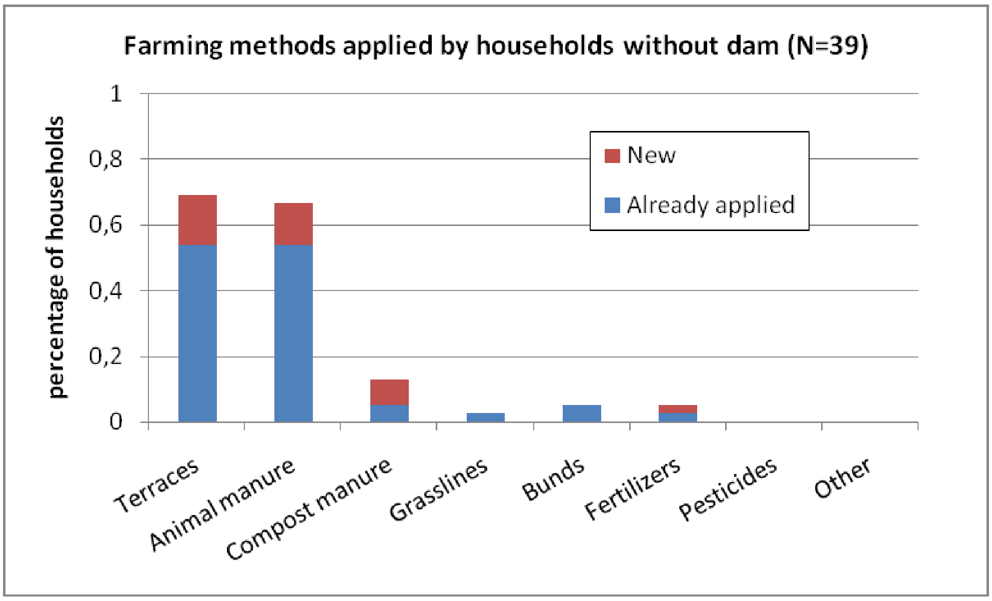

Figure 4.2 Applied farming methods now and five years ago.

In total, 31% of the present-day farming methods of households with dam started after dam construction; for the households without dam this percentage is 24%. The average number of categories of farming methods used per household is also higher for households with a dam. They use 1.96 methods on average, whilst the households without a dam only use 1.63 methods. Unfortunately it is unknown at what scale the methods are applied. Therefore it is impossible to do a statistical analysis to compare, for example, the amount of land with terraces and a households' income.

We assume that improved farming methods have a positive effect on crop production. It seems as if the households with a dam apply more farming practices, but the effect of this cannot be measured since the scale at which the measures are applied is unknown. The question remains whether the difference can be acknowledged as an effect of the sand dams[20], or as a cause of higher production itself -challenging the effects of the sand dams.

4.3 Primary benefits

4.3.1 Water accessibility

Most of the households can accurately calculate their daily water use because it is collected in 20L containers and carried home either by members of the households (men, women and children), a donkey or a worker.

The accessibility of water depends on both the availability of water in the primary water source during the year and the distance to walk to reach this source. If the primary source gets depleted before the end of the dry season, it also depends on the same properties of secondary source.

The dams are sometimes built in riverbeds that were already in use as a water source and sometimes it forms a complete new source. On average, the dams make a location significantly hold water 2.5 months longer ($z=9.57$, $p=0$). The average dam location is now depleted 1.1 months per year, slightly less than the primary sources of households without dams (1.2 months/year)[21], even though households with dams started to use more water (see §0).

Twelve of the 137 households claim the source holds water for a shorter period now than five years ago. Five of them are households without a dam; four of these had a dam but it broke down. Of the remaining seven, one had a dam that broke too recently to put the household in the group of households without a dam. Why the remaining six households with dam say that the water source gets depleted earlier is unknown. It can possibly be explained by increased water usage. Household 5.4 bought a generator and now uses 1227 L/day more than before dam construction and household 8.2 uses 510 L/day more. The remaining four, however, only use ten's of litres of water more per day.

Next to the prolonged water storage of the dams, 29 households also mentioned that the water table has gone up since the dams were constructed. All of these households have a

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20 It appears that a majority of the households spend their saved time on agricultural activities (see §4.3.4).

21 The relationship between increased water use and depletion time will be discussed later on.

dam, and when comparing the calculated dam density with the water table, both for a density for 800 meters (the average distance to walk for households with a dam) and for a distance of 500 meters, the density is significantly higher for areas where the water table has gone up (z=2.27; p=2.3*10^{-2} and z=3.73; p=1.9*10^{-4}, respectively).

Interestingly, the locations where the water table rose had significantly less rainfall in 2005: z=2.83; p=2.3*10^{-3}. From January until June 2006 and in the years of 2004 and 2006 there was also less rainfall in the areas where the water table rose, though not significantly (see Table 4.3). The rather unexpected fact that the water table rose in areas with relatively less rainfall not only negates the argument that dissimilarity in precipitation causes differences in social and economical welfare; it also indicates that sand-dams can effectively decrease a household's vulnerability with respect to variation in precipitation, especially in periods of reduced precipitation.

Table 4.3 Average rainfall and dam density for households claiming the water table has gone up and for the remaining interview locations.

		Rainfall 2006	Rainfall Jan-June 2006	Rainfall 2005	Rainfall 2004	Dam density (r=500)	Dam density (r=800)
Water table up	Average	1061.52	378.93	549.90	668.63	2.33	1.41
	St dev.	102.857	62.51	28.02	36.75	1.18	0.92
Water table same	Average	1064.82	382.92	566.06	672.26	1.14	0.97
	St dev.	77.28	51.80	24.57	30.94	1.60	0.94
Significance	Significant	no	no	yes	no	yes	yes
	z	-0.16	-0.32	-2.83	-0.49	3.73	2.27
	p	0.87	0.75	4.7*10^{-3}	0.63	1.9*10^{-4}	2.3*10^{-2}

4.3.2 Water use

Water consumption increases if the accessibility of water increases (van Haveren, 2004). For all interviews (N=174, thus including the 37 interviews from De Bruijn and Rhebergen), the overall water use of 117 households with a dam increased by a tremendous 345%, whilst the 57 households without dams use 4.4% less than five years ago (z=4.44; p=9.1*10^{-6}). This means that on a yearly base households with dam changed their water use from 70746 to 243739 L, while the households without dams decreased their water use from 125303 L to 119732 L. When looking more precisely at the five different categories of water use, only the 2006 interviews are usable[22]. In these interviews, water use increased by 321% for the households with dam and decreased with 3.1% for households without a dam (see Table 4.4). The daily used water of households without dams only changed in the irrigation category and therefore these households will not be dealt with in the next section.

[22] Unfortunately, the 2005 interviews were occasionally not complete.

Table 4.4 Change in water use since dam construction or in the last five years for the 2006 interviews (N= 137)

		Water use before dam constr. (L/day)	Water use after dam constr. (L/day)	Difference (L/day)
Households with dam (N=98)	Domestic water use	71.4	94.8	23.4
	Irrigated crops	109	462.6	353.6
	Rain-fed crops	0.5	1.2	0.7
	Livestock	4.7	13.8	9.1
	Brick making	2.3	31.5	29.2
	Total	188.0	603.9	415.9
Household without dam (N=39)	Domestic water use	102.3	102.3	0
	Irrigated crops	307.2	294.1	-22.4
	Rain-fed crops	0.5	0.5	0
	Livestock	9.6	9.6	0
	Brick making	1.1	1.1	0
	Total	421.4	408.3	-13.1

4.3.3 Categories of water use

The extracted water from the river is used for many different purposes, which can roughly be divided into five categories: domestic use, irrigated crops, rain-fed crops, livestock and brick making.

Domestic water use increased by 133%, to 94.8 L/day. In comparison to the total increase in water use this is just a limited amount. People could easily use more for domestic purposes, but apparently do not need it. Households without dam use slightly more water for domestic purposes, but it is unknown why.

Three quarters of all water is used for irrigation. Water use in this category increased from 109 L/day to 463 L/day, and thus increased most in absolute terms. The households without dam on average used to use more water per day for irrigation, but now use less than the households with dam. This average is largely based on three households; without those three the average would only be 18.7 (five years ago) and 4.6 (present) L/day (see Figure 4.3: only two dots –three households- use water for irrigation).

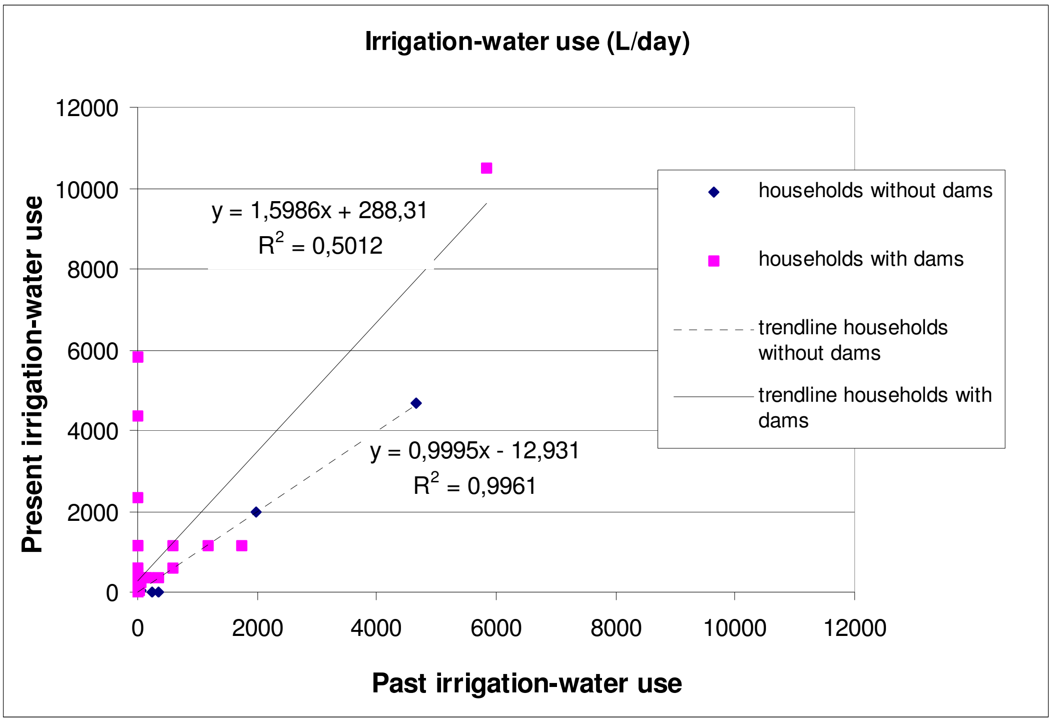

Figure 4.3 Present irrigation water use/past use (L/day). The limited amount of dots on higher uses indicate that the average is based on a few households. This is the case for households without dams both at the present and the past, and for the households with dams in the past.

Water use for rain-fed crops is irregular and only applied when crops are at risk of water stress. Most farmers therefore have no clue on how much water they use for this purpose and answered the question with 'zero'. The average is thus only 1.2 L/day, making up only 0.2% of the total water use. It can be assumed that the amount of water used to save dying crops is somewhat higher, but probably still a small share of the total water use.

Concerning livestock, only the water used to let animals drink at home is taken into account. Most households however water their livestock at the dam or at a river and have no idea how much the animals drink. Water for livestock therefore remains only a minor category in this calculation. The water use did however triple since dam construction, partly because the water accessibility improved, but also because expensive livestock (e.g. crossbreed cows) is kept at home (at zero grazing).

Brick making is only done a few months each year, at the beginning of the wet season (De Bruijn & Rhebergen, 2006). In these months, households use thousands of litres of water all at once[23]. For calculation-purposes this amount is averaged to L/day. Households without a dam used and still use only 1.1 L/day for brick making. Households with a dam already used twice as much, and increased their effort by 13.7 times. Brick making therefore has the biggest growth of all categories (See Figure 4.8). The increased amount of bricks available is used for personal house construction and to sell on a market to increase a household's income.

[23] Household 13.5 used by far the most: 104.000 litres (averaged to 285 L/day).

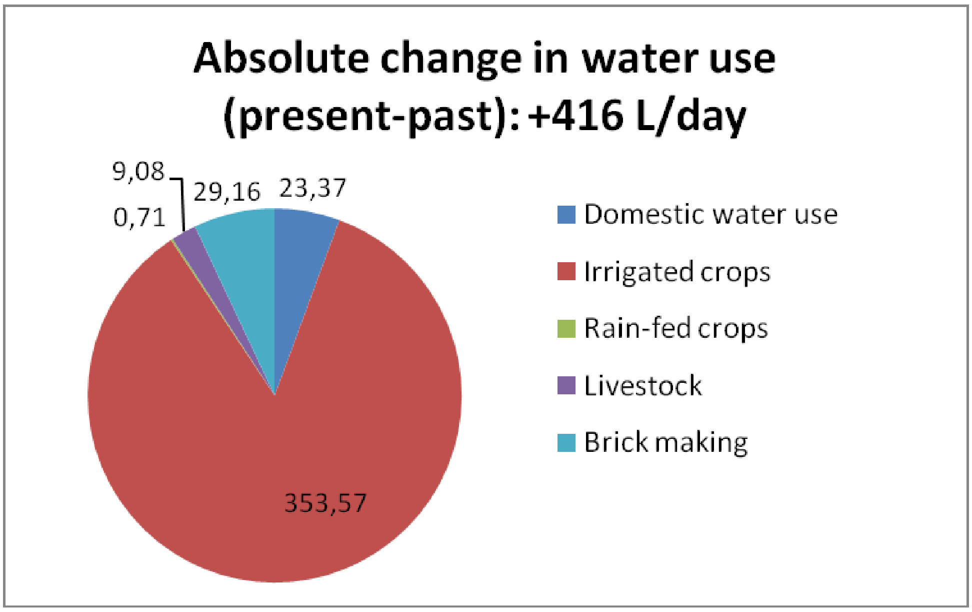

Figure 4.4 Change in water use for households with dams (N=98). Values (extra L/day) are included.

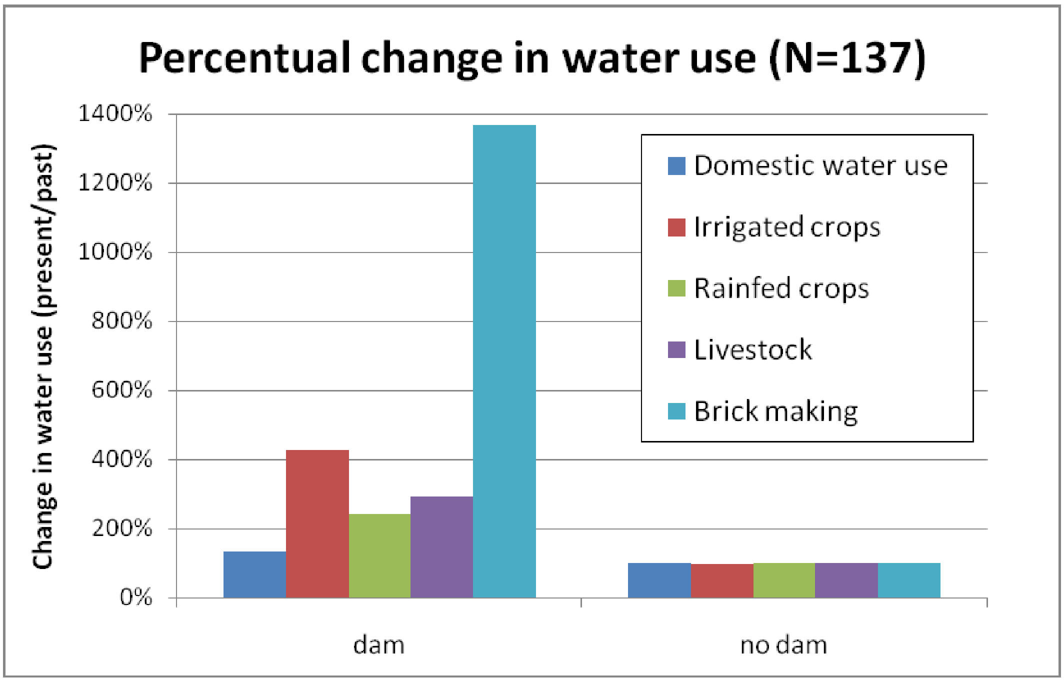

Figure 4.5 Change in water use (present/past), N=137.

The overall water use has increased tremendously for the households with a dam. The result can be seen in Figure 4.6: the number of households using less than 200 L/day decreased enormously (47 households in total); most households increased their water use. There are for example 5 new households using approximately 450 L/day. As the limited number of bars indicate, the households without dam mostly still use the same amount of water. The effect of this change in water use will be elaborated in § 4.4.

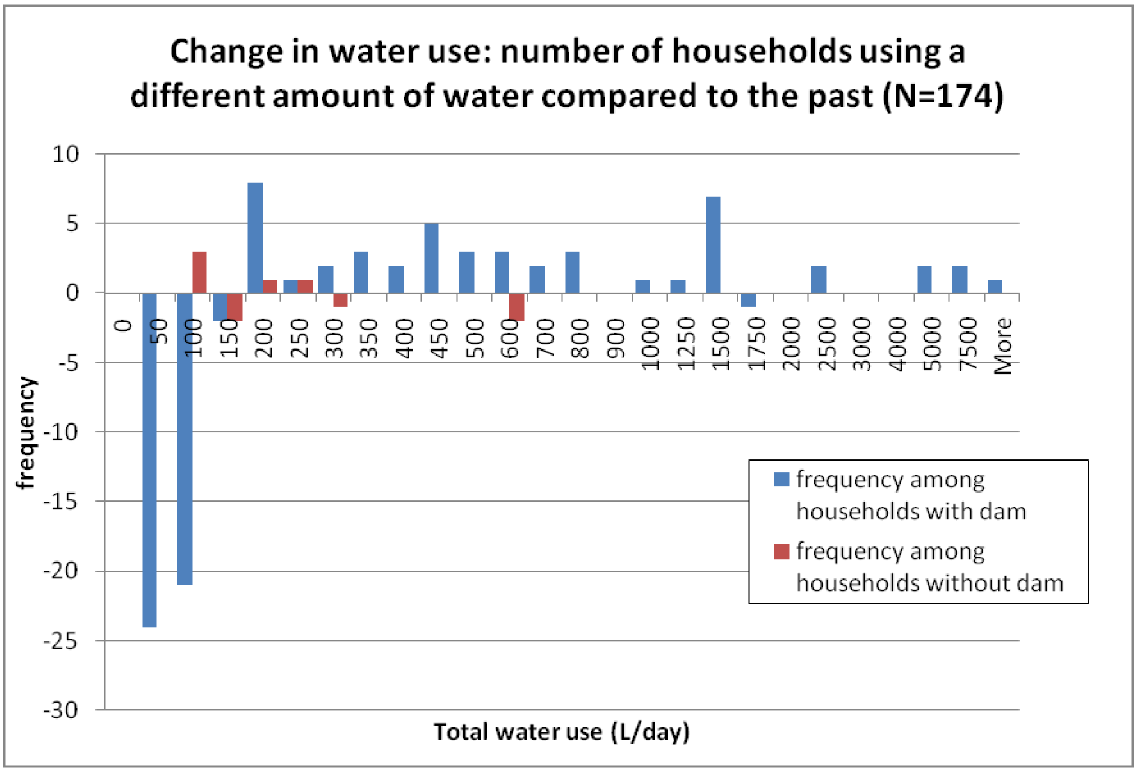

Figure 4.6 Number of households using a different amount of water per day, compared to before dam construction or five years ago. The dipping left side of the households with dam indicates that there are fewer households using 50, 100 or 150 litres per day; instead they started using 200-7500 L/day or even more.

4.3.4 Time availability

Distance to primary water source

Prior to dam construction the households with dam already lived closer to their primary water source, and this difference only became bigger since dam construction. The households without dams on average walked 3478m per fetch. Some of these households used to have a dam and walk a longer distance now, so the walking distance increased to 3501m. The distance of the households with a dam decreased from 2828m to 812m[24].

However, because of the higher water accessibility, people tend to fetch water more often. Whilst households without dams roughly fetch the same number of times each day (an increase from 1.67 to 1.69), households with a dam now fetch 2.43 times per day, exactly one time more than prior to dam construction. So the theoretical change in walking distance is 2016m, but because households with a dam fetch more often now, the actual distance decreased by 1705m. This means that the actual time saved on fetching water is also smaller than it theoretically is, but people have more water in return.

[24] The change in walking distance is significant: $z=5.95$; $p=2.61*10^{-9}$.

Time spend on fetching water

The households with a dam walk two times (back and forth) two kilometres less to fetch water now and of course this results in a lot of saved time. Next to the decreased distance to a water source, the scoop-holes people dig to reach water does not have to be as deep as before anymore and people do not have to stand in line anymore to fetch water. All in all, the households with dams save 95.7 minutes per fetch. When the number of times households fetch water is accounted for, the average household with dam saves 99.8 minutes/day.

Households without dams spend more time and energy now to fetch water. The average time increased from 82.1 to 84.6 minutes. Taking the number of times people fetch water into account, they spend an extra 6.4 minutes[25].

> **Distance inconsistency**
>
> Because of higher water accessibility, people tend to go and fetch water more often. For 21 households, this means that they actually walk more now than prior to dam construction. Household 5.1 for example used to walk 10 km to fetch water. Because of the large distance, the woman only fetched once a day. Now that the dam supplies the household of water 3 km away, she fetches water four times a day. The overall change = (3 km*4)-(10 km*1) = 2 km per day extra. However, she still saves more than three hours a day because fetching water became easier. however: and fetches more water of course.

Box 1 Distance inconsistency.

Many of the households with dam spend their saved time on agricultural activities. Some people spend their saved time on several different activities; amongst them are also income generating (other than agricultural) and domestic activities. Thirty-four percent says they don't save any time.

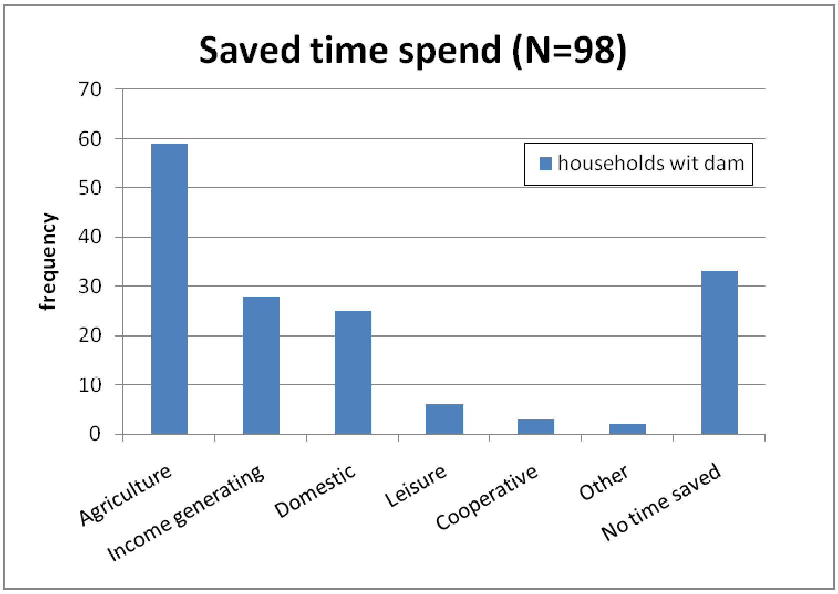

Figure 4.7 The way households spend their time saved on fetching water.

[25] This is in fact based on two households: household 15.1 walks further now, another fetches twice per day now.

4.4 Secondary benefits

4.4.1 Education

The percentage of educated people is higher for people with a dam (85% vs. 78%) because a higher percentage of people attended primary school. Households without dams however have a higher percentage of people who attended secondary school (26% vs. 24%).

For both groups one out of every eight children has had no education at all. The percentage is already lower than the adults' percentage, and will become even lower because many children did not yet reach the age to go to school. The children with dams are higher educated to some extent (See Table 4.5). Almost 19% is in secondary education or higher; for the children without dams this is only 12%. The difference is not significant (z=1.22) but one factor which was mentioned during interviews could be that children with dams have more time to go to school, or that there is more money available to send the children to school.

Both the differences between groups of adults and children are too small to explain differences in social and economic well being.

Table 4.5 Level of education of adults and children, as percentage of the total number of people.

		No education	Primary or higher	Secondary or higher	Tertiary or higher
Adults	Dam	15.2	84.8	23.8	3.8
	No dam	22.9	77.1	25.7	2.9
Children	Dam	12.3	87.7	18.7	4.6
	No dam	12.7	87.3	12.1	2.4

4.4.2 Agriculture

Irrigation

Households with a dam irrigate on average 0.244 acres of land (7.5% of total land), while the households without dam only do 0.055 (1.3% of total land). This difference is significant: z=3.33; $p=8.6*10^{-4}$. Before dam construction the households without a dam were on the same level and only irrigated 0.067 acres of land on average.

Interview 11.4 – irrigation contradiction

Household 11.4 already owned a ten feet deep well prior to dam construction and used 3000 L/day to irrigate 0.25 acres of land. Since dam construction, she only uses 2000 L/day. This could be interpreted as a step back, but according to her she needs less water for irrigation at the present. The water level in the well indicated that the water table has gone up and the farmland became more suitable for growing irrigated crops.

Box 2 Contradiction of irrigation-water use.

Overall, 17.4 of the 23.3 irrigated acres were newly irrigated in the past five years; 99.7% of that happened in areas with dams. Water availability and the distance of the primary water source can explain the difference. There is a strong correlation between present day irrigation-water use and the amount of irrigated land (R^2=0.497 and P=5.5*10^{-16}). As large amounts of water are needed for irrigation, most irrigated land is located close to the water source (see Figure 4.8). Because the distance to people's primary water source decreased significantly since dam construction, and because the water availability increased significantly, irrigation also increased.

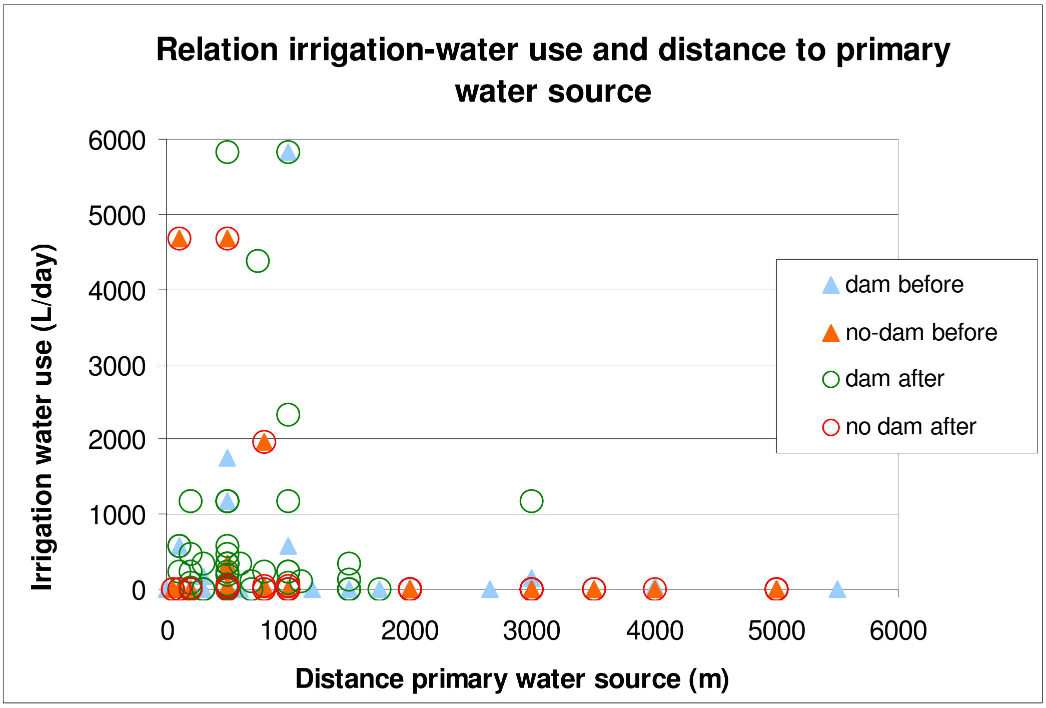

Figure 4.8 Water used for irrigation plotted against distance to people's primary water source. Clearly, water is only used for irrigation if the water source is located close to the crops.

Rain-fed crops

The value of the harvest of the households with dams increased with an average of 10.329 KSh/year, whilst the harvest of households without a dam decreased by an average of 39.489 KSh. This significant disparity (z=5.78; p=7.6*10^{-9}) shows what people already mentioned during the interviews: seventeen of the households without a dam actually claimed they had no harvest at all; fourteen others said their harvest decreased. None of the households with a dam had no harvest at all; only four claimed their harvest decreased. The explanation is two-fold: rain-fed crops of households with a dam are often thriving better because the water table has gone up and crops can be saved from starvation by little irrigation in elongated periods of drought.

Crop performance

Farmers with a dam on average grow 1.39 new crops they did not grow before dam construction. The new crops mostly include crops that need irrigation (e.g. tomatoes, kale, onions). New rain-fed crops are less common, but include e.g. pumpkins, maize, pigeon- and cowpeas and occasionally tobacco, miraa, cotton and flowers. Only five households without a dam grow new crops now, and four grow less. The average is exactly zero. The difference between the two groups is significant: $z=5.28$, $p= 1.31*10^{-7}$.

Overall, due to increased irrigation, new crops and higher crop yields the households with dams increased the profit per acre by 4.904 KSh/year. The households without a dam struggled with bad rains but could not irrigate: their income per acre decreased by 11.298 KSh/year[26].

Livestock

Livestock can be considered as a household's savings (H. Manzi, personal communication), but the value of the livestock does not always represent the wealth of a family. Generally more animals are for example kept in areas that are too dry for cultivation. These animals feed on weeds on their way to the watering place and are sold as a source of income. Animals –especially chicken- are also eaten when harvest fails and there are shortages of food.

Households without dams have more livestock. They have significantly more goats ($z=-2.06$; $p=0.040$) and donkeys ($z=-2.76$; $p=0.006$), and also have more cows and bulls. Because of this, the overall average value of their livestock is higher: 54342 KSh vs. 35935 KSh. The result is however not significant, because the differences between households within both groups are huge.

Types of livestock

As can be seen in Table 4.6, donkeys are mainly kept to carry water and other goods. The fact that households without dams keep more donkeys could be explained by the fact that their distance to the primary water source is larger than for the households with dam.

Goats are by far the most owned livestock. Goats are least expensive, easy to keep and easy to sell. Bulls are the most valuable group of livestock. A bull is expensive but many people have one because it is the only animal capable of pulling a plough. Donkeys and cows are used to pull carts as well, but the bull is much stronger.

Crossbreed cows produce far more milk than the local cows and are therefore much more valuable. Households owning a crossbreed do not take any risks and always feed the cow at home (zero grazing), whilst local cows are mostly tethered or taken along by a farmer to a watering place (free range grazing).

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[26] These numbers are based on the annual harvest. Extra costs, such as renting land, hiring day-labourers or equipment costs are not included.

Table 4.6 Value of Livestock. Different animals have different functions and values. The values given were the present values during fieldwork in June and July 2006 and are used in all calculations involving livestock.

Type	Main functions	Value (shilling)*	no. of #, households with dam	no. of #, households without dam
Cross breed cow	Milk, (meat)	28.000 – 50.000	0.09	0.13
Bull	Plough, cart, meat	15.000 – 20.000	0.84	1.31
Local cow	Milk, meat	10.000	0.74	0.92
Donkey	Carry harvest, water, charcoal,	10.000	0.49	0.92
Pig	Meat	15.000	0.04	0
Goat	Meat	800 - 1300	4.62	7.61
Chicken	Meat (when crops fail), eggs	100 - 150	Numerous	Numerous
Duck	Meat	100 - 150	Not applicable	Not applicable
Pigeon	Meat	Not for selling		

Fruit trees

Many households have fruit trees. Most fruit is for own consumption (children eat fruit for lunch); a few households consider selling fruit as part of their income. This might however change in the future, for many new trees were planted but most trees are still too young to produce any fruit.

Fruit trees need approximately five years of irrigation before they grow on themselves. With low water accessibility trees are hard to keep alive in the dry period. Therefore almost a third of the households without dams (11 of 37) have no trees at all, while five others complain that the trees are not producing[27]. Now that water is available for many people with dams, the trees can easily be kept alive by irrigation when necessary. Many new fruit trees were planted since dam construction: not only did 83% of the households with a dam plant new trees; seven of them started a tree nursery with over a hundred fruit trees. If these seven are kept out of the calculation, the households with dam on average planted 12.87 new trees: a significant difference ($z=3.30$; $p=9.8*10^{-4}$) with the households without a dam, who only planted 5.0 trees in the past five years.

There is also a significant difference in new tree species ($z=3.79$; $p=1.5*10^{-4}$): households with a dam planted 1.78 new trees on average, while the household without a dam only planted 0.69.

[27] Only four (4%) of the households with dams have no fruit trees, none of the households complained that the trees were not producing any fruits.

Tree nurseries

Another form of agriculture is a tree nursery, in which tree seedlings are grown on an irrigated plot until they are large enough to grow without being irrigated at set times (See Figure 2.3). After reaching this point, the seedlings sold or planted higher up in the valley. Full grown trees are used for firewood, charcoal burning, construction, windbreaks, shade, and for fruits, which can be sold or consumed to supplement diets. The leaves of the trees can also be used as fodder for livestock. The nurseries are often kept as a group (usually women), who divide the earnings after selling the trees (De Bruijn & Rhebergen, 2006). Besides economic benefits for the households involved, the planting of trees in the area is also beneficial to the environment, for example because of the necessary shade they provide for shrubs and plants (Manzi, personal communication).

4.4.3 Property

Only a limited number of indicators of the 2005 questionnaire were used because some questions proved to be inappropriate. Some of the assets are more practical (bicycle, generator, etc.), while others are more luxurious (television, radio, etc.).

It is clear that for both households with a dam and households without dams the means have increased the past five years. Especially the number of radio's, bicycles and cell phones is rising. Interestingly, households without dam had more means five years ago than the households with dam, and still have for most indicators (see Figure 4.9). However, the households with dams are increasing their assets more quickly than the households without dams. The cell phone, television, generator and 'other' (i.e. video (1x), solar panel (1x), water tank (1x) and wheel chair (1x)) are already more common among households with a dam. Of all indicators, the generator is most strongly linked to increased water availability. Only households with a dam have a generator; four out of five are bought after dam construction.

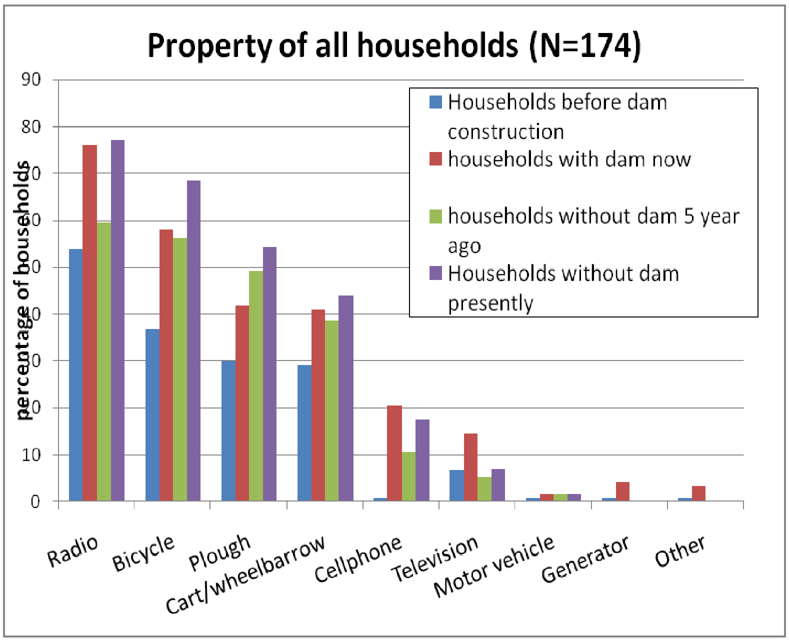

Figure 4.9 Property of all households.

4.4.4 Income

Several indicators were used to analyze the income of the households. The group can increase people's income because work can be divided more efficiently. Micro credits are sometimes used to invest in income increasing matter. Households are asked whether they think their income has decreased, stayed the same or increased, and finally an income was calculated from the harvest and income-related activities.

Group activity

Many different kinds of group activities exist. Simple group activities include working together on agricultural activities like vegetable growing, crop seeding and harvesting. More complex are having a tree nursery together or dividing tasks when it comes to goat keeping (one man can walk with 60 goats, in stead of six men with ten goats) or basket weaving (women weave together, one goes to a central market). One purely financial group activity is merry-go-round: every participating household donates a small amount of money every month, and receives a big amount every once in a while. With the big amount school fees can be paid or livestock can be bought. Of all households, 72% is involved in group-activities. This percentage is slightly higher for households with a dam (74% vs. 68%) and this is caused by higher percentage of households that started the group work after dam construction. Of all group work, 18.0% started after dam construction, whilst only 3.5% of the group activity of households without a dam is new. This could be explained by increased water availability (which is the case at least four times) or by good experiences of group work during the construction of the dam, but the question remains open.

Micro credits

Five different institutions in Kitui Town offer micro credits (Sanders et al, 2006). Interest rates are high: 16-26% (Sanders et al, 2006), and loans in agriculture are limited. The credit institutions do not like the cyclical nature of agriculture: they want a stable repayment of debts. Moreover, loans are mostly provided to businesses with stable profits for 1-3 years; start-up projects are hardly financed (Botzen & Sheremet, 2007). If the institution and the client come to an agreement, very limited training on financial mathematics and business management is provided prior to giving credit. The institutions are very profit oriented and do not seem to be interested in financing long-term communal projects (Botzen & Sheremet, 2007).

There is a slight difference in the number of households who ever heard of micro credits: 88% of the households with a dam know what micro credits are, 92% of the households without dams know this. This difference increases for the number of people who also use or used micro credits: of the 174 households 18% of the households with a dam answered the question positively, while 28% of the households without a dam use(d) them. During this study not much effort was put on finding out why these differences exist. However, from other studies it appeared that people are not told how to invest the money in their business and often pay personal expenses like school fees and health care using microcredit (Sanders et al, 2006; Botzen & Sheremet, 2007). The fact that more households without dams use micro credits can therefore be seen as a coping measure for bad harvests. Another explanation is given by Botzen & Sheremet (2007). They mention that small and medium agricultural businesses mostly have no access to micro credits, with the exception of livestock enterprises.

Income according to farmers

There are only three options for the question whether the income changed according to the farmer: increased, stayed the same of decreased.

Frequently heard reasons for increased incomes were a better harvest and better circumstances to perform brick making, grow vegetables or plant trees. Frequent answers for a decreased income are lack of rains, decreased capabilities to work (being sick or ageing) and the breaking down of a dam.

Many people actually interpreted the word ‘income’ as ‘purchasing power’. The question is therefore still a good indicator, but is wider than the amount of money earned only. Household 1.4 for example said her income has increased because she can grow crops now that she used to buy before dam construction. Household 5.5 said her income increased because vegetables became cheaper because everybody grows irrigated crops since dam construction, and household 12.4 said her income decreased because she has to pay school fees now.

The results reveal very positive effects of the sand dams (See Figure 4.10). Whilst 77.2% of the households without dams faced a decrease in income and only 8.8% increased their income, two-third of the households with dam increased their income and only 14.5% had a fall back in income.

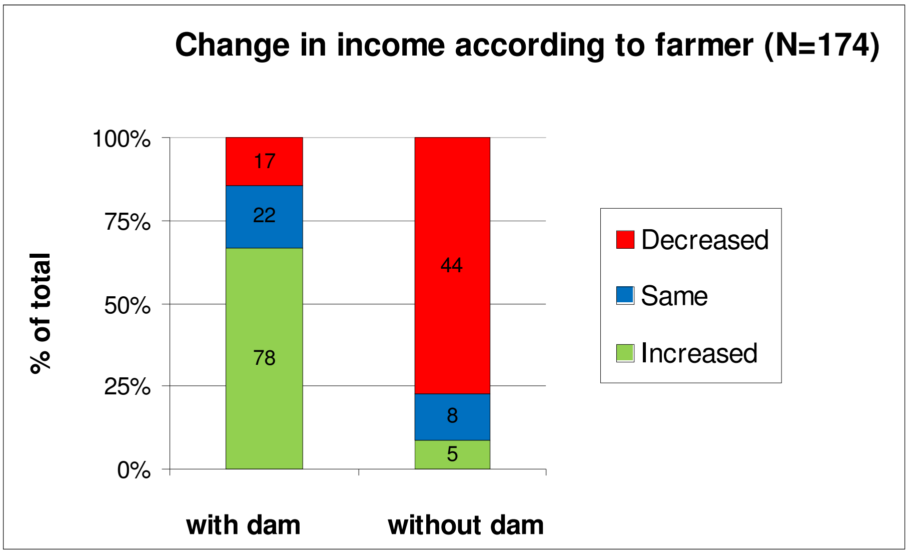

Figure 4.10 Change in income according to farmer. The percentages are derived from the number of households given in the bars.

Change in calculated income

The calculated change in income is based on four dam-related parameters: income rain-fed crops, irrigated crops, fruit and additional income, such as brick making[28]. It is important to note that it concerns the calculated income here, i.e. the amount of money earned if the entire harvest is sold[29].

The category ‘additional’ adds the most to the household’s income before dam construction (see Figure 4.11). Households without a dam earn 297 KSh/year more on additional income compared to five years ago, while the average household with a dam earns 10.653 KSh/year more on brick-making, rope making, basket weaving, cattle keeping, casual labour, etc. This difference is both based on time (basket weaving, bee keeping, etc.) and water availability (brick making, cattle keeping, etc.).

Because of bad rains in 2005, the harvest of households without a dam failed, decreasing their income by almost 40.000 KSh/year. Despite the drought, the households with dam managed to save and even increase their harvest, resulting in a 10.329 KSh/year income increase (see Table 4.7). Given this outcome, and the fact that rain was not the reason for it, one could even argue that the dams cause a difference of 50.000 KSh/year on rain-fed crops only.

The households with a dam earn more than 25 times as much on irrigated crops than the households without dams. This is a logical effect of both increased water use (+606 L/day) for irrigation and increased amount of irrigated land (+0.17 acres on average).

Selling fruit caused only a minimal change in income. Households without a dam earn nothing extra, the households with a dam 901 KSh/year (3.3% of the total change).

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[28] All categories of additional sources of income are: goat/sheep-keeping, cattle keeping, brick making, rope making, tree nursery, bee keeping, basket weaving, regular employment, casual labour and charcoal burning.

[29] There is some inconsistency in the data: the harvest of rain-fed and irrigated crops is accurately calculated for each household, but the harvest from trees is not. As a matter of fact, most trees are too young to produce fruits, and even if they do, most households do not sell their fruit. It can however be expected that more people start selling fruit when the young trees grow up, making the disparity between households with a dam and those without even bigger.

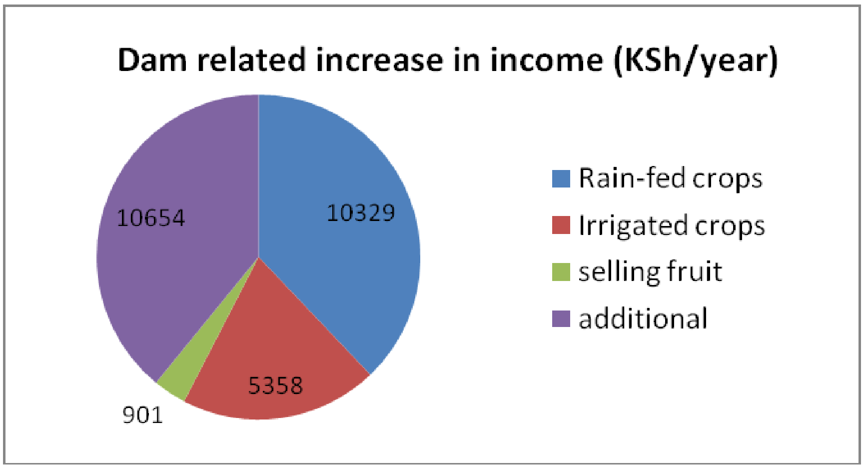

Figure 4.11 Change in income since dam construction.

Table 4.7 Change in income past five years or since dam construction.

	Households with dam		Households without dam	
	Average	St. dev.	Average	St. dev.
Rain-fed crops	10329	44355	-39489	46024
Irrigated crops	5358	15623	5.1	792*
Selling fruit	901	5230	0	0
Additional	10654	24418	297	1234
Total	27241.8	66511	-37851.3	45110

*The standard deviation is extremely high because the average is based on three households only

When the four categories are added up, it comes out that most people with a dam increased their income. Most of them only increased it marginal (i.e. between 0 and 20.000 KSh/year), but some of them in extreme numbers. Household 2.4 for example earns an extra 228.500, household 7.2 even 519.600[30]. Sixteen households increased their income with more than 50.000 KSh/year, seven with over 100.000. The average income increase is +27.242 KSh.

At the same time, the households without dams saw their harvest fail. Only three people managed to increase the income, of which one who has a tap since recently. Twelve households decreased their income with over 50.000 KSh/year, four with more than 100.000. The average decrease is -37.851 KSh.

The GDP per capita in Kenya gives an indication of the GDP/capita in Kitui Disctrict- was US$ 1240 in 2005 (http://hdrstats.undp.org/countries/country_fact_sheets/cty_fs_KEN.html); or 93.899 KSh (calculated with http://www.oanda.com).

[30] Household 2.4 saves 225 minutes per time she fetches water because the distance decreased by 7500m. She bought a generator and uses 906 liters of water more every day; her income increased this much because she started growing flowers for export. Household 7.2 saves 330 minutes per fetch; uses an extra 10125 L/day and increased the income by enhanced crop performance and irrigation of crops.

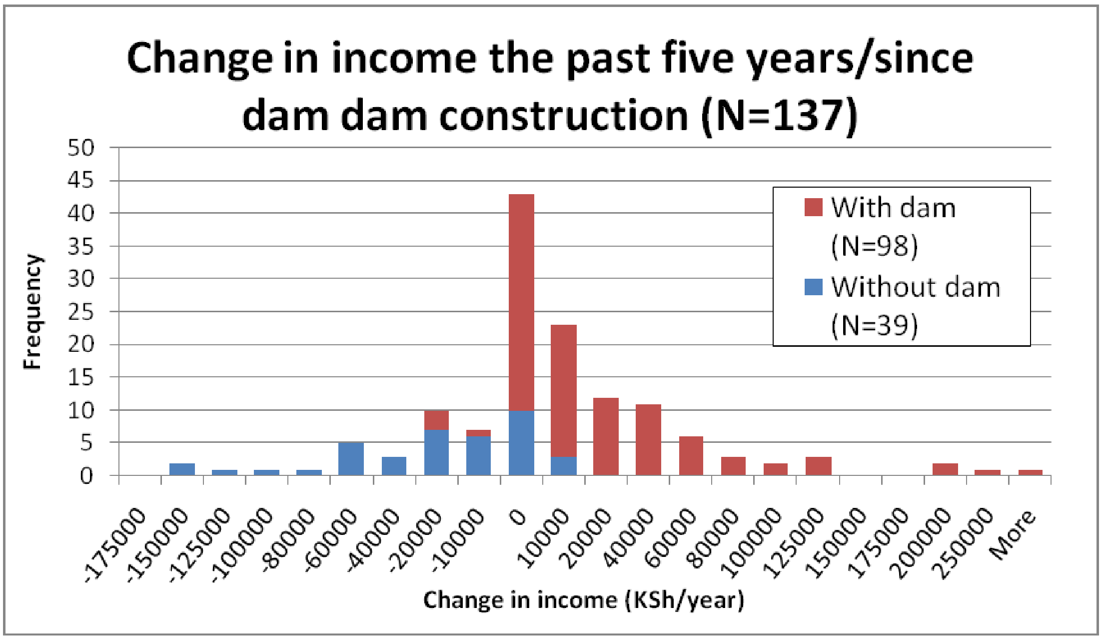

Figure 4.12 Change in income in the past five years or since dam construction.

4.4.5 Health

Common diseases

The information acquired on health of a household was inconsistent. Only after 26 interviews it was found that people not only respond *which* diseases they suffer from, but also *how much they suffer* from it, all in one answer. That means we know exactly from which diseases people suffer, but not always whether they suffer less because they have the disease less often, or because they can treat it better. Seven households with dam for example mentioned they suffer less from diseases because there is better food available since dam construction, but it cannot be assumed whether this helps preventing illness, or only helps healing[31].

However, results are still visible and can sometimes be dam related, both in a positive and a negative way (See Figure 4.13 and Figure 4.14).

The average number of diseases per households is equal for households with a dam and those without (1.80 and 1.79 respectively), and for both groups the most common diseases are malaria (90%), coughs and colds (29%) and amoebic dysentery (24%). However, a majority of the households without dam said their suffering had become worse, while the majority of households with a dam said it had become less. This accounts for all diseases, except for the hardly occurring disease of pneumonia[32].

[31] The same accounts for *positive* effects of cold weather (1x), *negative* effects of cold weather (8x), better hygiene (5x), God's grace (2x), more time available (1x), and a poor diet (1x).

[32] Only three people suffer from pneumonia; one does not have a dam and says the suffering has increased; two have a dam and say suffering has stayed the same or increased.

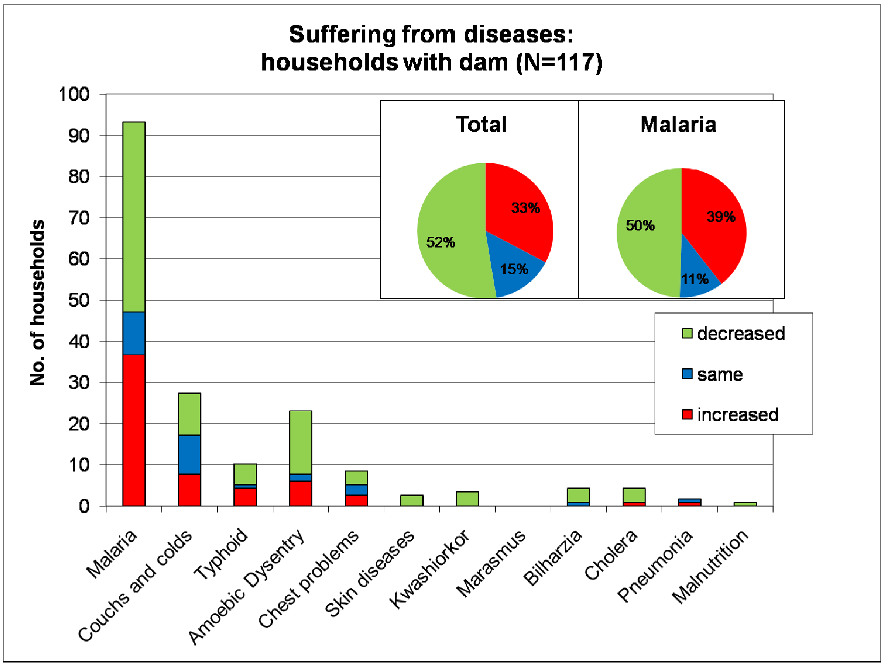

Figure 4.13 Suffering of diseases for all households with a dam (N=117). Categories refer to whether households have a disease more often and to how much they suffer from it. Malaria occurs most frequently: 93.2% of the households suffer from it; most people however suffer less from it than before dam construction (see pie chart inside).

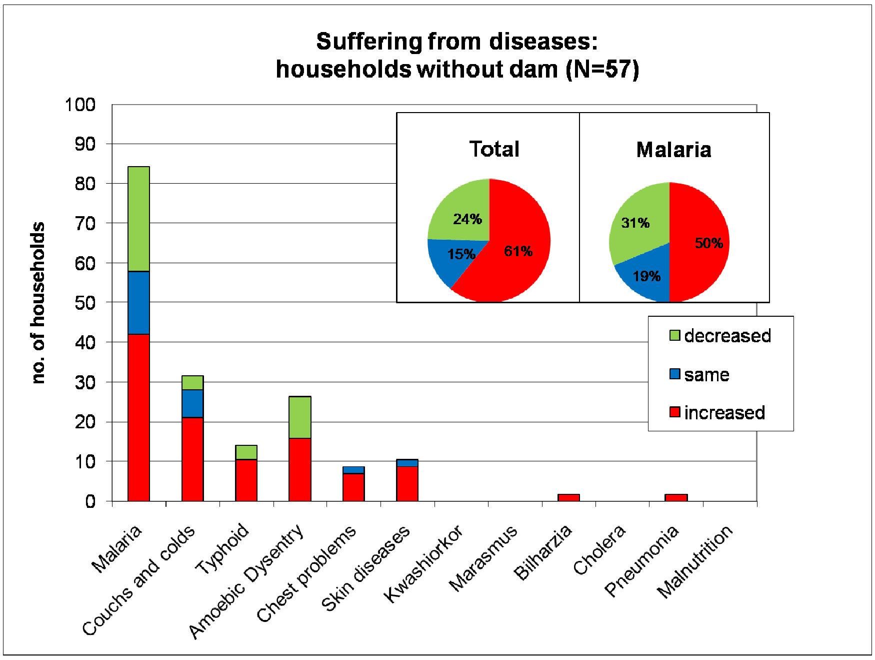

Figure 4.14 Suffering of diseases for all households without a dam (N=57). Malaria occurs most frequently: 82.4% suffers from it; most people suffer more now than five years ago.

Malaria

De Bruijn and Rhebergen (2006) found that 83% of the households with a dam mentioned an increase in malaria and concluded this could well be caused by dam construction. Now, after analyzing 174 interviews, the relationship between dams and malaria is better understood. It appears that five households with dam complain about increased standing water causing more malaria. Another eight said there are more mosquitoes since dam construction; six of the households without a dam also mentioned there are more mosquitoes. When added up and put in percentages the numbers are comparable: 11.1% of the households with dam say there are more mosquitoes, and 10.5% of the households without a dam complain about this. Overall, 82.4% of the households without dams suffer from malaria; on average they suffer slightly more than five years ago. More households with a dam suffer from malaria (93.2%), but their average suffering slightly decreased since dam construction.

Climate change

Thirty-two households said climate change caused a difference in suffering from diseases. Only six households, all of them using a dam, said it contributed in a positive way. The remaining 26 (13% of the households with a dam and 19% of the households without a dam) noted the negative effects of climate change. Although it was not specifically asked what people mean with 'climate change', three said it was warmer than before and nine said it was getting colder. Nineteen of the 32 households that mentioned climate change faced and increase in malaria, only four a decrease.

4.4.6 Coping mechanisms

The two analyzed groups have quite similar mechanisms to cope with drought (see Figure 4.14). Over 30% of all households (N=174) sell livestock and/or use off-farm income (either regular employment or casual labour). Over 5% of all households sells vegetables, burns charcoal or borrows food (including relief food).

There are only five categories in which the two groups differ. Selling livestock is applied by 46% of the households without dams, 14% more than the other group[33]. Regular employment has similar numbers, and households without dams also use remittance from children more often (9% vs. 0.8%). Households with dam sell bricks (9.4% vs. 1.7%) and trees (4.3% vs. 0%) more often. This is logically, because both practices have increased dramatically since dam construction (see §0 and §4.4.20).

None of the households mentioned anything about savings. This can probably be explained by the fact that many households use their livestock as a savings account.

33 The households without dams also have more livestock (see 4.4.20). Selling it is a common way to deal with droughts: it is seen as a households' capital (H. Manzi, personal communication). Supply and demand vary throughout the year, and so does the price.

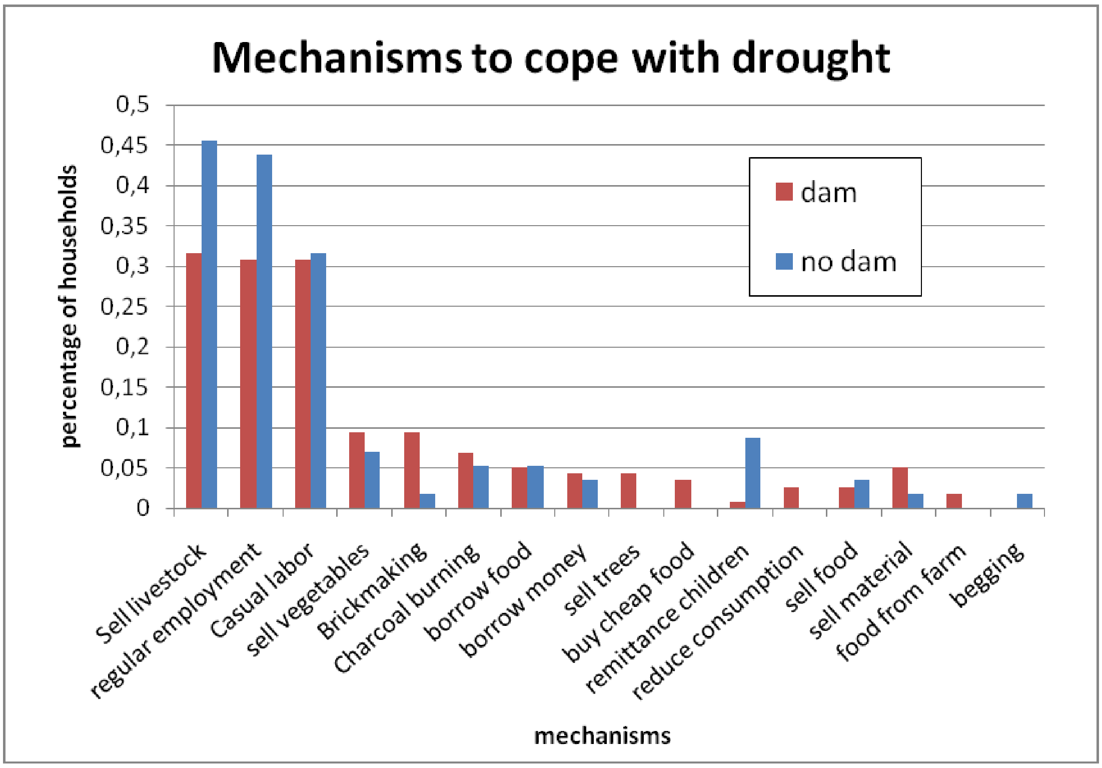

Figure 4.14 Mechanisms to cope with drought for households with dam and those without (N=174).

5. Discussion

5.1 Questionnaire considerations

Whilst conducting a survey, there is always the possibility of people giving false answers on questions. People can do this for many reasons, but in this case the main cause was that people hoped that we, from a Western country and comparatively rich, came to bring money or other support to families. However, not many households gave false information, and even if they did, there are several ways to deal with it.

Most lies were very obvious[34] and fortunately, our interpreter was very keen on this. She kept repeating questions in a different formulation until the right answer was given[35]. Another strategy was to start asking questions or confirmations to another member of a family when one seemed to be lying. Furthermore, in the questionnaire (see Appendix I 2006 Questionnaire) several questions were specifically added to crosscheck the answers given. Many other questions are usable for crosschecking. Irrigation, for example, is a direct subject of questions 2A, 2F, 4A, 4F and 7. If any ambiguity exists about the given answers, however, there are possibilities for clarification in questions 2G, 2H, 3C, 4B, 4C and 6D. This accounts for every important subject.

Still, some lies must have passed unnoticed. We believe, however, that the dataset is trustworthy and that the amount of interviews is sufficient to clear out false information.

5.2 Discussion of the results

The results of this research indicate that sand dams have a positive impact in the sense that they provide its users with more water, closer to their homes. The sand dams even work in a dry year like 2005 and can therefore be seen as effective measures to cope with climate variability. But even though the results prove more reliable than the results from previous studies, many points of discussion remain. In this paragraph these points of discussion will be dealt with in a chronological order.

5.2.1 Rainfall

The TRMM satellite rainfall data is considered to be very reliable (Bowman et al, 2003), but is not very precise. The data is provided in a raster with cell-size of 0.25 X 0.25 degrees[36]. This was downscaled to 0.1 X 0.1 degrees, but this act does not improve the quality of the data but just interpolates values to reappoint the cell sizes. The data was

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[34] One household for example complained that all members suffered terribly from most diseases in our questionnaire whilst at the same time all looked healthy; another households complained about the bad growing conditions and a low harvest while water was easy accessible for the households and the crops were looking very good.

[35] Once she told a man she would tell SASOL to remove the dam if he wouldn't stop lying. He thought removing an entire dam was impossible but she answered there were several ways to do so. The man then stopped lying immediately.

[36] This comes down to approximately 27 X 27 km for the study area.

also interpolated to smooth away errors, but certainly more detailed data would have provided a higher quality map –and more consistent results.

5.2.2 Farming methods

All farming methods except animal manure are more widely applied by households with a dam[37]. The effect of this cannot be measured since the scale at which the measures are applied is unknown. The question remains whether the difference can be acknowledged as an effect of the sand dams, or as a cause of a higher production itself -challenging the effects of the sand dams. There are two reasons to believe the former. First, the households with dams have a higher percentage of new farming methods, which can be explained by higher time availability and higher water accessibility –due to the construction of sand dams. Second, we are comparing changes between the present and roughly five years ago. So even if a household applied fantastic farming practices five years ago, its income still increased after dam construction.

5.2.3 Irrigation-water use

Though people can accurately estimate the amount of water they use on a daily base when it comes down to small quantities, the estimate of large quantities is biased. If 20L containers are used the number becomes hard to count; if a generator is used it is impossible to estimate the amount of water unless the capacity of a generator is known. The amount of water used for irrigation is therefore just indicative and can not be used for further calculations on the exact water use in Kitui District. The same accounts for water for brick making, but to a smaller degree since the abstracted water is only taken once and spread over the entire year for calculations.

The water-use bias counts for both households with dams and households without dams. There are for example two households without dams claiming to use over 4500 L per day for irrigation. If these two were not taken into account, the average daily water use of households without dams would decrease from 408.3 to only 173.8 L (-234.5 L). If we remove the bulk users from the households with dams, the amount would equally decrease from 603.9 L/day to 378.8 L/day (-225.1 L).

We chose not to treat the households using large quantities of water as outliers, because of several reasons. First of all, there are many of them. Second, it is hard to distinguish the outliers from ‘regular’ households: should we draw a line at 1000 L/day, 2000, or 5000 L/day? Third, because of the inequality concerns, one should not ignore the fact that there are households who increased their water use by tremendous amounts.

5.2.4 Livestock

It is interesting to see that households without dams have more livestock, but very hard to determine what this actually means. The relationship between a households’ purchase power and the value and type of livestock owned is difficult to understand. One would say that a higher purchase power would lead to more livestock, yet the opposite seems

[37] The animal manure could be explained by the fact that households without dam have more livestock.

true. According to Manzi (personal communication), households in dryer areas generally own more livestock because it is easier to keep livestock than to grow crops. Livestock eats weeds whilst underway to a watering place and so hardly needs feeding.

It would be interesting for future prospects to see what happens if increased water availability means a general decline in the overall amount of livestock.

5.3 Equal benefits and chances of future water scarcity

Despite the fact that most people know the community owns the dam, 29% of the households say that its benefits are not equally shared. This feeling of inequality is caused by a difference in ability to fetch water. This ability *inter alia* depends on whether people own a donkey, their health and the age of their children, but the major constraint on the amount of water one can fetch is the distance to a dam (provided water is available). The households owning land close to the dam can and will benefit more.

So far, there are no rules on how to divide water among households. Inequality in the study area so far only led to one conflict (see Box 3), but since water is a common property, and because people in general are not well able to divide a common property (tragedy of the commons), problems will rise in the future if all dam-holders start to use more water[38]. The Kwa Ndunda dam for example still contained far more water at the end of the dry season than was harvested (Borst en de Haas, 2006). But as soon as people start fetching an amount of water so high that a dam is depleted before the end of a dry season, water becomes scarce again[39]. And since water is fundamental for all activities in the area, clear and transparent laws or rules on how to divide the water among families are urgently needed. The 2002 Water Act supports greater community participation in water management and might prove to be helpful for the water groups and dam communities (De Bruijn & Rhebergen, 2006). As mentioned in §4.3.1 there are some locations where the source is depleted earlier now than before dam construction, which could be explained by strongly increased usage.

> **Sharing water**
>
> On one occasion the supervisor of the dam construction and owner of the land on which it was build refused to allow other people to fetch water, even though they helped to construct it. Mostly, however, people know that the dam is property of the community and that they all have the right to collect water individually and the responsibility to protect the dam as a community.

Box 3 Restricted dam usage.

5.4 Impact on the environment and erosion

The drainage of soils in Kitui District is generally low, resulting in high overland run-off and erosion. According to Manzi (personal communication) cutting of trees can easily lead to erosion when plants die because their shade is taken away when trees are cut. The sand dams can prevent some of this erosion. Moreover, if the water table increases be-

38 Water is not only used for irrigation, drinking, washing, etc.; household 13.3 actually sells the community water, converting common property in a private direct income booster.

39 Household 11.1 already pointed out that there will be more arguments about water sharing in the future. The woman said other people use more and more water, leaving less for her.

cause of dam construction, more plants and trees can grow, both increasing the soils drainage capacity and slowing surface run-off. Household 14.1 explicitly mentioned that the construction of the dam prevented her land from erosion.

Erosion is also the main reason for dams to break down. When the banks of the river in which the dam is build are eroded, water starts to flow around the dam and it becomes useless. Many people however do not see this problem and do not protect the banks or even grow crops on the actual riverbed; thereby even escalating erosion.

5.5 Downstream effects

One of the most disputable properties of sand dams is the downstream effect. If the proportion of precipitation stored by sand dams is too high, downstream areas will be negatively impacted. Borst & de Haas (2006) estimated the total amount of stored local precipitation to be 2.3% in the April-October season and 2.5% in the November-March season. Aerts et al (2006) used a spatial water balance model to calculate water availability and runoff on the basis of temperature and precipitation data and a number of land surface characteristics. Under current climate conditions and with 500 dams, he found slightly different numbers: 1.8% and 3.8%. He shows, however, that under the predicted changing climate conditions of both increased precipitation and increased evaporation, these percentages could rise to 3% and 20% by 2100. If another 1000 dams would be build, the percentages even rise to 11% and 60%. Obviously the latter percentage will have severe effects on the downstream area.

So at the present the downstream effect of sand dams is negligible, but it is important to keep climate change in mind while developing sand dams on a large scale.

6. Conclusion & recommendations

In the semi-arid Kitui District, two rainy seasons provide approximately 90% of the annual rainfall. The dry seasons are characterized by water deficits. Sand dams are build to increase water availability and accessibility in the dry seasons by storing it under a layer of sand. The local NGO (SASOL) built over 500 sand dams in Kitui District. The Institute for Environmental Studies (IVM) and ACACIA Institute study the hydrological and socio-economic effects of the sand dams within the scope of the ADAPTS programme.

6.1 Hydrological effects

Hydrological studies by the ACACIA Institute (Borst & de Haas, 2005; Hoogmoed, 2006) already proved that sand dams have a positive effect on water availability. They increase the volume of groundwater available and prolong the period in which groundwater is available for abstraction.

The coarse sand enables the fast response of the groundwater table on precipitation and protects groundwater from excessive evaporation because of low capillary forces (Hoogmoed, 2006). After the first heavy rainfall event, the riverbed aquifer is already recharged completely and the river starts to flow, leading to the conclusion that refilling of larger aquifers does not significantly influence downstream areas. According to Aerts et al (2006), only 1.8-3.8% of the annual local rainfall is stored at a sand dam.

Our research adds some information to the study of hydrological effects of sand dams. First, 29 households with dams (30%) mentioned that the water table rose since dam construction, even though –very surprisingly- a GIS analysis proved that they had less rainfall than the other households for 2004, 2005 and 2006. They did have a significantly higher dam density. Second, tantamount to the conclusion of Hoogmoed (2006), the dams prolonged the water availability of primary water sources significantly with 2.5 months.

6.2 Socio economic effects

6.2.1 Water accessibility

Overall, more water is available and it is much closer to people's homes. For the households with dams, the distance to the primary water source decreased by 1700 meters on average. The households spend 99.8 minutes per day less on fetching water whilst increasing their average use from 194 to 668 L/day (for N=174).

The situation of households without dams got worse. They walk an extra 90 meters each day and spend 6.4 minutes more on fetching water, while their water use decreased from 343 to 328 L/day.

6.2.2 Economic effects

Obviously, the increased water use and the saved time bring about positive social and economical changes. Many of these are agricultural. The households without dams all saw their harvest of rain-fed crops decrease; many had no harvest at all in the dry year of 2005. At the same time, the households with dam increased their harvest and diversified their income: they increased the number of different crops they grow and many also started irrigating. The percentage of irrigating households with dam increased from 12% to 44%; the percentage of the households without dams stagnated at 18%. Furthermore, households with dam planted more different species and a higher number of fruit trees. Again this can be explained by the increased water accessibility. People hardly earn money on the fruit trees though, because most trees are still too young.

Many households also started non-agricultural (group) activities to boost their income. Brick making is most popular: it is responsible for the highest increase in water use and the biggest supplement to many incomes of households with dams.

Overall, whilst the income of households without dams decreased significantly with -38.056 KSh/year, the households with dam managed to maintain or even increase their income with +27.241 KSh/year. This means a sand dam can make a difference of 65.297 KSh in a dry year like 2005[40], clearly demonstrating that the investment of US$ 35 per capita for such a long-lasting construction is extremely low.

6.2.3 Health

The households with dams and the households without dams have comparable percentages of households suffering on diseases. However, if we look at how much the households suffer, we see a clear difference. The majority of the households with dam cite their suffering decreased since dam construction, while a majority of the households without dam say the exact opposite. Unfortunately, because there was a bias in the questionnaire, it is unclear whether this means people suffer less often, or that they become less sick because they have access to better nutrition or medication.

6.3 Recommendations

This research proves that sand dams absolutely work in the sense that they provide users with better social and economic standards. They prove an excellent technique of coping with drought and climate variability, and are therefore recommended to be constructed in areas that face drought periodically or that will be under water stress due to future climate change.

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[40] The GDP per capita in Kenya –which gives an indication of the GDP/capita in Kitui Disctrict- was US$ 1.240 in 2005 (http://hdrstats.undp.org/countries/country_fact_sheets/cty_fs_KEN.html); or 93.899 KSh (http://www.oanda.com).

However, if dams are build, regulations need to be implemented on how to share the water among the households that participated in the construction. Benefits should be shared in an equal manner over families and time for the dams to have optimal effects on the long run. Second, future users should be well educated about the operation of a sand dam and how to use and maintain it, with a special focus on protection of the riverbanks.

References

Aerts, J., Lasage, R., Beets, W., De Moel, H., Mutiso, G., Mutiso, S. & De Vries, A. (2006). Robustness of sand storage dams under climate change. *Vadose Zone Journal, 6*, 572-580.

Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., Osman-Elasha, B., Tabo, R. & Yanda, P. (2007). Africa. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In Parry, M.L., Canziani, O.F., Palutikof, J.P., Linden, P.J. van der & Hanson, C.E. (Eds.). *Climate Change 2007: Impacts, Adaptation and Vulnerability.*Cambridge University Press, Cambridge UK, pp. 433-467.

Borst, L. & Haas, S.A. de (2006). Hydrology of Sand Storage Dams: a case study in the Kiindu catchment, Kitui District, Kenya.

Bowman, K.P., Phillips, A.B. & North, G. R. (2003). Comparison of TRMM rainfall retrievals with rain gauge data from the TAO/TRITON buoy array. *Geophysical Research letters, 40*(14), 91-94.

Botzen, W. & Sheremet, O. (2007). *Micro-credit and Climate Change Adaptation in Rural Kenya*. Institute for Environmental Studies, VU University, Amsterdam. 24 p.

Bruijn, E. de & Rhebergen, W. (2006). Socio-economic impacts of the construction of sand dams on communities in Kitui District, Kenya. VU University Amsterdam. 45 p.

COM (2007). 354. *Adapting to climate change in Europe – options for EU action.* Green Paper from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions.

District Commissioner Kitui (2002). *Kitui District Development Plan 2002 – 2008*. Kenya, 72 p.

ESRI (2001). ArcGIS Geostatistical Analyst: statistical tools for data exploration, modeling, and advanced surface generation. ESRI white paper, ESRI, New York.18 p.

FEWS NET. Famine early warning system network. http://www.fews.net/centers/?f=ke

Haveren, B.P. van (2004). Dependable water supplies from valley alluvium in arid regions. *Environmental Monitoring and assessment, 99*, 259-266.

Hellwig, D.H.R. (1973). Evaporation of water from sand, 3: the loss of water into the atmosphere from a sandy river bed under arid climate conditions. *Journal of Hydrology, 18*, 93-108

Hoogmoed, M. (2007). Analyses of impacts of a sand storage dam on groundwater flow and storage. VU University, Amsterdam. 165 p.

Huntingford, C., Lambert, F.H., Gash, J.H.C., Taylor, C.M. & Challinor, A.J. (2005). Aspects of climate change prediction relevant to crop productivity. *The Royal Society. 360*(1463), 1999-2009.

Kashyap, A. (2004). Water governance: learning by developing adaptive capacity to incorporate climate variability and change. *Water Science and Technology. 29*(7), 141-146.

Kasperson, J.X, Kasperson, R.E. &Turner II, B.L. (1995). *Regions at Risk: comparison of threatened environments.* The United Nations University. ISBN 92-808-0848-6 http://www.unu.edu/unupress/unupbooks/uu14re/uu14re00.htm#Contents .

Lasage, R., Aerts, J., Mutiso, G.C.M. & De Vries, A. (2007). *Potential for community based adaptation to droughts: Sand Dams in Kitui, Kenya.* ScienceDirect, Elsevier. http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6X1W-4NS2GK1-4&_user=4330089&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000024498&_version=1&_urlVersion=0&_userid=4330089&md5=9d9138072fbfdf335d9c36cf0fc03e7b#bib17

Louis Berger International Inc. (1983). *Arid and Semi-Arid Lands Development Project, Kitui District Water Resources Study,* Executive Summary, Government of Republic of Kenya.

Ministry of Finance and Planning (2001). *Poverty reduction strategy paper covering 2001-2004*, Kitui District.

Rempel, H., Nyaga, C.W., Manzi, H.K. & Graff, P. (2005). *Water in the sand: an evaluation of SASOL's Kitui Sand Dams Projec*t. SASOL Foundation, Mennonite Central Committee & Canadian Food Grains Bank. 55p.

Sanders, B., Kowalec, R. & Ndetei, D. (2006). *Research of Microfinance*. Ex-change website. http://www.ex-changer.nl/phpBB2/files/eind_rapport_hehe_klaar_157.doc.

Thomas, D.B, SASOL & Maji na Ufansi. (1999). Where there is no water; a story of community water development and sand dams in Kitui District, Kenya. ISBN: 9966-9642-0-7

United Nations (2000). *United Nations Millennium Declaration*. United Nations Resolution, A/RES/55/2, p.9

United Nations (2002). *Report on world summit on sustainable development.* Johannesburg, September 4, 2002.

UNEP (2006). *Harvesting Rainfall a Key Climate Adaptation Opportunity for Africa.* http://www.unep.org/Documents.Multilingual/Default.asp?ArticleID=5420&DocumentID=485&l=en.

Zaal, F. & Oostendorp, R.H. (2002). Explaining a miracle, intensification and the transition towards sustainable small-scale agriculture in dryland Machakos and Kitui Districts, Kenya. World Development, 30(7), 1.

Appendix I 2006 Questionnaire

Household No.:

GPS Location: S

E

Age of the Dam:

Question 1 Household

1A Education of the family	No of Adults		No of Children	
	Male	Female	Male	Female
No education				
Primary				
Secondary				

1B Percentage working as a farmer:..

Question 2 Agriculture

2A How much land do you... (Acres)	Irrigated	Rain-fed	Did you […] more, less or the same land before the dams existed?	How much extra land do you irrigate after construction of the dams?
Own				
Rent				

2B What crops do you grow on you farm?

How much new crops have you harvested	How much […] does your land produce?		What is the reason for the change in harvest? *
	Before	After	
Maize			
Beans			
Cow peas			
Pigeon peas			
Pumpkins			
Cassava			
Millet			
Sorghum			
Sweet potatoes			
Green grams			
Other…			

*Water-related, improved farming practice, increased land, enough time, inadequate rain, …

2C Have you planted any trees since dam construction?

What type of trees?	How many trees did you already have?	How many after dam	How much did you earn (total/time)
Mangoes			
Papaya			
Bananas			
Oranges			
Lemons			
Avocado			
Casta depo			
White Supporta			
Guava			
2D No of new tree species			
2E No of new trees			

2F Do you grow any irrigated crops?			Is the harvest more, less or the same as before?	Reason for change in harvest*
	Before	After		
Tomatoes				
Onion				
Kale				
Spinach				
Cabbage				
Other…				

*Water-related, improved farming practice, increased land, enough time, inadequate rain,..

2G What are your sources of water (water pump/shallow well/scoop hole)?

2H Which new farming methods do you apply?

Do you apply any of these or other new farming methods on your plots?		Did you also apply these methods before the dams existed?
Terraces		
Grass lines		
Fertilizers		
Contour Bunds		
Mulching		
Animal Manure		
Compost Manure		
…		

Questions 3: Assets

3A Which livestock do you own?

How many […] does your household own?		Is this more, less or the same as before the dams?	How many […] did you eat last season?	sell last season?
Goats/Shee				
Bulls				
Cows (lo-				
-				
Donkeys				
Pigs				

3B System of grazing:

3C Assets, implements and income

How many […] does your household own?		How many […] did your household own before the dams existed?
Bicycles		
Carts/wheelbarrows		
Ploughs		
Motor vehicles		
Transistor radio		
Television set		
Cell phone		
Generator		
Other…		

3D Sources of Energy

What are your sources of energy?	*Main*	Secondary	From where? Own land	Bought
Firewood				
Charcoal				
Kerosene				

3E Other sources of income

Does your household have other sources of income? (KSh/yr)		Did […] also take place before the dams existed?	*Change in income (KSh/yr)*	What is the reason for the change? *
Goat/sheep keeping				
Cattle keeping				
Brick making				
Tree nursery				
Bee keeping				
Basket weaving				
Regular employment				
Casual labor				
Charcoal burning				
Other…				

*Water related (+/-), improved farming practice, increased land, enough time, inadequate rain, better community organization, more leisure…

3E Have you heard of micro credits? (Y/N) Involved: (Y/N)

3F Are you involved in cooperative activity? (Y/N)

Is this new since dam construction? (Y/N)

3G Has the total income of your household […] compared to before the dams existed? (Increased/Decreased/Stayed the same)

3H What are the changes you made to your house after construction of the dam? What enabled you to make these changes?

Question 4 Water

4A Use of water

How much water do you use? (L/d)	Domestic		Irrigation		Rain-fed crops		Livestock		Brick making	
	Before	After	Before	After	Before	After	Before	After	Before	After
River										
Roof										
Dam										
Other										

4B distance to water

	What is the distance to your source of water in the dry season? (m)		When is this source depleted
	Before dam construction	After dam construction	Before After
Primary			
Secondary			

4C Time spend on water

How many minutes does your household spend for fetching water (min/day)			How many times per day do you fetch water?		Who fetches the water?	
			Before	After	Before	After
Total						

4D What does your household do with the time saved from fetching water?

Agriculture Domestic Income generating Cooperative Leisure

4F crisis management

	What were the methods you used to make money in the absence of rain?	What has changed since the construction of the dams?
Selling livestock		
Sell trees/fruits		
Sell household assets		
Casual labor		
Irrigate land		
Brick making		
Micro-credit		
Regular employment		
Other…		

Question 5 Health

What kind of common diseases does your household suffer from?			Are they more or less or The same as before? (Y/N)	Reasons for change?
	Before	After		
Malaria				
Cholera				
Typhoid				
Amoebic dysentery				
Coughs & Colds				
Chest problems				
Marasmus				
Other				

5B where do you let your animals drink?

5C Is it the same place as you get your own/domestic drinking water from? (y/n)

5D Is this source above/below your own drinking source?

Question 6 Dam ownership

6A Who does this dam belong to?

Community members	
Government	
Individuals	
Political party	
SASOL	
…	

6B Did your household participate in construction of the dam? (Y/N)

6C Is there any care/maintenance taken on the dam? What kind of?

6D Do you think every member of the sand dam community benefits equally from the sand dam?

Question 7 Cross check

What benefits have you realized from the sand dams?			
	First	Second	Third
Increased water availability			
Increased cash crop production			
Increased domestic food availability			
Increased livestock			
Increased sand for construction			
Increased income/ std of living			
Increased land value			
Better health			
Higher brick production			
Shorter distance			
….			

Appendix II Precipitation

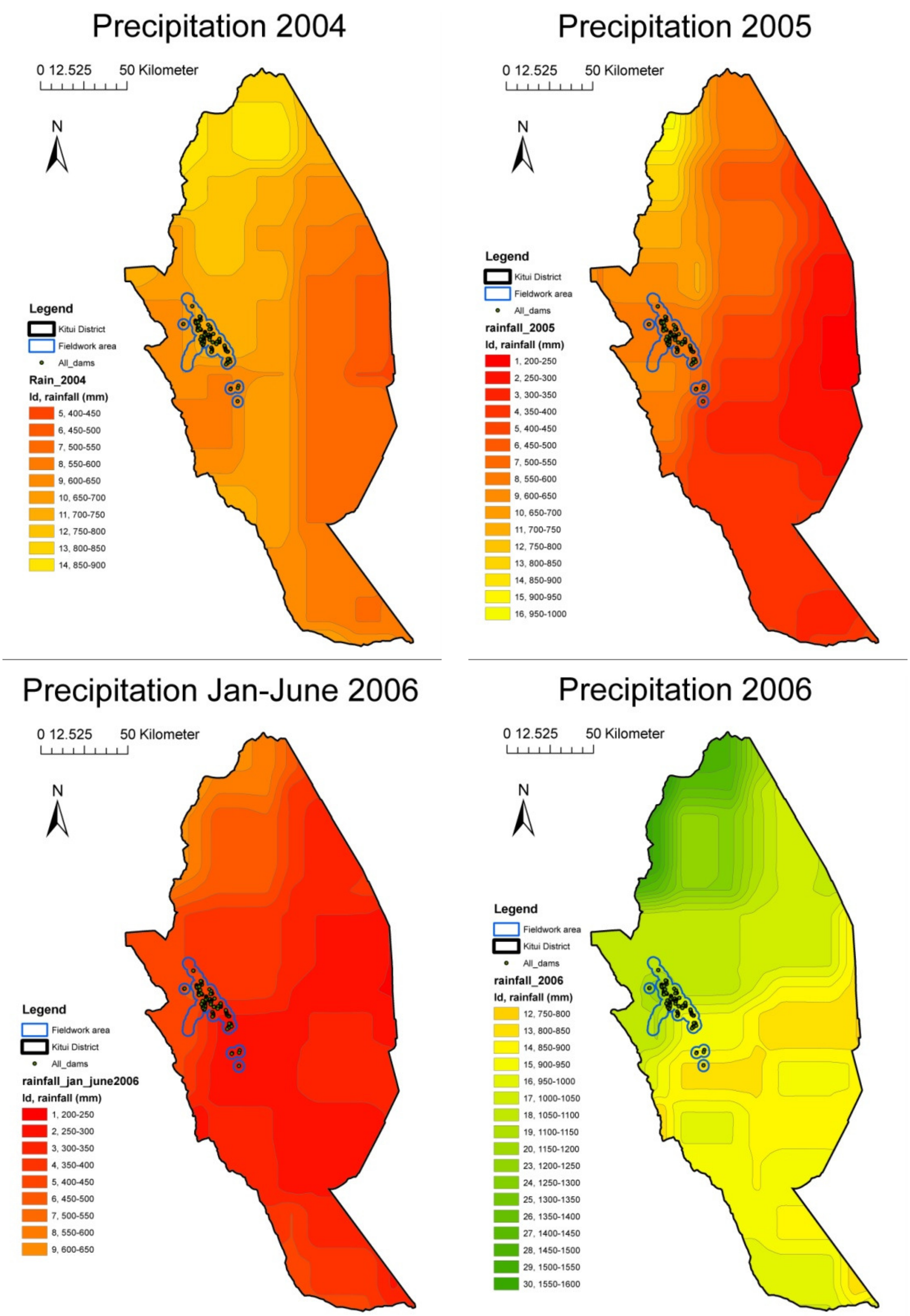

Figure II.1 Precipitation for 2004, 2005, Jan-June 2006 and 2006.

Appendix III Basic data

			HH with dam			HH without dam			Difference dam/ no dam			Correlation with changed time spend on fetching water		Correlation with change in water use (pres-past)	
			N	average	st dev.	N	average	st. dev.	N	z	p	N	R^2	N	R^2
Comparison	Land & man-power	Amount of land (acre)	98	3.25	3.34	39	4.27	3.73	174	-0.69	0.49				
		No. of farmers	98	1.856	1.527	39	1.930	1.501	137	-0.26	0.79				
		Farmers /acre	98	0.886	0.83	39	0.660	0.65	137	1.69	0.09				
	Children	Number of children	93	4.43	2.41	39	4.46	2.06	132	-0.07	0.94				
	Education	% adults >primary education	93	24.21	34.81	39	23.68	30.44	132	0.09	0.93				
Primary benefits	Time (min/day)	Time spend on fetching water before	96	109.86	108.93	35	83.78	71.78	133	2.29	0.02				
		Time spend on fetching water present	96	23.25	22.43	35	86.76	70.91	133	-5.23	$1.7E^{-7}$				
		Change in no of daily fetches	96	1.00	1.66	35	0.03	0.16	133	5.66	$1.5E^{-8}$	96	0.012	96	0.002
		Total time saved	96	99.83[41]	116.39	35	-6.76	34.96	133	8.08	$6.6E^{-16}$			133	0.012
	Water use (L/day)	Past water use	117	193.82	595.27	57	343.30	891.15	174	-1.15	0.25				
		Present water use	117	667.78	1451.3	57	328.03	891.11	174	1.90	$5.7E^{-2}$				
		Change in water use (pres/past)	117	7.88	19.15	57	0.98	0.21	174	3.90	$9.6E^{-5}$	96	0.06		
		Change in water use (pres-past)	117	473.96	1188.1	57	-15.26	69.59	174	4.44	$9.1E^{-6}$	96	0.012		
	Distance (m)[41]	Before dam constr.	98	2822.45	3497.9	39	3478.21	4691.3	137	-0.79	0.43				
		After dam constr.	98	806.63	640.82	39	3501.28	4682.5	137	-3.58	$3.4E^{-4}$				
		Decrease	98	2015.82	3364.0	39	-23.08	261.03	137	5.97	$2.3E^{-9}$	96	0.273	96	$5.7E^{-4}$
	Depletion time	Decrease in depletion time (months per year)	98	2.50	2.45	39	-0.15	0.79	137	9.57	0.29			98	0.005

[41] Adapted to the (changed) number of times households fetch water.

			HH with dam			HH without dam			Difference dam/ no dam			Correlation with changed time spend on fetching water		Correlation with change in water use (pres-past)	
			N	average	st dev.	N	average	st. dev.	N	z	p	N	R^2	N	R^2
Secondary benefits	Education	Perc. children > primary education	93	17.90	27.7	39	12.07	18.5	132	1.22	0.22				
	Income (KSh/year)	Calculated income	98	27241.8	66511.4	39	-38056.4	45041.8	137	6.63	$3.5E^{-11}$	96	0.073	98	0.43
		Change in profit per acre	98	5003.69	16766.4	39	-10765.7	11574.4	137	19.86	0	96	0.03	98	0.16
		rain-fed crops	98	10329.1	44355.1	39	-39489.7	46024.0	137	5.78	$7.7E^{-9}$	96	0.052	98	0.041
		irrigated crops	98	5358.16	15623.2	39	5.13	811.1	137	3.38	$7.2E^{-4}$	96	0.005	98	0.071[42]
		selling fruit	98	901.0	5229.6	39	0	0	[43]			96	0.021	98	0.137
		Additional	98	10653.6	24418.0	39	297.4	1234.5	137	4.19	$2.9E^{-5}$	96	0.055	98	0.647
	Rain-fed crops	New crops	98	0.4591	0.965	39	-0.0513	0.394	137	4.40	$1.1E^{-5}$	96	0.033	98	0.08
	Irrigation	New crops	98	0.938	1.485	39	0.051	0.868	137	4.35	$1.4E^{-5}$	96	0.10	98	0.24
		Irrigation: new acres since dam constr.	98	0.176	0.339	39	-0.012	0.151	137	4.48	$7.4E^{-6}$	96	0.01	98	0.246
		Irrigation: total (acres)	98	0.244	0.485	39	0.055	0.177	137	3.33	$8.7E^{-4}$	96	0.04	98	0.496
	Fruit trees	Perc. HH with new trees	98	83.67	37.2	39	35.90	48.6	[44]			[44]		[44]	
		Fruit trees: new species	98	1.78	1.93	39	0.69	1.30	137	3.79	$1.5E^{-4}$	96	0.004	98	0.13
		Fruit trees: new trees	91	12.87	15.15	39	5.00	11.14	130	3.29	$9.9E^{-4}$	91	0.03	91	0.004
	Micro-credits	% heard of	98	87.78	32.95	39	92.31	27.00	[44]						
		% ever used	117	17.95	38.54	57	28.07	45.33	[44]						
	Coop. activity	% involved	117	73.50	44.32	57	68.42	46.90	[44]						

42 There is, however, a correlation between income from irrigated crops and increased *irrigation*-water use: R^2=0.498.

43 For an F-test, the variance cannot be zero (this is the case for households without dams).

44 Answers to these questions were binary and can therefore be used neither for F-tests nor for correlation.