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Two waterfalls do not hear each other. Sand-storage dams, science and sustainable development in Kenya

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ABSTRACT

Recent success in economic terms of sand-storage dams in Kenya has stimulated efforts to study options to implement similar techniques on a larger scale in other regions in sub-Saharan Africa. There are several challenges related to developing sand-storage dams. Such systems necessitate addressing issues like ownership, labor investments and siting. This paper discusses experiences in Kitui applying the dimensions of construction planning, hydrological scale and water use. Tensions between stakeholders planning the intervention and benefiting from it are indicated to clarify the questions that need to be answered. It is argued that science can contribute to development interventions aiming at implementing sand-storage techniques elsewhere by narrowing the margin of error in answering relevant questions.

1. Introduction

Water conservation is a high priority in the drier areas of sub-Saharan Africa. Storage of water from the rainy season to the dry season, or even from wet years to dry years is highly important. People living in arid areas with highly variable rainfall, experience droughts and floods and often have insecure livelihoods. Small multi-purpose sub-surface water reservoirs recharged through infiltration are used to provide water for humans, livestock and crops in the Machakos and Kitui regions in Kenya. The groundwater dams obstruct the natural flow of water in wet seasons or periods, and provide storage of water during dry seasons or periods. Retaining groundwater is not a new concept: groundwater dams were constructed on the island of Sardinia in Roman times and by ancient civilizations in North Africa (Barrow, 1999; Oweis et al., 2001). The technology might be considered ‘simple’ but ‘effective’, reason for many to consider it a feasible object to be constructed within the context of development cooperation (generally Non-Governmental Organizations). A challenge is to develop an effective strategy combining effective, cheap and fast construction with a community based approach. This review paper discusses what lessons can be learned from the experiences in Kitui (Fig. 1) to upscale the construction of similar technologies in other areas. This discussion is made operational by focusing on three dimensions:

Planning: The different planning demands for construction versus sedimentation.
Scale: Hydrological effects of single dams versus multiple dams.
Use: Impact analysis on networks or single dams.

After introducing the context of the sand-storage dams in Kitui, we discuss for all three dimensions potential and actual tensions between perceptions and actions of (1) stakeholders planning the intervention ((non-)governmental organizations) and (2) stakeholders benefiting and/or contributing to the intervention (community members, water users). We do not offer solutions for these tensions, but clarify the questions that need to be answered. In a final paragraph we attempt to clarify how scientific research could help answer these questions.

2. Sand-storage dam development in Kitui

In the Kitui region, Eastern Kenya, around 500 sand-storage dams store water for livestock, minor irrigation and domestic use. In subsurface dams evaporation losses are lower and risks of contamination of stored water is reduced as well as direct contact is minimized and parasites cannot breed underground. Submergence of land, associated with surface dams, is not present with groundwater dams. A sand-storage dam basically functions as a sub-surface dam, except that its crest is raised above bed level (Plate 1). The sand carried by river flow during the rainy season will settle upstream of the dam; gradually the reservoir will fill up with sand. The sand bed is used to store water from the rainy

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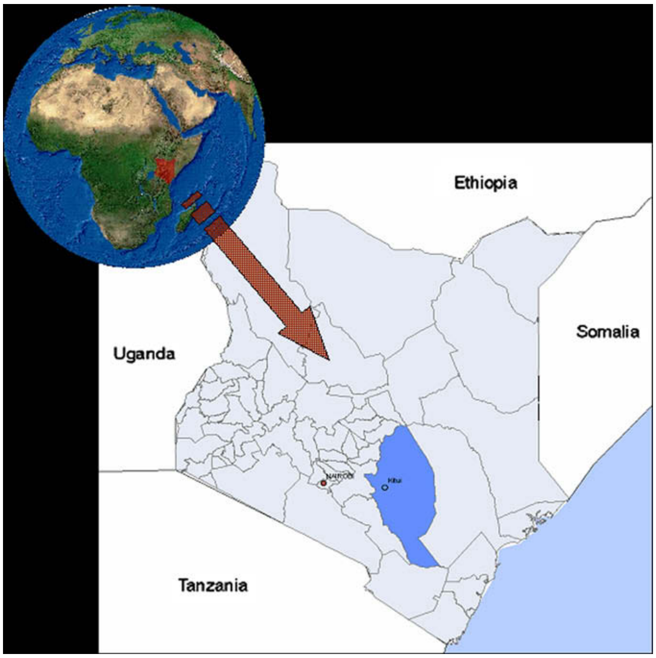

Fig. 1. Kitui in Kenya.

season. A single flash flood may fully recharge a sand reservoir. Upon full saturation of the reservoir, the remaining flash floods will pass over the dam. Typical heights of a Kitui sand-storage dam range from 1 to 4 meters above surface. The Kitui dams are all stone-masonry, sand-storage dams built in non-perennial rivers.

Water harvesting for crop production is not new in sub-Saharan Africa, although sand dams, that is water harvesting systems with a storage component for domestic water use and (supplemental) irrigation, are the least common of all water harvesting systems in sub-Saharan Africa (Falkenmark et al., 2001). The most common are in situ water conservation and runoff farming. An essential character of storage water harvesting structures is that they generally serve multipurpose uses, as they do in Kitui. Sand-dams are relatively cheap to implement (in Kitui one dam costs about 5000 US dollar plus several months of community labor). In the construction process, the benefiting community and the local NGO cooperate. In Kitui the complete design and construction process for a sand dam takes about 6 months. In a series of meetings (*barazas*), the community and the NGO discuss the planning of the intervention. Communities have to agree to provide labor for construction of the sand-storage dam.

Without a doubt, the Kitui dams are successful in general and deliver water. In the last 10 years, Kitui District shows growing economic activities, like horticulture, brick making and bee-keeping, which are all activities related to water use from sand-storage dams or to time-saving as water is readily available (see also Lasage et al., 2008). The economic success of the sand dam program has raised interest in the sand dam technology as a means to upgrade rain-fed agriculture in other environments in sub-Saharan Africa (Aerts et al., 2007; Lasage et al., 2008). Rain-fed food production has enormous relevance for global food security in the next few decades, given that the most rapid population growth and the lowest income countries are to a large degree located in the dry tropical and subtropical climate zones (Falkenmark et al., 2001). The question is why the technique is not adapted yet on a larger scale.

Falkenmark et al. (2001) mention several challenges directly related to development of storage systems in smallholder farming communities in sub-Saharan Africa (Fig. 2). First of all, such storage systems operate at a larger scale than within-field systems, often on a watershed scale, and thereby necessitate addressing issues like ownership, local institutions, and land tenure. Although in absolute terms structures may be cheap, they still necessitate relatively high capital and labor investments, usually too high for individual households. Simple as the structures may be, they are relatively complicated systems to design compared to field systems. Trial-and-error is not an option. Siting and design of the structures, necessitates technical know-how, especially to avoid the wrong type of siltation or leakage. Falkenmark et al. (2001) re-

Plate 1. Typical sand-storage dam with sand reservoir upstream.

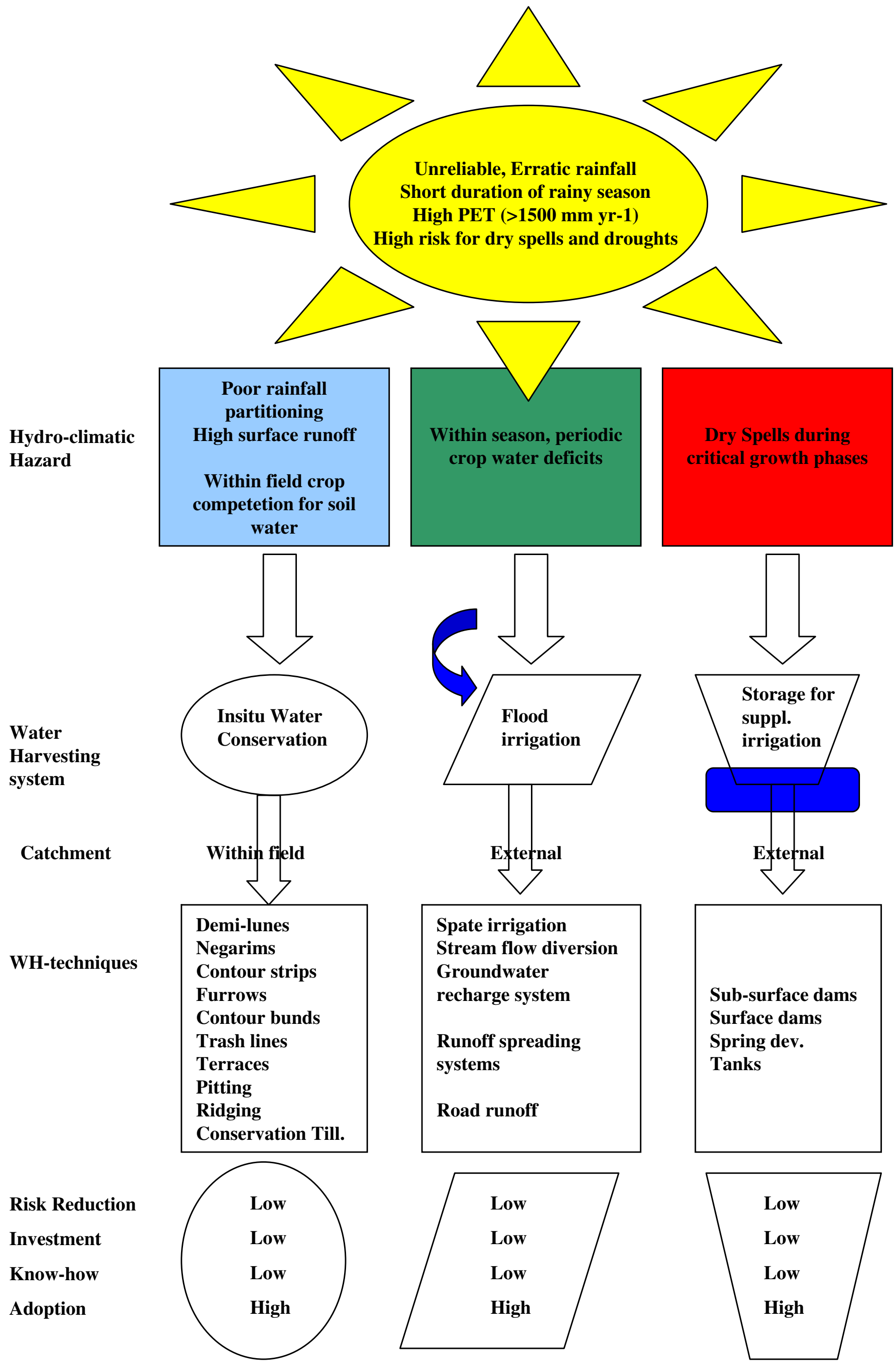

Fig. 2. Water harvesting and implications of implementation (Falkenmark et al., 2001).

fer to an expert in sand dam technology (Nissen-Petersen) claiming that in semi-arid parts of Kenya (which ones is not mentioned), some 80% of the dams are not performing as they should, due to poor design. Supporting institutions may have very little capacity nor interest to disseminate and assist.

3. Dimension 1: Planning

In Kitui the NGO does have clear interest and capacity to support the local communities in developing sand-storage dams. In the cooperation between NGO and community dam committees (consisting of villagers), the NGO plays an important role as it coordinates the community contribution. The NGO offers guidelines for the formation of dam committees based on characteristics of the composition of the committee (related to age groups, sexes, education levels, religious beliefs and political party affiliations). A typical sand dam committee has 13 members; the community decides on the composition of the committee. Once these two parties agree on the location for a dam the construction process starts. The community is mobilized to clear the site, collect locally available construction materials (sand, water and stones). The actual construction starts with digging a trench which is filled with rocks and mortar with the help of a trained artisan from the NGO. The community provides food and accommodation for the artisan. The NGO provides financial support to buy the most expensive input; cement. The community itself has to ensure that materials remain reserved for the sand-storage dam. This approach is successful; the expensive cement has 'walked away' only in very few cases.

Strengthening communal organization after construction was one of the major goals of the sand-dam program: "Community involvement and participation was the hallmark of this project. Community members contributed labor, sand and stones, artisan housing, and food for those working on the dams. Construction committees were formed, with women playing the dominant role (there was a 70:30 ratio of women to men) in project implementation, including volunteering labor for dam construction." (Kitui Sand Dams). It is claimed that "organizing for dam construction led to an improvement in community leadership and organization" (Kitui Sand Dams). This claim seems not to be supported by the research data. The functioning of the dam committees seems to end when construction of the dam has finished; low frequencies of dam committee meetings were found (Ertsen et al., 2005). A related issue is the perceived ownership of dams; a vast majority of the water users in the region perceives water sources as community property, while a considerable minority considers the NGO as owner of the sand dams. Apparently the participatory approach has not resulted in clear ownership. Although communities are encouraged to organize themselves in their own way and the community decides on the composition of the committee, this process does not result in clear communal activities and procedures after dam construction.

The strict predefinition of the project context may be a factor. The sand-storage dam is the single offer from the NGO to communities; it is almost an offer one cannot refuse. The Kitui sand dam project is not an exception: participatory planning appears to be least common in the choice of technology and/or service level (Van Wijk-Sijbesma, 2001). Furthermore, the sand-storage dams are 'delivered' within a strictly pre-defined planning period of six months. However, organizing takes time (Van Wijk-Sijbesma, 2001) The non-effectiveness on community organization level may have been aggravated by the fact that the dams need minimum maintenance. Committees may not want to meet without an issue to be addressed. Perhaps, astonishingly, the relative simplicity and reliability of the technology has even hampered further community involvement. Van Wijk-Sijbesma (2001) suggests a relation between the level of 'simplicity' of a technology and the potential for participation in projects employing the technology. For example, gravity systems would be relatively easy to maintain and repair with low recurrent costs compared to pressurized systems. Thus, gravity-based technologies would be better suited when aiming at organizing communities to manage their domestic water supply. Although this relationship has been claimed in Kitui[1], it is not clearly visible (yet) in the region.

Taking more time would coincide nicely with technical arguments to increase construction time of sand dams. Available literature (such as Nilsson, 1988; Stengel, 1968) suggests that it is preferable to build sand-storage dams in several stages over the course of three years to be fully effective. This allows the reservoir to gradually fill up with coarse sediment, as higher flow velocities will flush fine particles across the dam (Plate 2). The coarse sediments increase potential storage of the dam as they have higher porosities. Furthermore, abstracting water from the reservoir is easier for coarse material. Nevertheless, Kitui dams are built in one stage of half a year. The decision to build the dams in one period is based on the difficulty for the NGO involved to mobilize communities for three consecutive years and the difficulty for the community to mobilize the many resources needed in that same longer period. From a technical perspective, this decision appears to be defendable, as most dams appear to have no serious problems with the type of sediment upstream of the dam (Borst and Haas de, 2006). The Kitui case shows that the hydro-geological issue of sediment and available storage is directly linked to the issue of local management and community involvement. Apparently sand-storage dams can be "successful" and "unsuccessful" at the same time.

4. Dimension 2: Scale

When is a dam a success in hydrological terms? When it provides water every year? Every two years? How many months? What happens in very dry years? Obviously, water use will decrease the water volume and thus the water level upstream of the dam, but to what extent typically depends on the amounts used compared to the size of the dam, as shown by Hut et al. (2008). The results indicate that longer-term effects on groundwater levels to be expected depend strongly on the way the water is used. Household water use and river banks infiltration increasing seasonal storage can go hand in hand. However, when water in dams is used for higher water demanding activities such as (motorized) irrigation, the infiltration effect into banks may be minimal. But how robust are these dams on the longer term? How do they deal with dry periods, which may become more severe because of climate change? What happens with the groundwater system on the long run, when flows between dam reservoir and riverbanks and interactions between recharge and water extraction become important?

A dam can also be "too effective" and decrease water availability for water users further downstream. It is unlikely, however, that an individual farmer will effect on the downstream users of the resources he/she is tapping, but a network of dams as in Kitui may have considerable effect. It is clear that when one thinks of upscaling such a technology, "*it is important to have good pro-active knowledge on consequences of upscaling at the catchment and river basin scale.*" (Falkenmark et al., 2001, 75). To complicate the issue, applying water harvesting may actually not affect water availability downstream and in some instances even increase availability by enlarging groundwater base flow. Furthermore, when runoff generated upstream flows for only a couple of hours during and after intensive rainstorms, beneficial use of the water may be minimal. It may be the case that upstream water flow inundates flat seasonal wetland zones along its journey downstream and contributes to a large extent to open water evaporation. To understand water fluxes over seasons, including infiltration into the riverbanks and human water use, the temporal and spatial groundwater flow pattern needs to be known. Data from measurements over longer periods, or at least several years, are just starting becoming available for about two years, as only recently measurements in the Kitui area have started (Borst and Haas de, 2006). These measurements are too few to yet sustain the claim that the dense network of dams constructed in Kitui "*regenerates ephemeral (seasonal) rivers that now flow all year long.*" (Kitui Sand Dams)

What these measurements do indicate is that only about 2% to 3% of the total yearly runoff within the catchment directly associated with a single dam is stored in its reservoir. Therefore only this small percentage of the total flow of a seasonal river with dams is blocked. A word of warning is at place, however. These rather small percentages were estimated for dams in Kitui Central, an area with relatively higher rainfall (see below). In Kitui South, where rainfall is less and more erratic, dams may store higher percentages of rainfall and thus have higher impacts on users downstream. The

[1] "Sand dam technology is simple, and construction lends itself to participatory development, making it economically and socially effective" (Kitui Sand Dams).

Plate 2. Two new sand-storage dams with empty upstream reservoir.

other side of the coin is that in Kitui South there are probably less users downstream as well. Filling of the sand reservoir upstream of the dam in the rainy season is a matter of days and the reservoir maintains its high water content throughout the rainy season. In contrast the river banks upstream of the dam respond much slower to both rainfall and the changing water table in the river bed.

Another relevant issue when one wants to evaluate the (potential) effect of dams is the effects of groundwater storage over a period of several decades is a prerequisite to be able to determine whether this technology could be applied elsewhere. The work discussed in Hut et al. (2008) presents first results on this issue for a single dam. In other research (Orient Quilis, 2007) it was established that the influence area of one dam modeled as described in the paper was 350 m in downstream and upstream direction from the dam. With distances between the three dams at 500 m, it was expected that the three dams would show overlap of influence areas. The results indicate that the water levels in the vicinity of the three dams were the same as in the one dam case. However, further away from the dam water level rises were higher than for one dam, not only in the overlapping area but also in that area belonging only to the influence area of one dam. Our first estimate is that water level effects of three dams can be predicted by superpositioning the effect of one dam when distances between dams are not too low (Fig. 3). When the distance between the three dams was reduced to 250 m it was observed that the effects of the three dams were less pronounced compared to super positioning of three times the effect of each single dam. Distances mentioned here are dependent on the choice of soil parameters. The impact this may have on the ‘‘exportability” of sand-storage dams outside of Kitui will be addressed in the interventions section below.

The modeling results suggest that when several dams are built in a row in the same riverbed with such distances between them

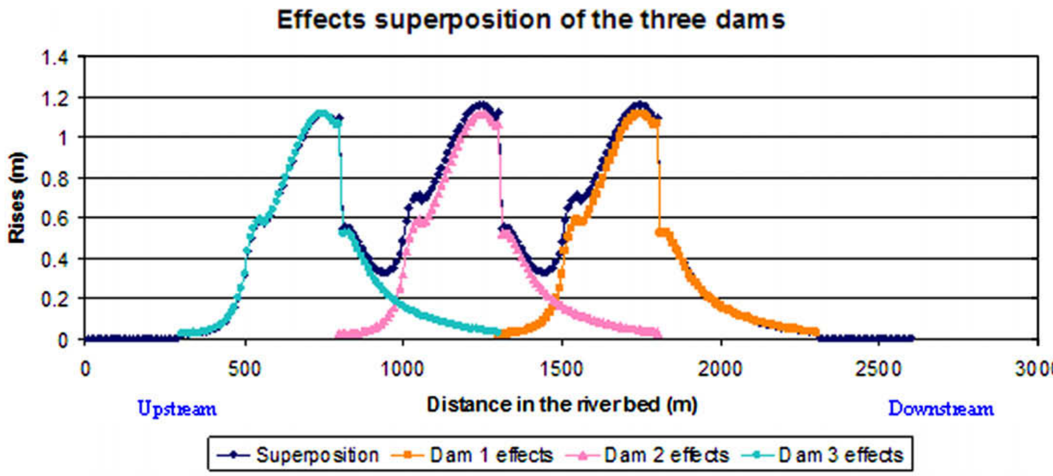

Fig. 3. Groundwater level effects caused by sand-storage dams (Orient Quilis, 2007).

than their influencing areas overlap, a global rise in the water levels occurs in the area. This means that when the purpose of the project is to raise the water levels in a certain area, multiple dams can be constructed close to each other in the target area. From the point of view of stored water volume, however, the closer dams are to each other the lower the water of volume stored will become compared to those volumes stored by the same number of single dams. The distance between dams in relation to the effects in water level caused by the dams is therefore an important criterion to consider when planning new sand-storage dams in a certain region. If the distance between dams is such that no overlaps of influence areas occur, dams behave as individual structures and effects on groundwater levels of single dams within a network can be added up.

5. Dimension 3: Use

For planning purposes, such general and longer term models seem appropriate. For understanding daily behavior, however, this modeling approach is not suitable. The simplification is based upon the idea of two clearly distinguishable seasons. In the dry season of a typical year, the upper aquifer will be unsaturated continuously. During the wet season, groundwater levels rise rapidly in response of precipitation and remain relatively constant. For longer term

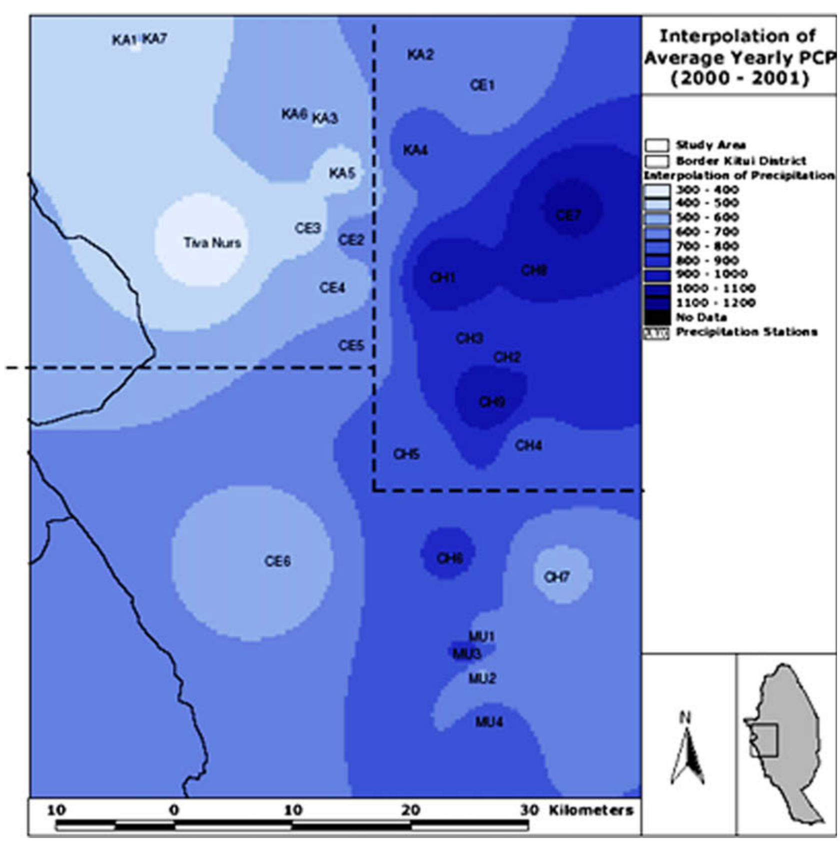

Fig. 4. Interpolation of the average yearly precipitation.

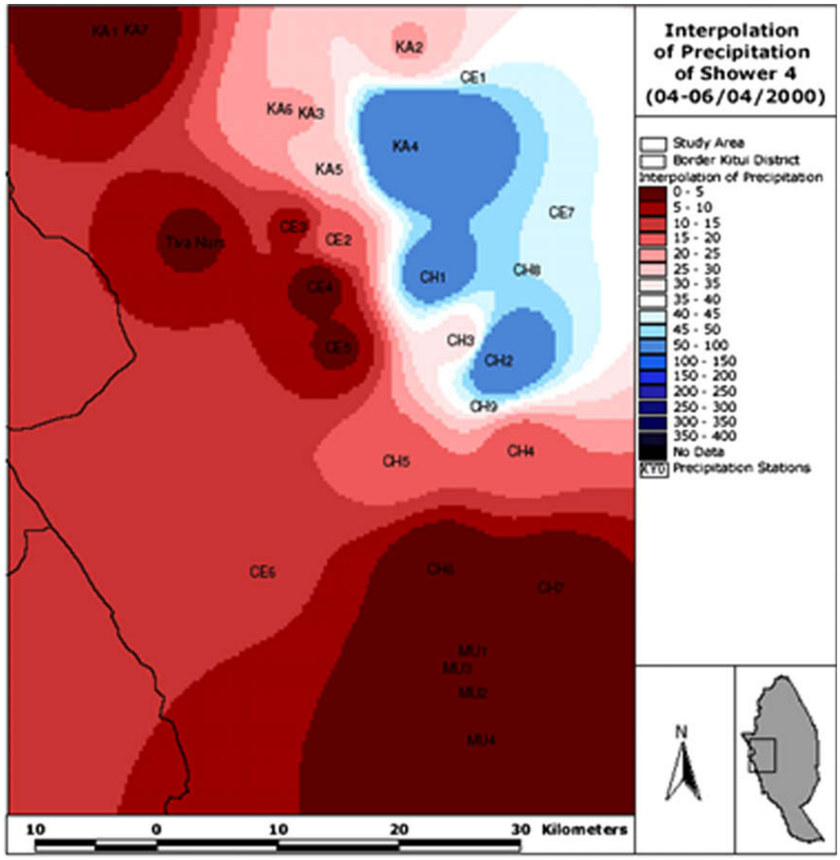

Fig. 5. Interpolation of the rainfall event 4th to 6th April 2000.

modeling, these simplifications are defendable. On the short term, however, temporal and spatial variability of rainfall is large, resulting in high risk for annual droughts and intermittent dry spells. Annual rainfall data has very little meaning for the land use decisions to be made by farmers. (Falkenmark et al., 2001).

Kitui District is characterized by rainy periods that are highly erratic and unreliable. Rain usually falls during a few intensive storms (Borst and Haas de, 2006; Mogaka et al., 2005; Nissen-Petersen, 1982; Opere et al., 2002). There are two rainy seasons, one from April to June (the so-called 'long rains') and one from October to December (the 'short rains'). Average precipitation in Kitui District is about 800 mm/year. With the Inverse Distance Weighted interpolation method, maps of annual rainfall indicate that Kitui District can be divided into three zones: the northwest with the lowest amount of rainfall, the northeast with the highest amount and the south with an intermediate amount of rainfall (Fig. 4). The importance of spatial distribution becomes even clearer when looking at individual rainfall, for which spatial variation can be quite dramatic. For a major rainfall event between 4th and 6th April 2000 rainfall amount vary between 0 and 100 mm (Fig. 5). For this shower a fairly clear pattern can be seen. The area which receives the highest amount of rainfall is situated in the northeast, and this amount more or less diminishes at locations situated further to the south and west[2].

For shorter periods, patterns within a season including daily changes need to be taken into account. From measurements of the rise of groundwater table in response of precipitation it is evident that the groundwater levels respond rapid in response of precipitation. The aquifer behind the sand dam fills up in immediate response to precipitation, which explains the functionality of sand-storage dams in semi arid areas with unreliable and scarce precipitation. Groundwater levels will decrease within a few days after rainfall and rise again after the next rain shower. Single rainfall events can influence the construction of a single dam. A dry year can lead to less favorable storage in a dam, which may influence the communities ability and preparedness to remain involved another year. Being able to determine such shorter term risks and options, which can be used in designing an intervention strategy before actually starting interventions, would be an asset. This would require another type of modeling, which needs to take into account daily variations but is not discussed in this paper.

A related issue is water use. In Hut et al. (2008) modeling results are discussed which indicate that longer-term effects on groundwater levels to be expected depend strongly on the way the water is used. It is shown that, to a large degree, household water use, including small scale agriculture and river banks infiltration can go hand in hand (Plate 3). However, when water in the dams is used for higher water demanding activities such as irrigation by pumping (as was observed in the Voi region in Kenya), the recharge effect of dams will be minimal. Furthermore, this issue links with the distribution of socio-economic benefits. Users close to the dam are in a position to take all water, whereas users further from the dam would benefit from more extended recharge. In Kitui it is clear that households on land adjacent to the seasonal rivers with dams are now earning more than they used to, as they are able to irrigate their crops during the three dry months of August, September and October (Kitui Sand Dams). It is not clear, however, how benefits are spatially varied through Kitui District (Lasage et al.,

[2] Research conducted within the REAL – Rehydrating the Earth Research Project (2002–2005) by the Katholieke Universiteit Leuven, Belgium.

Plate 3. Irrigated agriculture close to a dam.

2008). Furthermore, increased economic activities have not strengthened community institutions either, as these economic activities are individual or family-based.

6. Conclusive remarks: Interventions

We have discussed the dimensions of planning, focusing on the different planning demands for fast construction and suitable sedimentation; scale, emphasizing the difference between hydrological effects of single dams versus multiple dams; and use, stressing the need to study the impact of networks of dams and single dams. In all these dimensions, expectations and views of intervention agencies and benefiting communities may be different. In the Kitui case the NGO had a vision to create a network of dams to ensure water security for a larger area. Each community was dealt with separately and construction started in communities close to Kitui town for logistic and climatic reasons: distances were short and rainfall relatively abundant. Communities are more likely to be interested in their own water supply, especially when they have to invest much labor. This difference in scope between NGO and community is not a principal problem. Communities may recognize their problem, but see no options to solve them. We should not expect villagers to be able to plan new actions to change their situation. When it comes to sand dams, a Kitui farmer should be seen as his European colleagues. "*No farmer in Sweden would ever be expected to be able to perform the large task of assessing river flow, design diversions and water reservoirs. Instead they buy the service from private companies.*" (Falkenmark et al., 2001, 57).

Outside support or intervention does always bring along a principal issue of control (or power): who decides what? Which goals are to be more influential than others. Which of the two waterfalls will be loudest? We do not deny that this is a power issue. In a world full of power relations, it would be very strange that such important issues as water provision, particularly when considerable resources (money, labor, materials) are at stake would be not influenced by power relations. We would, however, like to stress that taking into account goals, views and knowledge of stakeholders is also a simple principle of sound design. Unfortunately in many cases, a successful technology starts to speak its own 'language' and figures as the best solution for all sorts of problems. In case such a technology does not fit too well in other situations attempts are made to change the situation in such a way that the technology becomes applicable. Development aid is a notorious example of this approach. Exactly for this reason there has been "*a tendency over the past 10–20 years in development efforts to be reluctant in relying on external knowledge and investments in rural development.*" (Falkenmark et al., 2001, 10).

Starting from the idea that a design process as part of an intervention aims to transform a request from loose data into a plan for an artefact, we would like to stress design processes being iterative processes. Obviously, the design moves from rough to detail. In early phases, main design components are defined, implicating that decisions taken at an earlier stage are more important than those taken at a later stage. However, conditions and criteria can be reviewed during the design process, whereby the design may restart at an earlier stage. Decisions are not necessarily definitive, but open for review when more, perhaps contradictory information becomes available. Design is also iterative as encompasses feedback from the context within which it has to be applied. Part of this feedback does come from users: they adapt structures or manipulate them, even (or particularly) in case they were not involved in the design process itself.

When, in any design, different actors actively try to (re) shape and (re) design the infrastructural facilities, both using formal interactions and informal activities, one might as well make these actions explicitly part of the design or intervention process. This has obviously also been promoted in the many participatory approaches applied within development cooperation. However, doing this is not straightforward. Van Wijk-Sijbesma (2001) found that a full range of user choices did not yet exist in the projects she studied. In none of those had women and men household members taken part in all six types of decisions Van Wijk-Sijbesma (2001) distinguished as key (Service initiation; Choice of technology and service levels; Locations of facilities; Local management; Maintenance; and Financing arrangements). As discussed earlier, the Kitui NGO selecting the technology is not alone, as user participation appears to be very uncommon for this aspect (Van Wijk-Sijbesma, 2001). In Kitui technical expertise is used to determine the dam site. However, this is not done on the basis of an analysis of assessing "*catchment size, runoff production, water balance accounting, and interpreting rainfall and climatic data.*" (Falkenmark et al., 2001, 57).

The experts of the NGO apply their expert knowledge gained in their years of professional experience. The dams are heavily overdimensioned and thus can cope easily with storm floods, which does not give a need for detailed hydrological analysis. Systematic studies on soil properties have not been the basis of the Kitui success either. Research may have confirmed the suitability of the short construction time in Kitui because the sediments are suited, but it is also clear, that this is specific for the Kitui sediments. The expert knowledge of the NGO in Kitui found a limit when dams were to be constructed in areas with clay soils without obvious rock layers close enough to the surface. This was reason for the

NGO to ask Delft University of Technology to study other dam construction options[3].

Such technical research on dam design is relatively simple to incorporate into an existing intervention program as in Kitui. Introducing similar technologies in other regions, however, is another matter (Ngigi, 2003; Probst and Hagmann, 2003). The call for upscaling itself was based on the success of the Kitui example. The final product, in this case a dense network of sand-storage dams, was the stimulus as it were. That brings along the question if it is possible to separate the final product from the process to develop that product. It took many years for the Kitui sand dam project to reach a status to be noted by outsiders. In the early years, the few ones who were asked to develop interest did not even do that! When transferring Kitui experiences to other regions within a formal and institutional setup, one of the prerequisites of the Kitui success may already be absent. It may very well be the case that Kitui has become a success because the Kitui sand dam program was low key and based on non-governmental initiative in the first years. Suppose one wants to develop a similar network of dams elsewhere, where to begin? Which community to start with? How to plan all these dams? How to avoid disappointment with stakeholders when quick expansion is not possible? Or how to avoid large-scale interventions which may speed up the construction process but run a risk disrupting existing social structures?

Finding answers to such questions is not a scientific privilege. There can be no scientific answer to the question how to start an intervention program. It is not even that likely that science will be able to produce a clear answer, as scientific answers are usually accompanied with reservations. This habit of science to put question marks everywhere, which some may call a strong disadvantage of scientific research, could be turned into an advantage. Within a development context research may not yield the final answer, but it could be useful in delineating the "room for maneuver". Science can contribute to successful implementation sand-storage techniques elsewhere by pointing out relevant questions and narrowing the margin of error in answering those questions. Upscaling sand-storage technology to other regions may give a positive contribution to sustainable rural development, especially if scientific research manages to show to stakeholders what steps to avoid.

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[3] Two groups of Master students from DUT have visited Kitui to study these alternative construction options in clayey soils in Kitui South in cooperation with the NGO Sahelian Solutions.