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Brazil, Kenya: Subsurface Dams to Augment Groundwater Storage in Basement Terrain for Human Subsistence[1]

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The objective of these initiatives was to evaluate the technical strategy, social benefits and economic effectiveness of so-called subsurface dams to augment aquifer storage in semi-arid basement terrains with very limited natural groundwater and high drought propensity. This is considered a possible low-cost technology that could aid the rural poor in their battle for subsistence in such areas. This study focuses on experiences gained by UPFE in north-eastern Brazil and by SASOL in Kitui-Kenya. This profile summarizes the field conditions and the principal findings, which are of broader geographical relevance.

Subsurface dams of one type or another (especially groundwater and sand dams) can be found in various countries, especially in semi-arid regions. The technology used is not new – but its efficiency in conserving groundwater, suitability for a participatory approach and relative simplicity has recently revived interest in the technique.

This study focuses on locations that represent the main national experience of this technology in:

northeastern Brazil in the *agreste* and *sertão* areas of the interior of Pernambuco State, where about 500 small subsurface dams were constructed during the 1990s

the Kitui District of Kenya, where the SASOL Foundation began constructing subsurface dams in 1995, and over 400 have been constructed and another 500 planned

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[1] The Kenya case study is based on the background paper Groundwater Resources (no. 8) prepared for the World Bank ESW Report “Towards a Water Secure Kenya; Water Resources Sector Memorandum”, April 2004.

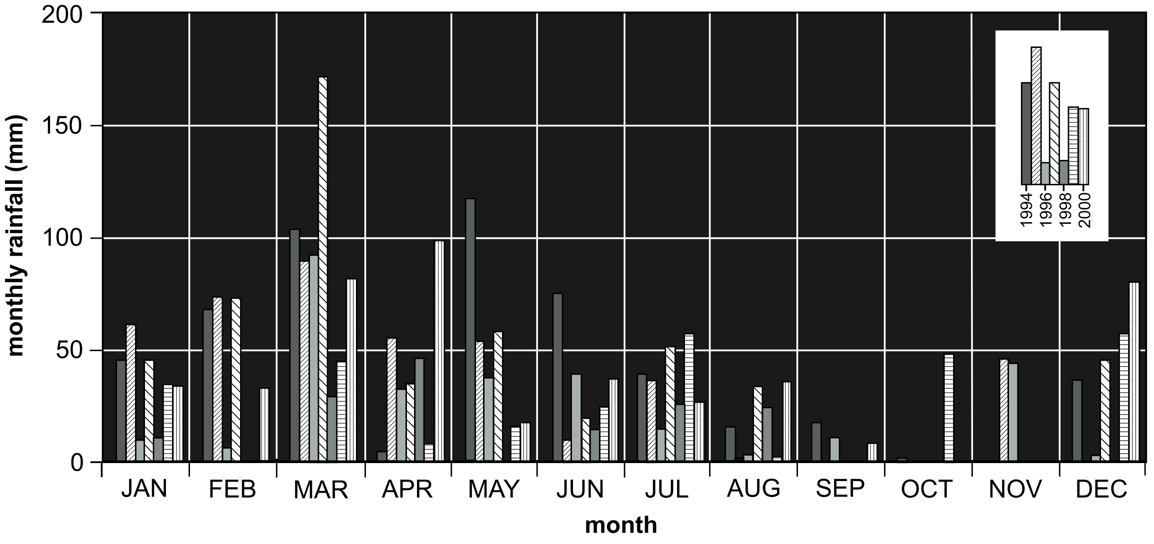
HYDROGEOLOGICAL FIELD CONDITIONS

This sub-region (Figure 1) encompasses some 88,000 km^2, with a population density generally in the range 25-75 persons/km^2. Its climate is semi-arid with an average precipitation below 600 mm/a, with an extended dry season from August to December (Figure 2), high drought propensity and a potential evaporation of above 2,000 mm/a.

Most of this extensive sub-region is underlain by crystalline basement rocks, which do not have a deep weathered mantle and are of extremely low groundwater transmission and storage capacity. The terrain has a subdued but significant relief and the occurrence of groundwater is for the most part restricted to thin coalluvial and alluvial deposits in small valleys, whose streams flow only for limited periods after major rainfall episodes usually in March-May.

In parts of the sub-region saline soils are developed and their presence can lead to significant levels of groundwater salinisation, which can be further aggravated by direct evaporation when impoundment results in shallow water-table.

Figure 1: Variation of monthly rainfall over annual cycle for 1994 – 2000 at a typical site in the field area in Brazil



The Kitui District is located in eastern Kenya and covers an area of 20,400 km^2 with a population density of 25 persons/km^2. The climate is classified as semi-arid with erratic bimodal rainfall occurring during October-December and March-May. The total rainfall ranges from 250-750 mm/a, and open pan evaporation is above 2000 mm/a.

A basement complex of metamorphic and igneous rocks, whose weathered mantle is of varying thickness, occupies much of the area. The southern side of the district is underlain by Permian deposits, while Tertiary volcanic deposits occur in the west, but overall groundwater resources are scarce and rivers only flow during the wet seasons. Black cotton soils occur in the western part of the district, but elsewhere distinctive red sandy soils of low fertility are present.

DAM CONCEPT & CONSTRUCTION

There two types of subsurface structure (Figures 2 and 3): (a) dams cut into the alluvial cover to intercept groundwater flow (groundwater dams) and (b) dams built in streambeds upstream of which a local aquifer is formed by sedimentation (sand dams).

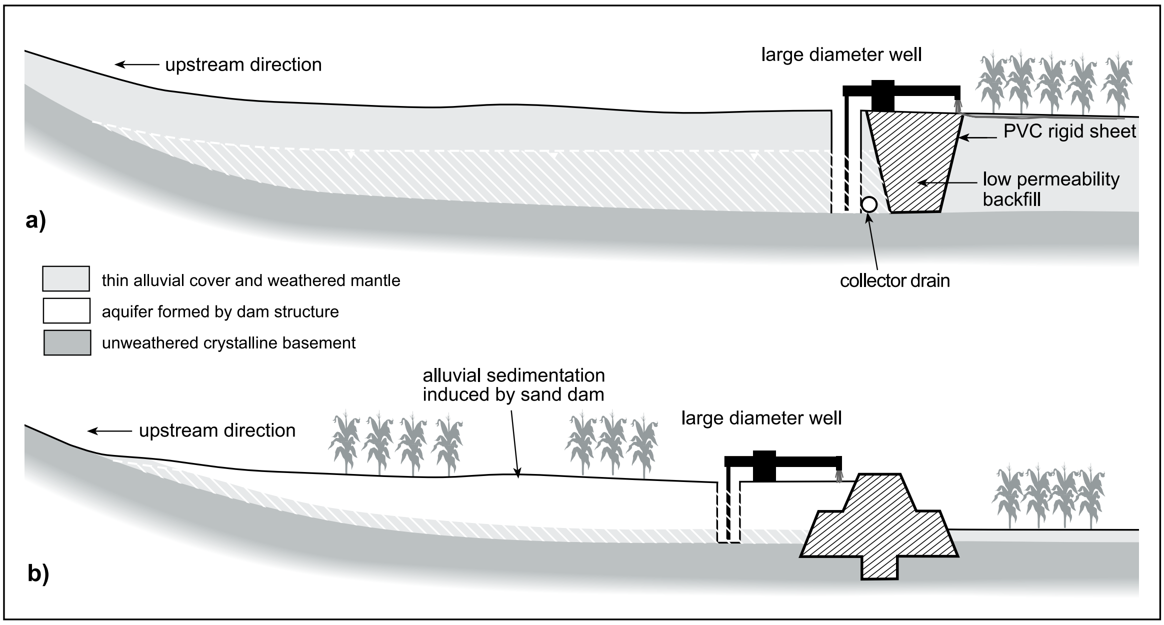
Figure 2: Subsurface dam construction in Brazil (left) and a mature dam in Kenya (right)

The storage capacity of a typical subsurface dam and reservoir (say in average of 4 m depth, 50 m width and 500 m length) will be some 10,000 m^3, assuming a drainable storage coefficient of 0.10. This is not sufficient for these dams to provide multi-annual regulation, unless their usage is only for human and animal consumption. However, intra-annual regulation makes possible the use of water for small-scale irrigation in the dry season, enabling the production of various crops.

The climate of the study area will normally be such that the construction of small surface dams to impound runoff will result in very high evaporative losses, making the underground dam an interesting alternative. Unconfined strata should be present within a shallow to moderate depth (preferably not more than 10 m), and underlain by a well-defined impermeable layer.

Sites with saline soils should be avoided for dam construction. While reduction in the salt levels through continuous water use is feasible, it requires operational procedures beyond those generally expected of small rural farmers. The periodic drying-out of subsurface reservoirs and/or maintaining their groundwater levels well below surface are the best ways to mitigate salinization tendencies.

Figure 3: Longitudinal sketch-sections to illustrate structure of (a) groundwater dams and (b) sand dams



The economic conditions of the sites are such that participatory or bottom-up approaches are essential in the dam construction (and obtaining maximum socio-economic benefits). Using locally available materials and community labour reduces costs and enhances efficiency, acceptance and dam life-span.

In summary the principal construction problems encountered and documented were:

- errors in site selection resulting in insufficient storage potential
- insufficient depth to reach relatively impermeable bedrock
- location in a soil type with very low infiltration capacity
- location in a soil type that could lead to severe groundwater salinization
- low-yielding abstraction wells due to poor construction
- land ownership constraints.

During the 1990s many underground 'alluvial cover' dams (Figure 2) were constructed in the sub-region and these fall into three main categories:

small structures up to 3 m deep constructed under 'government drought emergency job-generating programmes' at sites selected by municipal committees without technical advice and follow-up; they were manually excavated, incorporated plastic membranes and a large-diameter concrete-ring waterwells

similar-sized structures constructed under local initiative by NGOs with specialist advice, but filled with only recompacted clay and without a well for water abstraction

much larger structures up to 10 m depth (in areas of thicker alluvial cover) located by technical criteria and constructed with the aim of supporting small-scale irrigated agriculture in areas with some existing irrigated cultivation – they benefited from use of mechanical excavators and incorporated impermeable plastic membranes, improved large-diameter water wells and some technical monitoring.

The 400 streambed dams constructed in the Kitui District vary in size according to valley dimensions, and dam sizing must take into account the level of peak river flows. During construction the streambed and banks are excavated to reach an impermeable and sound strata, and on average the Kitui dams are between 2-4 m in height and around 500 m in length (but larger structures of 7 m in height and 2000 m in length also exist).

There are two construction types : one using a wall facing filled with bricks or stones and the other a timber framework filled with stones and mortar, but when stones were not available other materials (such as plastic foil, galvanized iron or clay lugs) were used. In some areas wells were constructed close to the upstream side of the subsurface dams (at 200 m maximum distance from the riverbed) for daily water collection and/or small- scale irrigation.

Dam design and construction were community-driven projects. A site committee was made responsible for mobilizing local resources for the construction; planning the work, and the operation and maintenance of the developed facility with SASOL members providing technical assistance and supervising construction.

EVALUATION OF DAM PERFORMANCE

Evaluation Process

The GW•MATE-supported field survey was carried out in two distinct phases. In the initial phase a widely distributed set of 151 of the known 500 dams were examined, and a preliminary assessment made of their current status, construction problems, groundwater availability and quality, type of use, its benefits and beneficiaries.

Using the results of the initial phase, a smaller set of dams, representative of the typical situations encountered, were selected for more detailed study from the municipalities of São Caetano, Ouricuri and Mutuca. Amongst these, 19 dams in the Mutuca area, developed primarily for small-scale irrigated agriculture, were subjected to systematic socio-economic appraisal.

Basic Utilization

Of the 151 dams visited in the first stage, 37% were essentially inactive, due to one or more of the above mentioned construction problems making their use by the community impossible. A further 13% were in good condition but little used by the local community as a result of availability of reliable surface water dams. The remaining 50% were in active multi-purpose use almost exclusively for a combination of domestic water supply, livestock watering and small-scale manual irrigation.

Socio-Economic Benefits

The second phase of more detailed socio-economic survey led to a number of conclusions and observations. The benefit of the subsurface dam in terms of improving the community's quality of life can be very significant, as a result of the increased variety and quality of food that can be produced. The dams often have an important role in livestock watering and the production of dry-season animal forage, even where slightly brackish groundwater develops. The cost breakdown for a typical dam is given in Table 1, but costs vary considerably with the scale and function of the structure.

Larger scale subsurface dams, such as those constructed around Mutuca, can sustain small-scale irrigation in the dry season and generate income for land owners and the community. The cultivation of three crops per annum was possible locally in this area. It is important to point out that the Mutaca area had a pre-exisitng tradition in small-scale irrigated agriculture, and in the Ouricuri area it was possible to stimulate one, whereas elsewhere (for example in São Caetano) this was not the case. The access to markets is an important consideration, and where this is difficult, crop prices and income generation will be much lower.

Construction of subsurface dams in localities experiencing near-total rural economic stagnation is not alone likely to transform the socio-economic condition. To obtain a positive impact, other factors need to be addressed, such as energy provision, investment capital and technical assistance. It is important to take this into consideration, since in cases like São Caetano and other municipalities that experienced subsurface dam construction as part of an emergency drought relief programme, community need, the first criterion for site selection, as well as other factors, were not adequately considered.

Table 1: Cost analysis (in US $) for construction of underground dams*

COST COMPONENT	REPRESENTATIVE COST**
Feasibility Study	210
Construction	1410^
Technical Support	275
Total	1895^^

* based on a typical dam of 4m maximum depth and 40m maximum length
** prices under local conditions in March 2001 (converted from Brazil Rs at rate of 2.0)
^ includes cost of a large-diameter well to abstract stored water
^^ US $410 less if manual (not mechanical) excavation used for underground dam and water well

The more detailed socio-economic analysis of dams constructed to support small-scale dry season irrigated agriculture in the Mutuca area (Table 2) suggested that the capital investment cost could generally be recovered within a few years of operation (in some cases after the first year). However, it should be noted that in the case of this appraisal:

on the one hand, Mutaca is an area of somewhat more favorable conditions for the construction of deeper dams with larger storage and also has more experience with irrigated agriculture

but on the other hand, the appraisal had to be restricted (because of the lack of long-term reliable data) to the situation in a 'normal hydrological year', when 6 out of the 19 dams evaluated were not in use.

Table 2: Cost-benefit analysis (in US $) for underground dams in the Mutuca area

PARAMETER	INVESTMENT COST	BREAKDOWN OF ANNUAL BENEFITS*			TOTAL ANNUAL BENEFIT*
		economy of time	value of animal production	value of crop production	
average for 19 dams in area	3,413	70	702	3,216	3,987
average for 13 dams active in study year	4,410	102	1,025	4,701	5,828
average for 8 dams with irrigated cropping	5,034	83	877	7,614	8,598
maximum values for individual dam	-	644	3,760	20,550	-

* prices for local conditions in March 2001 (converted from Brazil Rs at rate of 2.0)

Utilization and Evaluation

There are examples of subsurface dams in Kitui that already have been in operation for 25 years, and most that have been constructed subsequently are still fully operational. SASOL has conducted a number of studies on their use and socio-economic benefits, supplemented with work carried by students. A comprehensive hydrological, environmental and socio-economic evaluation is currently under preparation.

Socio-Economic Benefits

The main advantage of the Kitui dams is that they use simple inexpensive technology and can be constructed by local communities mainly with locally-available materials. The cost of a 60 m^3 dam, with a minimum life of 50 years and a storage of at least 2,000 m^3, is about US$ 7,500. Some 40% of overall construction cost is provided by the community.

Although detailed hydrological inventories are still lacking, initial assessments indicate that as a result of sand dam construction water-supplies are much more readily available during the dry-season, resulting in increased agricultural productivity. For example, at the Wii location only 2 productive shallow waterwells existed in 1999, before the building of 14 sand dams and associated on-farm water-harvesting structures, and today there are 39 waterwells operating.

In the Kitui area in general, SASOL have built consecutive dams at 0.5 – 1.0 km intervals along water-courses, and nearly 200,000 households have benefited through cutting the average time spent on water collection (primarily by women) from more than 5 hours/day to less than 1 hour/day. Therefore, more time is available for new economic activities, such as small-scale agricultural activities (vegetable cultivation, tree nurseries) and brick production (which requires a lot of water).

Increased crop production and better quantity and quality of drinking water-supply have improved the hygiene and nutrition of the people. This effect is also noticeable in livestock and poultry, which further increases nutritional intake and economic income. The greater food security has also insured the ability of the area to cope with drought.

A survey conducted in the Ithumula/Maluma location noted an increase in the annual income of its inhabitants, especially during the dry season, and 38% of householders interviewed reported that they were able to plant vegetables in the first year after dam completion with some having increased their agricultural activity three-fold and everyone having enhanced empowerment. Increased net income in the dry season was in the range US $ 75–1,625, compared to the pre-exisiting per capita income estimated at US $ 25.

The use of underground dams would appear applicable to other semi-arid regions with similar soil and climate, and equally unfavorable hydrogeological conditions. It is important to remember that the presence of unweathered and relatively impermeable bedrock at shallow depth is necessary for dams to augment groundwater storage, and that careful attention needs to be paid to the risk of build-up of soil and groundwater salinity. More detailed studies need to be, and are being, carried out to document the positive hydrological effects of subsurface dams and their socio-economic cost-benefit, both in Brazil, Kenya, and elsewhere, notably in India (see Ramasesha et al in the ISAR 4 Proceedings—Adelaide, 2002).

The human factor is essential for the success of subsurface dams. If there is no cooperative effort with, and subsequent ownership by the community, effective operation and adequate maintenance is unlikely to follow. Furthermore, continuing technical assistance in irrigated agriculture and waterwell maintenance will be required.

A fundamental part of increasing the life-span of the subsurface dams is the use of low technology construction techniques and locally available materials, to avoid the risk of neglecting maintenance because it is too costly.

Publication Arrangements

The GW•MATE Case Profile Collection is published by the World Bank, Washington D.C., USA. It is also available in electronic form on the World Bank water resources website (www.worldbank.org/gwmate) and the Global Water Partnership website (www.gwpforum.org).

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