# Aquifer Storage and Recovery and Surface Basins for a Greener Kilifi District

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**Abstract**
Kilifi District experiences 5-6 months of continuous dry weather and in some instances years of continuous dry periods. When the rains fall, they are short and intense causing ground erosion and siltation of surface water sources. Most of rainwater is discharged to the Indian Ocean through the numerous intermittent streams within the area. Currently, majority of the inhabitants of the district depend on food rations and perform no economic activities because of the harsh climatic conditions. The aims of this study were to investigate the suitability of the subsurface materials for storing the rainwater that is lost through run-off, to determine the methods that can deliver the water to the subsurface and to evaluate the expected performance of the storage structures. The process of conveying and storing water in the subsurface during times of abundance, and recovery of the stored water during times when it is needed is commonly referred to Aquifer Storage and Recovery (ASR). When executed well, ASR can recover and maintain groundwater levels thus making it available for domestic use and for agriculture. Several factors that control successful operation of ASR were analysed in a Geographical Information System (GIS) to pinpoint suitable areas. After pinpointing the sites, extensive fieldwork was carried out to compare the results of GIS analyses and the conditions on the ground. The results show that more than 50% of the pinpointed sites are hydrogeologically suitable for recharge. Storage zones comprise of a broad variety of aquifer lithologies at depths ranging from 10 to 100 m. The most notable characteristics of the subsurface are: the presence of salty formations; irregular aquifer system physical properties; sensitive and collapsing fine materials. There is also insufficient information on physical properties of some aquifers, ASR will need to commence in form of pilot projects. Once ASR projects are successful, crop production through irrigation and regeneration of indigenous trees will turn Kilifi District to a green environment.

***Key words*: *Kilifi District*, *Aquifer Storage and Recovery, Agriculture, Green Environment***

## 1. INTRODUCTION

Aquifer Storage and Recovery (ASR) is the process of conveying and storing water in the subsurface during times of abundance, and recovery of the stored water during times when it is needed. It is practiced in areas with distinctive wet and dry seasons. Kenya is generally classified as a water-scarce country by the World Health Organisation, though there are some areas of the country that have abundant water resources throughout the year while others have perennial acute water shortage. Kilifi District is located on the Kenyan Coast (Figure 1) and suffers acute water shortage sometimes experiencing 5-6 months of continuous dry weather or in some instances years of continuous dry periods. The dry periods leave the ground largely bare such that when the short and intense rains fall, they cause ground erosion and siltation of surface water sources. Most of rainwater is discharged to the Indian Ocean through the numerous intermittent streams within the area. A large percentage of people in Kenya, including 80% percent of the population in Kilifi District support themselves through subsistence agriculture. For the past ten years, the farmers in Kilifi have not harvested any crops due to persistent dry weather and unpredictable rainfall patterns. This has caused majority of more that 280,000 people to depend on food aid and live below the poverty line (Figure 2). Children are encouraged to attend school because they are provided food portions there unlike at home where they often take a day without a meal.

The Government of Kenya is exploring methods of minimizing reliance on rain-fed agriculture. Some pilot projects for ASR have been established in some parts of Ukambani Area and the levels of success are encouraging. However the results of these pilot projects cannot be replicated anywhere else in the country because of variability of rocks ranging from igneous, sedimentary and high-grade metamorphic rocks. Detailed investigation is therefore required to evaluate the possibility of ASR for many parts of the country and Kilifi District is one of the priority areas earmarked for ASR projects.

The aims of this study were to investigate the suitability of the subsurface materials for storing the rainwater that is lost through run-off, to determine the methods that can deliver the water to the subsurface and to evaluate the expected performance of the storage structures.

Records indicate there are 200 shallow and deep groundwater wells in Kilifi, most of which are out of commission at any one time due to depletion or elevated salinity. Although most of these wells are not in full operation, they provided a vast amount of data for analysing viability of ASR in the district. Aquifer storage can function in the manner of a traditional surface water reservoir but without loss due to evaporation. It may also increase availability of large volumes of water during severe, multi-year droughts to augment deficient surface water supplies for domestic use, agriculture and afforestation (Karanth, 1987). Another important consideration for ASR structures in Kilifi District is that they will have to be owned and managed by the local communities. This calls for simple and effective structures that can store water in the shallow subsurface. The structures considered for ASR in this study are injection wells and shafts for deep aquifers and surface basins such as percolation ponds, dams and contour trenches for shallow aquifers. Masinde Muliro University of Science and Technology (MMUST) provided funds for this noble research. World Bank is also encouraging similar effort through Carbon Credit Funds in which Community-Based Organisations in Arid and Semi Arid Lands (ASAL) undertake afforestation and are compensated for it.

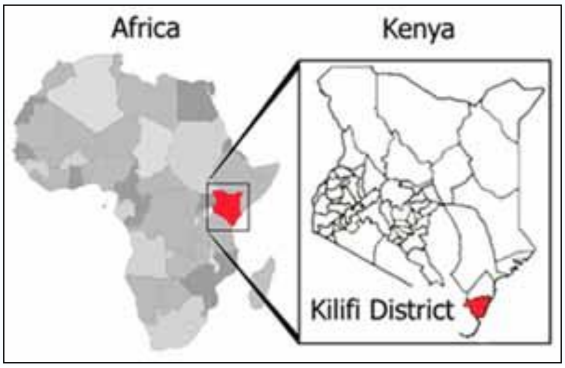


**Figure 1: Location of Kilifi District**

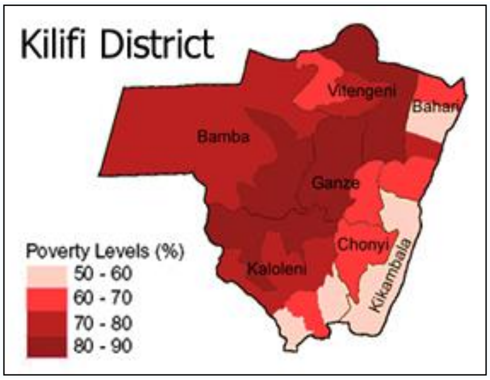


**Figure 2: Poverty Map of Kilifi District (Source: Kilifi District Development Programme)**

## 2. MATERIALS AND METHODS

The feasibility of ASR is governed by the following factors: availability of suitable site for establishing recharge facility; presence of suitable source to supply water of required quality in requisite quantity; lithological composition, thickness and permeability characteristics of soil in the zone of aeration and saturation; hydrodynamic conditions in the aquifer to ensure adequate head; cost benefit considerations and social benefits. Conducting ASR requires a good understanding of the vadose zone properties in order to properly design the recharge facility and evaluate potential sub-surface impacts. When near- and sub-surface hydraulic properties are not properly evaluated, ASR results in very costly pilot projects being required or design criteria not being achieved. To develop a full understanding of the subsurface materials, the following data was used: maps for regional climate, topography, geology, soil type, land use, population density/ poverty index; geophysical resistivity sounding; meteorological; satellite; hydrogeological and well inventory.

The study area shown in Figure 1 touches thirteen topographical sheets of Scale 1:50 000. Scanned copies of the topographical maps were georeferenced using Geographical Information System (GIS) and cropped together. The project limits were set so that only the relevant portions of the maps were available for digitizing. By tracing lines on-screen, rivers, contours and spot heights and roads were digitized on three different layers. The same procedure was followed for digitizing polygons of geology, soils and land use in three separate layers. Positions of wells and surface water sources, as well as meteorological stations were plotted on the georeferenced map on a separate layer. Drillhole logs from each location were manually drawn to scale and contoured to obtain the general subsurface profile, the composition, physical characteristics, depth, thickness and aerial extent of the aquifers. This enabled the postulation of the direction of groundwater movement in the subsurface and preparation of a hydrogeology layer. Surface resistivity measurements for 127 sites were used to develop a conceptual model of stratigraphy and faulting and compared with bore logs within the vicinity. Under the GIS environment all layers were used as overlays. Each overlay was considered as a theme and ranked depending on its contribution to a successful ASR project. Figure 3 and 4 below are samples of some features used as themes in GIS analyses.

In the GIS software system, spatial analysis was carried out to delineate suitable sites for the location of recharge structures. The various analysis functions used included spatial intersections, spatial differences, attribute queries, spatial selection, buffering, clipping, and spatial union among others. Using a different criterion for each type of ASR structure, procedural analysis was carried out eliminating unsuitable areas, combining areas having similar attribute values, intersecting landforms and so on. The structures considered applicable for ASR in Kilifi were wells, shafts, dams, percolation ponds and contour trenches. A map was prepared for sites that were found suitable for each structure. Finally an integrated map of the most suitable sites was prepared and used in extensive field survey. With the guidance of two members from the local communities, the pinpointed sites were visited to determine the accuracy of the GIS analyses. Given the likely small scale of the projects due to sparse population and based on available information, a tightly focused surficial mapping was carried out on the several sites recommended for ASR. Operational and non operational water ponds were analysed. Some sites along rivers pinpointed for dam and trench construction were visited and analysed for suitability, slope, capacity and catchment. Abandoned wells were analysed for possibility of recharge using decommissioned injection wells. Due to the need for joint decision making so that conflicts do not arise as well as for utilizing "local knowledge" on the siting and design of structures, discussions on the viability of the various projects were held with the local communities.

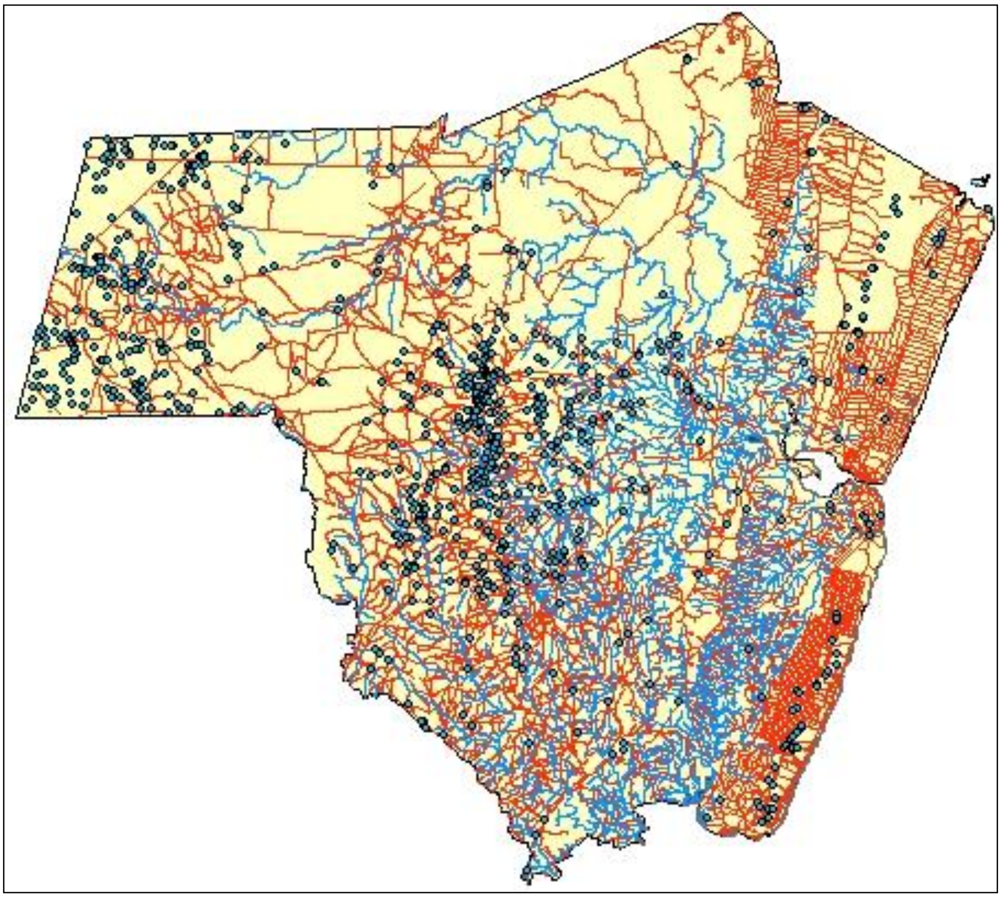

**Figure 3: GIS map combining water wells and pans (dark blue) as points, rivers (sky blue) and roads (orange) as polylines**

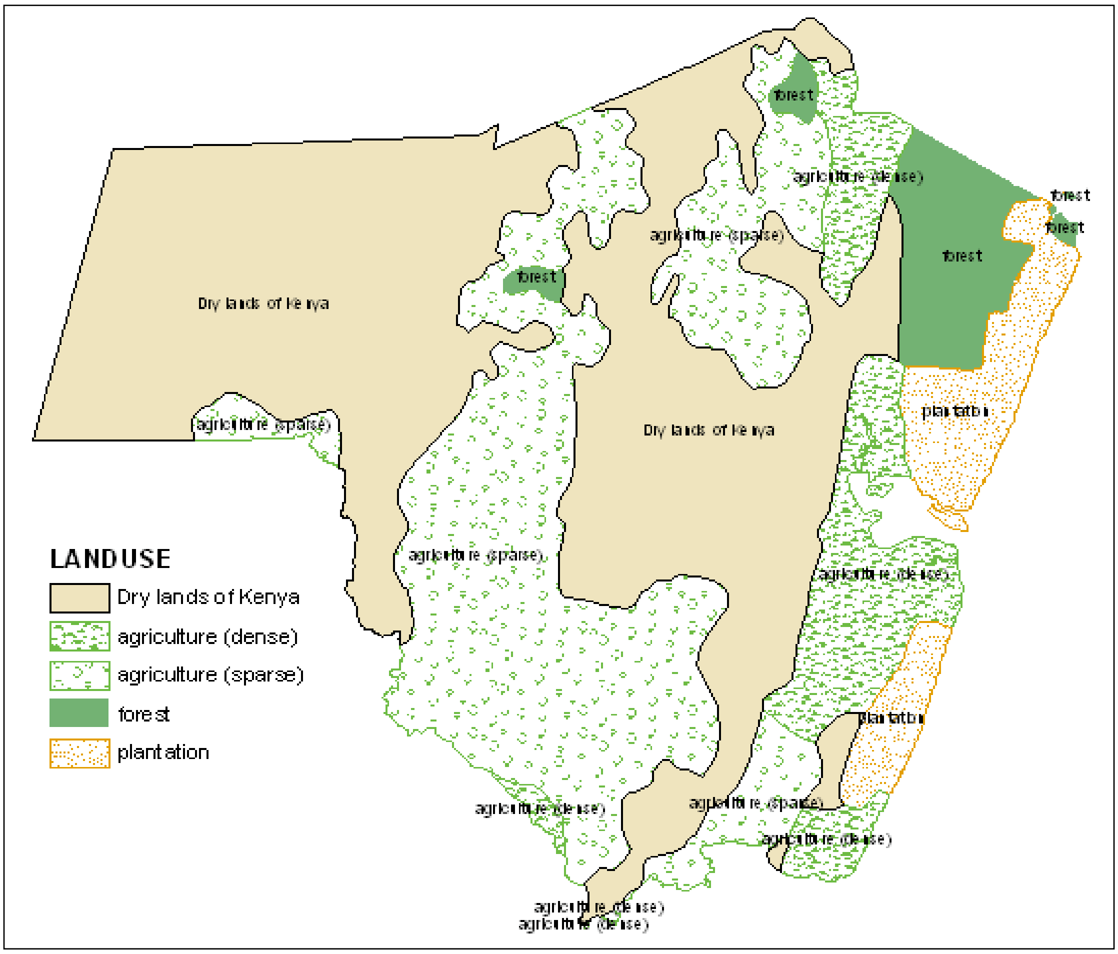


**Figure 4: GIS Land use map digitized as polygons (After Mallo, 1988)**

## 3. RESULTS AND DISCUSSIONS

GIS analyses produced the integrated map that represents sites that can be considered for aquifer storage as shown in Figure 5.

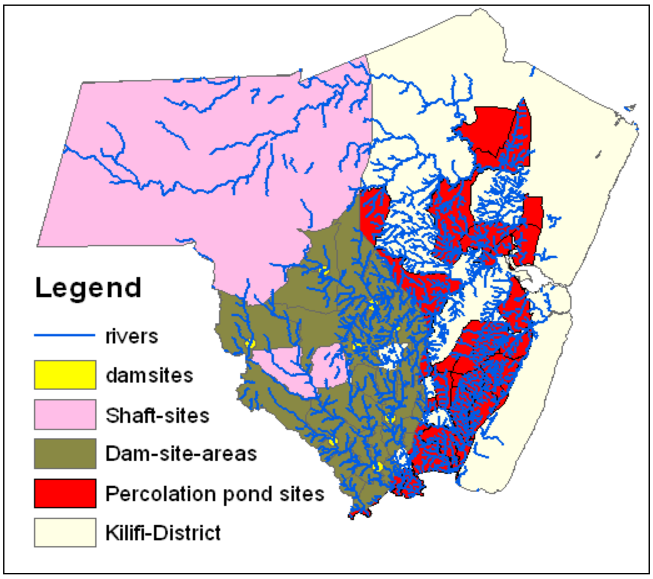


**Figure 5: Integrated ASR map produced from GIS analysis**

The geology of the area comprises coarse, medium and fine-grained sedimentary rocks laid in an aqueous and saline environment. The sediments were laid horizontally but due to subsequent faulting in the North-South direction some aquifers may be slightly inclined. The fault areas can be recognised on the ground surface despite the surface modification that has taken place over time. The boreholes and shallow wells are concentrated in some areas mainly based on the population and/or scarcity of water as can be observed in Figure 3. When bore logs from the same locality were contoured, some general characteristics of the subsurface materials were derived. Table 1 is a summary of aquifer characteristics for large areas in Kilifi District as represented on contoured logs. From the table, it can be noted that storage zones comprise of a broad variety of aquifer lithologies and water storage capability and thus design of ASR facilities will have to be suited to site conditions.

**Table 1: Summarized hydrogeologic conditions in Kilifi District (the locations are mapped in Figure 1)**

| Borehole(s) location | Aquifer (s) | Total aquifer thickness (m) | Water quality and aquifer condition |
|---|---|---|---|
| Vipingo in Chonyi | Coral sandstone, coral sands, gravelly sands | 16 | Good quality, saline with deepening or over pumping, caving formations |
| Roka and Tezo in Ganze | Sand, sandy clay, coral sands | 38 | Saline and bitter water. Salinity increasing with depth. Wells equipped with hand pumps perform better. Caving formations made sampling difficult |
| Kilifi plantations in Kikambala | Blue clay, sand coral | 24 | Good quality, caving problems |
| Bamba | Sandstones/ red shale/ grey gravel or sand | 15 | Saline/bitter water whose yield decreases with time |
| Kituu in Kaloleni | Sandstone (Maji Ya Chumvi Aquifer | | Water had iron taste and was non saline. hydrogen sulphide production on pumping |
| Vitengeni | Sands/sandstones | 40 | Good quality water when sealed at shallower levels |
| Jaribuni in Bahari | Soft sandstones | 8 | Saline, water loss during drilling, Very permeable layer |
| Kaloleni Market | Soft sandstones | 31 | Good but becomes saline with time |
| Mazeras in Kaloleni | Coral sands | 16 | Better water when pumped slowly, Caving formations |

Bore log descriptions for wells drilled within the same period and by the same driller such as the ones at Ganze and Bamba indicate that the strata are generally horizontal though the thicknesses differ from place to place. Encounter of caving formations and water loss during drilling indicates that the subsurface materials are loose and permeable and can easily store and transmit water. These characteristics can also represent fracture/fault zones and weathered old land surfaces. The drillhole logs indicate that most potential storage aquifers contain brackish or saline water while a few contain fresh water. These aquifers are also prone to groundwater decline and elevated salinity due to over-pumping. The potential sites for ASR correspond predominantly with coral sands, gravelly sands or sandstones at depths ranging from 10 to 100 m. The strata above the aquifers are mainly made of fine materials thus acting as barriers to water infiltration. This is the reason behind the unsaturated thick aquifers in Ganze, Vitengeni and Kaloleni and the prevalent wide cracks in buildings. This also implies that the water that is intended for ASR can be highly turbid. Groundwater with high concentrations of total dissolved solids (TDS) may lead to poor quality water being recovered by the ASR well (Pavelic et al., 2002), thereby limiting overall recoverability. Also, high TDS values may cause buoyancy stratification of stored water due to density differences between the ambient brackish groundwater and the recharged freshwater (Missimer et al., 2002).

For the ASR to be successful in Kilifi, water will have to be passed through siltation. The 'dry lands of Kenya' at Ganze and Chonyi (Figure 4) coincide with the largest concentration of seasonal streams with sufficient alluvial deposits and were selected for construction of percolation ponds. Percolation ponds are relatively simple to construct and maintain at high infiltration rates and are also less costly than subsurface methods if sufficient land is available. To construct the percolation ponds, the top layers of soil will be removed to reach more permeable layers in some places as much as 8 m below the surface. The excavated soil will be used to construct earthen berm walls (Flanigan et al, 1995). The size of the ponds can be 100 m by 100 m or more depending in the size of the catchment.

Dams were selected for use in Kaloleni area because of the larger size of the streams and availability of space for construction. The problems that can be foreseen with dam construction are the difficulty in finding the suitable materials for the simplest form of construction: the earthfill dams and also the presence of sensitive and collapsing soils in the vicinity of the selected sites. Concrete dams could be the most appropriate. But for this to be successful, thorough site investigation is recommended, to determine the extent of the sensitive soils as well as physical and mechanical properties of the soils. The dams will be built into a river or streambed that is usually or mostly dry to retain water so that more will infiltrate or percolate into the underlying aquifer. Such areas generally have high infiltration rates because of presence of thick layers of fluvial deposits.

River valleys and regions sloping between 1 and 2% are ideal sites for dams as they normally give the highest water storage (Jansen, 1988). Contour trenches will be created on the downstream area of the dam to divert water during periods of extremely high floods or when the infiltration rate is low. These trenches will lead water from the river into normal earth dams built a distance away on alluvial and permeable strata. The water in the ponds will be used for direct irrigation of crops and thus boost agriculture from 'sparse' to 'dense'. The dams and percolation ponds will thus recharge shallow aquifers and recovery of the stored water will be through adjacent shallow wells.

Percolation pond sites can witness quick regeneration of indigenous trees thereby attracting other biological resources and ecosystems that hitherto faced threats from recurring droughts. The 'Dry lands of Kenya' at Bamba have the largest concentration of water pans (surface basins) and wells that are either non-operational or dry up during prolonged dry weather. The subsoil in this area has very low permeability up to a depth of 30 m. This area was found suitable for construction of a pilot recharge shaft to help recover the groundwater level. Shafts effectively penetrate the less permeable strata in order to access the dewatered aquifer. The rechargeable zone of about 15 m thickness at Bamba does not contain water and thus has room for ASR. The recharge shafts are similar to ponds except that they are smaller in dimension, deeper and usually have sloped sides to increase the rate of recharge. Shafts can be circular, rectangular, or of square cross-section and terminate above the water table level or may be hydraulic connectors and extend below the water table. The diameter/width of these excavations may be 10 m or less whereas the depth will be determined by the depth of less pervious layer. The shafts will be backfilled with boulders, gravels & coarse sand.

Many of the abandoned wells cannot be used for injection or extraction of groundwater because they were either not developed fully or were sealed when water was found to be of no use. Recharge wells could be cased through the material overlying the aquifer and if the earth materials are unconsolidated, a screen can be placed in the well in the zone of injection. In some cases, several recharge wells may be installed in the same bore hole (Dreher and Gunatilaka, 1998). A relatively high rate of recharge can be attained by this method (Stuart, 1988). Injection wells are of 100 to 300 mm diameter, water is passed through siltation ponds or filter media to avoid clogging of injection zone. The depth of injection wells will be determined by the depth of rechargeable aquifer and can be 100-300 m. Costs of construction, operation and water pre-treatment can make this an expensive method of recharge. In addition, recharge volumes are low compared with the other methods, making the unit cost of recharge more expensive. The rate of infiltration of recharge water is also influenced by the soil type and pattern of structures. The subsoil in Kilifi being normally faulted in the north-south direction with throws towards the coast indicates the possibility of structural control of direction of recharge water. When water is recharged, it should be able to infiltrate without forming mounds that can affect structures on the surface or moving away from the structures designed for recovery of the water. Aquifers exhibiting low porosity or those where fluid flow is concentrated in fractures rather than aquifer pore space, may increase groundwater flow velocity or may induce high rates of diffusion (Anderson and Lowry, 2004); either of these phenomena may reduce recoverability of injected water.

The city of San Bernardino in southern California, for example, is on a lowland area several kilometres away from multiple artificial recharge projects that have successfully raised water levels and reduced pumping costs for ground-water users near these projects. Flow of artificial recharge water towards the city as a result of the gradient created has been associated to severe structural and water-related damages (Danskin and Freckleton, 1992).

Recharge rates decrease with time due to accumulation of fine grained materials and the plugging effect brought about by microbial activity (O'Hare et al., 1986). The quality of water may also change if chemicals in the recharge water react with those of the native ground water. It is not possible to fully understand these subsurface conditions before the commencement of ASR projects. Monitoring programs will also help in understanding of the effects of the recharge water on the salinity of the groundwater and more especially on the saline shallow aquifers. Efforts will have to be made to seal off saline deposits overlying rechargeable aquifers. Proper consultations and consensus building among the stakeholders are requisite for winning the commitment, participation and contribution of the beneficiaries for the ASR projects.

## 4. CONCLUSION

With relevant and adequate information about an area, GIS is a useful tool for pinpointing potential sites for aquifer storage. This ensures that during detailed study time is not wasted in investigating areas that are unsuitable and thus allows for more focused investigation of the suitable sites. In this study, detailed investigation determined that many of the sites pinpointed on GIS are suitable for ASR except for those areas where the local people have information that is not in records such as leakage of saline water from upper aquifers and causes of dam failure. To ensure that quality water is delivered to the target aquifer, some measures such as channeling water through siltation ponds to remove the sediments and sealing of upper saline formation will have to be put in place. Because of the non-uniform depth, thickness and physical characteristics of the aquifers as well as the fault pattern, ASR would potentially result in changes in local and regional flow patterns. There is need for joint decision making with the community so that conflicts do not arise and also the need to utilize "local knowledge" together with expert knowledge in sitting, design and maintenance of structures. Once recharge structures are successful, infiltration through the soil profile into the groundwater will increase and it will be important to note any changes in water levels in the existing wells that may not be within the vicinity of the recharged sites but are structurally interconnected. Surface storage will be conducive for regeneration of indigenous trees thus providing both soil and water conservation benefits. It is also envisaged that through ASR, crop production without dependence on rainfall will improve the living standards of the people within the vicinity of the recovery zones and turn Kilifi District to a green environment. However, clogging of the structures by fine sediments and reaction of chemically different waters is likely to occur.

## 5. RECOMMENDATIONS

Because of the unfavorable characteristics such as the presence of salty formations, irregular aquifer system physical properties, sensitive and collapsing fine materials and insufficient information on physical properties of some aquifers, ASR will need to commence in form of pilot projects. Pilot recharge tube wells can be implemented at Jaribuni and Mazeras where very permeable formations are found. A shaft extending to 30 m depth can be constructed at Bamba Market adjacent to depleted dry wells whereas small dams can be implemented in the several locations pinpointed because they can utilize local labour. For large dams, detailed geotechnical investigation is recommended.

## 6. ACKNOWLEDGEMENT

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