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Review of Water Resource Exploitation and Landuse Pressure in the Pangani River Basin

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Abstract—The Pangani River Basin, with a total area of 43,000 km^2 is one of the most important of Tanzania's river basins. Water and arable land are the most important resources. The water balance in the Basin is estimated at about 900 million m^3 per annum. The increasing water demands to meet various socio-economic needs are placing the basin under critical water stress. Irrigation abstraction and evaporative losses at the Nyumba ya Mungu reservoir are the major contributor to the observed water stress in the basin. Deforestation on the highlands and the use of traditional and environmentally unfriendly agricultural practices also have direct impacts on the water retention capability and may significantly contribute to the observed water stress in the basin. In addition, changes in climate regime, due to increasing temperature and reduced rainfall conditions, contribute to the reduced water supply. This coupled with the land degradation problems, has multiple effects on the coastal environments. Management options, using the limited water and land resources more innovatively and sustainably, have been suggested. These options include: 1- reforming the current water rights allocation system, 2- looking for long-term strategies for improving irrigation efficiency, 3- further promotion of innovative agricultural methods and 4- application of modern innovative techniques of water storage such as Aquifer Storage and Recovery (ASR) in preference to surface water storage systems.

INTRODUCTION

Water availability is one of the key issues in many global fora (FAN 2001; GWSP, 2005). The average global water availability reveals declining trends, with a 37% decline per capita availability of fresh water since the 1970s, as population growth and degradation of water supplies outstrips the capacity to develop new sources. The global water system is experiencing drastic changes due to both climatic changes and anthropogenic influence, with water abstraction for irrigation and its impoundment by damming being among the leading anthropogenic activities responsible for the changes (GWSP, 2005).

In Tanzania, the major reasons for water abstraction stem mainly from the need to improve national food security and the uncertainty of the rain-fed agriculture due to the deterioration of the rainfall conditions. Irrigation was therefore considered to be a viable solution for stabilizing and boosting agricultural production in Tanzania (Kalinga and Shayo, 1998).

Water impoundment by damming is driven by the ever-increasing demand for electricity due to demographic growth and national economic reforms and constitutes the most important motives for damming in Tanzania (URT, 1997). The estimated total energy consumption of Tanzania is more than 22 million tonnes of oil equivalent (TOE) or 0.7 TOE per capita, and is dominated by biomass-based fuel, comprising charcoal and fuelwood. Hydropower, coal, natural gas, solar and wind power and geothermal energy, which are

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currently highly under-utilized, are considered as potentially abundant energy sources (Kitova, 2003). Damming is considered to influence major reforms in the Tanzania's energy sector. The hydropower potential, estimated to be 4.7 GW but with currently only 10% utilized (Kitova, 2003), is considered to be a viable solution for boosting Tanzania's national energy capacity as well as reducing the usage of biomass fuel which has negative impacts to the environment (URT, 1997). Unsustainable use of biomass fuel potentially leads to increased land degradation problems with multipliable effects on water resource availability and people's livelihoods.

The scope and objectives of the study

Previous studies by Shaghude (2004a, 2005) provide a detailed account of the anthropogenic and environmental issues of the adjoining Rufiji basin in the context of past and present catchment pressures due to natural climatic change, land-use change and water impoundment by damming and its abstraction for irrigation. The focus of the present study is on the PRB (Fig. 1). The study reviews published work on the PRB in order to: 1- highlight related upstream anthropogenic and climatic issues and their linkage to coastal erosion north of Pangani river and saline intrusion at the Pangani estuary (Shaghude, 2004b), and 2- to recommend policy management options for the PRB.

THE STUDY AREA

The study area

The Pangani River Basin (PRB), with an estimated area of 43,000 km² (IUCN, 2003; Turpie *et al*, 2003), is one of the most important freshwater resources in Tanzania (Fig. 1). Some 5% (3,914 km²) of the basin lies in Kenya, but 95% of the basin is in Tanzania, spreading mainly over three administrative regions, Arusha, Kilimanjaro and Tanga. The main sources of flow to the Pangani

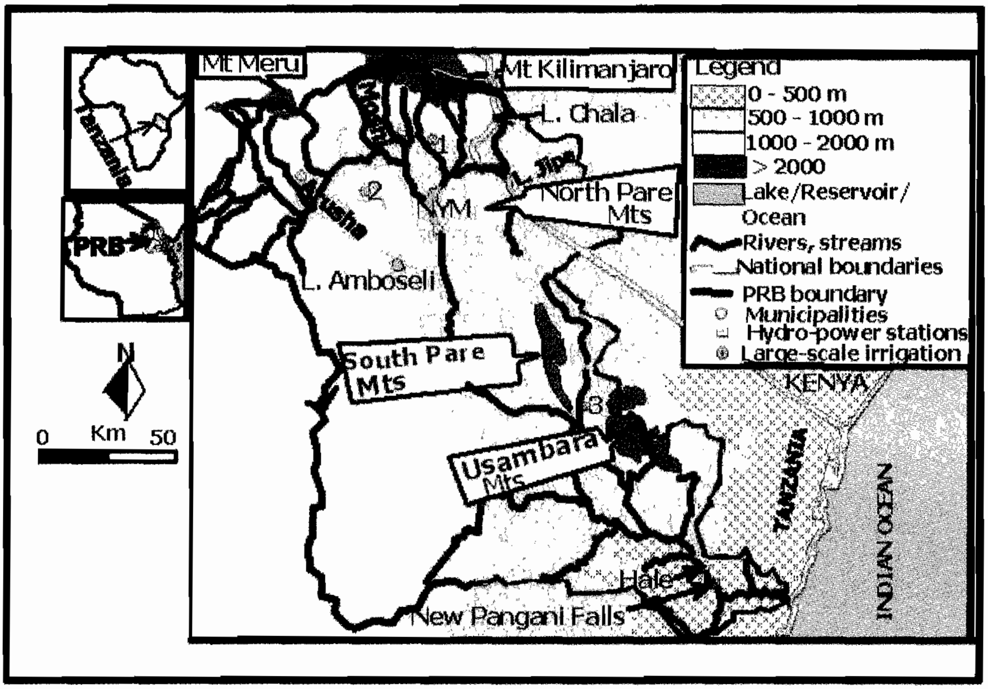

Fig. 1. Map showing the location of the Pangani River Basin, its boundary and important basin features, namely, main river tributaries, mountain ranges, lakes/reservoirs, locations of hydropower stations and major Large-scale irrigation schemes (1 = Lower Moshi, 2 = Ndungu and 3 = TPC. Observe the Kikuletwa and Ruvu tributaries feeding the Nyumba ya Mungu (NYM) reservoir from northwest and northeast, respectively

are the mountains of Kilimanjaro and Meru through the Ruvu and Kikuletwa tributaries, respectively, with additional flow sourced from the Pare and Usambara mountains.

The PRB has several small lakes (Fig. 1), Jipe, Amboseli and Chala, but the Nyumba ya Mungu reservoir, with a total surface area of 15,000 ha, a maximum water depth of 40m and a storage capacity of 875 Mm^3, is the most important surface freshwater storage in the Basin. Several wetlands also exist in the basin, namely, the Kirua swamp (about 900 km^2 or 90,000 ha), located at the downstream end of Nyumba ya Mungu, the Ruvu swamp, about 35 km^2 (3,500 ha), located immediately south of the Ruvu tributary at Lake Jipe, and another, about 40 km^2 (or 4,000 ha) located at the confluence of Ruvu and Kikuletwa rivers.

Geomorphologically, the Basin constitutes of two units, namely, the highlands and the lowlands also called the "Maasai steppe". The highlands, which comprise of steeply sloping mountain terrain rising from 1,000m to over 2,000m above sea level (Fig. 1), are characterized by abundant rainfall (1,200-2,000 mm), high biodiversity, intensive cultivation, urbanization and densely populated rural areas. The highlands hold more than 80% of the basin's inhabitants (IUCN, 2003) and annual population growth rates reach 4%. The lowlands, which comprise of low sloping terrain generally below 1,000 m descending to the coastal plain (Fig. 1), receive relatively low rainfall (<500 mm per year), and are characterized by low species biodiversity, scattered croplands, arid rangelands and smaller settlement areas. The population growth rates on the lowlands are close to 2% in average. The coastal plain, with its eastern African coastal and mangrove forests both of which are characterized by high species biodiversity, is an exception as it is characterized by high species biodiversity and high rainfall.

ANTHROPOGENIC PRESSURE ON THE PANGANI RIVER BASIN

The PRB is endowed with a wide array of resources, including water, arable land, forests, minerals and fish. Of these, water and arable land are by far the most important, directly or indirectly supporting the livelihood of most of the basin's inhabitants (IUCN, 2003). The expanding human population is increasingly intensifying the pressure on the available resources, resulting in conflicts and threats to environmental and future livelihoods of the people (GIWA, 2004; Payet and Obura, 2004). The pressure on the woodlands for instance poses significant threat to biodiversity and the water resource, with associated multipliable effects on the people's livelihoods (CEP, 1995). Moreover, the increasing pressure on the arable land leads to increased land degradation, which in turn leads to lower farming yields, which again leads to increased poverty level (CEP, 1995).

Population pressure

Historical analysis of the population statistics for the combined totals of the three administrative regions (Arusha, Kilimanjaro and Tanga), whose boundaries roughly approximate the PRB boundaries, show higher population growth rates between 1967-1988 than 1988-2002 (Fig. 2). The average annual population growth rates during 1967 and 1988 was about 6.6%, which decreased to about 1.0% after 1988. The low population growth rate after 1988 could be the result of the increased pressure on the arable land, which in turn had been the major impetus for emigration of people especially from the Kilimanjaro Region (URT, 1998; 2002a). According to URT (1998, 2002a), the Kilimanjaro Region has the highest negative net lifetime migration in Tanzania. This is mainly attributed to the fact that the two major ethnic groups in Kilimanjaro (the Wachagga and Wapare) have the tradition of seeking green pastures, and with the increasing pressure on the available land resource in the region, people with insufficient land were forced to seek alternative livelihoods options elsewhere in Tanzania (URT, 1998, 2002a). Seasonal emigration is also a common phenomenon in the Kilimanjaro Region, where the people seek supplementary livelihood options in other parts of Tanzania, but still maintain close ties with the land they own in the village regardless of its size (William, 2003). Such people usually pay periodic visits to their home villages, particularly during Christmas and New Year holidays, and also periodically send remittances

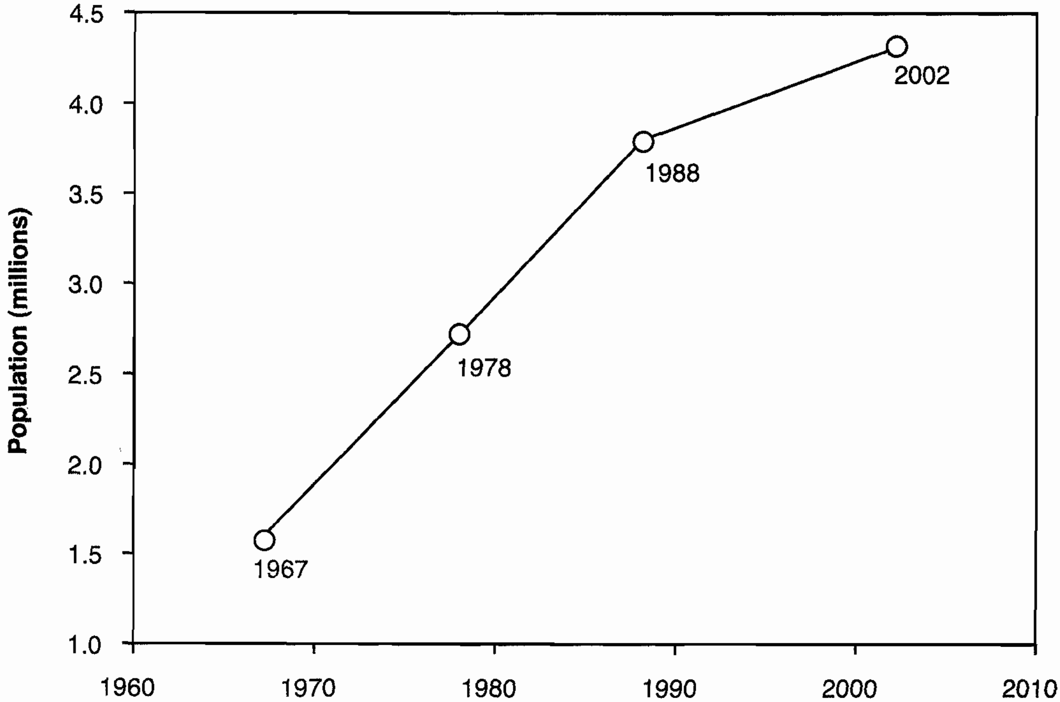

Fig. 2. Population statistics for the Pangani River Basin, represented by the population figures from three Administrative Regions (Arusha, Kilimanjaro and Tanga). Source: Regions of Tanzania - population history, http://www.statoids.com/utz.html

back home to serve the family and for attending their small farmlands.

Other studies show the population distribution in the basin has been highly influenced by the natural climatic and soil conditions and the advent of foreigners from Europe during colonial times (IUCN, 2003). The highlands, characterized by volcanic rich soils and abundant rainfall, have a high population density (700-1000 people per km^2) and support agriculture. The lowlands, in contrast, characterized by semi-arid climate and higher likelihood of exposure to natural calamities such as floods, have a low population density (<50 people per km). Farming intensity in the highlands was further increased by the advent of foreigners as a significant proportion of farmland was alienated to foreigners for plantation farming. On the Kilimanjaro highlands, the average landholding in 1943 was about 1.2 ha per household; this has since decreased to an average landholding of 0.6 ha per household (IUCN, 2003). Lowland landholdings farm are currently estimated at 10.5 ha per household. However, as plot sizes on the highlands approach the limit of viability to provide a livelihood, and soils have become exhausted by excessive cropping and irrigation, observations reveal that more and more people from the highlands are compelled to seek farmlands on the lowland areas and intensify the landuse pressure on the lowlands as well (IUCN, 2003).

Livestock

There are no historical records showing the growth of the livestock population in the basin, but the 2002 estimate indicates about 2.8 million cattle, 2.0 million goats, 1.2 million sheep and 12,000 donkeys (IUCN, 2003). Other studies report that cattle, sheep and goats have generally decreased in the highlands over the last three decades, due to conversion of open pasture areas to agricultural land (Yanda and Mpanda, 2001). The expanding livestock population may also potentially increase the pressure on the available water resource due to land degradation problems associated with large number of livestock, as has happened in the Great

Ruaha River of the Rufiji River Basin (Shaghude 2005).

Available water resource and its demands

The rainfall on Mount Kilimanjaro provides 1,600 million m^3 of fresh water annually (Hemp, 2005), 31% of which (or 500 million m^3) runs off in streams or percolates into groundwater. Other studies report that the rainfall on Mount Kilimanjaro provides about 55% of the surface water flow in the PRB and 60% of the inflow to Nyumba ya Mungu reservoir (IUCN, 2003). The contribution of other mountains to the surface and groundwater resources in the basin is estimated at 45% (equivalent to 400 million m^3 per year), suggesting that total available water in the basin is about 900 million m^3 per year.

Two types of irrigation systems have evolved in the PRB, large-scale irrigation systems (Fig. 1) located exclusively in the lowland areas where inadequate rainfall requires farmers to irrigate, and small-scale traditional irrigation systems, typically found in the highland areas because of the need to maximize yields in the small farm size. Most of these small farms are usually cultivated during both the rain season (where the farmers utilizes the rains for increasing farming productivity) and the dry season (where the farmers uses the irrigation water for farming productivity).There are no quantitative data revealing the historical development of the irrigated land area and the information concerning the current total area under irrigation in the Basin is unreliable. While Mujwahuzi (2001) presents an estimate of 40,000 ha for farmland currently irrigated in the Basin (cited in IUCN, 2003), the Kilimamjaro Region socio-economic profile of 1998 shows that there are about 52,000 ha under traditional irrigation system in Kilimanjaro region alone (URT, 1998), suggesting that the figures from Mujwahuzi (2001) were significantly under-estimated.

Most of the large-scale irrigation schemes were developed either during colonial times or after independence. Irrigation is practiced through efficient drip irrigation, utilizing large quantities of water due to large farm sizes and farming of water intensive crops such as rice. One of the largest of these schemes is the Lower Moshi Irrigation Scheme (Fig. 1), of about 5,300 ha (URT, 1998; Belden *et al.*, 2004). Other large-scale schemes include the Tanganyika Planting Company (TPC) located in Moshi (13,000 ha), the Ndungu Irrigation Project (about 4,000 ha), mainly for rice farming, and a few coffee plantations such as Burka (600 ha), and Kahawa Estate (55 ha).

The traditional irrigation systems date back to pre-colonial times where irrigation is facilitated through an extensive furrow network (about 2,000 furrows in total) with total length of 1,800 km (Makule, 1998; IUCN, 2003). Up to until 1990s, these furrows, which used to be unlined, were associated with significant water wastage (up to 85%), mainly through leakage and evaporation (Makule, 1998). The irrigation abstraction systems (large-scale and traditional) are estimated to use at least 400 Mm^3 per annum (IUCN, 2003).

The second major demand for the available water in the PRB is for hydroelectric power production. The PRB, contributing about 17% of the total available hydroelectric power in Tanzania, has three hydropower stations. The Nyumba ya Mungu dam, commissioned in 1968, is a storage reservoir for the power plant at Nyumba ya Mungu (8 MW) and two other power plants, Hale (21 MW) and New Pangani Falls (66 MW) located further downstream (Fig. 1). A minimum river flow of about 43 m^3/s is required for operating the plants, but recent studies report that, the Nyumba ya Mungu reservoir is unable to release more than 22 m^3/s (equivalent to 693 million m^3 per year) and often the flow may be as low as 15 m^3/s (equivalent to 473 million m^3 per year) limiting the hydropower production to as little as 37 MW (IUCN, 2003). This has an over all impact on the National Electric Grid system, which at times is compelled to impose severe power rationing country-wide especially when parallel hydropower shortage occur at Kidatu and Mtera in the Rufiji Basin.

Although the volume of water abstracted from the Pangani (between 493 and 693 million m^3 per year) to run the turbines is significantly high, the abstracted water eventually returns to the river and the water usage in this sense is non-consumptive. However, the impounded water at the Nyumba ya Mungu reservoir is subjected to significant evaporative losses due to its large surface area and geographic location in a region where temperatures are high. The evaporative losses constitute at least 30% of the total inflow to the reservoir (URT, 2002b). The total inflow to the Nyumba ya Mungu is estimated at 43.37m^3/s (TANESCO, 1994, cited in IUCN, 2003), suggesting that evaporative losses can be estimated at 13.0m^3/s or 410 Mm^3 per year. Other water demands in the basin are considered to be insignificant (Table 1). Thus, the discussed water balance shows that, the basin is currently experiencing critical water stress, with the needs of irrigation and hydropower being the dominant contributors to this situation.

Table 1. Estimated non-irrigation abstractions in the PRB after IUCN (2003)

Water usage	Annual water demand (M m^3)	
	1995	1915
Urban	26.0	60.0
Rural	19.0	30.5
Livestock	11.0	13.3
Total	56	103.8

OTHER PRESSURES ON THE PANGANI RIVER BASIN

In addition to the direct human pressures discussed, the basin is also affected by global or regional climatic changes, which significantly contribute to the observed trends in the water resource depletion and the degradation of the ecological and physical environments. Direct evidence for climatic pressure on the PRB is derived mainly from the historical pattern of rainfall and temperature records. With regard to temperature, 25 years (from 1970) of temperature records from nearby Lake Amboseli (Fig. 1), indicate an increase of mean daily maximum temperature at a rate of 2.75°C per decade (Agrawala *et al.*, 2003). These data are generally in line with the temperature maps of Hay *et al* (2002) in the Kilimanjaro area for the period between 1941 and 1995 (Agrawala *et al.*, 2003). In addition, rainfall data from four meteorological weather stations (Table 2) located on Mount Kilimanjaro reveal declining rainfall trends of between 2.5-12 mm per year at least during the last 60-100 years; suggesting a decrease of at least 250 mm of total annual rainfall per century. The vanishing glaciers on Mount Kilimanjaro are independent striking evidence for changing regional climatic conditions. In the year 2000, the areal extent of glacier cover on the mountain's highest peak was estimated at about 2.6 km^2 (Thompson *et al.*, 2002), reduced from 4.2 km^2 in 1972 (Hastenrath and Crescher, 1997) and 12 km^2 in 1912 (Oehler, 1912, cited in Thompson *et al.*, 2002). The distribution of moraines reaching down to an altitude of 3000 m is pointed as evidence that a much greater area of the mountain was formerly covered by ice during the ice age (Hastenrath, 1984). The earliest well-documented map of the ice fields on the peak of Kilimanjaro was made in 1912 revealing that 82% of mountain glacier area has been lost between 1912 and 2000 (Thompson *et al.*, 2002) and extrapolation of the changes in glacial coverage using the above data (for the years 1912, 1972 and 2000) show that the ice cap on Kilimanjaro will have disappeared before 2040 (Fig. 3).

Other large landscape changes that are indirectly linked to changing weather conditions include a significant increase in the number and intensity of wild fires on Mount Kilimanjaro. Although most of these fires are lit accidentally during human activities such as honey collection, poaching, grass burning during forest clearing for agricultural expansion (Agrawala *et al.*, 2003;

Table 2. Rainfall trends from four meteorological stations on Mount Kilimanjaro (with altitude given above sea level)

Station (altitude)	Span of data	Data source	Declining rate per year
Moshi (830 m)	1902 - 2004	Hemp (2005)	3.84 mm
Kilema (1430 m)	1911 - 2004	Hemp (2005)	5.72 mm
Kibosho (1430 m)	1922 - 2004	Hemp (2005)	12.02 mm
Lyamungo (1200 m)	1935 - 2000	(Agrawalar *et al*, 2001)	2.6 mm

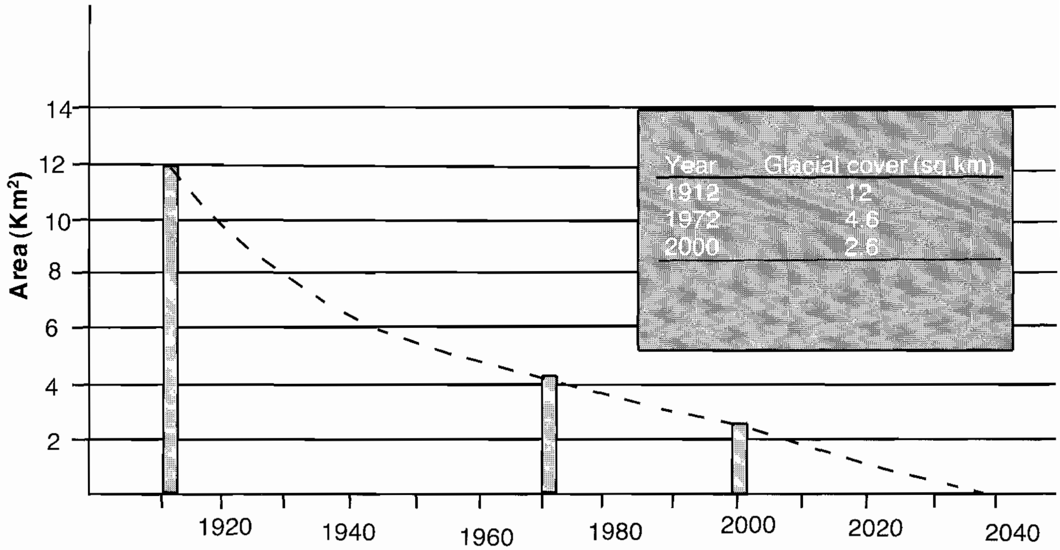

Fig. 3. Estimated glacial cover on Mount Kilimanjaro as a function of time. Note that the glacial cover is projected to have disappeared before 2040. The figures shown for the years 1912, 1972 and 2000 are from Thompson *et al.*, 2002

Hemp, 2005), their devastative effects are amplified by the dry weather conditions. The resulting landscape changes due to fire incidents and other human activities such as forest clearing for agriculture are in turn believed to have close linkages with the glacial recession on Mount Kilimanjaro. The loss of foliage causes less moisture to be pumped into the atmosphere, leading to reduced cloud cover and precipitation and increased solar radiation and glacial evaporation (Agrawala *et al.*, 2003).

STATE CHANGES AND ENVIRONMENTAL IMPACTS

Paralleling the cited anthropogenic and climate-related pressures on the catchment, significant changes have been observed on the basin's forests, comprising the afromountane forests, coastal forests, mangrove forests, Miombo woodland and riverine forests (IUCN, 2003). Of these, the afromontane forests located on the highlands are considered to be of greatest importance. This is due to their high level of endemism and high ability to deliver water (IUCN, 2003). In addition these forests support a wide range of socio-economic activities, including fuelwood and fodder collecting, charcoal and timber production, and honey harvesting. The increasing deforestation due to human pressure threatens both the future availability of the forest resource with its associated ecological biodiversity and its water retention capability for supporting the livelihood of people. While there are no quantitative estimates on water losses due to deforestation, there are some quantitative data on the extent and trends of deforestation in some parts of the Basin.

Despite the conservation efforts that have been undertaken, the forests are increasingly being threatened by human encroachment due to logging, agricultural expansion and settlements (Yanda and Shishira, 2001). The PRB is part of the larger Eastern Arc Mountain ranges which stretches from the Tanzania-Zambia border, through northeastern Tanzania and southeastern Kenya. It is believed that 77% of the forest cover on the Eastern Arc Mountain ranges has been lost during the last 2,000 years due to human encroachment (Newmark, 1998, cited in IUCN, 2003). Around Kilimanjaro mountain region, human encroachment due to logging, agricultural expansion and settlements has been paralleled by significant changes of the land cover (Yanda and Shishira, 2001). While at least 41 km^2 of natural forest (Fig. 4-a) disappeared between 1952 and 1982 (Yanda and Shishira, 2001), other significant changes are also evident on the other landcover types, namely the woodlands (Fig4-b), bushlands (Fig. 4-c) and grasslands (Fig. 4-d). The fast declining trends on some of these resources such as the forest plantations (Fig. 4-a), closed woodlands (4-b) and dense bushlands (Fig. 4-d) could be closely linked with the rising trends of woodland with scattered cultivation (Fig. 4-b), bushland with scattered cultivation (Fig. 4-c) and grassland with scattered cultivation (Fig. 4-d). Assuming that the observed trends between 1952 and 1982 continued unabated up to present, the declining trends of these resources calls for better management initiatives to rescue the diminishing resources.

Another change, directly linked with the cited anthropogenic and climatic pressure on the Basin, is the modification of stream flow in many parts of the PRB, including the Kikuletwa River (Fig.

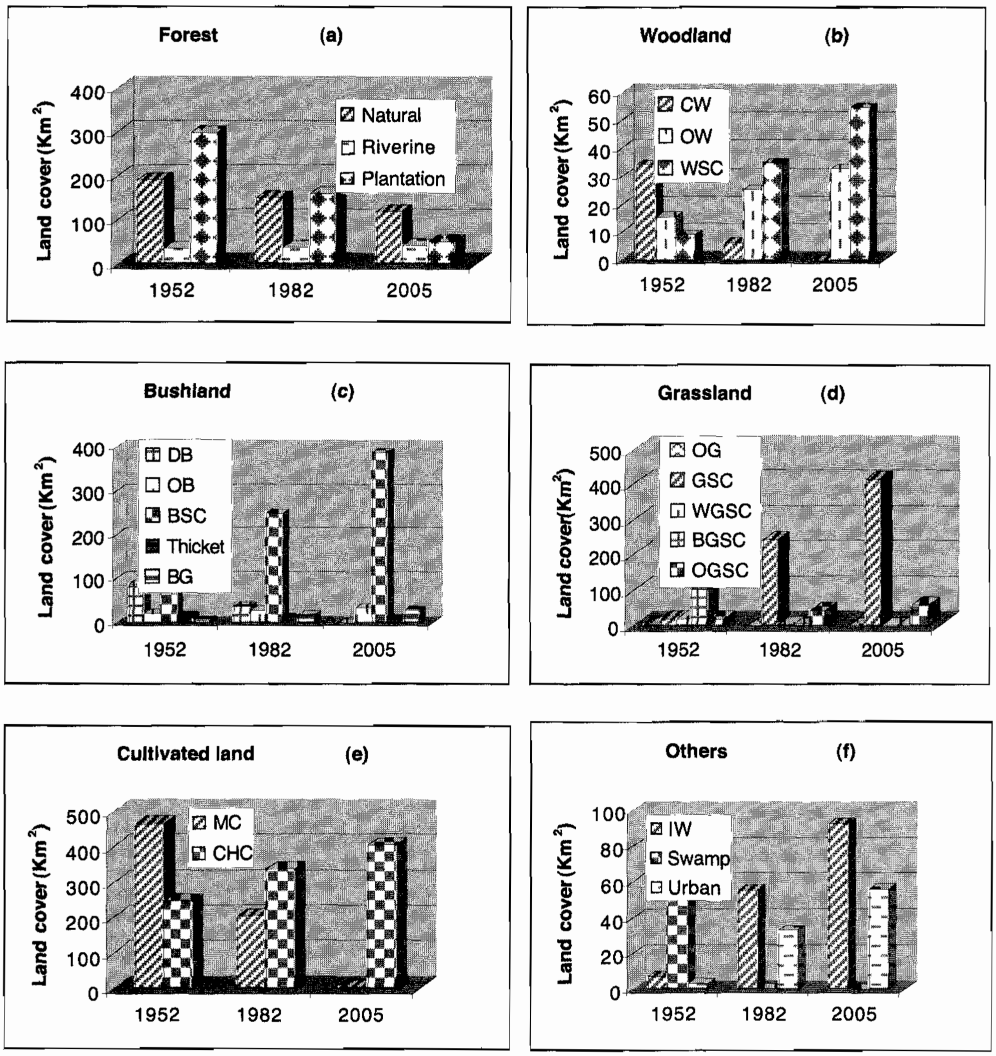

Fig. 4. Landcover changes on the southern slopes of Mount Kilimanjaro between 1952 and 2015. The data for 1952 and 1982 are obtained from Yanda and Shishira (2001) while the extrapolations for 2005 were done by this study. CW = Closed woodland, OW = Open woodland, WSC = Woodland with scattered cultivation, DB = Dense bushland, OB = Open bushland, BSC = Bushland with scattered cultivation, BG = bushed grassland, OG = Open grassland, GSC = Grassland with scattered cultivation, WGSC = Wooded grassland with scattered cultivation, OGSC = Open grassland with scattered cultivation, MC = Mixed cultivation, CHC = Cultivation with herbaceous crops and IW = Inland water

1) and even the main Pangani river at Hale (Yanda and Mpanda, 2001; GIWA 2004; Belden *et al.* 2004). Studies on the Kikuletwa river (Yanda and Mpanda, 2001) show that, while the wet season discharge may be more or less stable, the dry season flow shows reduced trends, suggesting that the flow is associated with irrigation abstraction, which mainly occur during dry seasons. As for the main Pangani River, it is reported that the flow has decreased over the last four decades from several hundreds to less than 37 m^3/s (UNEP 2004; Belden *et al.* 2004).

Siltation in the lakes/reservoirs, generally linked with upstream anthropogenic activities, is another major change within the PRB. In Lake Jipe the high level of siltation has significantly reduced the lake depth (GIWA, 2004). As for the Nyumba ya Mungu dam, siltation is also reported to be very high (GIWA, 2004), but due to its large storage capacity, reduction in the lake's volume is not currently an issue of concern. However, linkages between siltation in the Nyumba ya Mungu reservoir and the observed coastal erosion problem at the Pangani delta have been reported by other studies (e.g. Shaghude, 2004b).

Coastal erosion is one of the major environmental issues of concern in the Pangani delta (Shaghude, 2004b) and also in Kigombe, located about 20 km north of Pangani river mouth (UNEP, 2004; Nyandwi, 2004). Serious erosion at Pangani is reported to have started in the 1960s and the coastal section (Fig. 5) is currently eroding at the rate of 7-20 m per year (Shaghude, 2004b). The beach dunes at Kigombe village are also reported to be eroding very rapidly, where the village has been reduced to less than 50% during the last 70 years (Nyandwi,2004). Although high wave activity implicated as the major causative factor of this coastal erosion (Shaghude, 2004b; UNEP, 2004), it is believed to be exacerbated by the upstream damming at Nyumba ya Mungu (Shaghude, 2004a), which traps more than 50% of

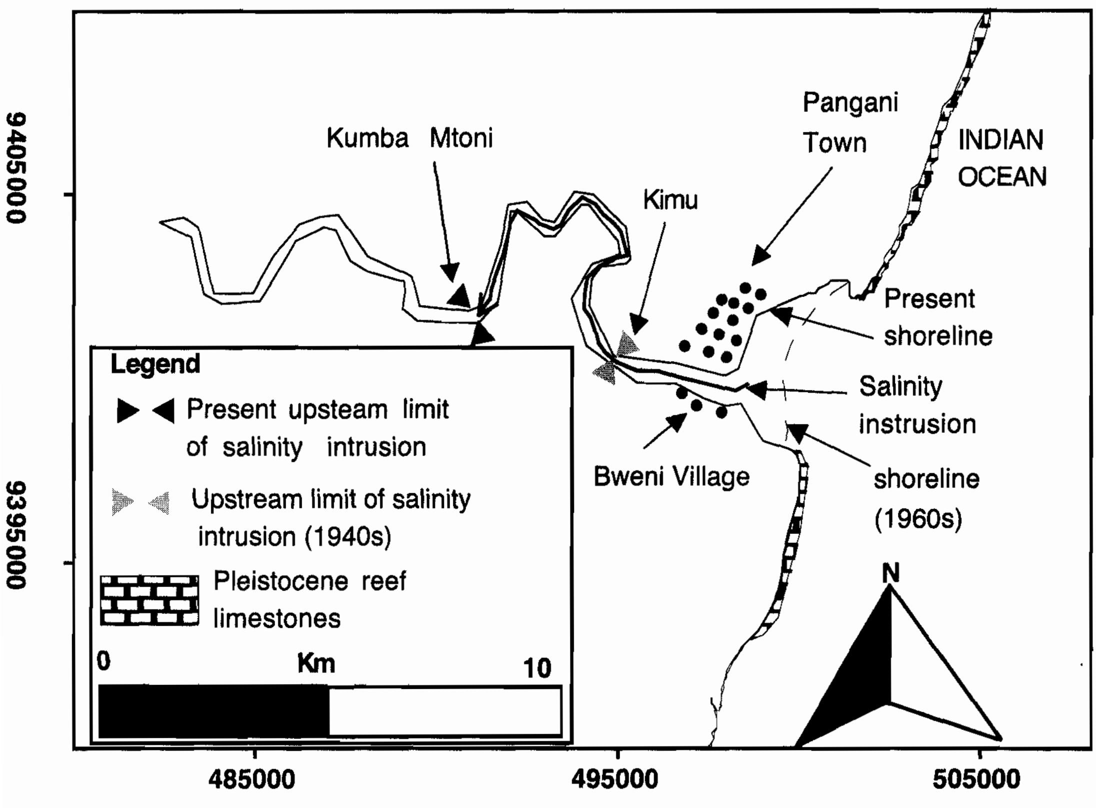

Fig. 5. The Pangani river estuary showing the current extent of salinity intrusion and extent of shore erosion since 1960's

the upstream sediments where the erosion rate is estimated at 24t/ha/yr (Ndomba, 2002). Moreover the timing of the damming at Nyumba ya Mungu correlates well with the historical data on observations of serious coastal erosion at Pangani and Kigombe sites.

Saltwater intrusion and salinisation of the coastal soils is another issue of socio-economic concern in the Pangani area, currently affecting the livelihood of local farmers (IUCN, 2003). Salinity intrusion in the vicinity of Pangani is also believed to have increased significantly during the last 60 years. Pangani Town residents interviewed during the study of Shaghude (2004b) report that, 60 years ago, crocodiles were common at Kimu located about 4 km upstream of the Pangani river mouth (Fig. 5). Today the crocodiles have been forced to move further upstream to Kumba Mtoni, as they cannot tolerate brackish water conditions (Shaghude, 2004b). The increasing trends of the salinity intrusion and salinization of the coastal soils is most likely linked with the decreasing trends of the Pangani river fresh water flow due to the increasing human pressure upstream.

RECOMMENDATIONS AND CONCLUDING REMARKS

It is apparent that the PRB is currently under critical water stress, resulting from both anthropogenic and other pressures with abstraction for irrigation and evaporative losses in the Nyumba ya Mungu reservoir the principal contributors. Little is currently known of the amount of water lost due to landuse changes as a result of human encroachment, however, it is evident that this has significant contribution to the current water stress in the basin. Other important factors contributing to water stress are climate changes especially decreasing rainfall and increasing temperature conditions.

Anthropogenic pressures can be minimized by implementing better management strategies and since water and arable land are the most important natural resources in the Basin, the management options should focus on using the available water resource more efficiently than it is being currently used, as well as using the available arable land more effectively.

Since the 1990's some management options have been instituted in the PRB to minimize water losses by irrigations, these include: 1- Allocation of water rights and 2- Improvement of the irrigation efficiency in the furrow networks. Following the establishment of the Pangani Basin Water Office (PBWO) in 1991, water right 'policy' was exercised as one of water conservation strategy. With this policy, water users are legally obliged to hold water rights issued by the PBWO, the cost of which depends on the type of the water use (Mujwahuzi, 2001). The main concern of the policy was to control the abstractions in the Basin, to ensure that adequate water would be available to the farthest downstream users, especially in the hydropower sector, which is of national interest. However, the policy faced major resistance from the traditional irrigational water users, who often were reluctant to apply for the water rights, believing that water is a gift from God. Illegal water abstractions (Table 3) are therefore reported to be significant (Makule, 1998). The legal and illegal water abstractions had each the capacity to abstract $30.7m^3/s$ and $40m^3/s$ (Mujwahuzi, 2001) respectively. Currently, there is not enough water to meet the increasing demand in the PRB (GEF, 2006). The water allocations set by the PBWB are generally influenced by the government interests and underscores the local community participation in water resource management. Lack of satisfactory technical information to guide the PBWB in setting water allocations to various users is also another issue of major concern (GEF, 2006). In a water stressed system such as the PRB, the water allocations need to be reviewed from time to time on the basis of the changing river flow regime.

Improvement of the irrigation efficiency was another water management strategy addressed by

Table 3. Legal and illegal water rights in the PRB: Source (Mujwahuzi 2001 cited in IUCN, 2003)

Region	Legal water rights	Illegal water rights
Kilimanjaro	431	1,497
Arusha	291	96
Tanga	202	501
Total	1028	2,094

the PBWO. In order to minimize water losses, control gates were installed at specified locations along the furrow network system and linings were introduced at some furrows to minimize seepage losses. These two measures aimed at improving irrigation efficiency from 20 to 50% (Makule, 1998). Due to the severity of the water stress problem in the PRB, the measures to improve irrigation efficiency from 20 to 50% should only be taken as short-term measures. Thus, the ultimate goal should be to have other long-term solutions, such as conversion of the furrows to pipeline networks. This would minimize not only the water losses due to seepages but also the evaporative losses in the transportation networks.

Other water management options which are recommended for integration in the PRB water management policy include: 1- measures to promote farming practices which are associated with minimum water losses (particularly in the mountainous areas), and 2- application of modern innovative techniques of water storage such as Aquifer Storage and Recovery (ASR).

Most of the farming practices currently in use were developed at times when both the water and land resources were considerably more abundant than they are now (IUCN, 2003) and given the current situation where both water and land are fast diminishing, most of the farming practices are no longer sustainable. Better farming practices, such as contour stone bunding, tied contour ridges, terrace farming and others should be promoted. In contour stone bunding stone bunds are laid along contours. The tied contour ridges consist of small earthern ridges of about 15-20 cm high, with an upslope furrow to accommodate runoff from a catchment's strip between the ridges. The terrace farming consists of a series of step like benches which are constructed along the sloping farm. For a detailed description of these farming practices and others the reader should see Critchley (1991). These farming techniques are already partially practiced in the PRB (pers. obs.), however, the extent of their applicability is not yet satisfactory. Promotion of these techniques in the PRB, would not only minimize water losses from agricultural irrigation, but also water run-off during the rains and soil erosion from the farmlands, thereby significantly reducing the farmland degradation problems and other associated downstream impacts such as siltation in dams.

ASR is one of the modern innovative techniques of water conservation which is increasingly receiving a wide attention in many developed countries such as United States, United Kingdom, Australia, Canada, South Africa and Israel, (ASR, 2004). The ASR refers to the process of recharge and storage of water in an aquifer system during times when water is plentiful and recovery of the stored water during times when it is needed (Pyne, 1995). Surface water is conveyed, via infiltration basins or injection wells, into sub-surface space (an aquifer) for storage and then pumped out when needed. The aquifer essentially functions as a water bank, where deposits are made in time of surplus, typically during rain season, and withdrawals are made when available water falls short of demand (Ecology, 2006). ASR is considered to be an attractive option to conventional surface storage in dams and reservoirs, as land-surface requirements for ASR implementation are significantly lower than for surface storage (BEST, 2001, Vecchioli, 1999). This is particularly important in areas where land is scarce or the price of land is high (BEST, 2001); in addition evaporative losses are generally non-existent in ASR systems (Nguyen and Mueller, 1996).

In the water budget of the PRB, the evaporative losses from the Nyumba ya Mungu reservoir constitute a very significant proportion and require further research. Feasibility studies in the PRB to explore whether ASR would be economically viable are therefore recommended and as the PRB is one of Tanzania's river basins, with highest amount of groundwater potential (Makule, 1998), further monitoring and research conducted over the long term is urgently required.

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