Understanding Watershed Dynamics and Impacts of Climate Change and Variability in the Pangani River Basin, Tanzania

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ABSTRACT

Watersheds and rivers are vital ecological features for the provision of hydrological services for the health, welfare and prosperity of human communities. Nevertheless, anthropogenic activities coupled with climate change and climate variability are blamed to have degraded watersheds and rivers and lowered their capacity to water. To restore the situation it is important to understand why and how water shortages are occurring. This paper reports findings of a study carried out to identify and assess drivers of water shortages and adaptation strategies to climate change and variability in Pangani River Basin of Tanzania. To assess the influence of climate change and variability on hydrological flow and water shortages, time series data on rainfall and temperature were compiled from the Tanzania Meteorological Agency. We also used structured questionnaires to collect data on villagers' perceptions about the drivers of water shortages and adaptation strategies. Results indicated a decreasing trend of water flow ($p < 0.05$) at Kikuletwa-Karangai gauging station along Pangani River Basin. Trend analysis indicated a slight decrease of rainfall and increase of temperature. Although there are no empirical evidence to associate climate change with the decline of rainfall and water flow, adaptation measure need to be put in place in order to fight against the increasing climate variability, reduced water flow and the projected climate change. Therefore, watershed conservation strategies should also focus on improving the welfare of the local communities. Therefore, involvement of stakeholders in the entire PRB is crucial towards watersheds conservation for steady flow of hydrological services.

Key words: *Water, Ecosystem services, Watershed degradation, Climate variability, Pangani River Basin*

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1.0 INTRODUCTION

Watersheds and rivers are vital ecological factors for the provision of ecosystem services (ES) for human consumption and ecological integrity (Costanza et al., 1997; Daily, 1997; De Groot et al., 2002; Landell-Mills and Porras, 2002; MEA, 2005). Providing water is an essential service by virtue of its integral role for domestic uses, hydro-power generation, industrial use, irrigation, and livestock production, among others (Brauman et al., 2007**;** De Groot et al., 2010). Sustainable water flow depends largely on the health and integrity of the watersheds from which the services originate. To maintain watershed health and sustainable water flow, integrated water resources management (IWRM) approaches (i.e. existence of a coordinated development and management of water, land, and related resources) should be in place (Solanes and Gonzales-Villareal, 1999; Jewitt, 2002; McDonnel, 2008). IWRM maximizes economic and social welfare without compromising the sustainability of vital environmental systems through the guidance of Dublin Principles. These principles states that: (1) Freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment; (2) Water development and management should be based on a participatory approach, involving users, planners and policy makers at all levels; (3) Women play a central part in the provision, management and safeguarding of water; and (4) Water has an economic value in all its competing uses and should be recognized as an economic good (Solanes and Gonzales-Villareal, 1999; Jewitt, 2002; McDonnel, 2008).

Understanding the capacity of a watershed to provide water is complicated due to various hydrologic components distributed heterogeneously within the watershed (Isik et al., 2013). Among the key characteristics that determine this capacity include the topography, forest cover and land use types, and more importantly, the climate of the particular watershed (Brauman et al., 2007; Isik et al., 2013).

Climate is a key factor in water supply planning and rainfall availability. To a great extent, climate influences the amount of water flowing through the water cycle (Middelkoop et al., 2001;

Changnon, 2003). In addition to climatic factors (such as rainfall and temperature), watershed runoff depends on the topology, soil, underlying geology, and land use/cover of the watershed. In general, the higher the rainfall, the more water is available. Low precipitation and droughts reduce the availability of water supply. Temperature influences water availability and other watershed services. The higher the temperature, the greater the amount of water lost from the Earth's surface and returned to the atmosphere through evapotranspiration (Middelkoop et al., 2001; Christensen, 2004; Mwamila et al., 2008). Climate and hydrological records are used as a firmer basis for quantifying relationships between climate change (CC) and the amount of water available in rivers and aquifers (Arnell, 1998; 2004; Middelkoop et al., 2001; Christensen, 2004; Mwamila et al., 2008).

A few studies (Zorita and Tilya, 2002; Yanda and Munishi, 2007; Munishi et al., 2009) completed so far in Tanzania indicate enormous variability in terms of climatic variables such as rainfall, temperature, and stream flow or levels. Current trends in major river basins indicate a decrease in runoff of about 17% over the past decade (Munishi et al., 2009). Hydrological studies carried out in the country (Valimba, 2005; 2007; Yanda and Munishi, 2007; Ndomba et al., 2008) have shown a decreasing trend in the dry season flows for some of the perennial rivers, possibly implying a decrease in the annual rainfall in the area or increased evapotranspiration resulting from increasing temperatures and CC impacts.

In recent years, CC has posed a serious threat to human beings and the environment. Its adverse impacts are also felt in the Pangani River Basin (PRB), where the amount of water availability has declined in recent years (Kulindwa, 2005; Mwanyoka, 2005; Notter, 2010; Lalika et al., 2011). A reduction in rainfall, mean annual run-off, and the seasonality of freshwater flows has also affected sediment transport to the Pangani estuary, consequently reducing water quality (Shaghude, 2006; Sotthewes, 2008). This reduction is attributed to a decrease in dissolved oxygen and an increase in inorganic nutrients in the water (Hellar-Kihampa, 2013; Kedziora et al., 2011). Changes in water flows along the PRB have had a serious, negative impact on the abundance and diversity of flora and fauna in the system, including aquatic resources used for people's livelihoods (Newmark, 1998; Notter, 2010; Lalika et al., 2011). Other ecological effects associated with low water flow include the disappearance of fish species, loss of aquatic plants, water pollution caused by heavy metals (Hellar-Kihampa, 2013), lower capacity for nutrient cycling, and intrusion of saline water (Sotthewes, 2008).

Reduced rainfall in the PRB that supported rain-fed agriculture for quite some time has compelled small and large-scale farmers to turn their attention to irrigated agriculture and other activities. Currently, irrigated agriculture is the main economic activity in the PRB. Unfortunately, some cultivation techniques, irrigation practices, and land uses contribute further to the degradation of watersheds and water pollution (Hellar-Kihampa, 2011; Kedziora et al, 2011; Hellar-Kihampa, 2013). Anthropogenic activities, for instance, have a strong influence on the quality of the river catchment related to differences in their micro-contaminants (Hellar and Kishimba, 2005; Terrado et al., 2006; Li et al., 2008; Hellar-Kihampa, 2013). According to Brodie and Mitchell (2005) and Buck et al. (2004), croplands, horticulture, gardening, and livestock-keeping contribute to high concentrations of nitrogen and phosphorous, along with pesticide residues and enrichment of some major elements (Cl, Na, Ca, and Mg). Furthermore, urban land uses has been associated with elevated concentration of trace elements (As, Cu, Cr, Zn, Cd, Mn, Pb, Ni and V) (Hellar-Kihampa, 2011; Hellar and Kishimba, 2005), and nutrients ($NH4^{+}$, $NO3^{-}$, $NO2^{-}$, $PO4^{3-}$ and $SO4^{2-}$), both in water and sediments (Butler and Davis, 2004; Fitzpatrick, 2005).

Apart from using irrigated agriculture as an adaptation strategy in response to low rainfall, other local communities have reverted to gold and tanzanite mining in Usambara Mountains and Mererani deposits as alternative livelihood options after the failure of rain-fed agriculture. However, mining activities contribute to water pollution through the release of heavy metals such as As, Hg, Zn, and Pb (Angelo et al., 2007; Donkor et al., 2006; Sampaio da Silva, 2009). Therefore, the concern over the impacts of CC is linked not only with associated water scarcity, but also is driven by water pollution along the PRB (Hellar-Kihampa, 2011). Accordingly, better strategies for the sustainable watershed management and adaptation to water shortages and rainfall fluctuation across the entire PRB are required in the face of increasing demand for water. Although efforts to tackle the challenges of water availability and watershed conservation at the river basin scale has been increasingly recognized since the 1990s (Ngana, 2001; Kulindwa, 2005; Notter, 2010; Msuya, 2010; Turpie et al., 2005; 2007; Ngana et al., 2010; Lalika et al., 2011), limited information exists to establish a link between CC and its adverse impacts on water availability in the PRB. Moreover, the manner in which the natural environment responds to CC and variability is critically important to human well-being and for designing adaptation strategies. Understanding these links should help policy makers come up with definitive solutions to the problems of water scarcity and adaptation strategies to the adverse impacts of CC in PRB. The objectives of this paper are to analyze changes in stream flow in Kikuletwa River and water levels at Nyumba ya Mungu (NyM) Dam and rainfall and temperature trends in PRB, as well as to examine adaption strategies to water shortages and CC in PRB.

2.0 MATERIALS AND METHODS

2.1 Description of the study area

2.1.2 Location

This study was conducted between 2011 and 2013 across 8 villages, namely Kaloleni, Chekereni, Rau River, and Mabogini (in Kilimanjaro Region) and Lekitatu, Karangai, Msitu wa Mbogo, and Kikuletwa (in Arusha Region) along Tanzania's Pangani River Basin (Figure 1).

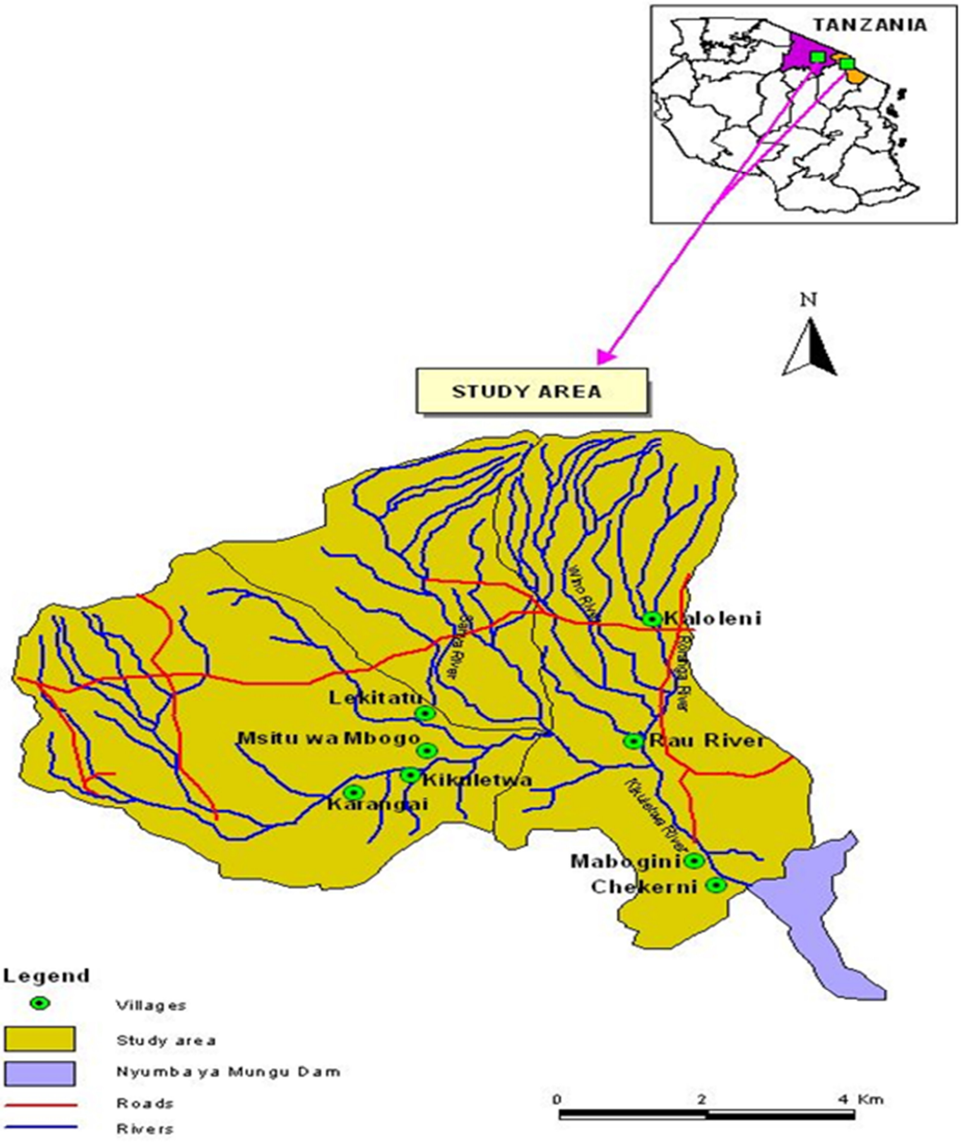


Figure 1: Location of the study area along the Pangani River Basin, Tanzania

The PRB extends from the northern highlands to the north-eastern coast of Tanzania. It lies between latitude 03º 05' 00" and 06º 06' 00" South and longitude 36º 45' 36" and 39º 36' 00" East. PRB is the largest river basin within the Pangani Basin (PB) and covers an area of about 43,650 km^2 and 3, 900 km^2 (IUCN, 2003). The terms "PRB" and "PB" have different meanings. The former refers to the basin where the Pangani main river and its river tributaries, whereas the latter incorporates the PRB and other three smaller basins, i.e., Umba, Zigi-Mkulumuzi Coastal and

Msangazi Rivers catchments (Figure 2) (IUCN and PBWO, 2008). PB is also a shared transboundary resource between Tanzania and Kenya.

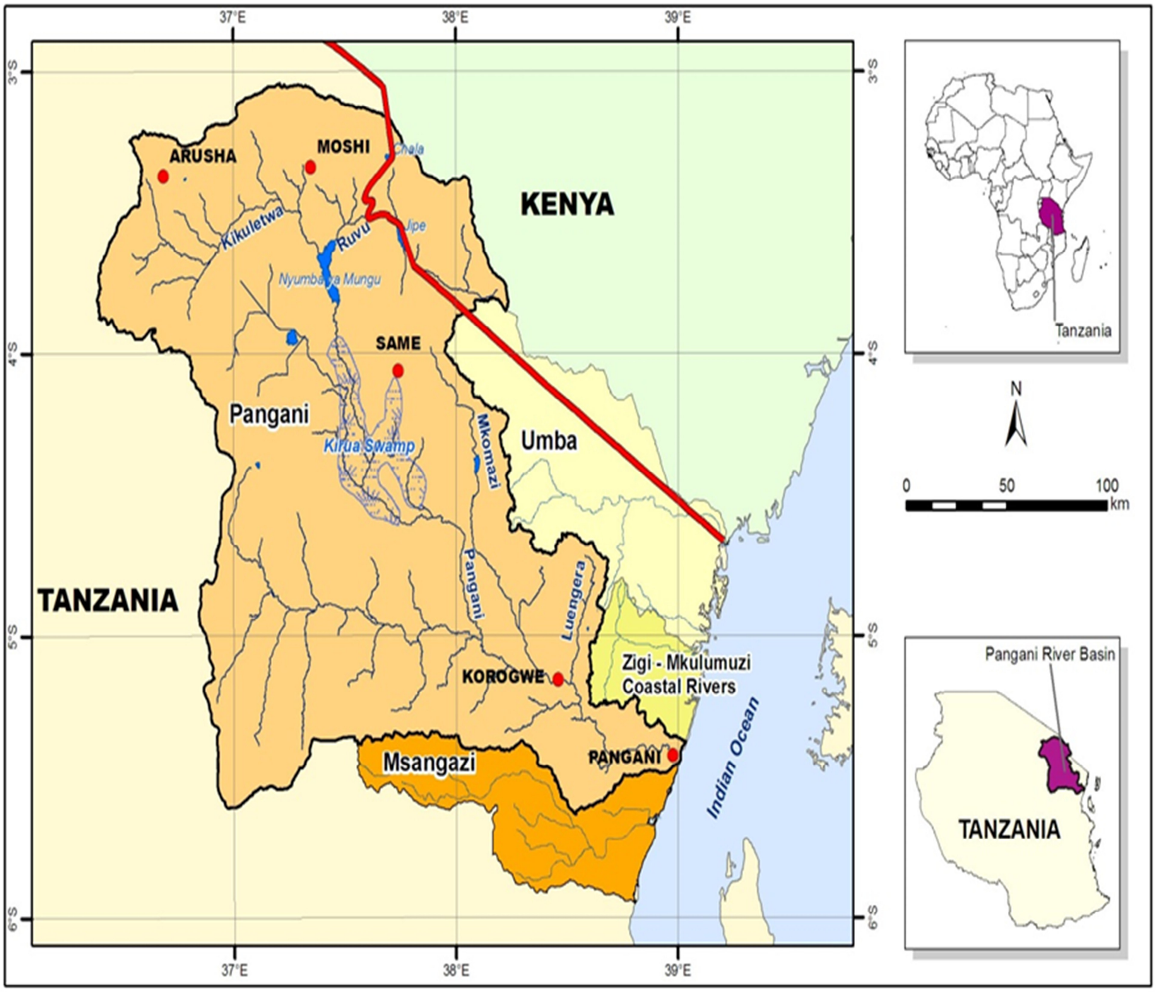


Figure 2: Location of Pangani River Basin and Pangani Basin, Tanzania. Source: King et al., 2008

2.1.2 Hydrology and drainage pattern

The hydrology and drainage pattern in the PRB catchment varies considerably. The PRB comprises of several sub-catchments of widely different characteristics. The Pangani River (PR), which is referred to (in other publications) as Pangani Mainstem, rises as a series of several small streams and springs on the southern sides of the Africa’s highest peak, Mt. Kilimanjaro, and on Mt.

Meru (IUCN; 2007; IUCN and PBWO, 2008). These streams (Nduruma, Tengeru, Sanya, Malala, etc.) create the Kikuletwa and Ruvu Rivers (Himo, Muraini, etc), which drain further downstream into the Nyumba ya Mungu Dam (NyM) (IUCN; 2007; IUCN and PBWO, 2008; 2011). Other river tributaries from Eastern Arc Mountatins (i.e. Pare and Usambara mountain ranges), namely Mkomazi and Luengera, join the PR before reaching the Indian Ocean through Pangani estuary.

2.1.3 Nyumba ya Mungu (NyM) dam

Nyumba ya Mungu (NyM) Dam (with catchment area of 9,320 km^2) is a wetland of ecological and economic importance along PRB. The overflow of the dam, the PR, flows for 432 km before emptying into the Indian Ocean at Pangani estuary. The NyM Dam is the largest water body in the PRB. The dam was constructed in 1965 to enhance river flows for hydropower generation; however, in later years, irrigation potential was recognized and incorporated into plans (Mulungu, 1997; Ndomba et al., 2008). The current decrease in rainfall and temperature increase has resulted in water scarcity for irrigation water (upstream of the dam), thereby creating water use conflict between the irrigation sector and hydropower generation. During construction, the maximum depth of the dam was 29 m and live storage capacity was 871.5 m^3.

As stated in the Water Master Plan of Kilimanjaro Region, the dam was designed mainly for water regulation (Mulungu, 1997). Besides the power station at NyM Dam, there are two power plants downstream at Hale and New Pangani Falls (NPF). Apart from its irrigation and power production potential at the proceeding hydropower stations, water discharged from NyM Dam is essential for regulating services, including nutrient cycling, at Kirua Swamp (which is located downstream) and enhancing ecological processes (e.g., hindering salt water intrusion and coastal erosion) at the estuary mouth in Pangani Town (Sotthewes, 2008; Shaghude, 2006).

2.1.4 Forest and vegetation types

Variation in vegetation in the PRB range from forests on mountain slopes to semiarid grasslands (IUCN, 2003). Major vegetation includes forests, woodlands, and bushland, along with grassland thickets and plantation forests (Turpie et al., 2005). Plantation forests have replaced natural forests in the highlands, and the larger part of the lowlands is composed of woodland, bushland, grassland, and thicket. Forests perform vital hydrological functions in the PRB, including the regulation of run-off, prevention of soil erosion, storage of water, and improvement of water quality (IUCN, 2003; Msuya, 2010). According to IUCN (2003), types of dominant forest types in the PRB include: *mangrove forests* (located at the confluence of the Pangani River and the Indian Ocean protecting the coastlines, protecting soft sediment shorelines from erosion, trapping sediments, and recycling nutrients); East *African coastal forests* (containing remarkable biodiversity and endemism); *afromontane forests* (playing key part in hydrological functions); and *riverine forests* (controlling erosion along the river banks). Research and previous studies on forest health conducted in the PRB shows that between 1952 and 1982, catchment forests in the PRB declined at a fairly high rate of 3.8% of forest cover per year (Newmark, 1998; Lambrechts et al., 2002).

2.1.5 Population and economic activities

By 2007, the PRB contained an estimated 4.5 million people, the population density of which varied between highlands and lowlands. About 90% of the basin's population resides in the highlands with some 900 people per km^2, while lowland densities are around 65 people per km^2 (IUCN, 2003). The main causes of forest degradation and deforestation include encroachment for settlement and agriculture, as well as increasing demand of forest products (mainly timber and fuelwood) (IUCN, 2003). In terms of human population, the PRB is a densely populated area in Tanzania, posing serious challenges to sustainable watershed management (Msuya, 2010).

2.1.6 Climate

Variations in the local climate in the PRB are mostly related to topography. The flatter, lower-lying south-western half of the Basin is arid and hot, while the mountain ranges along the northern and south-eastern catchment boundaries have cooler, wetter conditions. The high-altitude slopes above the forest line on Mt. Meru and Mt. Kilimanjaro have an Afro-Alpine climate and receive more than 2500 mm of rainfall per year. Mean annual rainfall increases in a southerly direction along the mountain ranges, and varies from about 650 mm per year in the North and South Pare Mountains to 800 mm per year in the Western Usambara Mountains, and 2000 mm per year in the Eastern Usambara Mountains.

2.3 Data collection and **analysis**

2.3.1 Sampling procedures

For hydrological, rainfall, and temperature data, we earmarked the main hydrological and weather stations in Arusha, Moshi, Same, and Tanga. For socio-economic data (questionnaire surveys), we sampled villages located along the PRB. Within each of the identified eight villages, a random sampling technique was adapted to identify respondents, and 10% of the total households in each village were selected for interviews. Each household head was numbered in the village register books, and the households we selected corresponded to those we identified through using a table of random numbers. Household heads were interviewed, but wherever the heads of the household were not around, we randomly chose a member within that particular household who was 18 years or older. According to Tanzania regulations and laws, anyone 18 years or older is regarded as mature person.

2.3.2 Data collection methods

2.3.2.1 Data on rainfall and temperature

We used mean monthly rainfall and temperature data for the period between 1970 to 2012 from selected synoptic stations along the PRB to assess regional climatic trends. The synoptic stations involved in this case include Arusha, Moshi, Same, and Tanga (Table 1).

Table 1: Location of weather stations along Pangani River Basin, Tanzania

Station	**Latitude**	**Longitude**
Arusha	5^{0}08’ S	39^{0}07’E
Moshi	3^{0}37’ S	36^{0}63’ E
Same	4^{0}08’ S	37^{0}73’ E
Tanga	3^{0}43’ S	37^{0}06’ E

We obtained data from Tanzania Meteorological Agency (TMA), the designated meteorological authority in Tanzania mandated to provide meteorological services for the United Republic of Tanzania.

We collected data for the two bimodal rainfall seasons, i.e., data for October, November, and December (OND) as one cluster and March, April, and May (MAM) as the second cluster. Our preference for the two bimodal seasons was based upon the increased likelihood of retrieving reliable data. Rainfall data were recorded from standard rain gauges for the interval of three hours for the period from 1970 to 2012. When recording rainfall data, standard rain gauges affixed with a special bottle are normally inserted in the ground for capturing rainfall drops. Afterwards, water from the bottle is taken to the laboratory for measuring its quantity (in millimeters) using a special measuring cylinder. At the gauging station, the total rainfall recorded is normally reported on the second day at 0900. As a result, we obtained cumulative data for daily rainfall collected from the first day at 0900 in the morning to the next day at 0900 in the morning.

2.3.2.2 Data on hydrological flow

For data on hydrological flow, two types of information were collected: data for water flow at different agro-ecological zones along Kikuletwa River, and water levels at NyM Dam (Table 2).

Table 2: Location of gauging stations along Pangani River Basin, Tanzania

Station code	**River/ Dam**	**Location/zone**	**Latitude**	**Longitude**	**Catchment size (km^2)**
1DD55	Kikuletwa	Karangai	3^0 26'S	36^0 51'S	245
1DD54	Kikuletwa	Power station	3^0 27'S	37^0 17'S	2220
1DD1	Kikuletwa	TPC	3^0 31'S	37^0 17'S	2849
1D8C	NyM Dam	NyM	3^0 48'S	37^0 30'S	9320

Note: TPC is an abbreviation of Tanganyika Plan Company.

To measure water level, data were recorded using a graduated vertical staff gauge and automatic water lever. Water levels were measured and recorded in the daily gauge record (DGR) form (H3) and in writing pads. These measurements were taken twice a day in the morning and in the afternoon. Later on, the data were transferred to MS Excel for mathematical computation and figure drawing.

2.3.2.3 Socio-economic data

We used both quantitative and qualitative methods in primary data collection. For quantitative data, structured questionnaires were the main tool of collection. The structured questionnaire covered questions on water utilization, adaptation methods in response to CC and water shortages, type of crops irrigated, payment methods for water utilization, and other issues. Before commencing field work, questionnaires were pretested to eliminate ambiguities or correct for omissions. During field work, one researcher and two research assistants administered the structured questionnaires in the study villages. A total of 360 respondents were interviewed in eight villages as indicated in Table 3.

Table 3: Interviewed respondents in the study area

Region	District	Village	Total households	Respondents
Arusha	Meru	Lekitatu	250	25
		Karangai	480	48
		Kikuletwa	640	64
		Msitu wa Mbogo	420	42
Kilimanjaro	Moshi Urban	Kaloleni	490	49
	Moshi Rural	Chekereni	550	55
		Rau river	340	34
		Mabogini	430	43

For qualitative data, we carried out informal and formal interviews. This enabled us to to supplement quantitative data and triangulate on findings collected by other means. Additionally, we used a checklist of questions to collect information from key informants. A key informant in this study was defined as a person knowledgeable in a specific area of specialization. Moreover, we undertook a literature review and collated relevant unpublished documents for secondary data collection.

2.3.2.4 Data analysis

Rainfall and temperature time-series data for the March–May (MAM) season were aggregated on a daily, weekly, monthly, and finally yearly basis. Trend analysis for both rainfall and temperature for each of the stations was then performed. For hydrological data, daily, monthly, and seasonal flows were then used to compute average, minimum and maximum yearly flows in the PRB (Valimba, 2005; 2007). Afterwards, data were entered in MS Excel, where linear regression analyses were conducted to determine possible trends.

The 360 structured questionnaires were coded, cleaned, and wherever applicable, data from open-ended responses were categorized and transferred to enable further analysis. All quantitative analyses were performed using Statistical Package for Social Sciences (SPSS) version 20.0.

3.0 RESULTS

3.1 Water level trends and water flow in PRB

The trend from early 1970s to late 1990s in Nyumba ya Mungu (NyM) Dam indicated that the highest level was 689.7masl in 1990, whereas the lowest level was 684masl in 2000 (Figure 3). As depicted by Figure 3, water levels in NyM have been in decline (with exceptions from 2001) since its establishment in mid 1960s.

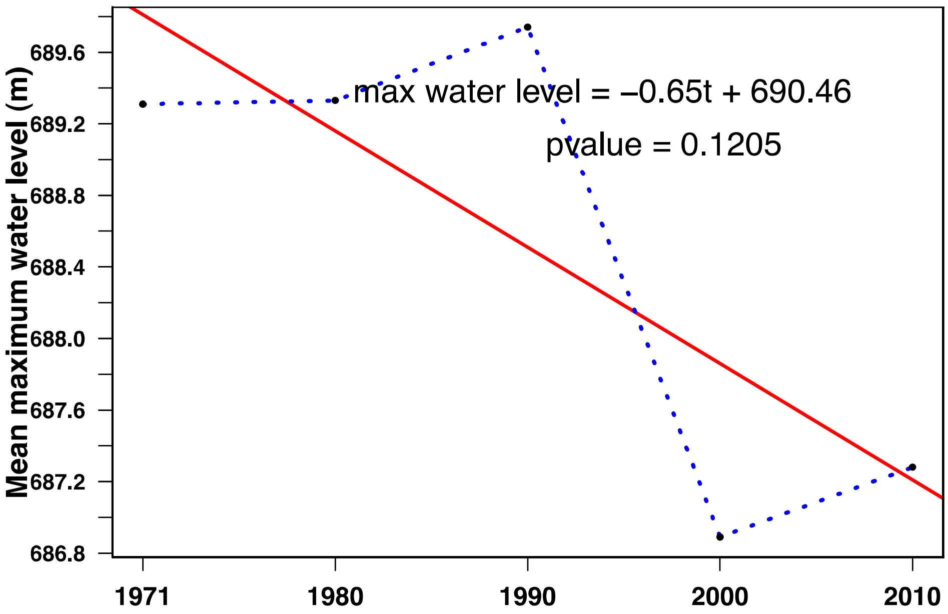


Figure 3: Trend of water level at Nyumba ya Mungu dam in PRB, Tanzania

Figure 4 shows the annual maximum and annual mean flow for the Kikuletwa River at Karangai gauging station, Tanzania. Both the maximum and mean flows show a statistically significant downward flow. The statistical significance and R^2 values are given in Table 4.

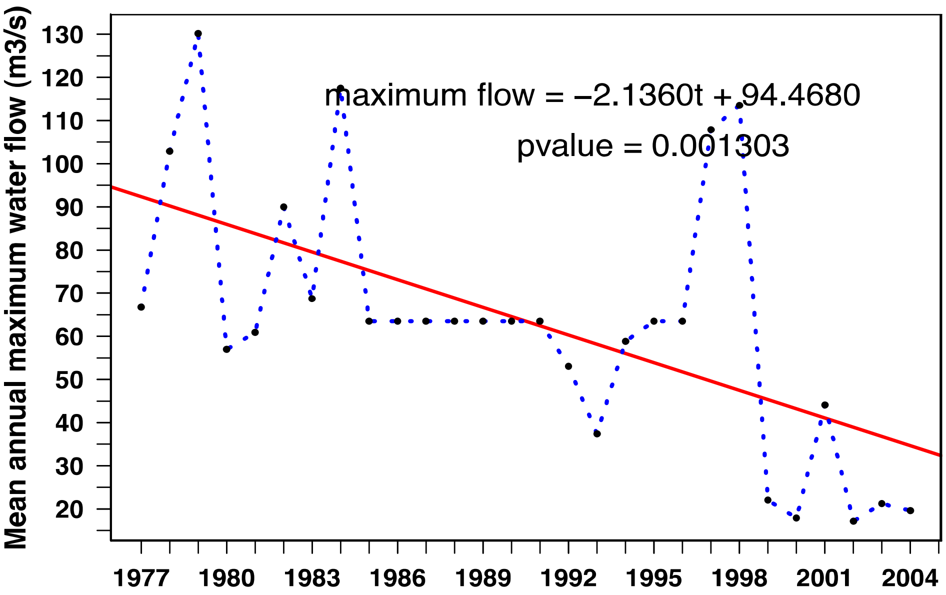
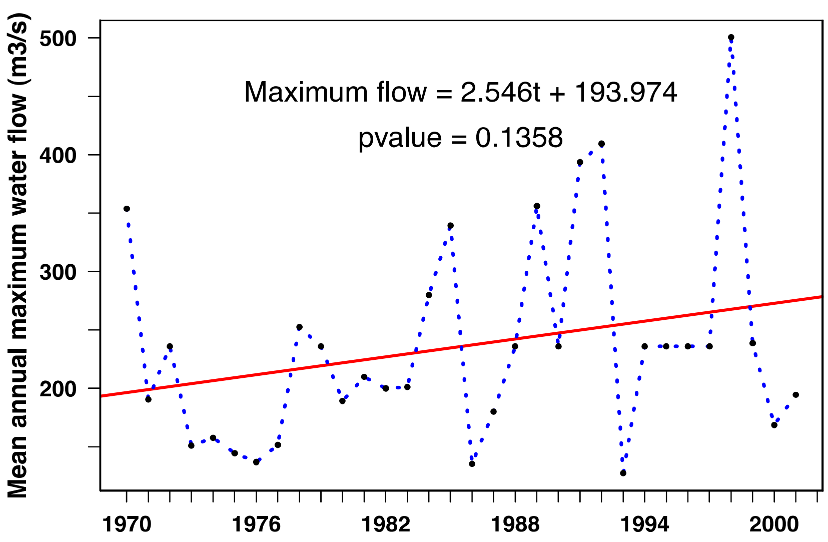


Figure 4: Maximum and mean water flow in Kikuletwa River at Karangai gauging station, Tanzania

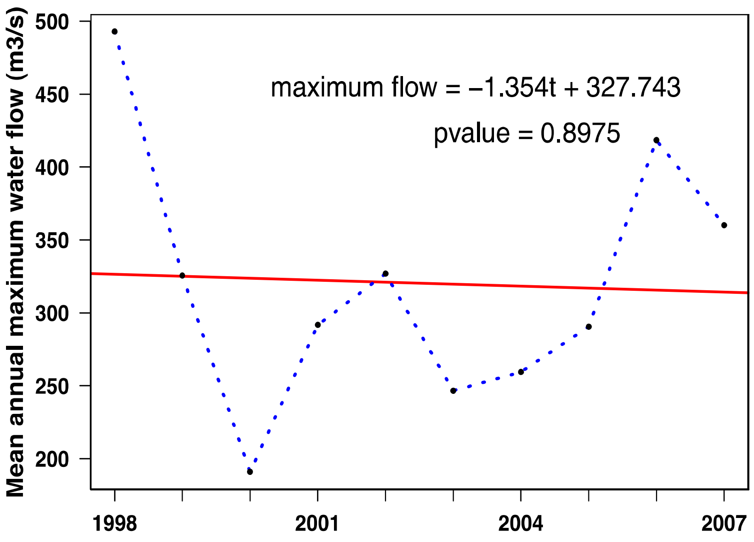
Normally, the PRB region experiences a high/long rainfall season (*masika*) during March, April and May (MAM). This season influences the maximum and mean flow as revealed in Figure 4. For example, Valimba (2005; 2007) found that the flow increased with the onset of rains in March and that high rainfall during the long rains *(masika)* upstream of NyM reservoir contributed to highest flows in April and May.

Figures 5a and 5b show the annual maximum and annual mean flow for the Kikuletwa River at the Power gauging station and the TPC station. A linear regression analysis was performed on these flows, but the trends were not statistically significant. The statistical significance and R^2 values are given in Table 4.



A

Figure 5: Maximum and mean water flow at Power gauging station Tanzania



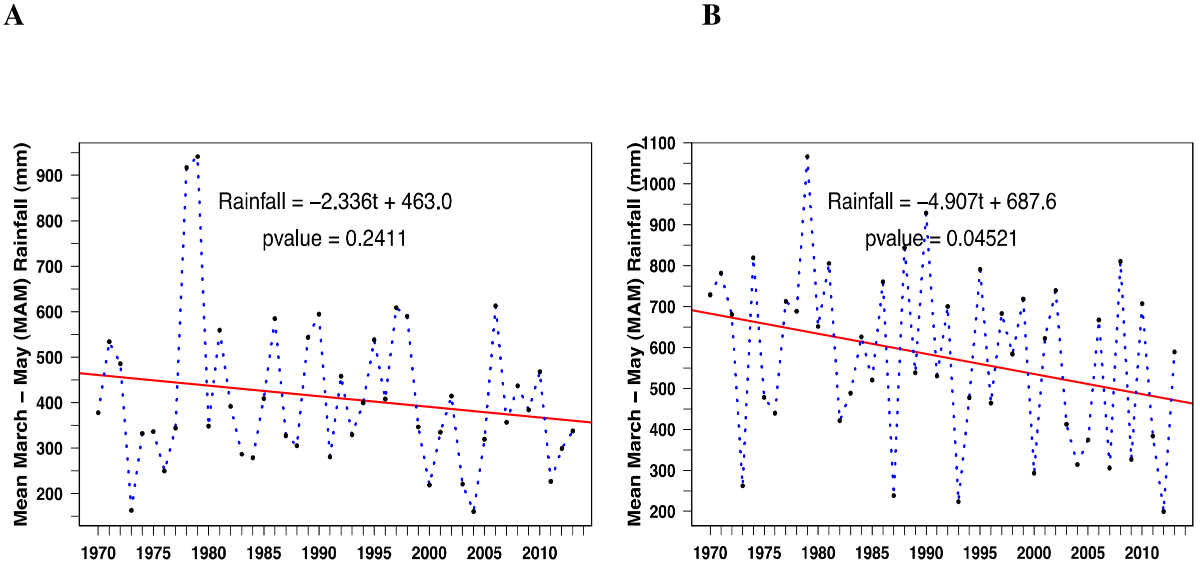
B

Figure 5: Maximum and mean water flow at TPC gauging station, Tanzania

3.2 Trend analysis for Rainfall and temperature patterns in PRB

3.2.1 Rainfall trends

In the PRB, the long rain season (*masika*) is experienced between March and May (MAM), while the short rain season (*vuli*) is normally experienced between October and December (OND). The *masika* is more important for agriculture activities than the *vuli*. Trend analyses for mean MAM seasonal rainfall at four meteorological stations in PRB are presented in Figure 6. The MAM rainfall for Moshi shows a statistically significant downward trend at the 95% level. The other stations show a slight decreasing rainfall trend, but are not statistically significant.



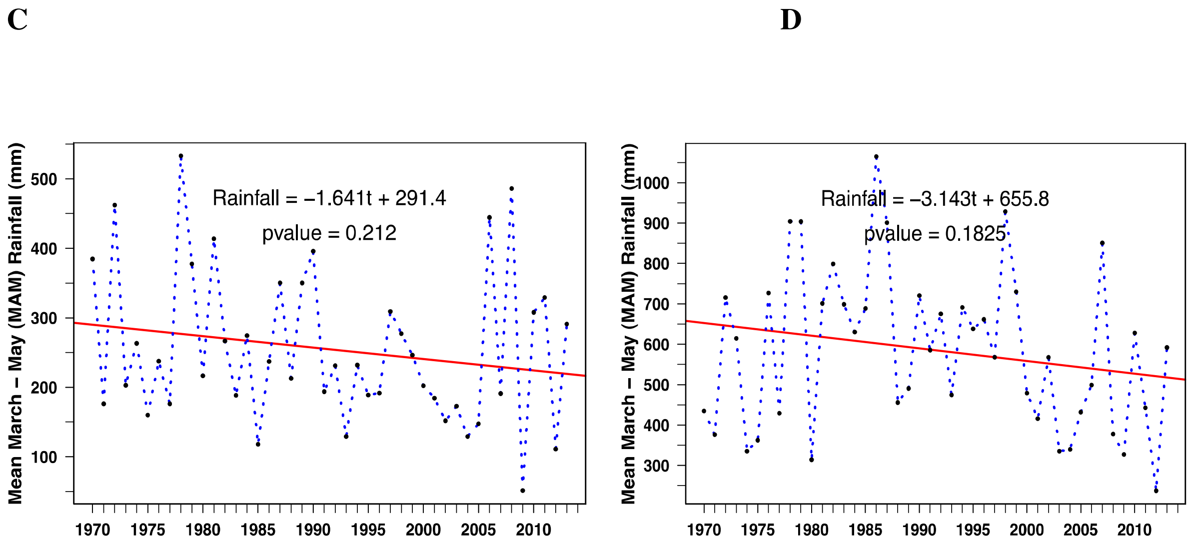


Figure 6: Trend in mean MAM rainfall at four meteorological stations in PRB, Tanzania

Table 4: Summary of the trend of mean and maximum water flow in Kikuletwa River along PRB Tanzania

Station	**Dependent variable**	**Independent variable (number of years)**	**Intercept**	**Slope**	**R^2**	**p-value**	**Lower 95% confidence**	**Upper 95% confidence**
Kikuletwa River at Karangai gauging station	Mean Flow	19	2819,9	-1,3957	0,266	0,02**	-2,58	-0,21
	Maximum flow	19	4628,9	-2,2931	0,357	0,01**	-3,87	-0,72
Kikuletwa at Power station	Mean Flow	25	119,68	0,02	0,00	0,98*	-4,98	5,07
	Maximum flow	25	-3723,5	0,61	0,015	0,57*	-4,98	8,82
Kikuletwa at TPC[1] station	Mean Flow	10	8820,17	-0,57	0,03	0,57*	-12,59	13,01
	Maximum flow	10	3032,17	-0,13	0,00	0,89*	-24,84	22,13

Note: ** = Significant at $p < 0.05$

* = Non-significant at $p < 0.05$

[1] = Tanganyika Plan Company

Results in Table 4 indicate a statistically significant ($p < 0.05$) and negative trend for both mean and maximum flow for the Kikuletwa River at the Karangai gauging station. The flow trends at the other two gauging stations were not statistically significant at $p < 0.05$.

3.2.2 Temperature Trend

Figure 7 shows the mean MAM maximum temperature for Arusha, Same, and Tanga meteorological stations and the mean MAM minimum temperature for Moshi meteorological station. Temperatures show an increasing trend at all four stations, but only records from Moshi and Same are statistically significant at the 95% significance level.

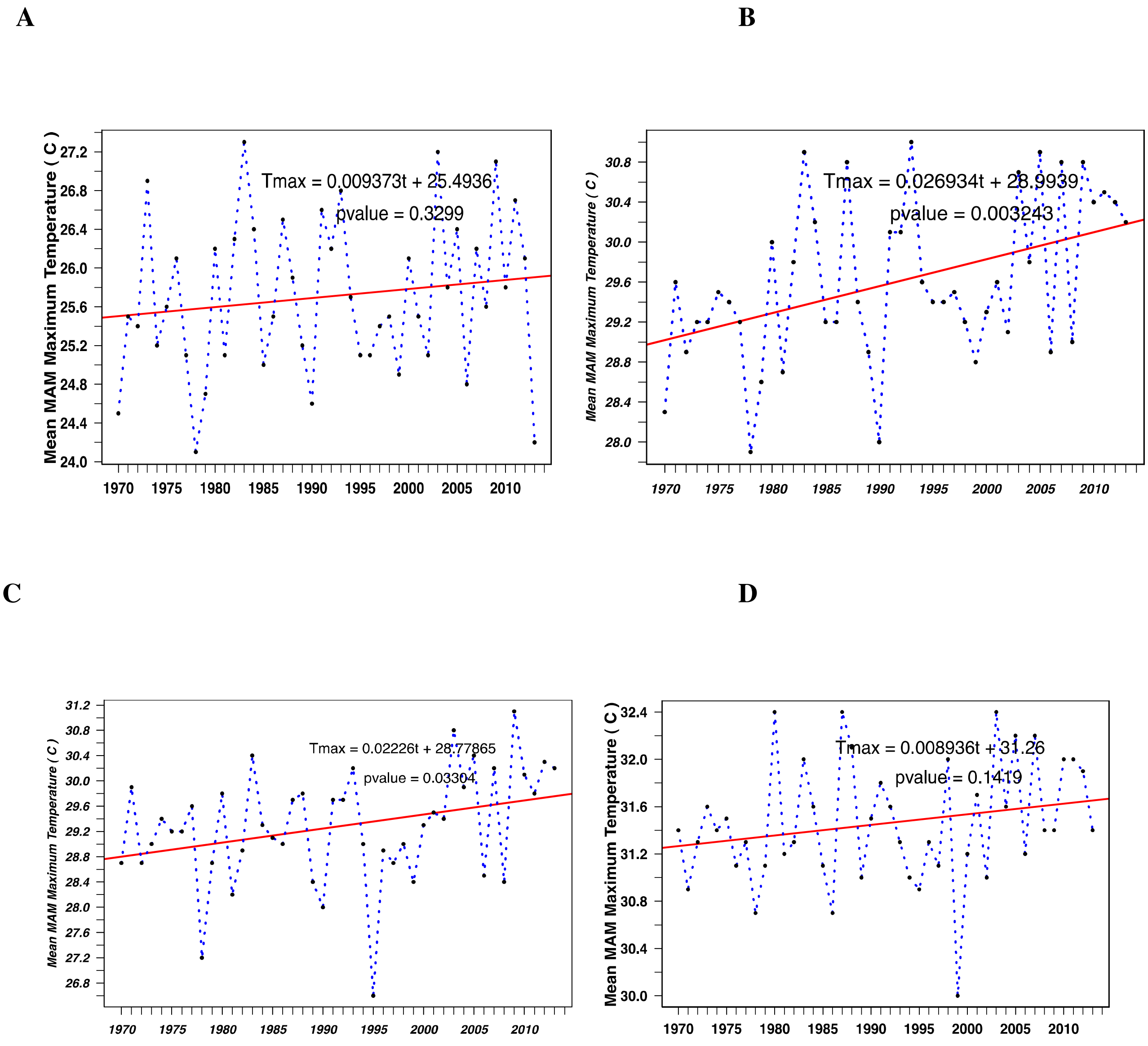


Figure 7: Trend in MAM temperatures at four meteorological stations in PRB, Tanzania

3.2 Socio-economic characteristics of respondents

The vast majority of respondents (98.2%) were involved in agriculture, whereas 1.8% of them were employees. Irrigated agriculture was the main socio-economic activity, and the main water sources for irrigation include rivers, springs and bore holes. The majority of respondents (84.1%) had primary education, 8.8% never went to school, and 7.1% had secondary education. In terms of marital status, 79.3% of respondents were married, 11.7% widowed, 3.6% separated, 2.7% singles and 2.7% were divorced. Of respondents, 62.3% were males and 37.7% females. Given the fact that majority of respondents engage in agriculture, the socio-economic characteristics of the people in the study have important implications to resource management and water utilization as a whole.

3.2 Main drivers of water reduction in PRB.

Water reduction is attributed to a number of factors, ranging from natural to human-made. Some of the reported drivers are presented in Table 5.

Table 5: Drivers of water reduction in PRB, Tanzania

Driver	**Counts**	**Percentages**
Climate change	65	58.6
Population increase	36	32.4
Watershed degradation	8	7.2
Water abstraction by investors	2	1.8

Of all respondents, 58.6% recognized CC as the main driver of water shortages and reduction in PRB. Increase of human population (32.4%) was given as another reason for the water shortages in PRB. Two factors were found to account for the population increase in the study villages: natural increase (through birth) and population movement due to displacement and in-migration (Maro, 1975; Mbonile, 2005; 2001; 1999a; b; Maddox et al. 1996). Among others, reported effects of water reduction in PRB included poor crop harvest, hunger, and income reduction.

3.3 Adaptation strategies to water reduction in PRB

A number of adaptation strategies are in place as a response to PRB water scarcity (Table 6). Smallholder farmers spent their time abstracting water during night hours. We found that almost 35% (Table 6) of smallholder farmers irrigate their farms during the night. Although this method would reduce the amount of evapotransipiration, the strategy could prove dangerous since farmers from nearby villages looking for irrigation water might be more likely to attack at night. Similarly, dangerous animals such as snakes are less visible at night, making attacks harder to avoid. With respect to social life, abstracting water during the night is a loophole for some individuals to involve themselves in illegal practices (e.g., theft) and spousal infidelity.

Growing crops that tolerate drought condition is the recommended coping strategy for dealing with water reduction. Given the probability of less rainfall, some of the smallholder farmers opted to grow maize, sorghum, vegetables, and legumes instead of paddy. Of all respondents, 21.1% (Table 6) indicated that they were obliged to shift from paddy irrigation to other crops due to the scarcity of irrigation water.

Table 6: Adaptation strategies against water shortages

Strategy	Counts	Percentages
Abstracting water during the night	38	34.9
Switching to drought resistant crops	23	21.1
Guarding water over night	20	18.3
Shifting to other economic activities	14	12.8
Water rationing	8	7.3
Using bribes	6	5.5

We also found that in the case of extreme water scarcity, smallholder irrigators spent their nights guarding water from illegal abstraction. Similarly, a shift to other economic activities and even water rationing were also used as adaptation strategies against water shortages in the villages studied. Petty trading, small scale mining, and working as casual laborers are a few of these alternative socio-economic activities.

4.0 DISCUSSIONS

4.1 Influence of rainfall and temperature on hydrological flow

Water level in NyM Dam has been in decline in recent years, although this trend is likely not solely caused by rainfall fluctuation, temperature increase, or climate change and variability. The downward trend in water level and reduced water flow at the Karangai gauging station may be due to a combination of factors. These factors may include: type of land uses adjacent to water sources in the watersheds, rainfall variability, excessive water withdrawals by large scale users who are located upstream, illegal water abstraction, and poor irrigation farming methods. While reduced rainfall affects rain-fed agriculture, water flow fluctuation affects the majority of smallholder irrigators who depend on water flowing downstream for irrigation purposes.

Fluctuation and change of river regime (i.e. day to day, season to season and year to tear) play a decisive role in determining river health and ES. Reduced rainfall and increased temperature have both contributed to the reduction of water flow along Kikuletwa River, consequently affecting the water level and ecological functions. Anthropogenic climate change may not be the cause of decreased rainfall (Figure 6). Variation of rainfall might have been due to natural climate variability over time and space. With regard to temperature, slight increases (Figure 7) may have led to increased evapotranspiration, which could lower water levels in NyM Dam or reduce runoff and water flow in Kikuletwa River.

The observed declining trend in water level (Figure 3) and water flow (Figure 4) have adverse impacts on the provision of ES, environmental flow, and ecological process along PRB. Mwamila et al. (2008) found that the reduction in high-flow occurrences has great negative impacts on fish in terms of productivity, whereas higher flows led to swamp and floodplain formation and flooding conditions necessary for fish spawning, feeding, growth of young fish species and flushing through of nutrients from floodplains into the river, thus increasing reproduction and fish population. Apart from ecological consequences, reduced water level in NyM Dam affects the country's economy (production of hydroelectricity) and the livelihoods of smallholder farmers across the PRB who depend on the outflow for irrigation activities (Msuya, 2010; Notter, 2010). In addition, unsustainable land use practices (that stimulate soil erosion and sedimentation) have major effects on natural ecosystems. Reduced water levels in NyM Dam (Figure 3) in recent years (King et al., 2008; Ndomba et al., 2008) have negatively impacted hydropower production, fish catches, and other and ES (IUCN and PBWO, 2007). This is further confirmed by the fact that the full capacity of the water supply in NyM Dam (1, 134.8 million m^3, which includes an inactive storage volume of 260.3 million m^3) is no longer attained as it was in the past (Valimba, 2007; Ndomba et al., 2008). When the volume of water in storage drops below 553.5 million m^3 (just less than 50% of the full supply volume), releases from the dam are reduced to 57% of the downstream demand (Valimba, 2007). This situation compromises the maintenance of ecological functions and provision of ES (water) downstream. Rises in temperature (Figure 7) are contributing factors, together with the melting of the ice caps in the Kilimanjaro Mountains, thereby jeopardizing the sustainable water supply and other ES in future.

Reduced water volume at NyM Dam has affected human activities that used to provide livelihoods to the local communities living around it. For example, fish breeding and fish supplies, such as tilapia species (*i.e. pangani*, *zili* and *jipe*) and catfish (*kambale*), are no longer as bountiful as they were in the past (Valimba, 2007; Ndomba et al., 2008; Turpie et al., 2007). Due to a recent water volume fluctuation in Kikuletwa River and NyM Dam, the fishery activities have become seasonal, with fisheries being most active from March to June. The plausible explanation is that this is a period of high rainfall, with large amounts of water enhancing fish breeding.

Similarly, lower water volume in NyM Dam would reduce reservoir releases, discharge, and the ecological processes in Pangani (Mainstem) River, such as fish breeding, nutrient cycling, and sedimentation processes in Kirua swamp, which depends greatly on the outflows from NyM Dam. Pangani Basin Water Office (PBWO) and International Union for Conservation of Nature (IUCN) (2011) indicated that different parts of the river flow regime have different effects on the health status of the river and its associated hydrological services downstream. For instance, when NyM Dam receives an influx of water from its main inlets (Kikuletwa and Ruvu Rivers), it releases water (outflows) into Pangani Mainstem, which eventually causes flooding downstream at Kirua Swamp. This process enhances fish breeding, migration, and ample flood plain for fish feeding. However, lower rainfall and increased temperature negatively affects these ecological and biological processes.

4.2 Socio-economic characteristics of respondents

Based on findings presented in section 3.1, agriculture could be not only an opportunity for local communities to make their ends meet and improve their living standards, but could also be a serious threat to the future provision of watershed services. If 98.2% of the respondents rely on agriculture for their livelihood, there is a risk that watershed areas would be degraded in search for fertile land and irrigation water at the expense of nature conservation. We feel that although agriculture provides ES like food, expansion of agricultural would undermine the capacity of the watershed to provide other ES in the future such as water provision, climate regulation, soil erosion control, and biodiversity conservation (Costanza et al., 1997; De Groot et al., 2002). Similar observations were echoed by Kedziora (2010), who found that many weaknesses in agriculture activities in the past resulted in the deterioration of landscape functions and loss of ES.

Given that current agriculture activities in PRB are influenced primarily by the rainfall availability, erratic rainfall caused by CC threatens food supply in the area. With rain-fed agriculture being carried out up to the edges of watershed areas, this is an indication of future problems with respect to the sustainability of watersheds and their associated ES (Kulindwa, 2005; Notter, 2010; Lalika et al., 2011; Ngana et al., 2010).

With decreasing rainfall coupled with increased temperature, switching to irrigated agriculture could serve as an adaptation strategy, but it could also lead to worsening water shortages in PRB. Given the presence of considerable large-scale commercial irrigation (e.g. sugar and flowers), we think that this strategy would also lead to significant water reduction to the downstream smallholder farmers who engage in smallholder irrigation. Similarly, we feel that water abstraction for large-scale irrigation could further reduce water used for ecological functions downstream. These ecological functions include nutrient cycling and water regulation essential for i) aquatic life, ii) controlling the salt water intrusion at the Pangani estuary (Notter, 2010, Sotthewes, 2008; Mwamila et al., 2008), and iii) reducing the impacts of water pollution (Hellar-Kihampa, 2011; Hellar-Kihampa, 2013; Hellar and Kishimba, 2005).

4.3 Main drivers of water reduction

Opinions from respondents (Table 5) revealed that CC was ranked first among the drivers preventing watersheds from performing their vital ecological functions, including hydrological services. Watersheds in the upper basin at Mounts Meru and Kilimanjaro have played an important role in regulating steady water flow and erosion control for many years. However, CC has contributed to the current ice cap melting at the summit of Mount Kilimanjaro, a situation which is threatening the maintenance and sustainability of water flow and the availability of multiple ES along PRB. Due to recent extremes in climate conditions, the delivery of hydrological ecosystem services in the PRB varies significantly over time. The capacity of Mounts Meru and Kilimanjaro (the water towers in PRB) to provide water to their immediate surroundings and downstream are the most affected. CC in PRB has affected rainfall and the availability of water for irrigation. A decline in rainfall, along with an increase in temperature in the study area (as supported by Figure 6 and 7), has increased pressure for water utilization.

As described by Mbonile (2005), population movement is another factor that contributes to the degradation of watersheds and subsequent reduced water flow along PRB. This statement was echoed by our study, in which 32.4% (Table 5) of respondents gave their views that population increase was among the drivers for water reduction. The current study revealed that massive population displacement and migration resulted in high water demands to satisfy the incoming population. In this study, we viewed water shortages caused by population increase in two parallel fronts. First, we found that people who migrated upstream established farms near watershed areas, thereby degrading water sources and other critical zones for watershed conservation. Secondly, we viewed water shortages as a function of population increase beyond the capacity of the watersheds to provide water for the rapidly growing population. Thus, population increase reduces the capacity of these watersheds to provide water and other ES. Policy measures (e.g., equal distribution of social services, targeting marginalized communities, and provision of livelihood opportunities in the area of origin) could stop these human population movements, thereby safeguarding watersheds.

4.4 Adaptation strategies to water reduction

Since the watershed has been degraded and failed to mitigate CC change, we feel that adaptation is the final strategy and best way forward. For instance, in the past it was unusual for smallholder farmers to stay overnight abstracting irrigation water. But due to watershed degradation coupled with the impact of the CC, these farmers are now sometimes obliged to spend hours during the night irrigating their farms, which is unusual as well as dangerous. In some villages (e.g., Mabogini), irrigation officers forced smallholder farmers to grow maize instead of paddy as adaptation strategy in response to water shortages. In addition to overall switching to maize from rice, some of the smallholder farmers adapted to short term rice varieties (e.g. *Saro, IR 54 and IR 64*) and short term maize varieties such as SEED CO *(e.g. SC 403)* and PANNAR *(e.g. PAN 4M-19, PAN 6 and PAN 63).* Water rationing was also a well-known and widely used strategy across the study villages. Although water abstraction during the night was favored by the majority of smallholder farmers, we think that growing drought-resistant crops, switching to less water-demanding crops, and water rationing are the best alternatives that should be applied elsewhere in areas with similar problems.

With respect to adaptation through water rationing, the application of the concept of IWRM was well established in the study villages where PRB catchment and its sub-catchments were treated as basic management units (Jewitt, 2002; McDonnel, 2008). Along the Kikuletwa River Sub-Catchment, for instance, water rationing was based on geographical characteristics, such as topography, location, distance from the water intake and proximity to the river and irrigation canals. Canal irrigation managers and river basin committees had regular set down meetings for supervising water rationing and monitoring water flow along their respective sub-basins in an integrated way. IWRM represents a paradigm shift towards water management in PRB and, if maintained, it could bring about a lasting solution for watershed conservation, integrity and functioning of ecosystems, and sustainable flow of water (Jewitt, 2002; McDonnel, 2008; Solanes and Gonzales-Villareal, 1999).

5.0 CONCLUSIONS

This study has determined that agriculture is the main socio-economic activity in the study region, playing a key role for providing food (provision ecosystem services) and enhancing the income of smallholder farmers along PRB. As a consequence, the major concern should be management of scarce water resources, which are currently under increasing stress because of increased use in various socio-economic activities, especially irrigated agriculture. Although there is no scientific evidence to support the effect of CC and climate variability on reduced rainfall and water flow, adaptation measures need to be in place in order to overcome water stress problems.

The population influx in PRB has increased demands for ES from watersheds. Therefore, there is a pressing need to design a holistic approach for sustainable utilization of ES and conservation of watershed resources for improving their capacity to retain and release water gradually, as well as enhancing the welfare of the local communities near the watersheds. Furthermore, opinions from respondents indicated that CC and population increase play key roles in water shortages and watershed degradation in PRB. Even if we didn’t prove this speculation scientifically through evidence-based empirical experimentation, CC and climate variability have widely been held responsible for detrimental effects on rainfall and water flow reduction along PRB. Given that watersheds and rivers have already been degraded, emphasis should be placed on adaptation measures as the way forward in response to the current rainfall and water scarcity problems.

The current study has also indicated the temporal variable patterns of seasonal flow variations, with the maximum peak during the months of March, April and May. Over the period between 1970 and 2012, the study illustrates changes of water flow, water level fluctuation and reduction of rainfall. Thus, in order to enhance sustainable water flow, joint efforts and holistic approaches among stakeholders dedicated to watershed conservation are fundamental. Moreover, we propose the implementation of integrated water resource management (IWRM) for enhancing the sustainability of water flow along PRB. This is one way of abiding by the Dublin Principles that advocate sustainability through *environmental integrity, economic wealth, and social justice*, that is, the way of promoting economic and social wellbeing of the local communities who are the primary beneficiaries and guardians of ES from watersheds. Adaptation strategies developed in response to CC and climate variability require innovative measures to be shared, disseminated and implemented at a wider scale among stakeholders along river basins. Therefore, the current study is one of such means to share research knowledge and disseminate to the widest extent possible for enhancing conservation goals and sustainable use of ES.

Conflict of interest

There is no conflict of interest in this article. This work is a small portion of a PhD research project financed by the government of Belgium through the Belgium Technical Cooperation (BTC).

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