

THE ECONOMICS OF CLIMATE CHANGE IN TANZANIA

WATER RESOURCES

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TABLE OF CONTENTS

EXECUTIVE SUMMARY	iii
1. INTRODUCTION	1
2. CLIMATE CHANGE AND WATER RESOURCES IN TANZANIA.....	4
3. DOMESTIC WATER SUPPLY	9
3.1 Urban water supply	11
3.2 Rural water supply	13
3.3 Adaptation	13
4. HYDROPOWER	16
Adaptation.....	18
5. CONCLUSIONS	20
REFERENCES.....	21
INTERVIEWS.....	25

EXECUTIVE SUMMARY

Water resources are a critical to Tanzania's economy: water is key to agricultural sector performance; piped water systems provide input into industrial production and support the workforce in urban areas; water in rivers and reservoirs generate over half of the country's grid electricity through hydropower installations; and water flows through the ecosystem provide numerous provisioning services while also supporting the tourism sector. With renewable water resources per capita of 2,291 m³, Tanzania is currently not classified as water scarce, but due to projection population growth it is expected to be so by 2015. The country is also challenged by a high degree of water resource variability both spatially and temporally. National mean annual rainfall is 1,071 mm but the Lake Tanganyika basin and the southern highlands can receive up to 3,000 mm annually while about half the country receives less than 762 mm annually. Temporally, the northern parts of Tanzania experience a bimodal rainfall pattern (long rains from March through May and short rains from October to December) while the rest of country is unimodal, with the majority of rainfall coming between December to April. The El Niño/La Niña South Oscillation (ENSO) phenomenon can also result in substantial impacts on intraseasonal variability.

A number of studies projecting the impact of climate change on water resources in Tanzania have been undertaken, ranging from Mwandosya *et al.* prepared over the period 1994-1998 to the most recent by University of Cape Town's Climate System Analysis Group, completed in 2010. Most studies used multiple General Circulation Models (GCMs) and generally concluded that while future rainfall patterns were uncertain, some areas of the country, such as the Pangani basin area, may receive more rainfall under various climate change scenarios and other areas, especially the central region, might receive less; the CSAG study also suggested there would be a seasonal shift in rains, with less rainfall early in the season and stronger rains later in the season, which agrees with another major study (Hulme *et al.*, 2001) on projected rainfall changes in East Africa. In terms of temperature increases, the two studies concluded that it would be in the range of 1.5°C - 2°C for the first half of this century and around 2°C - 4°C for the second half. These findings are also within the range predicted for East Africa by the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In terms of the impact of climate change on water flows in Tanzania, there is much less agreement: Mwandosya *et al.* (1998) predicts increased flows in the Rufiji basin and decreased flows in two other key basins (Wami-Ruvu and Pangani); another study (de Wit and Stankiewicz, 2006) projects a rise in perennial drainage to a total of 136% in central Tanzania and 125% in northwest Tanzania by the end of this century; and a third (Strzpeck and McCluskey, 2006) suggests by mid-century on a national basis streamflows will be between 80-100% of 1961-1990 flows and only 80-90% of base period flows by 2100. Finally, in assessing the predictions of these studies, it must be noted that other drivers of climate and water resources, such as land use change and the impact of ENSO, were often either not considered or inadequately incorporated. This issue, coupled with widely-ranging predictions on population growth and the rate of urbanization, means that a key challenge for Tanzania in terms of planning adaptation strategies will be the high degree of uncertainty about its future climate.

Adaptation strategies for the domestic water supply sector...

Adaptation strategies for hydropower..

1. INTRODUCTION

Water is a critical input into Tanzania’s economy. It underpins the performance of the agricultural sector, which employs 80% of the workforce and accounts for 45% of the country’s GDP and 55% of foreign exchange earnings. River basins provide drinking water for the workforce in Dar es Salaam, Arusha, Morogoro, Kibaha and Dodoma, economically important areas of the country in which industrial activity is highest. Water is also an input into industrial production: for example, mining, a key sector in Tanzania’s Development Vision 2025, depends on reliable water. Hydropower provides 55% of the country’s power generation. Adequate water flows support Tanzania’s forests, grasslands, and coastal resources, which provide provisioning services (such as food, fodder, fuelwood, timber and other products) and other services (water purification, climate regulation, cultural and supporting services). Water flows in national parks and protected areas support the tourism sector, a key foreign exchange earner.

In 2007, Tanzania’s renewable water resources per capita was 2,291 m³ (WRI, 2010), which is not classified water scarce according to the Falkenmark Water Stress Indicator. However, the country’s population has grown rapidly in the last 50 years, going from 10 million in 1960 to approximately 45 million in 2010 (UN ESA, 2010). The projected population for 2015 is 52 million, at which point the country’s per capita water resources will fall below 1,700 m³ per person, the definition of water scarcity. By 2030 the population is expected to be around 75 million and by 2050 it is projected to reach 109 million, further lowering per capita water resources (Figure 1).

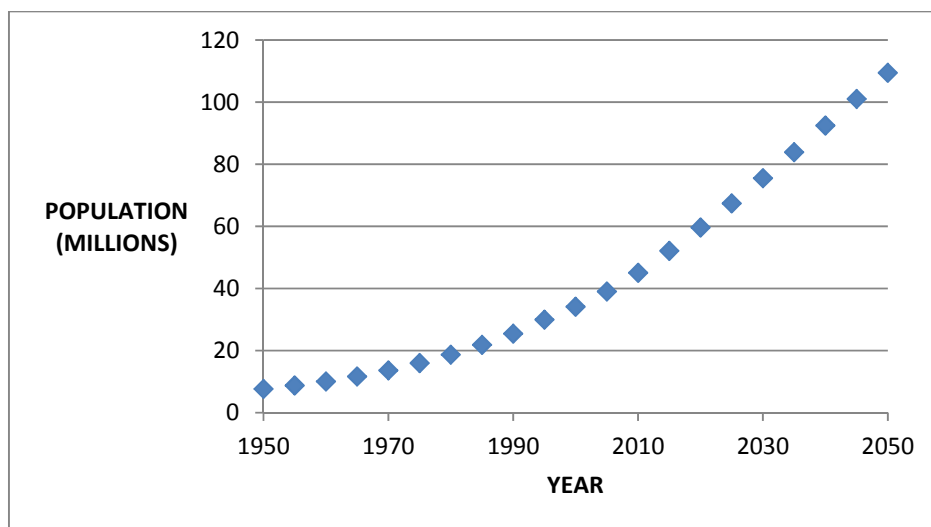


Figure 1: Tanzania’s historic and projected population growth through 2050
Source: based on data from UNESA, 2010

However, evaluating per capita water availability on a national basis is misleading, as water resources are unevenly distributed spatially; the appropriate scale is thus the local or regional level and within river basins or sub-basins (UN Water, 2006). Tanzania's annual rainfall varies from 500-1,000 mm over the majority of the country with a national mean annual rainfall of 1,071 mm but there is significant sub-regional variation: the Lake Tanganyika basin and the southern highlands can receive up to 3,000 mm annually (FAO, 2005) while about half the country receives less than 762 mm annually (Shemsanga et al, 2010). Figure 2 illustrates this variability.

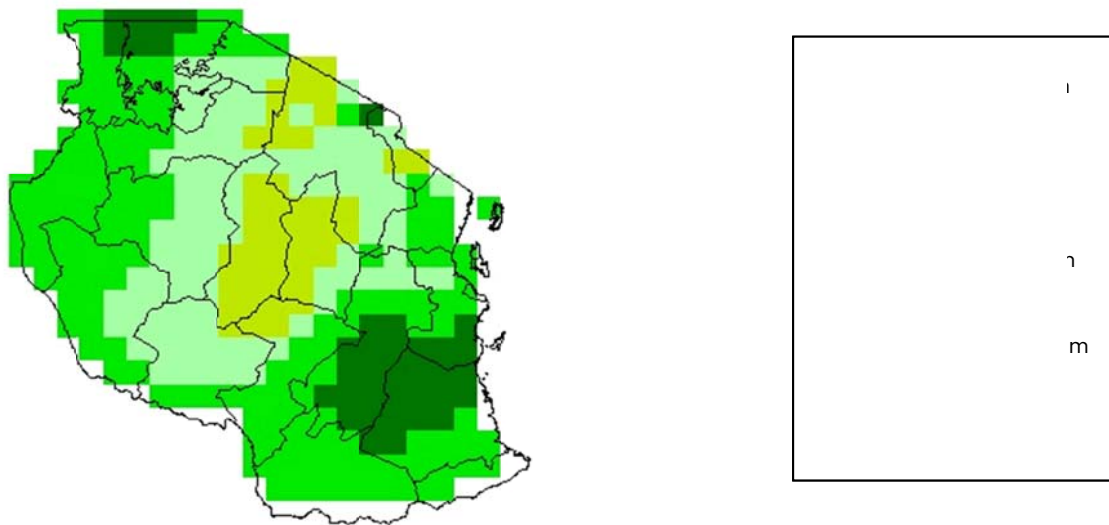


Figure 2: Average annual rainfall in Tanzania
Source: FAO (2010)

Water resources also vary temporally, with the country divided between regions with a bimodal rainfall pattern and those with unimodal rainfall. Bimodal rainfall is primarily seen in the north eastern parts of Tanzania (area around Arusha, Moshi and Same), north western areas (Lake Victoria Basin), and the northern part of the country's coastal belt (including Dar es Salaam, Tanga and Morogoro). In the bimodal pattern, there are long rains (called *Masika*) from March through May and short rains (*Vuli*) from October to December. Under the unimodal pattern seen in the rest of the country, most of the rainfall comes over the period from December to April.

Rainfall in coastal Tanzania is also affected by the El Niño/La Niña South Oscillation (ENSO), which impacts intraseasonal variability during the *Vuli* and *Masika* periods (Kijazi and Reason, 2005). However, the impacts are more pronounced on the northern coastal areas (4°-8° S) than the southern (8°-12° S) areas. Generally, El Niño brings above average rainfall and La Niña results in lower rainfall over the northern coastal area, with more impact during the *Vuli* season than *Masika*; these effects are mostly caused by longer rainy seasons during El Niño and late onset of the rain during La Niña. For the southern

coastal areas, the impacts of ENSO are less coherent, apparently due to the transition between the opposite responses over East and southern Africa.

Tanzania has eight river basins (Figure 3). The country is also riparian to the three largest freshwater lakes in Africa - Tanganyika, Victoria and Nyasa - which represent a huge natural storage capacity for Tanzania, holding almost 400 times the mean annual runoff from all of its rivers (Meena and Raphael, 2008). About half of the country's surface runoff comes from rivers flowing into the Indian Ocean (including the Pangani, Rufiji, Wami, Ruvu, and Ruaha rivers); part of the rest drain into the lakes Victoria (Meri, Maru and Kagera rivers), Tanganyika (River Malagarasi), Rukwa, Bubu, Eyasi and Manyara as well as the Lake Nyasa/Zambezi River system (Songwe and Ruhuhu rivers).

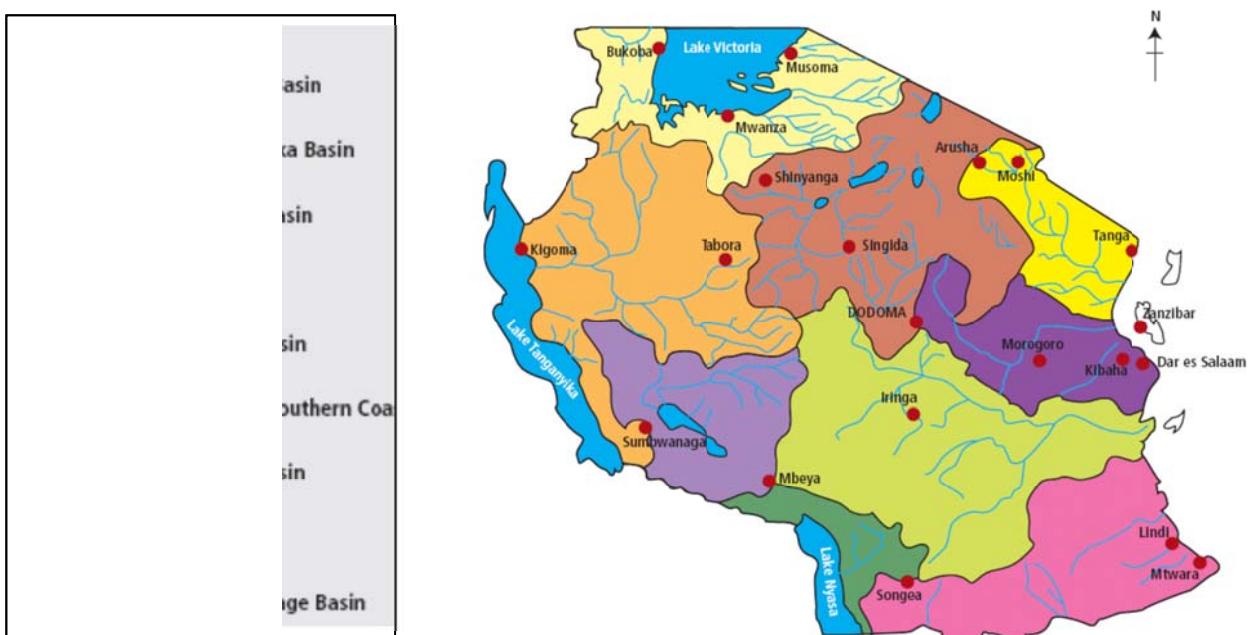


Figure 3: River basins of Tanzania
Source: URT (2007)

2. CLIMATE CHANGE AND WATER RESOURCES IN TANZANIA

One of the earliest and most comprehensive studies on climate change in Tanzania was Mwandosya *et al.*, 1998, which was undertaken over the period 1994 to 1996 by Tanzanian researchers with support from the US Country Studies Programme. In addition to modeling rainfall and temperature increases and assessing changes in water flows, the study also estimated impacts in terms of crop production (maize, cotton and coffee), malaria, sea level rise and grasslands and forests. This study has been very influential in the country: it is the starting point in Tanzania's Initial National Communication and its National Adaptation Programme of Action and referenced in many other government documents. The lead author, Professor Mark J. Mwandosya later became Minister of Environment and is now the Minister of Water.

Employing a General Circulation Model and using 1951-1980 as the baseline, the Mwandosya study compared baseline climate projections to the '2XCO₂' scenario, which assumes a doubling of baseline concentration of greenhouse gases by 2075. Major findings were:

Temperature increases:

- Increase of 3.6°C to 3.8°C in the western and south western parts of the country;
- Increase between 2.7°C and 3.1°C in the south eastern, eastern and north eastern zones of the country ; and
- Increases would occur during both the southern hemisphere's summers and winters, but would be greater during the latter (June, July and August), when the increase would be from 2.5°C in the south eastern part of Tanzania, 4°C in the central and western parts and between 3-4°C in the remaining areas.

Rainfall changes:

- Increase of 5-45% in northern and south eastern areas of the country, with the highest increases occurring close to Mount Kilimanjaro; and
- Decrease of 5-15% in central, western, south western, southern and eastern parts; and

Recently another study of climate change in Tanzania (Jack, 2010) was undertaken by the Climate System Analysis Group (CSAG) at the University of Cape Town. This work employed a downscaling methodology (Self Organising Map based Downscaling) with nine global climate models. For each of these, the first simulation was of the period 1961 to 2000 forced by observed greenhouse gas concentrations. Two other projections were done using the development scenarios of B1 and A2. The two periods investigated were 2046–2065 and 2081–2100. The simulations were downscaled regionally within various locations in Tanzania (Dar es Salaam, Dodoma, Kilimanjaro, Mbeya, Mwanza), generating climatological summary statistics.

The main conclusions of the CSAG study were:

Rainfall changes: rainfall was projected to increase during the late part of the summer with possibly some drying in the early summer period, indicating a seasonal shift of weaker rains early in the season and stronger rains later in the season. Further, it did not appear that the later period (2081-2100) would have significant wetting compared to the earlier period (2046-2065), suggesting there may be a limit on precipitation.

Temperature changes: in general across the 9 GCMs, for the earlier period the predicted temperature change was around 1.5°C for the B1 scenario and 2°C for the A2 scenario. For the later period, increases were around 2°C for the B1 scenario and as high as 4°C for the A2 scenario.

A third study (Hulme *et al.*, 2001) looked at rainfall in East Africa over the twentieth century and found 'some evidence of long-term wetting' (Figure 4). The authors then used 7 GCMs to project climate change using four scenarios for three periods of this century (2020s, 2050s, and 2080s): (i) A2 with high climate sensitivity; (ii) A1 with medium climate sensitivity; (iii) B2 with medium climate sensitivity; and (iv) B1 with low climate sensitivity. The results indicated rainfall increasing by 5-30% over the December – January season and decreasing by 5-10% during the period July – August in East Africa.

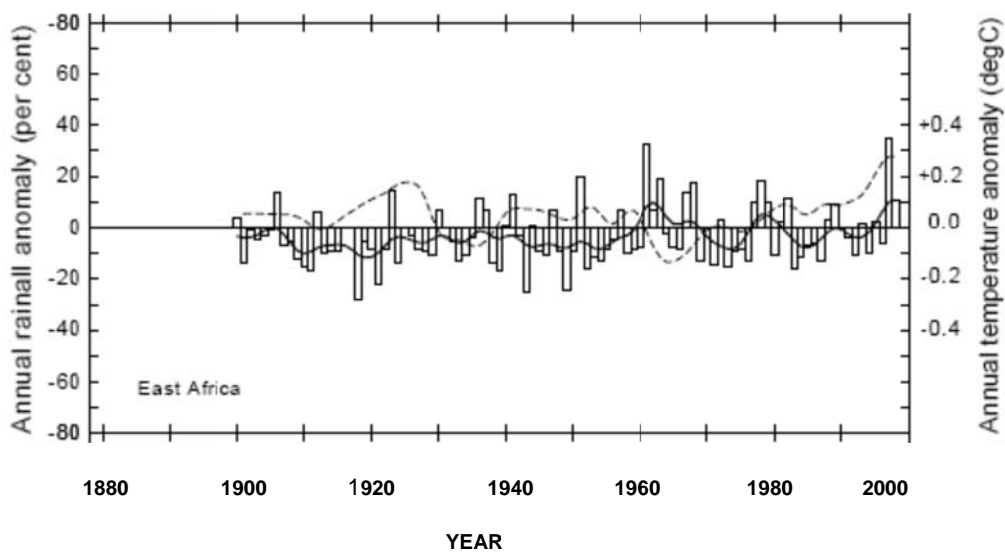


Figure 4: Annual rainfall in East Africa, 1900-1998 (histograms and bold line) and mean temperature anomalies, 1901-1998 (dashed line).

Source: Hulme *et al.*, 2001

In reviewing the evidence, the projected temperature increases are in the same range for both the Mwandosya and the Jack studies and also coincide with the projections for Africa of the IPCC Fourth Assessment Report (Boko *et al.*, 2007). The projections on rainfall are less clear: Boko *et al.* describes the rainfall picture as 'complicated' due to significant spatial and temporal variability; similarly, Jack notes

the projections ‘show large uncertainties’ and the Mwandosya study predicted very different rainfall impacts at lower spatial scales. The Hulme projections suggest an overall wetting trend but greater seasonal variability, with increased rainfall during the southern hemisphere’s summer and decreased rainfall during the winter.

In addition to rainfall and temperature changes, the Mwandosya research also investigated impacts of climate change on river runoff using the Water Balance (WATBAL) model, which considers catchment rainfall and evapotranspiration. The researchers chose three basins – Ruvu, Pangani and Rufiji – because of their economic importance to the country: the Ruvu basin is the source of water for Dar es Salaam, while the Pangani and Rufiji provide water for hydropower and irrigation.

The study projected the following in terms of annual river runoff changes:

- Ruvu River: decrease of 10%;
- Pangani basin: decrease of 6-9%; and
- Rufiji basin: increase of 5-11%

Another source of data on climate-related water flow changes comes from de Wit and Stankiewicz (2006), which considered variable changes in precipitation in order to assess changes in drainage across Africa by the end of this century; two of the sites analysed were in Tanzania: the city of Dodoma in central Tanzania and a rural area in northwest Tanzania. Dodoma sits at the intersection of the Rufiji and Wami-Ruvu basins, while northwest Tanzania is part of the lake basins of Victoria and Tanganyika, thus the latter represents an area different from the ones analysed in the Mwandosya research. The scenario used was the B1, normalised to the historically-observed precipitation in Africa for the 20 year period 1979-1998. As the two locations are in the area projected to experience a 10% rise in rainfall by the end of this century based on a composite of 21 GCM models, this suggests a rise in perennial drainage to a total of 136% in Dodoma and 125% in northwest Tanzania (Table 1).

Table 1: Percentages of perennial drainage that will remain following a given change in precipitation

Area	Rainfall (mm/y)	During	10% drop	20% drop	10% rise	20% rise
Dodoma	551 ^a	1922-1989	64%	27%	136%	173%
Northwest	670 ^b	1979-2000	75%	50%	125%	150%

Source: de Wit and Stankiewicz, 2006

^a from www.worldclimate.com

^b from the CSAG station data archive for rural districts

A continent-wide study of runoff (Strzpeck and McCluskey, 2006) also employed the WatBal model, using as inputs the climate variables of the 1961-1990 climatology and physiological parameters (soil properties and land use) derived from global datasets for 0.5° latitude/longitude cells across Africa. Five GCMs for A2 and B2 were used to generate the climate change scenarios, from which the WatBal model was used to examine the impact of each scenario on runoff and evaporation. The projections for 2050

showed a ratio of 0.8 to 0.9 of the 1961-1990 streamflow under the low scenario and 0.9-1 under the high streamflow scenarios; for 2100, both the high and low scenarios projected the ratio to be 0.8-0.9 of the baseflow (Figure 5).

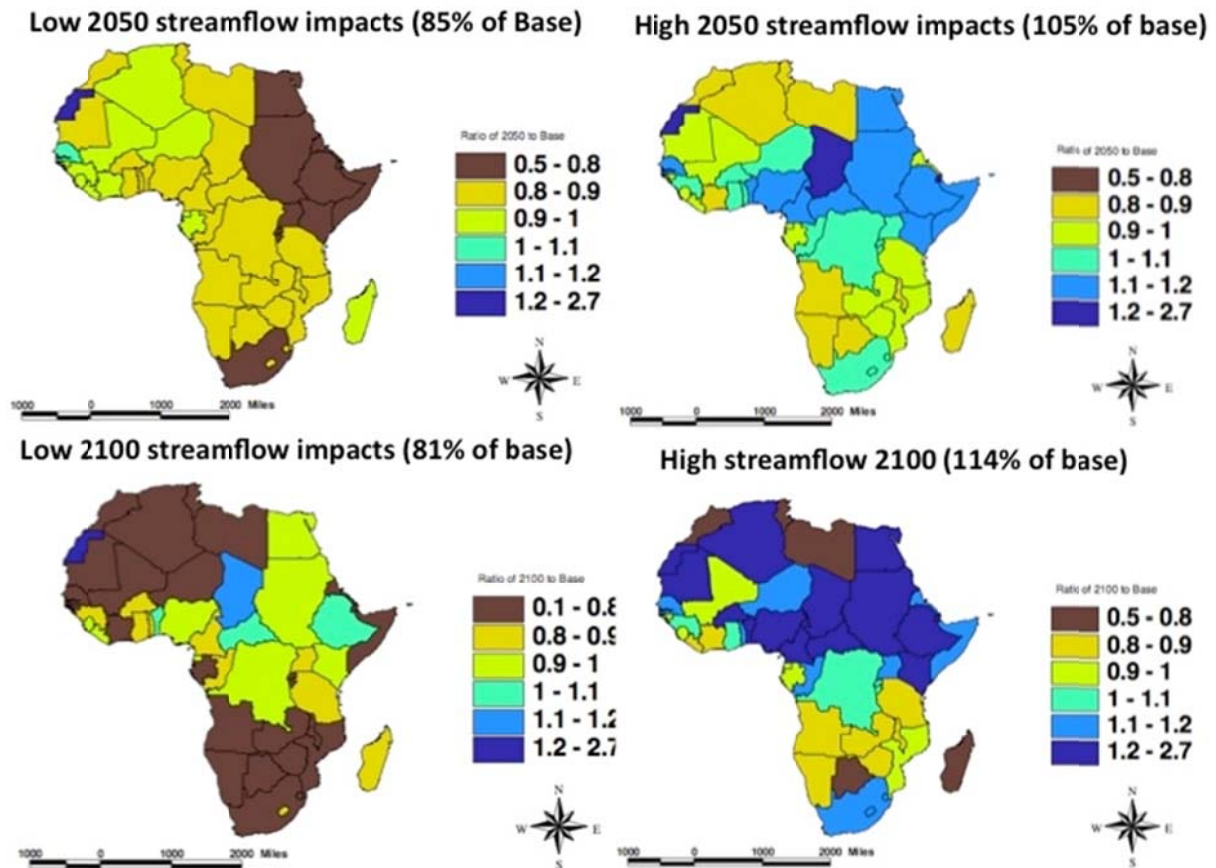


Figure 5: Projected high and low streamflow impacts for 2050 and 2100
 Source: Strzpeck and McCluskey, 2006

Thus, as with the rainfall data, the studies produce different results on the impact of climate change on water flows in Tanzania. Mwandosya *et al.* (1998) predicts increased flows of 5-11% in the Rufiji basin by 2075 based on the 2XCO₂ scenario, while the de Wit and Stankiewicz study project a rise in perennial drainage to a total of 136% in central Tanzania and 125% in northwest Tanzania, based on a 10% rise in rainfall by the end of this century. Both sets of data thus project increased flows in parts of Tanzania, though vary on the total percentage of the increase; the Mwandosya study also suggests possible decreased flows in two key basins (Wami-Ruvu and Pangani) under the 2XCO₂ scenario. The Strzpeck and McCluskey research suggests on a national level, streamflows in 2050 will be between 80-100% of 1961-1990 flows, whereas by 2100 the streamflows will be only 80-90% of the base period flows.

Lastly, in assessing all of the studies discussed above, it must be noted that other drivers of climate and water resources were either not considered or inadequately incorporated. For example, land use change is not sufficiently addressed in GCMs (Hulme *et al.*, 2001), though there are ongoing efforts to quantify the interaction between land use change and regional climate change (Olson *et al.*, 2008). Land use change also has a major impact on runoff and thus is potentially a strong influence on downstream water availability, both in terms of quantity and quality. A 2010 Soil and Water Assessment Tool (SWAT) analysis of the Wami river basin considered the impact of an expansion of irrigated agriculture of water flows in the basin. As Figure 6 below shows, the flows would be lower during the dry season but higher in the wet season, due to increased runoff under the changed land use patterns. The increased flows during the rainy season would also be expected to include much more sedimentation and siltation. Expansion of livestock and the accompanying potential for overgrazing would also increase soil erosion and siltation of rivers (World Bank, 2004).

The impact of ENSO is also an issue in GCMs, with the response of ENSO events to global warming poorly understood (Hulme *et al.*, 2001), which affects climate change projections and also may impact on future estimates of water resources.

In summary, one of the challenges for Tanzania in terms of planning adaptation strategies will be the need to consider the high degree of uncertainty of its future climate. While temperature change predictions are fairly consistent, rainfall patterns and water flows projection vary widely, including both spatially and temporally within seasons. Factors such as land use change, ENSO and population growth also have the potential to change the level of water resources available, further complicating the divergent scenarios.

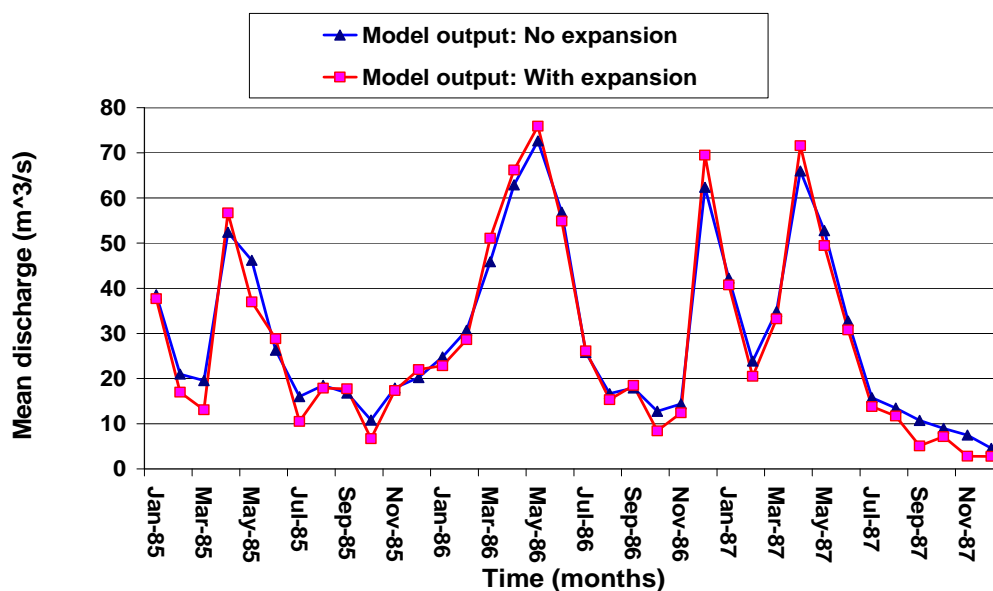


Figure 6: Results of SWAT analysis to examine impacts on water flows under a scenario of expanded irrigation in Wami river basin
 Source: Kongo *et al.*, 2010

3. DOMESTIC WATER SUPPLY

The above discussion of projected climate change impacts on water resources makes clear the degree to which sources of domestic water will be affected. Piped water systems in the largest cities in Tanzania source their water from the country's rivers: the Wami-Ruvu river basin supplies water to Dar es Salaam (population of 3+ million), Morogoro, Kibaha and Dodoma, while the Pangani supplies drinking water to the Kilimanjaro District, which includes the city of Arusha (population of 1+ million). Urban areas also use groundwater as a supplemental source to meet demand. Zanzibar is the exception, drawing the bulk of its water supply from groundwater alone. Tanzanians living in rural areas similarly draw water from ecosystem sources and from groundwater accessed through public and private wells. Uncertainty regarding future rainfall patterns and river flows, combined with ambiguity in projected population growth and urbanization rates as detailed below, will complicate planning for adaptation in Tanzania's domestic water supply sector.

The most recent information on access to water supply in Tanzania comes from the 2007-2008 HIV/AIDS and Malaria Indicator Survey (Tanzania Commission for AIDS, 2008), which interviewed 9,144 households selected from 475 sample points across the country (Table 2). The survey showed that over half of Tanzanians had access to an improved source of drinking water, though the figures for urban areas were much higher than the total for rural areas.

Table 2: Source of drinking water

SOURCE	URBAN	RURAL	TOTAL
IMPROVED	82.1	48.0	56.4
Piped water into dwelling/yard/plot	23.1	2.5	7.6
Shared tap/standpipe	30.3	3.9	10.4
Public tap/standpipe	15.8	15.0	15.2
Tubewell/borehole	3.7	0.6	1.4
Protected dug well	7.1	15.8	13.7
Protected spring	2.1	10.0	8.0
Rainwater	0.0	0.1	0.1
NON-IMPROVED	17.7	50.0	42.0
Unprotected dug well	8.8	28.4	23.6
Unprotected spring	2.0	17.6	13.8
Tanker truck/cart with small tank	5.8	0.9	2.1
Surface water	1.1	3.1	2.6
MISSING	0.2	2.0	1.6
TOTAL	100.0	100.0	100.0

Source: Tanzania Commission for AIDS, 2008

As Figure 7 indicates, rapid urbanisation has meant access to improved sources of drinking water has actually declined over the last decade, though there has been an upward trend since 2005 (van den Berg *et al.*, 2009).

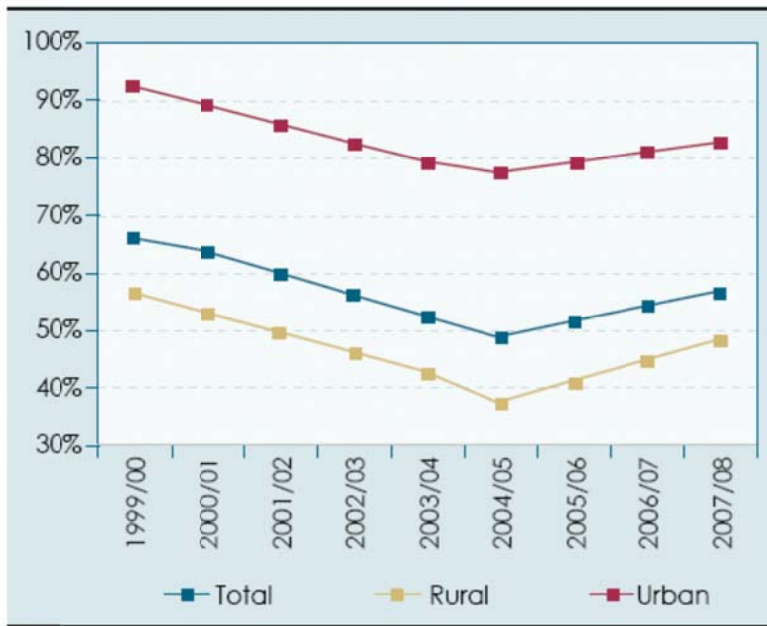


Figure 7: Access to improved water sources

Source: van den Berg et al., 2009

The sources of drinking water were also very different between urban and rural locations: for example, over half of urban households had access to piped water either within their household plot or through a shared tap, whereas less than 7% of rural households enjoyed that type of access.

A major challenge in planning is the uncertainty over the rate of urbanization. Tanzania’s last census, in 2002, showed the urban population was 22.6% of the total population. As WaterAid (de Waal and Nkongo, 2005) has pointed out, UN population figures for 2000 overestimated the urban population and its early projections for 2015 ‘greatly overestimate’ the urban population (Figure 8). The 2009 Revision Population Database now estimates the 2010 urban population at 26.4%, with projections of 28.9% for 2015 (down from the earlier projection of 47%) and over 50% by 2045. A World Bank study found that 17% of the population living in mainland Tanzania resided in high-density settlements not officially recognized as urban; using a density-based perspective, the level of urbanisation was 33.5% (Muzzini and Lindeboom, 2008).

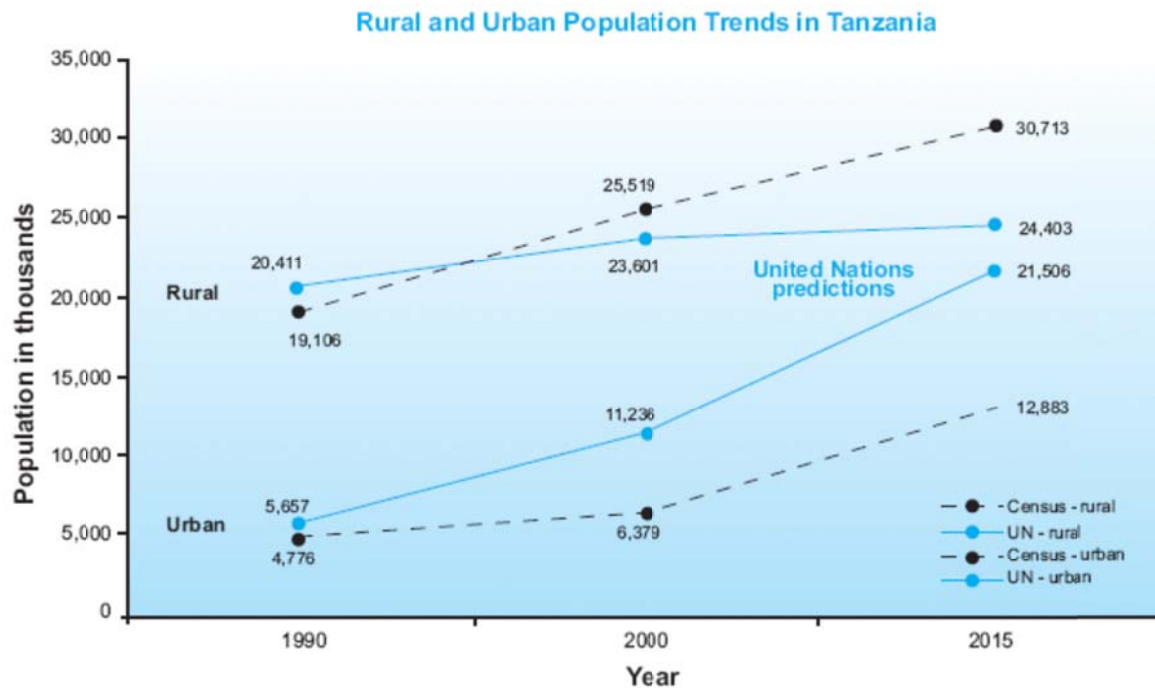


Figure 8: Urban and rural population projections by UN and Census

Source: de Waal and Nkongo, 2005

3.1 Urban water supply

The 2007-2008 HIV/AIDS and Malaria Indicator Survey described above showed that almost 70% of urban dwellers in Tanzania had access to piped water, with 17.7% relying on unimproved sources of water and 12.8% using water from wells or springs. Urban dwellers' access to improved sources of water has declined in the last two decades, going from 88% in 1991 to only 80% in 2007 (van den Berg et al., 2009). Access to piped water in urban areas has declined even more rapidly, going from 79% in 2000 to only 62% in 2007. The capital city, Dar es Salaam, experienced the largest drop: access to piped water declined from 93% in 1991 to 58% in 2007. Rapid urbanisation is one of main causes of these declines.

However, the above data indicates only connectivity and does not reveal actual service levels. Urban water suppliers at all levels are failing to meet current demand: the 19 urban water authorities' water production to demand is 71% (Table 3); for the smaller providers it is 36.4% for small towns and 38.2% for district level providers (URT, 2010b).

Table 3: Percentage of demand met for drinking water in major urban areas

Urban Water and Sewerage Authorities	Population in service area	Production vs demand (%)
Lindi	44,000	26
Kigoma	144,853	31
Sumbawanga	90,000	42
Mtwara	102,457	44
Musoma	132,000	45
Singida	81,662	58
Dar es Salaam	2,860,149	61
Shinyanga	135,166	61
Babati	64,00	69
Tabora	152,075	70
Mwanza	515,000	72
Songea	104,516	75
Morogoro	286,580	81
Iringa	134,831	83
Arusha	356,933	85
Dodoma	267,660	86
Bukoba	68,875	88
Mbeya	262,000	90
Moshi	156,234	94
Tanga	240,000	98

Source: adapted from Tables 3.1 and 3.2, Water Sector Status Report 2009 (URT, 2009)

Accompanying the falling rates of connectivity to piped water systems, the 2007-2008 survey showed that urban households were increasingly relying on private wells (10%) and water vendors (7%). A recent report (World Bank, 2010) notes:

Groundwater, from water wells (boreholes and hand-dug wells), now supplies one-fourth of urban dwellers and is the fastest-growing source of improved water supply in African cities by far. With utility coverage rates falling in urban Africa, groundwater has essentially stepped into the breach, and the rapid growth of boreholes shows the appetite for lower-cost solutions.

The report continues by noting the ratio of hand-dug wells to boreholes is unknown.

Other challenges for the country's urban water supply include over abstraction of flows upstream – some unauthorized – and catchment degradation; for Dar es Salaam, salt water intrusion due to over-pumping of groundwater, the absence of adequate storage and a breach in the Ruvu River bank are additional problems (World Bank, 2006).

3.2 Rural water supply

In rural Tanzania, access to improved water sources has increased 35% in 1991 to 42% in 2007, mostly due to increasing dependence on other improved water sources, especially groundwater (van den Berg, 2009). Currently, about 50% of Tanzanians living in rural areas have access to clean drinking water. A total of 31.7% of the rural population rely on ecosystem sources (springs, streams, rivers, ponds and lakes) and 28.5% access domestic water from open public wells.

Sustainability of rural water supply systems is a major challenge: a study by WaterAid (Taylor, 2009) found that almost half of improved waterpoints were non-functional. Further, 25% of waterpoints had stopped working only two years after installation. Another study undertaken 2006-2009 by different researchers (Jiménez and Pérez-Foguet, 2010) reported that 50% of functional improved waterpoints surveyed had either quality or seasonality problems. The latter study also found that hand pumps were the systems with the poorest sustainability record.

3.3 Adaptation

It is clear from the above discussion that the sector is already challenged by the existing development deficit. In view of this situation, the projected climatic change impacts - possible increased in intraseasonal variability of rainfall and/or lower river flows, increased evaporation of water bodies due to higher temperatures – will exacerbate those problems and substantial new investment will be needed.

Catchment management would be an effective adaptation strategy for domestic water supply in both urban and rural areas, as would be shifting from shallow wells to deeper boreholes. For urban areas, demand management will be a no regrets measure; infrastructure for storage would be required if demand management is insufficient and/or under scenarios of higher climate change. For rural areas, instituting rainwater harvesting and undertaking waterpoint mapping to increase functionality will be needed.

Adaptation measures for urban and rural: Catchment management and reliance on deep groundwater

An adaptation strategy that Tanzania can pursue for both the urban and rural sectors is investing in catchment management. Water basin management is an effective measure for securing water resources of sufficient quantity and quality for domestic supply; as noted above, most urban areas source their water from rivers and streams, as do those living in rural areas. Thus, a basin programme that manages abstractions for various demands and considers land use impacts on water resources will be central to ensuring safe sources of drinking water. Catchment management also has cross-sectoral benefits, most notably to agriculture, ecosystems, and energy through hydropower generation.

In addition to safeguarding surface water sources, catchment management can also be instrumental in ensuring groundwater resources are used sustainably and not subject to pollution. Groundwater supplies are important to domestic water supply in Africa because they often tend to hold water of good quality as well as typically store larger quantities of water than their annual recharge, enabling the maintenance of steady supplies even during low rainfall seasons (Calow and MacDonald, 2009). Shifting away from shallow dugwells – which are vulnerable to contamination, especially in urban areas – and handpumps – which tend to have poor reliability – would also be a sound strategy for both urban and rural areas (Foster *et al.*, 2006). For the drier areas of the country (*e.g.*, Dodoma, Singida, Shinyanga, Tabora, Mwanza, Mara, Arusha, Coast and Southern Kilimanjaro), groundwater is the most viable supplemental source of domestic water (URT, 2010a; Foster *et al.*, 2006).

Urban water supply adaption

As described above, future rainfall patterns and streamflows are uncertain: one study predicts less rainfall in both of these basins while results from other studies indicated a trend toward more wetting. However, the studies do suggest a seasonal shift of rains, with possibly less rain earlier in the wet season. The streamflow data from Strzpeck and McCluskey suggest that at the national level, streamflows in Tanzania will be 80-100% of 1961-1990 flows by mid-century and only 80-90% of the base period flows by 2100. Given that the bulk of urban water supply in Tanzania is drawn from the country's rivers and springs, the projected reduced river flows will require significant levels of adaptation.

As Tanzania approaches water scarcity, demand management - controlling illegal connections and leaks - will be the key adaptation measure as well as a no-regrets strategy. Dar es Salaam's provider, DAWASCO, is currently losing 56.7% of the water it pumps due to leaks and illegal connections (URT, 2010b) and less than 30% of households served have meters (UN-HABITAT, 2010). Tanzania's other urban water supply authorities averaged a total of 36.4% of non-revenue water. The country also has 102 smaller water suppliers (district, small towns and national water projects) whose performance has been judged unsatisfactory by Tanzania's Energy and Water Utilities Regulatory Authority, which identified insufficient water sources or water production capacities and dilapidated infrastructure as contributing to the poor performance. Thus, demand management is a strategy that should be implemented immediately, even before the range of possible climate change impacts are factored into the decision.

Increased storage capacity may also be needed, including possibly the construction of a reservoir in the Ruvu basin to store water for Dar es Salaam. Another adaptation strategy that has been raised is to shift Dar's source of drinking water to the lower Rufiji river basin (Meena and Raphael, 2008; Agrawala *et al.*, 2003), a hugely-expensive undertaking that would only be justified if reduced flows in the Wami-Ruvu basin are borne out and/or Dar's population growth exceed the basin's capacity.

Rural water supply adaptation

Adaptation measures for the rural sector include development of groundwater wells and rainwater harvesting structures. Key aquifers are expected to subside or dry up due to climate change-induced slower rates of recharge, which will require shallower wells to be replaced by deeper – and more expensive – boreholes (Ehrhart and Tweena, 2006). Using the most recent figure of 50% for rural households without an improved source of drinking water from the 2008 HIV/AIDS and Malaria Indicator Survey, the UN MDG target for drinking water supply in Tanzania of 75% coverage and the 2015 UN estimated rural population of 37 million, that would require presently supplying approximately 9.25 million rural residents with a safe source of drinking water. Using WaterAid's figures (de Waal and Nkongo, 2005) for water supply of US\$25 per capita for shallow wells and springs and US\$50 per capita for small piped schemes from boreholes of springs, the cost of upgrading Tanzanians living in rural areas without improved drinking water from shallow wells and springs to the small piped systems drawing on boreholes and springs would be US\$23 million. This figure thus represents the potential additional cost of the rural drinking water target if shallow wells and springs are unusable under climate change projections.

Rainwater harvesting systems could be used for domestic water supply as well as a source of agricultural water and could provide an additional service of storage as a buffer against greater intraseasonal rainfall variability. In Zanzibar, in particular, rainwater harvesting has been identified as cost effective measure; one study (MDG Centre *et al.*, 2007) estimates the cost at US\$2.4 million for runoff catchment systems and US\$1.2 million for rooftop rainwater catchment.

Given the large number of waterpoints that are non-functional, mapping of rural waterpoints to serve as an input into district-level planning has also been identified as a necessary tool to ensure sustainability (Taylor, 2009; SNV, 2010; World Bank, 2010; Jiménez and Pérez-Foguet, 2010) and thus could help Tanzania cope with climate change-induced stresses on rural water sources. Standardization of technologies might also boost functionality: data from WaterAid indicate there is a relationship between the dispersion of technologies within a district, with less dispersion of technologies linked to higher rates of functionality rate (van den Berg *et al.*, 2009).

4. HYDROPOWER

The majority of Tanzania's power generation – 55% - comes from hydropower. Of that total, over 80% of hydropower is generated in the Rufiji basin (the tributaries of the Great Ruaha River and the Kihansi River); the rest is generated on the Pangani River in northern Tanzania. Previously, Tanzania's reliance on hydropower was much higher: in 2002, 97% of the country's grid-based electricity came from hydropower (World Bank, 2004). But in 2003, both the *Masika* and the *Vuli* rains failed in most parts of the country, resulting in flows of two-thirds of the average flow over the previous 25 years; Mtera was hit even harder, receiving just 40% of average flows over the previous 60 years. The drought resulted in the Mtera dam being mined and the country started 2004 with Mtera just above the minimum level for power generation. When the *Vuli* rains failed again in 2003, Tanzania Electric Supply Company (TANESCO), a national parastatal, turned to a private provider, Songas, which began producing power using Jet A1 fuel using refurbished gas turbine units in Ubungu; the monthly cost was US\$8 million to purchase the Jet A1 fuel to produce 80 MW at Ubungu and to buy energy from another plant (World Bank, 2004). After this experience, Tanzania began developing alternative power sources, especially thermal generation. The World Bank estimated that the cost of the incremental thermal generation due to the drought was about US\$67 million from January 2004 to February 2005. Another World Bank report two years later stated that power rationing was 'causing huge losses' in a number of sectors and put the cost to the economy at \$1.7 million *per day* (World Bank, 2006).

Energy-related impacts due to periods of low rainfall and drought have resulted in lower economic growth. The Central Bank of Tanzania has estimated that in 2007 the economy grew 1.1% slower than expected due to electricity shortages (NAPA, 2007). Similarly, in 1997 growth dropped to 3.3% from the previous year's 4.2%, also due to power shortages and in 1994, industrial growth declined by 3.8%, attributed mainly to electricity shortages and load shedding (World Bank, 2004). A 2009 study that considered possible impacts on hydropower by 2030 under 'moderate climate change' and 'high climate change' scenarios projected losses of 0.7% and 1.7% of GDP due to decreased rainfall in the central region of Tanzania, where 95% of the country's hydropower installations is expected to be located by 2030 (ECA, 2009).

Tanzania has on average 63 days a year with power outages (World Bank, 2010). During periods of load shedding, larger businesses and wealthy households turn to small diesel generators, which results in higher carbon emissions as well as air and noise pollution in urban areas; smaller businesses and the majority of households are unable to afford this option (Ngeleja and Mwiwaha, 2009). Only an estimated 40% of businesses have their own generators to protect against electricity interruptions (ECA, 2009). The World Bank analysed the economic cost of power shortages by quantifying the cost of running these backup generators and the losses from foregone production; for Tanzania, it estimates this has resulted in a loss of over 4% of GDP annually, adding that power shortages act as a drag on economic growth in the long term (World Bank, 2010). The draft 2004 Investment Climate Assessment noted inadequate electricity supply was one of the major constraints confronting Tanzanian industry and a major obstacle to the start-up of new businesses in the country.

In addition to current unmet demand, the electricity supply system is projected to expand significantly: from 81 to 300 kWh per capita.

There are four main impacts on hydroelectric installations from temperature and rainfall change (Mukheibir, 2007):

- i. Surface water evaporation
- ii. Reduced run-off due to drought
- iii. Increased run-off due to flooding
- iv. Siltration deposits

The greatest climate change-related impact on water resources is expected to come from increased evaporation of water from reservoir surfaces due to higher temperature. The largest dam in Tanzania is Mtera, with surface capacity of 605km² at full supply level. Postel *et al.* (1996) assumes that an average of 5% of gross reservoir capacity is lost per year due to evaporation; for Mtera, total storage (live and dead) is 3700Mm³, which would be a loss of 185Mm³. However, Postel *et al.*'s 5% is a worldwide average and given that the dam is located near the equator, losses would be expected to be higher: by comparison, Nasser Dam in Egypt loses 11% of its capacity each year (Gleick, 1994).

Tanzania's Initial National Communication identified damage to hydropower installations due to flooding on the Rufiji River as a possible impact of climate change (URT, 2003). While past flooding has not resulted in damage to turbines, it has been a problem for the dams, which are filling with sedimentation. TANESCO notes that the smaller projects, such as Hale and Pangani are filling rapidly and may be completely full within 15 years time; at that point, they will only run at 30-40% of capacity and will be not able to be used to meet peak demand, essentially becoming run-of-the-river installations (per comm, Tesha and Rubagumya).

Table 4: Hydropower in Tanzania

NAME	RIVER BASIN	AGE	% OF TOTAL HYDRO INSTALLED CAPACITY	TOTAL GENERATING CAPACITY (MW)
Kidatu	Rufiji	35	35.9%	204
Kihansi	Rufiji	10	32.3%	180
Mtera	Rufiji	22	14.4%	80
Pangani Falls	Pangani	15	12.2%	68
Nyumba ya Mungu	Pangani	42	1.4%	8
Hale	Pangani	43	3.8%	21
TOTAL GENERATING CAPACITY (MW)				561

Source: URT (2009a)

Adaptation

There are three suggested adaptation strategies: demand management; diversification of energy sources; and basin catchment management programs.

Demand Management

Given the current power deficit and frequent loading shedding, which results in large economic losses to the Tanzanian economy, demand management would be a no regrets strategy. The September 2009 update to the Power System Master Plan (PSMP) notes that:

Implementation of DSM [demand-side management] to achieve significant demand reductions is a lengthy process that requires sustained effort and both technical and financial resources.

The report goes on to state that demand management was not considered a 'realistic option' for reducing plant equivalent reductions (20-30 MW) in the mid-term (URT, 2009a). However, a recent study advocates for demand management, stating that the implementation of energy efficiency measures such as demand reduction can remedy the majority of the country's predicted future shortfalls in power at a negative cost (ECA, 2009).

Reducing transmission losses is another no regrets demand management strategy. The PSMP notes that a loss reduction programme to address the 12% in losses in the sector might provide some benefits (though these benefits were not considered high enough to include this option in the PSMP). According to Pye, et al. (2010), however, current losses from transmission amount to over 23%; the study advocates instituting a utility efficiency program to reduce technical and economic losses from the existing transmission and distribution network.

Diversification of energy sources

As noted above, Tanzania has cut its reliance on hydropower in half over the past eight years in recognition of its vulnerability to disruption of power supplies due to drought and erratic rainfall. Frequent power outages continue, however, constraining Tanzania's economic growth, as does a high cost per kilowatt hour. Thus, Tanzania must diversify its source of energy further. While this can be achieved by an increasing reliance on coal and natural gas (ECA, 2009), which is the strategy outlined in the PSMP, this could prove problematic: in addition to potential environmental impacts from extraction and air pollution, there may be constraints in years with very low rainfall due to the demand for cooling

water (Pye, *et al.*, 2010). A better option would be to pursue renewables such as solar, wind, geothermal and sustainable biomass; in rural areas, renewable micro and mini-grid generation options are also a possibility. This would preserve the country's ability to access carbon finance incentives and avoid future economic impacts from a possible carbon tax while achieving a low carbon growth path.

Another diversification strategy that would address both the challenge of inadequate power supplies and the high cost per kilowatt hour would be for Tanzania to pursue grid interconnection with neighboring countries. Currently, the country is considering a 330kV transmission line that would run from Zambia across Tanzania to Kenya (Ngeleja and Mwiwaha, 2009). Other possibilities are a tri-national project at Rusumo on the Kagera River, involving Burundi and Rwanda and potentially adding 21 MW for Tanzania, and another on the Kagera at Kikagati near Murongo with Uganda, adding 10 MW (Ngeleja and Mwiwaha, URT, 2009a).

Due to the small scale of national power generation systems, the cost of a kilowatt hour in East Africa is higher than other regions: \$0.18 per kilowatt-hour with an average effective tariff of \$0.14 per kilowatt-hour, compared with \$0.04 per kilowatt-hour in South Asia and \$0.07 in East Asia; regional trade could cause the average costs of power production to fall toward \$0.12 in eastern Africa (World Bank, 2010). The transmission line connecting Zambia and Kenya through Tanzania discussed above is envisioned as linking East Africa to the Southern African Power Pool (SAPP). The returns to cross-border transmission for the SAPP have estimated as high as 120%, with an average cost of production of \$0.07 in southern Africa (World Bank, 2010). Thus, the interconnection could cause Tanzania's average cost per kilowatt-hour to fall by one-third or more.

In addition to reducing unit costs, developing regional power trade based on hydropower generation would also results in significant savings in terms of carbon emissions.

Catchment management programs

As Tanzania's population grows and the country moves closer to water scarcity, basin catchment management programs will be essential to ensuring water resources are put to the most economically-efficient uses. Catchment programs will not only be a strategy for dealing with potential conflicts over water usage but can also be instrumental in protecting hydropower reservoirs from siltation by monitoring upstream land use. Basin management is further recommended as the benefits will accrue across sectors: agriculture, domestic water supplies and ecosystem services.

5. CONCLUSIONS

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