Vulnerability of Hydro-Electric Energy Resources in Kenya Due to Climate Change Effects: The Case of the Seven Forks Project

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Abstract

This paper examines the impacts of climate change on hydroelectric resources in Kenya, with a focus on the seven forks hydroelectric project. Dam construction and water development projects create complex wide-ranging ecological and environmental effects. While the design and characteristics of each hydropower plant play a vital role in determining its vulnerability; comparative resilience of individual reservoirs to the climate change effects are vital in determining reproach strategies. Masinga dam, commissioned in 1981 and the largest of the Seven Forks Hydro Electric Power (HEP) project was focal in the study; its most essential roles are to regulate water flow into subsequent dams and control downstream flooding of Tana system. Seven Forks supplies about 55% of Kenya's hydro-generated energy (Masinga - 40, Gitaru – 225, Kiambere – 168, Kindaruma – 72, and Kamburu – 100 MW respectively). The research utilized both primary and secondary data. Data analysis methods utilized both descriptive and inferential statistics. The research findings indicated that the catchment temperature is rising by 0.02^0C annually, the rains are declining by 3.9 mm annually, Masinga reservoir inflow is dropping by 0.74 cumecs annually, and thus the average power output operates below capacity by up to 16 GW Hour annually. This drastically affects HEP generation levels and operation of the Seven Forks power project.

Key words: Climate change, hydroelectric power, inflow, cumecs, catchment, and vulnerability

1.0 Introduction

Greenhouse gases (GHGs) concentration in the atmosphere is a primary driver of climate change. Efforts to alleviate climate change effects like reduction of GHG emissions can be traced back to the United Nations Framework Convention on Climate Change (UNFCCC) (UNDP, 2007). Major attributes of climate change include: temperature rise reduces flora and fauna resources; and change in rainfall intensity and runoff trends exacerbates water stress. This heightens global fresh water resources distribution which varies greatly in space and time due to their unreliable and erratic spatial-temporal distribution (Saleh, 2005). As man continues to harness the existing surface water resources through erection of dams for hydropower generation, the extreme climate change resultant events like flood, droughts and cyclones are devastating most socioeconomic and environment structures (UNDP, 2007). The global water stored in built reservoirs is approximately 3400 Km^{3}yearly (Saleh, 2005).

HEP generation is however progressively becoming susceptibleto climate change related events and resultant processes like reduced reservoir storage capacity due to siltation (Walling, 2008).

Hydroelectricity is the main form of renewable source of energy world over. In Africa, it's recorded that the effects of climate change are severely affecting HEP plants especially in areas that experience low annual rainfall (Bowyer, 2005). For instance, the early 1970s Sahel drought was devastating and yet recurrence of such events are on the increase as witnessed in the mid-1980s, 2000 and 2009 in Kenya (UNDP, 2007; Tarhole and Lamb, 2003; Ogallo 1993). Snow and glaciers on mountains like Mt. Kilimanjaro and Mt. Kenya which acts as water towers are receding fast due to continued rise in continental temperatures for the past 100 years as illustrated by IPCC, 2001; this is greatly attributed to climate change effects. Lack of adequate water in river flows especially during dry season is severely impacting HEP generation, leading to either reliance on diesel power or power rationing which adversely affects environment and distracts investment plans and economic growth.

Effects of climate change on hydroelectric generation has great effects on Kenya's development, this calls for urgent redress measures to avert more devastations.

2.0 Study Area

Tana River basin covers nearly 21 % of the total national landmass of Kenya, and has an aerial coverage of about 126,927km^2(Agwata, 2006 and NEMA, 2004). River Tana flows for about 1,200 m from the source in central Kenya highlands to the mouth at the Indian Ocean, it's the lifeline of the seven forks HEP project.Masingareservoir is located at latitude 00^{0}89' south and longitude 37^{0}59' east (Bunyasi et al., 2013). Masinga dam is the largest reservoir of the Seven Forks HEP project and therefore most important in controlling the Tana River system (Agwata, 2006; NEMA, 2004) and the seven forks hydropower project.

Table 1: Hydropower Output Capacity of the Commissioned Plants

Station	H.E.P Capacity (MW)	Commissioned
Masinga Power Station	40	1981
Kindaruma Power Station	72	1968
Kiambere Power Station	168	1988
Kamburu Power Station	100	1974
Gitaru Power Station	225	1999

Source: Wikipedia, 2012

Masinga dams' strategic location and function makes it more susceptible to effects of climate change like reduced inflow rates due to highly invariable rain pattern and increased evapotranspiration rate due to general temperature rise, the effects directly transcends to subsequent plant because Masinga dam's essential roles are to regulate water flow into subsequent dams and controlling downstream flooding.Masinga Dam has an installed capacity of 40 MW, this is far much less compared to other seven forksproject plantsaggregate output (Gitaru – 225, Kiambere – 168, Kindaruma – 72, and Kamburu – 100 MW respectively).

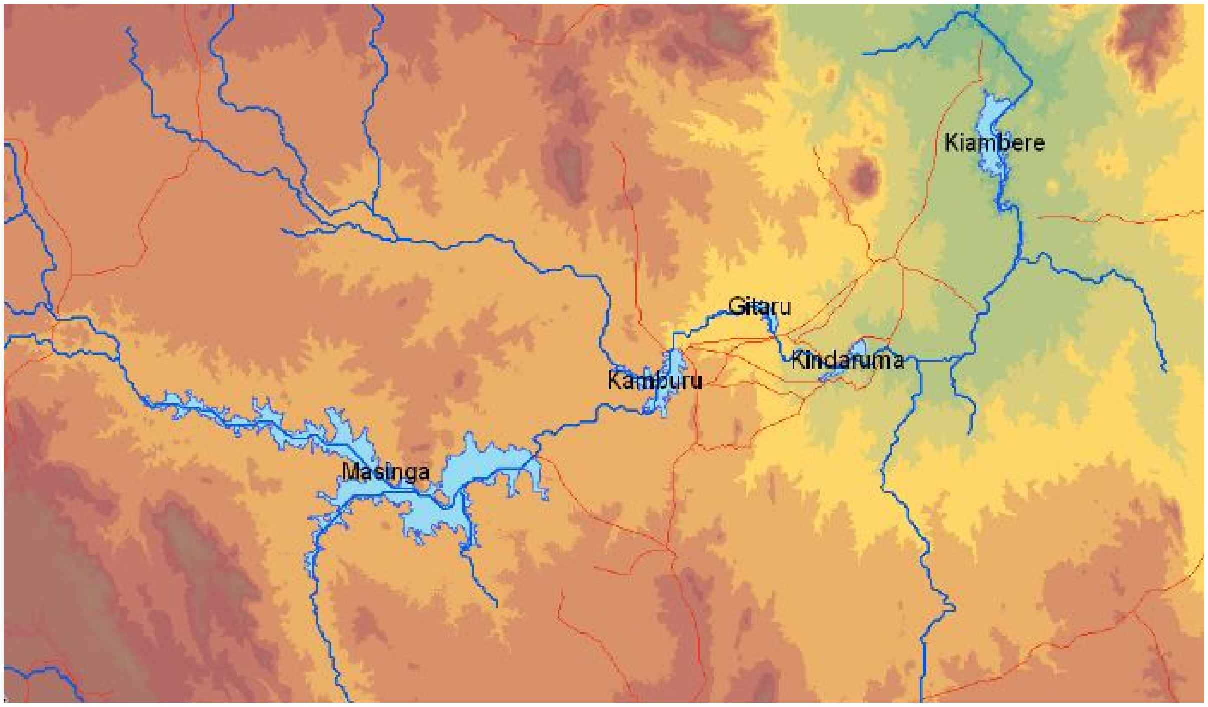

Figure 1: Relative location and size of the hydropower plants
(Source: Droogers, *et al.*, 2006)

3.0 Methodology and Study Objectives

The objective of this study was to assess the effects of climate change on water resources and hydropower generation capacity of the seven forks project. The underlying purpose of the study was to suggest land resource management strategy that informs sound policy formulation and implementation so as to help alleviate climate change effects on water resources and hydropower generation. This research was informed by the soil and water assessment tool (SWAT) model, this model was an improvement on previous models developed by Dr. Jeff Arnold in early 1990s (Arnold, 1987 in Gassman, 2007). SWAT is a catchment scale model that can be used for predicting the impact of land management approaches on hydrology and sedimentary regime in a large catchment with varying soils, land uses and management approaches over a long a duration (Neitsch, 2005).

This study utilized primary and secondary data to overtly address the research objective, and as a result varied categories of data was collected. Secondary data included LANDSAT satellite images between 1976 and 2011, dam in-flow and discharge data, climatic data and topographic maps. Methods of data collection varied with data type. This studyutilized both inferential and descriptive analytical techniques. The quantitative data was analyzed using statistical software; SPSS. The satellite images were analyzed using ArcGIS 10.0 and ERDAS IMAGINE to define land use/ land cover change using the Normalized Difference Vegetation Index (NDVI).

4.0 Results and Discussions

4.1 Summary of the research findings

Specific climate change indicators and resultant effects on the seven forks hydropower output based on Masinga dam trends have been summarized in Table 2. The table represents the catchment average Maximum, Minimum, and arithmetic mean annual temperatures (degrees Celsius; ^{0}C). The average annual rainfall intensity in millimeters (mm). And the aggregate reservoir discharge (spillage and power generation) in million cubic meters per year (M m^3/yr).

Table 2: Summary of Climate Change Indicators and Effects

YEAR	Mean Min Annual Temp. (^{0}C)	Mean Max Annual Temp (^{0}C)	Mean Annual Temperature (^{0}C)	Annual Mean Precipitation (mm)	Reservoir Inflows (m^3/s)	Reservoir discharge (Mm^3/ yr)
1981	12.28	23.08	17.68	1,131	**	**
1982	12.43	23.32	17.88	1,186	102.6	**
1983	12.72	23.98	18.35	984	65.3	**
1984	11.72	23.73	17.73	767	33	**
1985	11.57	22.98	17.28	952	80.2	**
1986	11.73	23.58	17.66	956	70.9	**
1987	12.17	24.62	18.40	665	54.7	**
1988	12.47	23.54	18.01	1,214	93.8	66.4
1989	11.83	22.90	17.37	875	90.2	86.8
1990	12.05	23.24	17.65	1,079	120.1	115.5
1991	12.11	24.03	18.07	1,052	58.7	64.4
1992	11.81	23.62	17.72	660	55.6	45.9
1993	12.03	23.29	17.66	890	58.1	59.5
1994	12.34	23.69	18.02	1,183	83.7	53.4
1995	12.32	23.75	18.04	1,045	88.5	82
1996	12.33	23.87	18.10	722	46.4	62.6
1997	12.48	24.52	18.50	1,622	111.8	84.9
1998	12.86	23.69	18.28	1,151	157.5	172.3
1999	12.31	24.18	18.25	587	48.1	59.7
2000	12.28	24.71	18.50	604	21.4	40.3
2001	12.90	23.94	18.42	1,021	60.4	32
2002	13.03	24.10	18.57	1,032	85.4	64.2
2003	12.37	24.38	18.38	1,100	90.6	92
2004	12.67	24.43	18.55	860	51.9	59.8
2005	12.59	24.42	18.51	681	48.3	54.9
2006	12.89	24.10	18.50	1,337	76.2	50.9
2007	12.41	23.66	18.04	973	37	83.5
2008	12.25	23.86	18.06	743	35.2	59.4
2009	12.97	24.50	18.74	734	22.8	24.3
2010	13.17	23.78	18.48	949	98.6	67.2
2011	12.57	24.33	18.45	814	66.1	67.8

Where ** means no data records available
(Source: KMD, WRMA, KENGEN and MWI records; 2012)

4.2 Temperature trends

The earliest dam to be commissioned of the seven forks project was the Kindaruma power plant in 1968. But based on Masinga dam which was sampled for the study; commissioned in 1981. Over the past three decades the catchment temperatures have steadily increased on aggregate. The average monthly and yearly temperatures in the upper Tana catchment which is the source of head waters that drive the multiple power plants indicate an increasing trend. Temperature projections based on Table 2 reveals that the mean minimum and maximum annual trend designateaccrued temperature rise at 0.78^0C and 0.45^0C respectively from early 1980s to 2012. Sustained decadal temperature rise of 0.21^0C would yield 1^0C rise in mean temperatures in about 50 years. It isimportant to be life to the fact that increased temperatures equivocally would yield greater evapotranspiration rates and diminishing surface water availability. Resultant increase in precipitation due temperature rise may not essentiallyyield surplus water because evapotranspiration rates and water conservation efforts are major determinants of the water balance scenarios in specific areas thus directly affecting water availability.

This temperature rise rates in the upper catchment coupled with declining trends of precipitation intensity would result into water deficit, this greatly hampers hydroelectric output capacity of the plants especially during dry seasons. Though the increase in temperature is anintricate phenomenon that can be accredited to both artificial and natural processes.

Past studies have proved that temperature variations act as stimulito both micro and macro environments' hydrological processes due to its effect on both evapotranspiration rate and soil moisture retention ability. For instance, according to Arnel and Reynard (1993) research findings, potential evapotranspiration simulations showed that based on temperature rise only, evapotranspiration in England and Wales would increase by over 10% by 2050. Climate change related events like increased evaporation rates, decline in rainfall intensity, season alteration, extreme whether events like floods and droughts are more devastating and recur more frequently. Increased catchment temperatures as shown in Figures 2conforms to global warming effects. Climate change results in increasingly unpredictable weather patterns, making hydropower plants ineffective due to reduced reservoir inflows to non-sustainable levels during dry seasons.

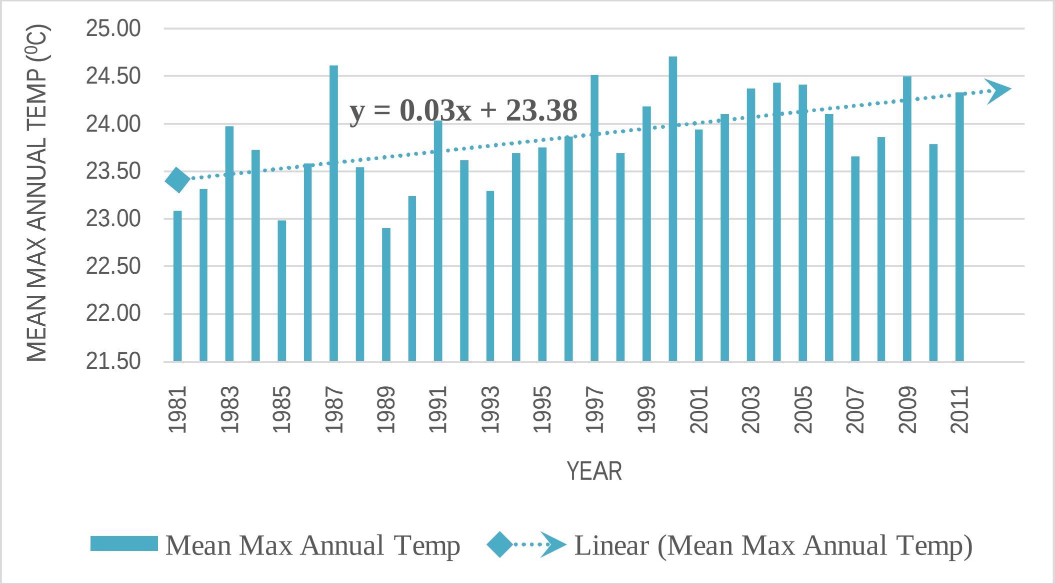

Figure 2: **Trend of annual mean maximum temperature in Upper Tana Catchment**
(Source: KMD, 2012)

Dry seasons occur between the long and short rains season in April – June and September - December respectively. The dry season between January – March had the highest mean maximum temperature of 26^0C and 27^0C as indicated in Table 3, for the entire study period. Increased catchment temperatures drastically affect the catchment water balance. This increases the possibility of soil erosion occurrence during the rainy seasons as soil is left bare and vulnerable to catchment runoff which collects sediments, physical and biological inputs on its path. This yields sediment inflows, increased reservoir sedimentation lowers the reservoir capacity which is vital for HEP. Adverse change in stream flow and sediment regime due to increased catchment temperatures puts Kenya’s main source of hydroelectricity at stake.

Table 3: Average monthly minimum and maximum temperatures between 1981 and 2011

Mon Cat.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min	10	10	12	14	14	13	12	12	12	13	13	11
Max	26	27	27	25	23	22	20	21	24	25	24	24
Mean	18	18.5	19.5	19.5	18.5	17.5	16	16.5	18	19	18.5	17.5

(Source: KMD, 2012)

4.3 Upper TanaCatchment Rainfall Trends

Rainfall distribution and intensity is an essential component in determining catchment hydrology. Temperature increase and decrease in annual rainfall rates presents the most intricate hydrological processes. Decline in hydropower generation in the recent past is mostly due to immense spatial variability of catchment uniqueness and rainfall patterns, and increased evapotranspiration. Moving averages of the annual average precipitation in the Upper Tana catchment for the past three decades since 1981 has significantly varied. Generally, scarce rains are recurring after about two to four year and the trend is becoming more persistent.

Figure 3 indicates that the average annual precipitation in the area is gradually but steadily declining. The graphs trend line has a gradient of about negative 3.93 mm, this implies the catchment precipitation is declining by about 39.3 mm every decade. Declining catchment precipitation has direct repercussion on hydropower plants in the following ways: this trend adversely affects reservoir siltation rates, evapotranspiration and river recharge levels especially during the dry season. Figure 3 indicates that the upper Tana catchment has had mean annual temperature range of about 1035 mm. Even though the catchment precipitation decline is gradual, highly invariable precipitation pattern endangers ability of catchment river flows to sustain economic and steady hydropower generation.

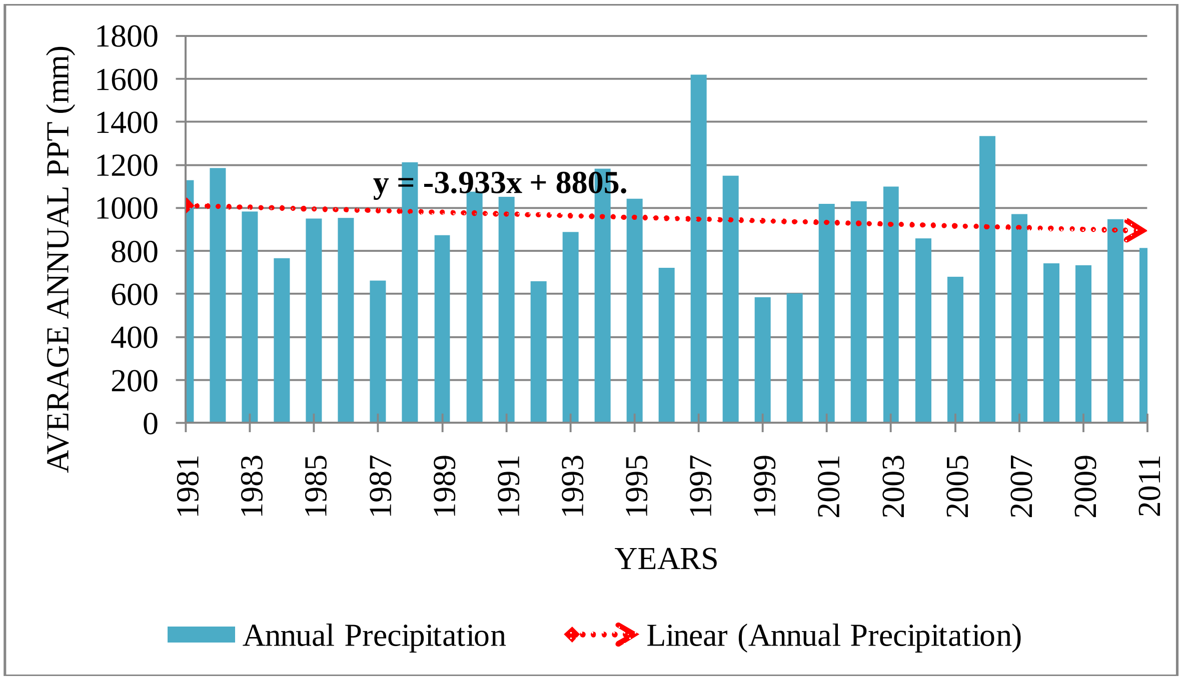

Figure 3: Average annual rainfall intensity in the Upper Tana catchment

(Source: KMD, 2012)

Sporadic rain pattern in the catchment, temperature rise and increased evapo transpiration rates expose the area to more extreme climatic events like flash floods, soil erosion and droughts. Flash floods generate mixed fortunes i.e. while they quickly fill the hydro reservoirs they don't provide sustainable water supply and hasten reservoir sedimentation reducing its dam head height and storage capacity. The annual catchment precipitation decline and average temperature rise at the rate of 3.93 mm and 0.21^0C respectively conforms with the US Geological Survey Report of 2010 in which it was shown that the long rains (March and June) received in central Kenya had dropped by over 100 mm since 1970s. This phenomenon was attributed to the general warming of the Indian Ocean. The rise in catchment temperatures as rain intensity declines would negatively affect the area's land-cover, water towers recharge ability and thus river discharge and reservoir and surface evapotranspiration rates on annual aggregation. Through a complex process these events result into low reservoir recharge and discharge rates below power generation requirements especially during dry season, this forces the government to rely on nonrenewable energy sources which hasten greenhouse gas emissions driving climate change further.

4.4 Seven forks recharge at Masinga Reservoir

Masingais the largest reservoir of the seven forks project but has the least power output at 40 MW as indicated in both Table 1 and Figure 1 respectively. The main purpose of the dam is to store water and regulate flow during dry season and to control downstream flooding of the Tana River system.

While subsequent reservoirs have other sources of river inflows apart from Masinga discharge as illustrated in Figure 1, during the dry season the river flows are inadequate to supply water for optimal operation of the power plants. At such instances, Masinga reservoir discharge is increased to sustain downstream plants generation requirements. The reservoir is under the Tana and Athi River Development Authority (TARDA), but it's operated by Kenya Electricity Generating Company (KENGEN). Thus the reservoir inflow record is centered on KENGEN's dam test flows in cumecs, they're estimated based on daily dam levels. Like the catchment precipitation trends, the reservoir's inflow rates are steadily declining. In the recent past, increased occurrence of extreme weather events like drought and evaporation have resulted in ceasing power generation at Masinga plant while subsequent dams operate below capacity due to water deficiency.

The composite moving mean trend yields a gradient of about negative 0.736, meaning on average the annual reservoir inflows are decreasing at the rate of 0.736 annually. This decline translates into about 23.55 cumecssince the commissioning of Masinga plant up to 2012. Based on Figure 4, lowest inflow rates are on the increase as from the year 2001 with the year 2009 recording the lowest inflows on record at 24.3 cumecs (a year that Masinga plant operation was halted and the reservoir water levels declined to worrying levels). Such reduction in reservoir inflows unswervingly threatens the operation of the Seven Forks Project, because Masinga reservoir plays regulatory functions for subsequent dams and sediment trapping as a more recent function.

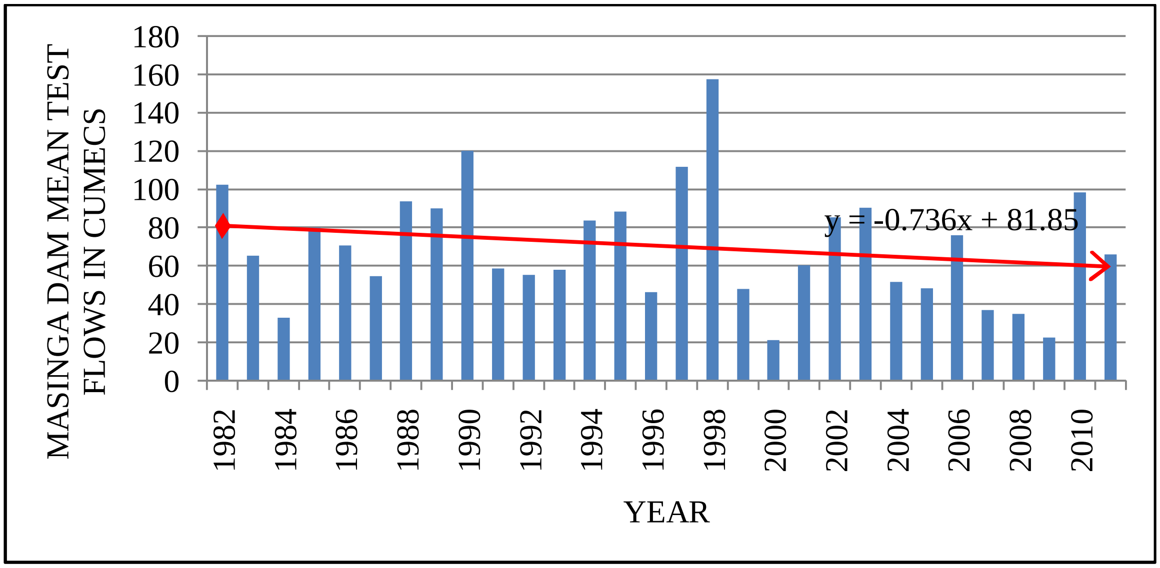

Figure 4: Masinga reservoir inflow trend (in cumecs)
(Source: KENGEN, 2012)

The seven forks power plants recharge rate based on Masingareservoir as a vital entry point yielded a range of 134.7 cumecs of the annual average inflow levels between 1982 and 2011. Figure 4 well illustrates the magnitude and trend of inflow variations. Obviously, variations in inflow are as a result of alternating scarce and abundant rainfall pattern, high evapotranspiration rates and increasing catchment temperatures. Low inflow rate is already a course to worry for water resource managers and energy sector in Kenya. This is illustrated by the recent increase in investment in fossil fuel energy source, spirited exploration in solar and geothermal energy sources and endeavors to importmore power from Ethiopia and Uganda. Decreased recharge of Masinga reservoir is echoed by the depreciating dam levels between 2001 and 2011, at the rate of about 0.58 m annually. This not only puts doubt on the reservoirs ability generate power optimally but also threatens storage and supply of requisite headwaters for the seven forks plants to generate power optimally during the dry season/ rain scarce years.

Masinga dam’s Full Surface Level (FSL) is about 1095.5 m a.s.l, however the average dam level for the past one decade is about 1,050.85 m a.s.l. Generally, Masinga dam’s FSL has been about 6.1 meters below capacity, this transforms into significant reservoir storage capacity and has a far reaching effects on hydropower generation both at the plant and at subsequent plants. The minimum dam height required to begin power generation at Masinga is about 1035 m a.s.l, trend analysis of the annual dam level based on monthly moving averages reveals that within the past decade the dam height dropped below the minimum height required to generate dam head in 2009 at 1035.2 m a.s.l. In August, 2009 the monthly dam average levels was record least at 1023.6 m a.s.l, this is about 11.4 m below the optimal operation dam height (Oludhe, 2011).

Linear equation of the annual average dam levels is $y = -0.583x + 1054$; simply put the average annual dam height is declining at the rate of about 0.58 m.

Based on the average dam level for the past decade of 1050.85 m a.s.l and the current reduction rate, Masinga dam will attain its minimum dam head height of 1035 m a.s.l in approximately 27 years from now and thus making power generation technically impossible especially in rain scarce years or during dry seasons.

This is far less than the dam's design/ projected lifespan.The greater the dam level the better the dam head efficiency and thusless water is used to generate a single unit of energy; and the higher the dam level the greater the reservoir's surface area and thus higher water storage capacity. Therefore, sustained decline in the dam level will negatively influence the plants power generation capacity especially during dry seasons where inflows are minimal.

4.5 Climate change effects on seven forks hydropower generation

Climate change effects on water resources and subsequently hydropower generation presents an intricate relationship which requires incised analysis to affirm the extent of climate change related events on sustainability of hydropower resources as a significantly reliable source of renewable energy in Kenya. Highly invariable weather patterns as depicted above has far reaching impacts on power plants. Catchment temperature rise at an average rate of 0.21^0C annually, partly illustrated in Figure 2 implies the catchment floral biodiversity will be stressed and reduced leaving soil predisposed to agents of erosion. On the other hand the Upper Tana catchment precipitation trend indicates that the rains are declining at a rate of about 3.93 mm annually, and the rains are becoming more scarce and sporadic as illustrated in Figure 3. The rapidly increasing water stress was echoed in UNDP (2007) Human Development Report of 2007/ 2008 as was captured from NEMA (2003). In this report, Kenya's renewable surface water is about 19,500 M m^3 translating into a mere 650 m^3 per capita, this is below the globally recommended per capita of 1,000 m^3 edging the country into the category of water scarce states.

Most vital climatic factors including rainfall trends, temperature and evapotranspiration are all conducive to driving the catchment into chronically water scarce area when the county's per capita water is expected to drop to 250 m^3 in the year 2025 as Kenya's population is projected to reach 60 million people (NEMA, 2003). This conditions reduce catchment precipitation and thus river recharge ability of the upper Tana catchment water towers which primarily encompass Mt. Kenya, the Aberdares and Nyambene hills, while increasing reservoir sediment loading and evaporation rates. Sediment loaded water wears the water ways gearsthrough its abrasive effect, amassingrepair and maintenance costs and thus the cost post of per unit power generation. The wear of the water ways diminishes the plants performance, resulting into a loss of energy generationefficacy of the equipment leading to reduced energy margins and afterwards operation costs.Siltation may lead to blockage of the machines cooling system leading to upsurge in temperature within the oil and generator air coolers (Bunyasi et al., 2013). High temperatures have domino effects in unit isolation leading to power generation capacity of the plants.

Manmade reservoirs require immense resources to put up and this is usually justified through their long term returns and need to stabilize power generation even during dry seasons. However recurring extreme climatic events deep into water towers like floods and droughts threatens these structures and their operation.

For instance, during rainy season large amounts of sediments may be deposited in deep parts towards the reservoir head into the dead stock reserves of Masinga reservoir which lately has a vital role of de-silting the Tana River system. When this process fills up the reservoir's dead stock reserve, subsequent sediment laden floods will go through the dam blocking the intake into the generation plants. This may lead to power generation blockages adversely distressing electricity production.

Figure 5 illustrates the change in energy output in giga-watts per hour (GWh) and reservoir inflow rates in Million m^3 (MCM) in the months of April to June. Figure 5 also indicates a positive correlation between reservoir inflows and energy output, with the latter as dependent variable. In a span of 20 years the plant has annual average annual production levels of 15 years below normal (BN) and only two years with above normal (AN) production levels. Though the reservoir inflows significantly shoots above normal in the years 2002 and 2003, the energy output does not commensurate because this comes after a severe drought which had adversely reduced the reservoir water.

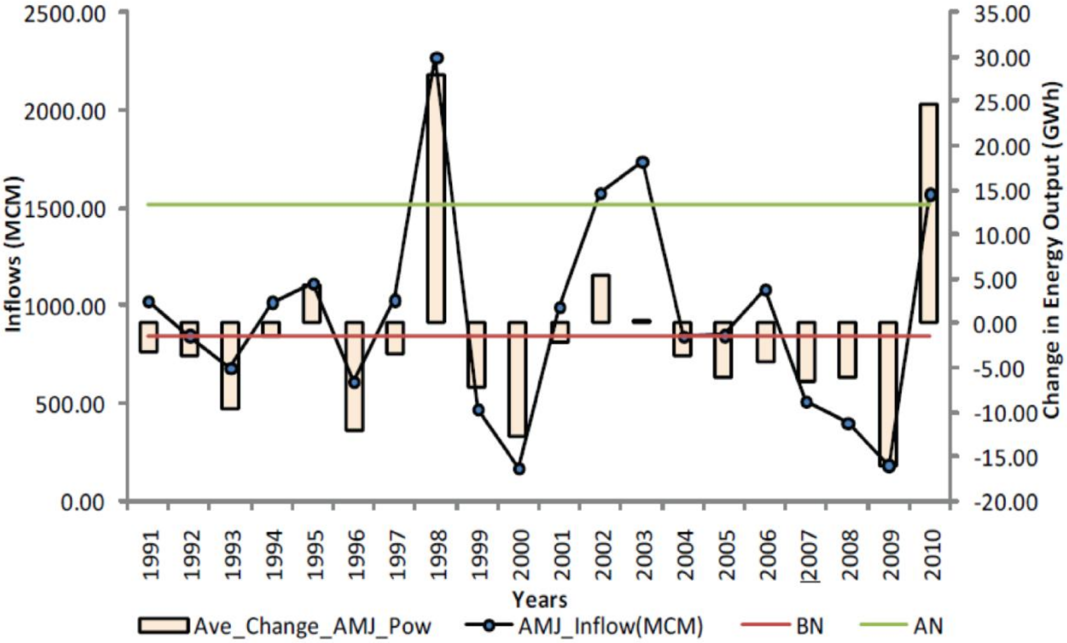

Figure 5: Annual average variations of power output at Masinga Dam during the long rains

Source: Bunyasi et al., 2013 obtained from Oludhe, 2011

As Masinga inflow rate continue to decline at a rate of 0.74 cumecs annually, the decline in power output at the plant is bound to increase as evidenced by the decline in the average dam level at the rate of 0.58 m annually. The bulk of Kenya's hydropower is obtained from the seven forks project with five plants operational and lined-up along River Tana.

This trend endangers Kenya's hydropower base contributing about 55% of national energy requirements, as an alternative the nation may have to rely on non-renewable energy sources. Though the plant's turbines water uptake rate may be sustained at its normal rate of 45.9 m^3/s for the period,

Figure 5 indicates out-rightly that the dam's power generation efficiency is below its power production potential of 350 GW Hours per year at water head of 49 m (http://globalenergy). Meaning the aggregate power output variation for most of this period functions below optimal capacity by up to about 16 GW Hour per year, this can be credited to the dam's operation with water up to 11.4 m below its FSL and hence its maximum water head height of 49 m as was the case in August 2009 (Bunyasi et al., 2013). This is essentially because when the dam operates below its maximum height, more water is used to generate single unit of power due to reduced pressure.

5.0 Conclusion and Recommendations

5.1 Conclusion

While climate change is a global phenomenon, intensity varies on spatial temporal basis and specific areas should tailor their own catchment management approaches and policies to cushion water resources and energy sector from the effect of climatic events like precipitation, temperature variation and evaporation rates. The upper Tana catchment challenges directly threaten hydropower generation are: highly fluctuating river flow, sediment laden floods, scarce and sporadic precipitation and extreme evapotranspiration rates.

For instance, there is a very strong correlation between catchment precipitation and temperatures, sediment laden run-off, river recharge throughout the year, monthly and annual dam levels and hydroelectric production efficiency at the plants.As the dam inflow rates decrease at annual average is 0.736 m^3/s and continual effective and efficient power generation of the seven forks project has increasingly relied on the ability of the dam to store adequate runoff during the rain seasons to sustain its operations. However this trend is subjective to many factors in the catchment including anthropogenic activities, land use/ land cover change, precipitation rate and trends, temperature levels and evaporation trends. Thus, there is need to put in place structures that will ensure effective environmental conservation to mitigate climate change effects so us to safeguard efficacy of the seven forks project all year round and in the long run.The combination of degraded catchment, vegetation loss, temperature rise and erratic rains presents favorable conditions for catchment sediment discharge, soil susceptibility, water resource degradation and reduced power generation efficiency.

5.2 Recommendations

Climate change is a complex and multi-facet phenomenon which requires colossal efforts from a broad range of stakeholders, locals, and central and local governments input working in unison towards specified objectives to improve local areas ecological resilience on climatic conditions.

This study in view of these aspects postulates a climate change and upper Tana catchment management strategy involving a broad range of stakeholders including: Water Resource Management Authority (WRMA), Kenya Electricity Generating Company (KENGEN), Tana and Athi River Development Authority (TARDA), Kenya Forest Service (KFS), Water Resource Users Associations (WRUAs) and Community Forest Associations (CFAs) within the area, Local Authorities affected and the central government, and most vital as well the local community including land owners and users in the catchment.

Based on the complexity of aspects of climate change, the management strategy recommended is based on a concession amongst major stakeholders whose undertakings either directly or indirectly impacts the natural resource bases like land cover, water resources,reservoir sediment loading regime and other hydro-energy resources.

The management strategy should inform sound policy formulation whichin the long run seeks to ensure sustainable river recharge and flow, retention of sediment at the source, sustainable and reliable weather patterns, and ability of the hydropower plants to withstand eventualities.

The strategy encompasses environmental planning techniques, sustainable land resources development, devising a catchment information database for informed decision making, research and development, and forest conservation and protection of riverine and vegetated wetland areas.

Most important the following should be put in place to ensure relevant policies enforcement and compliance is achievable: develop and maintain a comprehensive climatic data for analysis of meteorological and hydrological trends; utilize different climatic projections to study anticipated impacts on water resources, nature and man to inform licensing of hydropower generation plants; and monitor meteorological and hydrological parameters using remote sensing devices.

Table 4: Climate change and upper Tana Catchment Management Strategy

Action Areas	Activities	Actors
Forest Resource Conservation	➢ Promote adoption of alternative sources of energy like solar power, biogas and wind energy to reduce pressure on forest resources ➢ Strengthen the enforcement of Forest Act 2005 by empowering community policing strategy and promotion of agro-forestry ➢ Increase KFS fire fighting capacity and actively involve communities in controlling forest fires ➢ Promote alternative income generation activities to alleviate over reliance on forest resources by forest adjacent communities ➢ Forest rehabilitation and conservation through a forestation and agro-forestry ➢ Community involvement and awareness building for forest resource conservation.	KFS, KWS, TARDA, WRMA, Community Forest Associations (CFAs), KENGEN, Central Government, Community
Environmental Planning	➢ Formulation and implementation of Catchment Environmental Action Plans (CEAP) ➢ Community awareness building on the benefits and need for environmental protection ➢ Rehabilitate degraded environments like forest ecosystems and farmlands ➢ Environmental monitoring and progress evaluation through periodic EIA and EA	TARDA, KFS, NEMA, WRMA, KENGEN, Community
Catchment information database for informed decision making, research and development	➢ Development and operation of a joint Information Management System Database (IMSD) for climatic data (precipitation and temperature), stream flows and catchment sediment discharge, change in forest covers, agricultural data (acreage under crop production, yield and climatic requirements), and population trends ➢ Research and development funds should be set aside to continually provide new knowledge and strategy for catchment management to match the changes in weather patterns, population dynamics, soil types and new emerging challenges	KMD, WRMA, TARDA, Ministry of Agriculture, Ministry of Planning, KENGEN
Sustainable land resources development	➢ Enhance enforcement of the land use policy ➢ Providing timely weather information for planning to ensure rains and runoff are prepared for to reduce soil erosion	Ministries of Agriculture and Lands, Local Authority

References

Agwata, J. F. (2006). *Resource Potential of the Tana Basin with Particular Focus on the Bwathonaro Watershed: Kenya*. Summer school: FWU, Vol. 5, Participatory Watershed Management Plan. Accessed 12TH April, 2012 from FWU, Vol. 5, Participatory Watershed Management Plan

Arnell, N. W., & Reynard, N. S. (1993). *Impacts of Climate Change on River Flow Regimes in the United Kingdom.* Institute of Hydrology: NERC, Water Directorate, July 1993

Arnold, J. G., & Williams, J. R. (1987). Validation of Simulator for Water Resource in Rural Basins. *Journal of Water Resource Planning Management:American Society of Civil Engineers* ASCE 113: (2): P 243-256

BlackshearB., T. Crocker, E. Drucker, J. Filoon, J. Knelman, and M. Skiles, (2011), *Hydropower Vulnerability and Climate Change: A Framework for Modeling the Future of Global Hydroelectric Resources*. Middlebury College Environmental Studies Senior Seminar

Bobotti, O. K. (1998). *Masinga Reservoir Capacity and Sedimentation, Kenya*. A World Bank Project: Tana and Athi Rivers Development Authority, TARDA Report, Vol. 2: Data Annexes

Bowyer, P. (2005). *Weighing up the benefits against the environmental disadvantages; is it feasible or desirable for hydroelectric power to be developed on a much larger scale in the future*. Accessed December 20, 2011 from http://peter.mapledesign.co.uk/writings/physics/2005_Hydroelectric_Power_Feasible_or_Desirable.pdf

Bunyasi, M. M, S. M. Onywere, and M. K. Kigomo, (2013), *Sustainable catchment management: assessment of sedimentation of Masinga reservoir and its implication on the dam's hydropower generation capacity*. Vol. 3, No. 9; Pg. 166 – 179. International Journal of Humanities and Social Science. Accessed on 14TH June, 2013 atwww.ijhssnet.com

Gassman, P. W., Reyes, M. R., Green, C. H., & Arnold, J. G. (2007). *The Soil and Water Assessment Tool: Historical Development, Applications and Future Research Directions.* USDA: ARS. Accessed 8th January, 2012 from http://www.card.iastate.edu/environment/items/asabe_swat.pdf

http://globalenergyobservatory.org/geoid/40364. Accessed 12TH April, 2012

IPCC (2001): *Climate Change 2001: Synthesis report,* Cambridge University Press, Cambridge

NEMA (2003): State of Environment (SOE) report for Kenya, 2003

NEMA. (2004). *Kenya's State of Environment Report: Chapter 7, Fresh Water, Coastal and Marine Resources*. Nairobi: Government Printer

Ogallo L. A., (1993),*Dynamics of Climate Change over Eastern African Proc*. Indian Academy of Sciences, Vol. 102, No. 1; Pg. 203 – 217

Oludhe, C. (2011). *Impacts of Climate Variability on Power Generation within the 7-Forks Dams in the Tana River Basin*. KMS 10TH Conference Special Issue: Journal of Meteorology and Related Sciences, Vol. 5 PP 2

Schaefli B, B. Hingray, and A. Musy, (2007), *Climate change and hydropower production in the Swiss Alps: quantification of potential impacts and related modelling uncertainties*. Vol. 11, No. 3: Pg. 1191 – 1205; Hydrology & Earth System Sciences

Tarhule, A. and LambP. J., (2003),*Climate research and seasonal forecasting for West Africans: Perceptions, Dissemination and Use? Bull*. Am. Meteor. Soc. 84(12): Pg. 1741 – 1759

United Nations Development Programme (UNDP), (2007), *Human Development Report 2007/2008: Climate Change and Human Development in Africa; Assessing the Risks and Vulnerability of climate Change in Kenya, Malawi and Ethiopia*. Climate Prediction and Applications Centre (ICPAC), Intergovernmental Authority on Development (IGAD)

US Geological Survey Report. (2010). *Famine Early Warning Systems Network Informing Climate Change Adaptation Series: A Climate Trend Analysis of Kenya—August 2010*. USAID. Accessed 17TH April, 2012 from http://pdf.usaid.gov/pdf_docs/PNADT233.pdf

Walling, D. E. (2009). *The Impact of Global Change on Erosion and Sediment Transport by Rivers: Current Progress and Future Challenges*. Paris, France: UNESCO

WRMA, (2010), *Natural Resources Management Project: Physiological Survey in the Upper Tana Catchment*, Nairobi

www.kengen.co.ke. Accessed 12TH April, 2012