UNDP/GEF PROJECT, RAF/93/G31: BUILDING CAPACITY IN SUB-SAHARA AFRICA TO RESPOND TO THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE

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CHAPTER 7: ENERGY SECTOR- A CASE STUDY ON HYDROPOWER

7.1 Statement of the Problem

Atmospheric concentrations of greenhouse gases have been increasing rapidly (IPCC 1994). This increase has been attributed mainly to human activities. The composition of the atmosphere has thus changed considerably and will continue to do so in future. Such changes are capable of affecting the surface climate of the earth and can have possible consequences on both natural and man-made resources, thereby threatening both marine and terrestrial ecosystems. Deleterious effects of these consequences will affect the well-being of man through impacts on important sectors such as health, agriculture, transport, industry, and water resources (IPCC 1990; 1995). To these sectors, energy is crucial for their development but energy itself is also vulnerable to the effects of climate change. Negative changes in energy production will therefore seriously affect global industrialization programs as well as national economies considering that global demands for energy have been rising at an annual rate of 2% (IPCC, 1995).

Kenya, like most developing countries relies on biomass (mostly woodfuel and charcoal) as the biggest source of energy, contributing about 73% of the total energy requirements. It is used by over 80% of the rural population, mostly for cooking and heating. In addition to biomass, the other two major sources of energy in Kenya are petroleum and electricity. The domestic sector is the largest consumer (59%), followed by industry (15%), transportation (11%), agriculture (10%), and commercial (5%) sectors (Kenya/Canada Energy Advisory Project, 1991).

When considered in terms of social-economic development, human settlement infrastructure, as well as manufacturing, electricity is the most important form of energy in Kenya. Currently, it is generated from several sources including hydropower, gas turbines, geothermal power and diesel engines. Of the total amount generated, hydropower contributes over 76%.

Hydroelectricity generation depends on availability of water, which in turn depends on the prevailing climate. Fluctuations in rainfall and temperature can affect evapotranspiration rates which in turn can determine the channel flow and power generation rates. In this regard, the hydropower source of electricity becomes the most vulnerable to climate change effects. This study therefore focuses on hydropower development in Kenya in relation to the impacts of climate change that are anticipated in future.

7.2 Objectives of the Study

The objectives of this study were:

1. To assess the vulnerability of hydropower to climate change.
2. To assess the impacts of climate change on hydropower resources development in Kenya.
3. To suggest potential mitigation and adaptation strategies to climate change in relation to hydroelectric energy production in Kenya.

7.3 Justification for the Choice of the Study Area

The study area is located on the upper Tana River catchment basin. The selection of this area was based on two major reasons: First, over 80% of the hydroelectricity generated in Kenya is harnessed from River Tana, the rest being produced from River Turkwel; and second, adequate historical data on climate, channel flow and power generation are available for the generation sites (for periods of over ten years). This would enable a reasonable assessment of baseline scenarios.

Tana river is the largest and most important river in Kenya. Its catchment covers some 100,000 Km^2 which is about 18% of the total land area in Kenya. Its length from the source to the Indian Ocean is over 1000 km. Annually, it drains 3740 million m^3 of water which is equivalent to 19.1% of the total perennial river flow in Kenya. In addition to supplying water for irrigation (2300 million m^3), the river also provides water to municipalities in the upstream districts. The basin area also includes Mt. Kenya within summit at 5199m A.S.L., the second highest mountain in Africa, from which the Tana river originates. The river is fairly confined within its banks up to the Kora Rapids. Downstream of Kora Rapids the river spreads out into the floodplain during periods of high flow. That catchment area includes a wide range of climatic conditions and vegetation, including alpine glaciers, afro-alpine moorland and high-altitude forest through to semi-arid and arid plains, and humid coastal delta.

The following physiographic regions can be defined in the river basin.

- An upper catchment area of 9,4200 km^2 upstream of Kamburu with altitudes above 1000m A.S.L.
- A middle catchment area of 21,370 km^2 between Kamburu and Kora Rapids with altitudes between 1000m and 200m A.S.L.
- A lower catchment are of 65,160 km^2 downstream of Kora Rapids with altitudes below 200m A.S.L. This section includes the floodplain.

The entire basin covers four provinces: Coast, Central, Eastern and North-Eastern. The upstream area also touches the Nairobi Province. According to the 1989 census, the five provinces hold a population of 10.411 million people which is 48.5% of the total population of Kenya.

Hydropower development on the River Tana began in 1968 with the completion of the Kindaruma dam construction. The power plant has an installed capacity of 44 MW. Thereafter followed the construction of four other dams with power plants at Kamburu (94.2 MW) in 1975; Gitaru (145 MW) in 1978; Masinga (40 MW) in 1981; and Kiambere (144 MW) in 1988. In addition, relatively small hydropower stations such as Wanjii (7.4MW) and Tana (14.4 MW) have been in operation in the upper tributaries. As at 1996, the total installed capacity in the Tana river was 489 MW which is 60.5% of the total installed capacity (806 MW) in the interconnected system in Kenya. Table 7.1 shows that the annual energy output/consumption from the Tana river is estimated at 2800 GWh at the minimum, compared to the total national supply in 1995/96 of 3312 GWh (KPLC, 1977).

7.4 Data and Methods

Data on temperature and monthly rainfall totals dating back to 1961 were obtained from the Kenya Meteorological Department, Nairobi. The following stations in the upper Tana River catchment basis were covered:

- Kamweti Forest Guard Post (Site No. 28) on 4CC sub-basin
- Kiambere Market (Site No. 52) on 4ED sub-basin
- Kiandongoro Hydrometeorological station (Site No.4) on sub-basin 4AC
- Nyeri Ministry of Works (Site No.7) on sub-basin 4AC
- Kiritiri Chiefs Camp (Site No.54) on sub-basin 4ED
- Embu Meteorological Station (Site No.41) on sub-basin 4DD

Power generation data (monthly totals) were obtained from the Ministry of Energy and from the Kenya Power and Lighting Company, Nairobi. Only three power stations with generation records of over 15 years were considered.

- Gitaru Power Station (between sites 46 and 47)
- Kindaruma Power Station (between sites 49 and 50)
- Kamburu Power Station (between sites 43 and 44).

Table 7.1: Gross Generation and Consumption of Electricity

POWER	CAPACITY INSTALLED (MW) as at 30/06/97	EFFECTIVE PRODUCTION (MW)	1994/95 GWh	1995/96 GWh	1996/97 GWh
HYDRO					
Tana	14.4	12.4	78	97	84
Wanji	7.4	7.4	27	51	48
Kamburu	91.5	84	485	485	446
Gitaru	145	145	704	701	926
Kindaruma	44	44	213	239	230
KPLC	6.2	5.4	22	29	24
UEB (Imports)	30	0.0	187	149	144
Masinga	40	40	200	225	215
Kiambere	144	144	996	1031	1028
Turdwel	106	106	379	229	353
TOTAL HYDRO	628.2	588.2	3290	3312	3497
THERMAL					
Kipevu	75	58	216	224	200
GEOTHERMAL					
Olkaria	45	45	290	390	393
GAS TURBINE					
Nrb.South	13.5	12	16	59	6
Kipevu	30	30	31	112	168
DIESEL Stat.					
Ruiru	1.5	1			3
IPPs	11.4	11	2	2	7
WIND					
Ngong	0.4	0.4	1	1	1
Inter System Total	805	745.6	3848	4100	4274
ISOLATED DIESEL					
KPLC Station	3.8	3.5	10	11	11
REF Stations	5.4	4.6	7	8	11
TOTAL	9.2	8.1	17	22	22
GROSS GENERATION	815	753.6	17	4119	4296

Nearly 50% of the Tana River Basin depends on Mount Kenya as the main source of river flow. The rates of the flows fluctuate considerably from month to month and from year to year, and are influenced largely by temperature and rainfall. In order to assess current trends and future effects of such fluctuations it is necessary to pick on a few regions within the upper Tana River basin whose data would help establish how river flows in Tana Basin are likely to vary with climate, and how they are likely to affect power generation. The following four regions were studied.

- Sub-basin 4CA2 (Site No.26) with mean annual rainfall of 1620mm (Chania)
- Sub-basin 4BE2 (Sites 13-17) with mean annual rainfall of 1477 mm
- Sub-basin 4CB4 (Sites 25-27) with mean annual rainfall of 1826mm
- Sub-basin 4AC3 (Sites 3-5) with mean rainfall of 2016mm

River flow data for these regions were obtained from the Meteorological Department, University of Nairobi, and from the Ministry of Water Development, Nairobi. Typical data on the catchment areas and mean discharge characteristics of these sub-basins and the power generating stations down stream are given in Table 7.2.

Table 7.2: The Catchment Areas and Mean Water Discharge Rates of the Upper Tana River Sub-Basins and Power Generating Stations.

Sub-Basin	Catchment Area (Km^2)	Mean Drainage between 1957 and 1990 (m^3/sec)
4CA2	518	8.79
4CB4	316	7.11
4BE2	3672	64.37
4AC3	1078	18.96
Masinga (4DE)	7335	91.28
Kamburu (4ED1)	966	118.03
Gitaru (DEDI)	9520	118.26
Kindaruma (4ED2)	9807	118.46
Kiambere (4ED3)	11975	121.67

Source: JICA (1997)

7.2.2 Impacts and Vulnerability Assessment Models

Assessment of the conceptual framework models available showed that such models were not applicable to this study and were therefore dropped. We chose to use simple empirical correlations and time series hydrographs to obtain general trends. In addition, the model of Yates (1994) was used to study the effects of rainfall and temperature changes on river flow, the results of which were used to predict future impacts on power generation.

7.2.2.1 Time Series Hydrographs:

Monthly river flow data for Sub-basin 4CB (1961-1995) were plotted against time to obtain time series hydrographs. These hydrographs were used to obtain baseline scenarios and assess future effects of flows on power generation in the Tana River Basin.

7.2.2.2 Lagged Correlations

The effects of rainfall and river flows on power generation are usually felt one to two months following the onset of the rains. Therefore, to determine relationships between these variables, it is necessary to correlate current generation data with individual rainfall and river flow data for the preceding twelve months. These are referred to as lagged correlations. For this study the average total monthly rainfall data and river flows were correlated with current power generation levels to check any significant relationships that would help predict trends.

7.2.2.3 Effects of Temperature and Rainfall Fluctuations on River Flows:

The effect of temperature rise above the normal (by 0-4^{0}C expected from GHG emission effects), and rainfall fluctuation of ± 20% of the current levels for the upper Tana basin on stream flows was studied using the model of Yates (1994).

7.3 Power Generation Status in Kenya

The hydroelectric power potential in Kenya is roughly estimated to be 6000MW or about 30,000GWh. However, half of this is located on small rivers most of which are uneconomical for exploitation.

Currently, Kenya produces 753.6 MW of electricity against a total installed capacity of 815 MW and peak demand of 805 MW. Of the effective production, 588.2 MW is harnessed from hydropower, 103 MW from thermal and geothermal sources, 41 MW from gas turbines, 20.1 MW from diesel engines and 0.4 MW from wind power (Table 7.1). The data indicate that demands for electricity outstrip supply, and to meet this shortfall, an additional 30 MW is currently imported from the Uganda Electricity Board (KPLC, 1997). The data in Table 7.1 also show that the total consumption of electricity has steadily increased. In 1994/95 the total output was 3866 GWh, increasing by 6.5% to 4119 GWh in the 1995/96 period, and by 4.3% in 1996/97 to 4296 GWh over the 1995/95 level. Because of fluctuations in peak demands for electricity, there have been frequent power cuts around the country, with some consumers being subjected to rationing of electricity supply during certain periods of the day, all year round.

7.3.1 Government Focus on Power Generation and Development

The Government of Kenya recognizes the social-economic growth stimulus which has been provided by an efficient and vibrant basic infrastructure. As such is has been consistent with its policy to regularly update the electric power development plans, especially on the Tana River basin whose development would have a significant impact on the local and national socio-economic scope.

The current 20-year power development plan projects the demand for energy at 5.3 billion KWh and at 912 MW for peak power in the year 2000/01, rising to 13.8 billion KWh and to 2,400 MW, respectively by the year 2016/17. These demands were calculated without taking into account any climate change effects that are anticipated in the future. The Government intends to meet these projected demands by investigating various electricity supply options on a regular basis in order to ascertain the least economic cost supply packages. The options do not solely involve hydropower generation but also extend to other sources such as geothermal power and fossil fuel based generation covering both petroleum and coal fired plants.

On the basis of the twenty year least cost power development plan which was recently updated to cover the period 1997-2017, the Government has proposed to develop eight electric power generation projects with a combined capacity of 550.5 MW during the first five years of the plan. The implementation of the plan has already started and this stresses the Government's ambition to meet the projected demand for electricity by the year 2020. The eight projects and the deadlines for implementation are listed below. The detailed designs and feasibility studies of these projects have been already completed.

- The 30 MW rehabilitation of the gas turbine plant at Kipevu during the 1998/99 fiscal year. This project is currently being implemented.
- A 75 MW medium speed power plant at Kipevu by 1999/2000.
- A second 75 MW medium speed plant also at Kipevu by 1998/2000. This project is to be implemented by an independent power producer (IPP).
- Several medium speed diesel power plants to be constructed by IPPs with a total installed capacity of 110 MW by the year 2003.
- A 72.5 MW third unit at Gitaru hydro-power station by 1999/2000.
- A 64 MW geothermal power plant at Olkaria by 2001/2002.
- A second 64 MW geothermal power plant at Olkaria by 2001/2002. This project will be implemented by an IPP.
- A 60 MW hydro-power plant on river Sondu-Miriu by 2003/04.

In addition, the feasibility study of two hydropower projects on Mutonga and Grand Falls has been completed and the Final Report is being studied by the Government (JICA, 1998). When completed, these two projects will have an installed capacity of 60 MW and 120 MW, respectively, and irrigation schemes of about 25000 hectares in total will be developed in the downstream areas of the two projects.

7.3.2 Analysis of Past Trends

(a) Discharge vs Power Generation Analysis

Today's technology allows the transformation of about 90% of the kinetic energy of water into electricity. A flow rate of around 4000 litres per second (or $4m^3\ s^{-1}$) is used to produce one KWh of electricity, assuming there is a vertical difference in elevation of 100m. Since hydropower units need a constant flow of water with as little sediment as possible (to reduce wear on the turbines), major dam constructions are usually necessary, particularly on rivers with high flunctuations in flow. Reservoirs created by the damming of rivers regulate the river flow and act as sediment settlement "tanks. The discharge downstream of the dam is thus changed in terms of flow regime and quality.

Generally, the higher the amount of rainfall in an area, the higher the flow rates and consequently the higher the power generation since the reservoirs will be constantly full of water, and therefore the channel flow and power production will be positively correlated. However, deviations from these expectations do occur and are usually attributed to activities upstream within the basin, including land use practices that lead to poor vegetation cover and hence accelerated runoff or reduced flows due to diversion of water to other point uses such as irrigation. Typical lagged correlations between power generation and monthly rainfall for Kiritiri and Embu meteorological stations are presented in Table 7.3. Analysis of the correlations shows that relationships are only significant for the dry season months when power generation apparently depends on rainfall and water quality. During the rainy season, surface run-off tends to carry suspended particles which escape the sedimentation process in the dams. These particles reach the turbines and necessitate frequent shut-off of the machines for cleaning to avoid breakages thereby affecting generation. Moreover, as the dams remain full during the wet season, power generation does not necessarily increase due to the fact that the turbines can not exceed their maximum installed capacity. Hence correlation for the wet season months are expected to give non-significant relationships.

For the Kiritiri gauging station in region 4ED significant positive correlations were obtained for the March/December (0.559), March/November (0.529), February/December (0.571), January/December (0.501) and February/January (0.605) months (Table 7.3).

Table 7.3 : Correlation of power generation and rainfall

(a). Kiritiri

	11	10	9	8	7	6	5	4	3	2	1	0
Dec.	0.21	0.31	-0.14	0.08	0.32	0.01	-0.44	0.18	0.36	0.29	0.34	0.39
Nov.	-0.05	0.39	0.24	-0.30	-0.11	0.17	0.05	-0.05	0.20	0.13	0.25	0.20
Oct.	0.31	0.23	0.32	0.01	-0.12	-0.22	0.20	0.12	0.27	0.28	-0.32	0.26
Sep.	-0.185	0.27	0.31	0.17	0.094	0.11	0.19	0.111	0.21	0.257	0.455	-0.051
Aug.	-0.163	-0.041	0.194	0.325	0.26	0.041	-0.084	0.406	-0.088	0.267	0.387	0.372
July	0.095	-0.195	-0.088	0.446	0.364	0.053	0.072	-0.092	0.447	-0.074	0.298	0.45
June	-0.285	-0.119	0.155	0.127	0.038	0.017	0.149	0.076	-0.426	0.212	0.162	0.15
May	-0.012	-0.156	-0.215	-0.221	-0.002	-0.26	-0.248	0.202	0.014	-0.53	0.115	-0.149
April	-0.201	0.034	-0.132	-0.048	0.143	-0.068	0.262	0.19	0.165	0.163	-0.013	0.42
Mar.	0.247	0.086	-185	-0.24	0.168	0.325	0.113	0.529	0.559	0.356	0.136	0.327
Feb.	-0.196	0.139	0.134	-0.01	-0.182	0.356	0.14	0.048	0.255	0.571	0.605	0.227
Jan.	0.409	-0.04	0.024	0.308	0.058	-0.287	0.237	0.264	0.221	0.424	0.501	0.377

(b). Embu

	11	10	9	8	7	6	5	4	3	2	1	0
Dec.	0.023	-240	-0.028	0.164	0.337	-.056	-.394	-.218	0.218	0.348	0.464	0.323
Nov.	0.225	0.082	-0.253	-0.14	0.054	0.285	-.077	-.058	-.108	0.18	0.349	0.369
Oct.	0.078	.256	0.063	-0.266	0.031	0.024	0.39	-.055	0.043	0.053	-.054	0.192
Sep.	-0.198	0.223	0.275	0.116	-.301	0.391	0.213	0.089	0.01	0.183	0.261	-.125
Aug.	-0.05	0.647	0.202	0.148	0.221	-.336	0.132	0.243	0.074	0.236	0.258	0.138
July	-0.104	-.052	-0.046	0.245	0	0.088	-.117	0.214	0.413	-0.06	0.276	0.475
June	-0.124	-.239	-0.12	0.115	0.214	-.235	-.101	-.036	-.225	0.283	0.11	0.148
May	0.051	-.034	-0.323	-0.165	0.132	0.163	-.318	-.014	-.254	-.342	0.159	-.006
April	-0.247	-.091	-0.125	-0.179	0.088	0.099	0.446	0.209	0.229	-.124	0.26	0.424
Mar.	0.306	0.138	-0.353	-0.371	-0.02	0.075	0.259	0.286	0.43	0.383	0.183	0.44
Feb.	0.102	0.209	0.3	-0.219	-.367	0.009	0.108	0.244	0.091	0.338	0.514	0.056
Jan.	0.071	0.165	0.211	0.343	-.106	-.354	-.011	0.345	0.413	0.386	0.423	0.29

Correlations for the Embu Station were not significant except for the February/January months (0.514) (Table 7.3). For Kamweti Station (4CC), significant relationships were obtained for the months of December/January (0.571), February/January (0.543) and January/November (0.534). However, a highly significant negative relationship (-0.631) was noted between generation for April and rainfall for July the previous year possibly due to mechanical problems experienced during the wet season of that year. Correlation data for the Kiambere sub-basin (4ED) were highly significant and showed the strongest relationships among all the stations. The correlations were highest for the months of March/November (0.544), March/December (0.537) and December/December (0.527). The many significant relationships obtained for this station make it the most appropriate station for comparative studies on power generation and climate change effects. For Nyeri station situated on the 4AC sub-basin, only two relationships were significant: Correlations values were highest for the months of November/October (0.543) and April/September (0.538). These periods strongly coincide with the wet seasons of the year, contrary to what is expected and to what has been noted for other stations. Similarly, the Kiandongoro Station again on 4AC sub-basin had only two relationships that were significant. Highest correlation was for the months of February/February (0.579), followed by July/April (0.502). The latter relationship clearly explains the observation that generation picks up a few months following the onset of the rains to cater for water clarification and sedimentation processes which frequently clog the turbines and necessitate temporary closures.

(b) Time Series Hydrography

The time series hydrographs for the Embu sub-basin show that there has been a general decline in flow between 1961 and 1995, from over 50 million m^3/sec on average during the period 1961-1971 to just under 25 million m^3/per sec during the first half of this decade. With this trend, the decline is expected to continue and will affect reliability in hydropower generation.

7.4 Baseline Scenarios

7.4.1 Power Generation in the Country

Table 7.1 showed that the major sources of electric energy supply are hydropower geothermal, followed by conventional thermal and diesel generation sources. The relative importance of each source is supported by data in Table 7.4, which also shows the mean annual growth rates.

Table 7.4: Current Power Generation Sources and the Mean Annual Growth Rates

Year	1997	86/87	89/90	92/93	95/96	86/87-95/96
Hydro	1288	1792	2517	2974	3163	6.52
Oil-Thermal	205	168	97	59	224	3.25
Geo-Thermal	-	374	336	272	390	0.47
Diesel & Gas turbines	2	58	24	22	193	14.29
Imports	160	211	174	273	149	-3.79
Total supply	1655	2603	3148	3600	4119	5.23
Station use	22	28	33	29	52	7.12
Net supply	1633	2575	3115	3571	4067	5.21
Total sales	1407	2228	2662	3005	3407	4.83
Maximum Demand (MW)	269	430	20	596	648	4.66

Source: JICA 1997

Table 7.4 shows that the net electric energy generation, total energy sales and maximum power demand have been increasing by average annual rates of 5.2, 4.8 and 4.7%, respectively for the past 10 years.

7.4.2 Demand Forecast

The electric power and energy demands for the country were forecast up to the year 2010 by Acres International Ltd (Acres) in their `Kenya National Power Development Plan, 1992-2010' report prepared in 1992. These demands have since been reviewed and updated by JICA (1997) using regional and national data. The review was made for three scenarios: reference, low and high growths. The reference growth forecast was made assuming that the improvement in the performance of the Kenyan economy will be realized with greater efficiency of new capital investments and higher growth rates in the agricultural and industrial sectors than experienced. Although this forecast sounds optimistic, it allowed for appropriate planning of the power development.

The low growth scenario was based on continuation of historic growth rates in Kenya since 1979 with some marginal improvement; while the high growth forecast was based on the assumption that Kenya's target of economic development plan will fully be materialized. This scenario is however optimistic, but allowed consideration of the high growth limits under the present situation. Table 7.5 gives the results of the different growth scenarios.

Table 7.5: Demand Forecast Scenarios for the period 1995/96 - 2019/20

Scenario	1995/96	2005/06	2015/16	2019/20	% Average Growth Rate (1995/96 to 2019/20)
Reference Forecast					
Energy Sales (GWh)	3287.6	5851.5	10569.7	1338.7	6.01
Peak Load (MW)	670.3	1251.2	1687.5	2852.4	6.22
Gross Generation (GWh)	4121.9	7244.8	12996.6	16341.6	5.91
Low Forecast					
Energy Sales (GWh)	3287.6	5481.0	9396.6	11635.5	5.41
Peak Load (MW)	670.3	1175.4	2020.0	2500.5	5.61
Gross Generation (GWh)	4121.9	6806.3	11608.0	14325.4	5.33
High Forecast					
Energy Sales (GWh)	3287.6	6313.0	12246.5	15903.3	6.79
Peak Load (MW)	670.3	1345.5	2607.0	3382.3	6.98
Gross Generation (GWh)	4121.9	7791.1	1498.5	19377.5	6.66

Source: KPLC information

The forecast of the reference growth scenario indicates that:

(a) Requirements of energy and peak power demand will continuously and steadily increase in the nation at annual growth of 6.0%and 6.2%, respectively during the period 1995/96 to 2019/20.

(b) Gross energy generation will have to increase annually at a rate of 5.9% to meet the national energy requirements.
(c) Gross generation required will be 5364.6 GWH in the year 2000/01, 7244.8 GWh in 2005/06, 9727.0 GWh in 2010/11 and 16,341 GWh in 2019/20.

Average annual growth rates of energy until the year 2019/20 are forecast to be 5.9% and 6.7% for reference, low and high growth respectively. Peak demands forecast in the scenarios will increase at mean annual growth rates of 6.2%, 5.6% and 7.0% for reference, low and high growth scenarios, respectively.

7.5 Climate Change Impact Analysis

7.5.1 Impact of Climate Change on River Flows and Power Generation

Using a water balance model described previously by Yates(1994) the effects of increase or reduction in rainfall, and increase in temperature on river flows in the Embu region of the upper Tana River basin were determined. The results (Table 7.6) show that at current temperatures, an increase in rainfall by 20% above the present level is expected to increase flows by up to 40%. By contrast, a reduction in precipitation by the same percentage will decrease flows by up to 10% assuming temperatures remain stable at present level. The increase in river flow confirms the correlation analysis discussed earlier.

Table 7.6: Impact of Climate change on river flows for the Upper Tana Basin

Temp.(T)	Precipitation(P)				
	P+0%	P+20%	P+20%	P-10%	P-20%
T+0°C	normal	+28.4%	+39.6%	-2.0%	-10.5%
T+1°C	-1.0%	+12.0%	+23.4%	-10.6%	-22.2%
T+2°C	-16.3%	-6.0%	+3.3%	-25.9%	-35.6%
T+3°C	-28.2%	-19.7%	-11.2%	-36.5%	-45.2%
T+4°C	-31.4%	-23.4%	-15.2%	-39.5%	-47.8%

An increase in temperature by 4^0C with normal precipitation will lead to a reduction in flows by over 30%. This can be attributed to increased evapotranspiration, aridity and increased use of river water for other purposes such as irrigation agriculture. The reduction in river flows will lead to insufficient water in the reservoirs and hence low hydropower production.

However, the worst scenario is that where climate change will be manifested in temperature increase and rainfall decrease. Should this happen the analysis shows that an increase in temperature by 4^0C and decrease in rainfall by up to 20% will decrease river flows by upto 48%. This scenario will have serious consequences: most operations that use power will be paralysed by the more frequent power supply interruptions. In addition demands for water upstream by leaving population will more than double at the high atmospheric temperatures encountered. Further still, the combined decrease in rainfall and increase in temperature will aggravate the soil erosion processes in the basin. The result of this development will be a decrease in vegetation cover and increase of sediment load in the water. This will lead to frequent breakdown of the turbines at the power stations, hence cause frequent power cuts and reduced industrial activity in the country.

7.5.2 Socio-Economic Impacts

(a) Temperature Effects

Currently, very few buildings and installations are equipped with facilities that would cope with changes in climate. Temperature increase above the current normal levels, for example, will make rooms hot and uncomfortable to stay in. This will necessitate installation of air conditioners for effective cooling. Demands for air conditions due to temperature rise will be greater in the commercial than in the residential sector due partly to internal heat gains from lighting, office equipment and occupants; and temperature rise effects greatest impacts will be felt most in the high humidity areas such as the coastal belt and lake regions. On the other hand, a decrease in temperature will necessitate installation of room heating devices. Either way, electric power demands will increase thereby worsening the current power shortages unless the proposed hydropower expansion programme is fully implemented. Increased power cuts due to increased demands will hit the manufacturing sector and seriously affect the already dwindling economy. During periods of drought, higher temperatures will also cause soil degradation through wind erosion, leading to dust pollution. This will necessitate installation of extraction chambers which will also require additional electricity for operation.

(b) Rainfall Effects and Demands for Water

The National Water Master Plan(JICA, 1992) reveals that Kenya has about 470,000 ha of irrigation potential of which 133,000 ha(about 28%) are in the Tana River Basin. Of the 133,000 ha, some 19000 ha are presently in use and over 85% remains undeveloped. Of the area so far developed, about 7000 ha are under commercial large scale development, mostly coffee in the upper catchment area; about 4000 ha are under small holder schemes and farms while the remaining 8000 ha are under tenant based schemes managed by authorities such as the Tana and Athi Rivers Development Authority (TARDA). The existing large scale irrigation schemes include Bura, Hola, Tana Delta and Mwea.

The Tana river basin therefore has human settlement infrastructure which imposes demands for water. The domestic water demands are both residential and non-residential. Since the demands can be linearly related with the population growth, the future requirements are estimated on the basis of population growth. The estimated population dependent on the Tana River in the year 2005 is 555,500 people. It is therefore expected that at the current human population growth rate, residential, commercial, public, livestock and industrial water demands will continue to increase in the future. A change in climate, especially rainfall will have consequences on water demands.

Decrease in precipitation will lead to reduced water availability (and hence reduced channel flow). This will be worsened by the projected increase in water demands due to agricultural activities in the basin. Decreased Channel flow will in turn affect power generation rates and exercabate the frequent power rationing. On the other hand, increase in rainfall will lead to flooding in the lowland areas and high sediment load which will affect power generation.

7.5.3 Impact of Extreme Weather Conditions on Power Generation and Supply

Extreme weather events caused by climate change will lead to less reliable supply of electricity by affecting transmission. In a majority of cases, such events will necessitate strengthening of transmission lines which in turn will call for extra spending and strained national budget. Power generation from wind will also be affected through wind damage to photovoltaic installations. Temperature increase will have a negative effect on power generation from both steam and gas turbines which rely heavily on availability of cooling water (Solley et al, 1988). Reduction in power generation from sources other than hydropower will lead to an increase in peak demands and more frequent power rationing

7.6 Adaptation Options

In summary, climate change could

(i) Increase or decrease flow of hydroelectric potential depending on the weather pattern.

(ii) Affect power generation from sources other than hydropower by affecting the production technology. For example, excessive wind force will damage installations at Ngong while reduced water availability will lead to a reduction in the cooling effect at the thermal and gas turbine station, resulting in decreased power generation from these sources.

(iii) Affect power transmission lines, depending on precipitation amount and seasonality.

(iv) Affect reliability in hydroelectric power output through changes in rainfall amount and regimes or conditions of temperature, insulation, wind and humidity, all of which affect evaporation from reservoirs. For example, reduction in rainfall will cause a reduction in humidity hence increased evaporation.

Energy is a very important sector and many recommendations regarding the susceptibility to climate change have been made on global scale. In order to adapt to these effects of climate change in Kenya, it would be necessary to assess:

(a) How climate change will affect the technical aspects of design of the hydroelectric power generating equipment and installation.

(b) Design of new buildings in the light of changing energy use characteristics such as space heating, room cooling and air conditioning.

(c) Reservoir management and storage capacities. Since reservoir management alone, however efficient it may be, can not mitigate the additional risk of floods, additional reservoir storage for flood flow would be needed to counter extreme weather events (Lettenmaier and Sheer, 1991).

(d) The impact of greenhouse gases on other renewable resources such as biomass. Measures to increase biomass production will be important in reducing total dependance on hydropower for energy.

(e) The degree of vulnerability of thermal and gas turbine engines to the impacts of climate change. Such data will help the policy planners to determine the susceptibility of hydropower to peak power demands in the country. This is in view of the fact that Kenya has no plans to develop fossil fuel and nuclear power, and as such will continue to rely heavily on hydroelectric power for energy needs.

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