CLIMATE CHANGE AND AFRICAN AGRICULTURE
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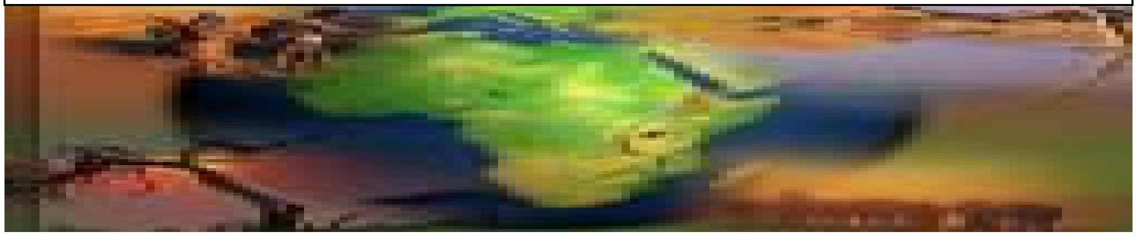

Vulnerability of water resources of Lake Tana, Ethiopia to climate change[1]

One of the most significant impacts of climate change is likely to be on the hydrological system, and hence on river flows and regional water resources. This will be particularly true in arid and semi-arid areas of Africa where water resources are very sensitive to climate variability, particularly rainfall.

This study assesses the vulnerability of the water resources of the Lake Tana sub-basin. Climate change is predicted to have serious implications for the hydrology of the sub-basin, affecting the magnitude and seasonality of surface flows, and increasing the frequency of extreme events such as drought and floods. The severity of predicted impacts, using different models in different months, varies widely, and the months in which floods and drought are predicted to occur also vary from model to model. But all the models agree that river flow will be reduced, by amounts ranging from15% to 80% of the monthly mean, in some months of the year all over the basin.

The decrease in river flow might cause small streams to dry up completely, and the magnitude of flow of the medium to large rivers will decrease significantly. There is no reservoir in the sub-basin, so most of the small-scale water developments' existing water supply schemes draw directly on rivers or natural lakes. The supply of drinking water for humans and livestock depends mainly on river flow, so a decrease in the flow will have a severe impact. Because agriculture in the basin is mainly rainfed, an uneven distribution of rainfall and a decrease in or total failure of rainfall will cause crops to fail.

On the other hand, the predicted increase in river flow in some months of the year will cause floods, as the natural river and stream channels may not be able to accommodate the increase. Overflowing of the channels of the minor and major rivers and an abnormal rise in the level of the lakes will flood agricultural fields and human settlements.

The overall objective of this study was therefore to assess the vulnerability of

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[1] This Policy Note is prepared by R Hassan based on Tarekegn & Tadege, 2006, Assessing the impact of climate change on the water resources of the Lake Tana sub-basin using the Watbal model, *CEEPA Discussion Paper No. 30, CEEPA, University of Pretoria.*

water resources under various climate change scenarios and to evaluate adaptation options for reducing the potential adverse effects on the water resources of the sub-basin. The specific objective was to identify management strategies that could minimize the damages and economic losses caused by increased frequency and magnitude of flood and drought, and to enhance institutional response to the adverse effects of climate change. The study used a water balance hydrological model to assess climate change impacts on runoff at the sub-basin.

The WatBal model and study site

The model used is a version of a conceptual rainfall-runoff model called WatBal (Yates 1996), which can be applied to gridded data. This model was chosen because it suited the objectives of the study and the data availability and is recommended as giving good results in assessing the effect of climate change on water resources. The model simulates changes in soil moisture and runoff. It is essentially an accounting scheme based on a conceptualized, one-dimensional bucket that lumps together both the root and upper soil layer. The model comprises two elements. The first is a water balance component that describes water movement into and out of a conceptualized basin (Figure 1). The second is the calculation of potential evapotranspiration, which is computed using the FAO Penman-Monteith approach (Monteith 1965).

The model was applied to the Lake Tana sub-basin in Ethiopia, which is located at the headwaters of the Blue Nile (Abay) basin. The drainage area of the lake is 15,319 square kilometers, of which 3100 is the lake area. The geographical location of the Tana basin extends from 10.95^{o}N to 12.78^{o}N latitude and from 36.89^{o}E to 38.25^{o}E longitude. Based on the rainfall pattern, the year is divided into two seasons: a rainy season, mainly from June to September, and a dry season from October to March. In the southern parts of the basin the months of April and May are an intermediate season when minor rains often occur. Of the total annual rainfall, 70% to 90% falls in the June to September rainy season.

The mean annual flow at the outlet of Lake Tana is about 3.5 billion cubic meters and it varies from a maximum of 7 billion cubic meters to a minimum of 1 billion cubic meters in high and low water years, respectively.

The WatBal model parameters, which define the size of the store and the rate of water removal from it, are derived in part from physical characteristics and in part by calibration. The inputs are the monthly rainfall and climatic data required to estimate potential evapotranspiration. Water enters the soil moisture store through precipitation and is removed either by evapotranspiration, surface runoff or subsurface runoff. The water balance component of the model comprises three parameters related to: i) surface runoff, ii) sub-surface runoff and iii) maximum catchment water-holding capacity.

Surface runoff is described in terms of the storage state and the effective precipitation. Sub-surface runoff is a function of the relative storage state. Total runoff for each time step is the sum of the surface and sub-surface runoff components.

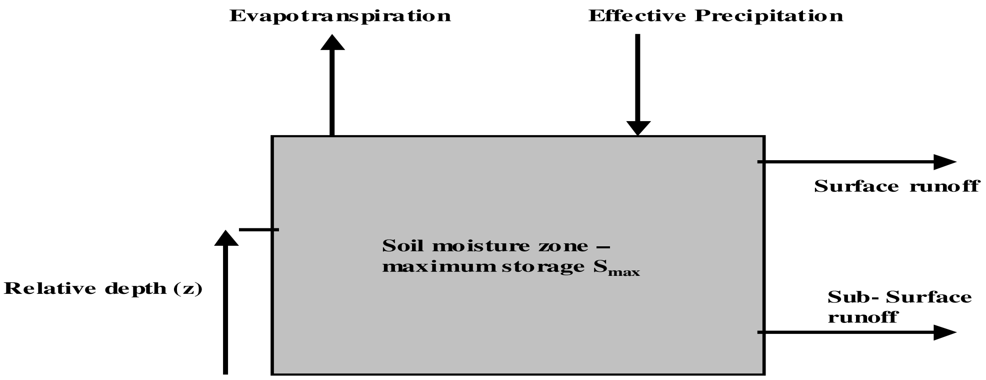

Figure 1: Simplified version of the WatBal model that is used to compute gridded runoff

Data availability and analysis

The WatBal model requires meteorological and hydrological input data in a monthly time-step for rainfall, temperature, relative humidity, sunshine hours and monthly flow data at the sub-basin outlet. Monthly cumulative rainfall, mean minimum and maximum temperatures, mean relative humidity and mean sunshine hours data were compiled for all available stations in the basin. Most of the stations for which data were collected are located inside the basin and some are located around it. The length of record of these stations varies from few years to more than 30. The monthly river flow data of Abay at Bahir-Dar, located at the outlet of the lake, is available for more than 35 years.

Taking into account the length of record, continuity of data availability, concurrent period of observation and the distribution of stations in the sub-basin, nine meteorological stations were selected for the study. The distribution of these stations within the sub-basin is not even. Hence, to minimize the error introduced by spatial variability, the Thiessen Polygon method was used to estimate the areal rainfall. For temperature, humidity and sunshine hours, the arithmetic means of the stations' data were used. The period selected for both calibration and validation was from 1978 to 1997.

Calibration and validation

In order to test/verify the WatBal model's ability to simulate runoff in the basin, the record was split into two parts. The data for the first ten years (1978–1987) were used for calibration purposes and the second ten years (1988–1997) for validation. To determine the value of each model parameter during calibration, a trial and error procedure with a range of logical values was used. The simulated and observed runoff values were plotted simultaneously and visual examination of the plots was carried out in each run to determine the best combination of parameter values. In addition, statistical measures were used to measure the difference between the observed and simulated values. The statistical measures used were the correlation coefficient (r), the coefficient of efficiency (R2) and the average monthly error in mm/day.

After calibration, the model parameters were validated for their ability to simulate runoff. If the graphical observation and the statistical measures gave satisfactory results in the calibration and validation periods, the parameter values and the modeling work were taken as satisfactory. The parameter values for the sub-basin are given in Table 1 and the correlation coefficient, coefficients of determination and monthly average error in mm/day are shown in Table 2.

Table 1: Calibrated model parameter values

Parameter	Values	Parameter	Values
Maximum storage, Smax (mm)	670	Direct runoff coefft., β	0.0
Sub-surface coefft., γ	1.8	Ground covers index, GC	0.2
Sub-surface coefft., α	4.5	Priestly Taylor coefft.	1.26
Surface runoff coefft., ε	3.0	Base flow (mm/day)	0.04
Initial storage, Z	0.23	Latitude (degree, north)	12

Table 2: Model efficiencies in calibration and validation periods

Station	Period	Correlation coefft.	Coefft. of efficiency	Av. error mm/day
Abay at Bahir-Dar	Calibration	0.88	0.73	0.17
	Validation	0.84	0.69	0.32

Climate change scenarios

To assess the impacts of climate change, it is first necessary to specify a number of plausible future climates. The types of climate scenarios used in this study are synthetic or incremental scenarios and scenarios from General Circulation Models (GCMs).

Synthetic scenarios describe techniques where particular climatic elements are changed by a realistic but arbitrary amount, according to a qualitative interpretation of climate model prediction for a region (IPCC Technical Guidelines, 1994). Synthetic scenarios are used to assess the sensitivity of the basin to climate change. For this study a different set of possible climate changes in temperature and rainfall was considered: an increase in temperature of 2°C and 4°C, and changes in the amount of rainfall by -20%, -10%, 0%, +10% and +20%.

GCMs produce estimates of climatic variables for a regular network of grid points across the globe. There are a number of GCMs worldwide which evaluate the equilibrium response of the global climate to an abrupt increase, commonly the doubling of atmospheric concentration of CO_2 by 2075 (equilibrium response). Recently, simulations have been made of climate response to a time dependent increase in greenhouse gases (transient response), (IPCC 1994).

Although various GCM outputs are available, their predictions of the amount of climate change differ. After comparing the GCMs' results with the trend of historical data for the country, results from three GCMs, CCCM, GFD3 and UK89, were selected to assess the impact of climate change on the sub-basin. For the stations used in the modeling, the monthly changes in temperature and rainfall predicted by these models under a $2xCO_2$ scenario were used to assess the possible impact on the water resources of the sub-basin.

Vulnerability assessment

For the synthetic scenarios, changes in temperature and rainfall were applied to the historical record for 1978–1987. The calibrated model was run for each combination of possible changes in monthly bases. The simulated runoff was then compared with that of the present situation, i.e. without change in climate. An increase in temperature of 2^oC with no change in rainfall decreases the mean annual flow by 11.3%. But if the rainfall is decreased by 10% and 20% the decrease in runoff is 29.3% and 44.6% respectively. On the other hand, if the rainfall is increased by 10% and 20%, the mean annual runoff increases by 6.6% and 32.5% respectively. This shows that the sub-basin is more sensitive to changes in rainfall than to changes in temperature.

For the GCM scenarios, the vulnerability of the Lake Tana sub-basin was assessed on the basis of the CCCM, GFD3 and UK89 climate change predictions for rainfall and temperature. The University of Colorado provided the predicted changes in rainfall and temperature on a monthly basis for the stations considered in the study (Strzepek & McCluskey 2006). These changes were applied to the observed data and the change in runoff as compared to the present situation was computed and is shown in Table 3. Table 4 presents the extreme impacts predicted.

The CCCM and GFD3 GCMs predict a reduction of 18.2% and 12.6% respectively in the annual runoff, while the UK89 GCM predicts wetter conditions and as a result an increase of 2.5% in annual runoff.

The change in the monthly runoff values is more important than the overall annual change and is significant in the sub-basin The first two GCMs predict a reduction of monthly runoff by as much as 32% and 28% in the main rainy month of July. They also predict a significant reduction in rainfall in the short February to April rainy season.

In conclusion, the water resources of the Lake Tana area are highly vulnerable to climate change, especially in the distribution of runoff throughout the year. With climate change, the runoff may become much more seasonal and as a result small streams may dry up completely for part of the year.

Table 3: Monthly percentage change in runoff under GCM scenario

GCM	Jan	Feb	Mar	Apr.	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
CCCM	-8.3	-6.3	-4.6	-7.0	-25	-29	-33	-23	-14	-25	-30	-17	-18.2
GFD3	-6.7	-4.3	-3.9	-2.7	-7.7	-17	-28	-20.5	-5.1	-16.9	-26.0	-14.8	-12.6
UK89	-2.0	-0.2	-0.5	-5.7	-20.9	-22.4	28.9	34.4	4.9	8.4	6.6	-4.2	2.5

Table 4: Predicted extreme impact over the Lake Tana sub-basin

GCM	Impact predicted for the seasons	
	Max. decrease in %	Max. increase in %
CCCM	-32 in Jul	--
GFD3	-28 in Jul	--
UK89	-22 in Jun.	+34 in Aug.

Adaptation options

The technological, economic and policy adaptations available will differ greatly depending on the hydro-climatic zone, the level of economic development and the relative sensitivity of the water resource system to potential climate change. The IPCC Technical Guidelines (IPCC 1994) list six generic types of behavioral adaptation strategy for coping with the negative impacts of climate:

- Prevention of loss: involving anticipatory actions to reduce the susceptibility of an exposure unit to the impacts of climate.
- Tolerating loss: where adverse impacts are accepted in the short term because the exposure unit can absorb them without long-term damage.
- Spreading or sharing loss: where actions distribute the burden of impact over a larger region or population beyond those directly affected by the climate event.
- Changing use or activity, involving a switch of activity or resource use from one that is no longer viable following a climatic perturbation to another that is, so as to preserve a community in a region.
- Changing location: where preservation of activity is considered more important than its location, and migration occurs to areas that are more suitable under the changed climate.
- Restoration: which aims to restore a system to its original condition following damage or modification to climate. This is not strictly adaptation to climate, as the system remains susceptible to subsequent comparable climatic events.

Table 5: Adaptation options for Lake Tana sub-basin

Adaptation option	Option effectiveness for:	
	Floods	Drought
Construction of reservoirs for hydropower, irrigation, water supply, flood control and/or multipurpose uses.	High	Medium
Construction of dykes	Medium	-
Use of ground water	-	Medium
Relocation of settlements from flood prone areas	Medium	-
Afforestation	Medium	Medium
Improvement of water management systems	Medium	Medium
Establishment of flood forecasting and drought monitoring system	High	Medium

Another way to adapt is to modify the threat, i.e. to attempt to control the environmental phenomenon itself. For example, a flood may be controlled by flood control structures and a drought may be alleviated by cloud seeding. The main way to modify long-term climate change is to slow its rate by reducing greenhouse gas emissions and eventually stabilizing the concentration of these gases in the atmosphere. Table 5 lists some ways the Tana sub-basin might adapt to the negative effects of floods and drought.

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The agricultural sector in sub-Saharan Africa is predicted to be especially vulnerable to climate change because this region already endures high heat and low precipitation, provides the livelihoods of large segments of the population, and relies on relatively basic technologies, which limit its capacity to adapt. This series of Policy Notes reports on the methods and results of the first continent-wide study of this kind assessing how the economic well-being of African farming communities is currently affected by climate, predicts how future climate change effects may unfold under various possible global warming scenarios, and evaluates the roles adaptation to climate change could play. The study is based on collaborative research efforts conducted in 11 countries: Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Niger, Senegal, South Africa, Zambia and Zimbabwe. The sampled districts used as the unit of analysis cover all key agro-climatic zones and farming systems in Africa. This is the first analysis of climate impacts and adaptation in Africa on such a scale and the first in the world to combine cross-country, spatially referenced survey and climatic data for conducting an analysis that uses economic impact assessment methods, river-basin hydrological modeling and crop growth simulation techniques.

All the reports produced under this GEF/WB/CEEPA funded project, *Regional Climate, Water and Agriculture: Impacts on and Adaptation of Agro-ecological Systems in Africa*, are found on CEEPA e-Library at its website link (www.ceepa.co.za/discussionp2006.html) and can also be accessed directly through the project link (www.ceepa.co.za/Climange_Change/project.html)

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