CROPWAT EXERCISE REPORT FOR ZAMBIA

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PREFACE

The reports in this special series are the result of a multi-country research activities conducted under the GEF funded project: *Climate Change Impacts on and Adaptation of Agro-ecological Systems in Africa*. The main goal of the project was to develop multipliable analytical methods and procedures to assess quantitatively how climate affects current agricultural systems in Africa, predict how these systems may be affected in the future by climate change under various global warming scenarios, and suggest what role adaptation could play. The project has been implemented in 11 countries: Burkina Faso, Cameroon, Ghana, Niger and Senegal in west Africa; Egypt in north Africa; Ethiopia and Kenya in east Africa and South Africa, Zambia, and Zimbabwe in southern Africa. The study countries covered all key agro-climatic zones and farming systems in Africa. This is the first analysis of climate impacts and adaptation in the Africa continent of such scale and the first in the world to combine cross-country, spatially referenced survey and climatic data for conducting this type of analysis.

The analyses reported in this series focus mainly on quantitative assessment of the economic impacts of climate change on agriculture and the farming communities in Africa, based on both the cross-sectional (Ricardian) method and crop response simulation modeling. The cross sectional analysis also allowed for assessing the possible role of adaptation. Moreover, the project employed river-basin hydrology modeling to generate additional climate attributes for the impact assessment and climate scenario analyses such as surface runoff and streamflow for all districts in the study countries.

The Centre for Environmental Economics and policy in Africa (CEEPA) of the University of Pretoria coordinated all project activities in close collaboration with many agencies in the involved countries, the Agriculture and Rural Development (ARD) Department of the World Bank, the World Bank Institute (WBI), the Food and Agriculture Organization (FAO), Yale University, the University of Colorado, and the International Water Management Institute (IWMI). The project received supplemental funding from TFESSD, Finnish TF, NOAA-OPG, and CEEPA. We are grateful for the invaluable contributions of all these institutions and all individuals involved in this project. All opinions presented in this report series and any errors in it are those of the authors and do not represent the opinion of any of the above listed agencies.

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EXECUTIVE SUMMARY

The Zambian climate is favorable for agriculture production, with abundant arable land receiving 650mm annually in the southern part of the country and 1800mm in the north. Groundwater resources are also abundant in the Congo/Zaire and Zambezi river basins. The combined irrigation potential for these areas in Zambia is 523,000ha, of which only 46,400ha (9%) is being used, mostly by commercial farmers cultivating sugar, wheat and plantation crops. The majority of agricultural production remains rainfed and therefore production varies according to variations in rainfall. Agriculture's contribution to GDP, however, has continued to fluctuate significantly from one year to another, as the sector still remains highly vulnerable to climatic and economic variables. Threats of land degradation and desertification have further aggravated the situation.

To determine the ultimate effects of climate change, researchers will need to look at the future extent and effects of land degradation, the quantification of future rainfall variability, the actual response of plants to the combined effects of increased concentrations of CO_2 and elevated temperatures, the consequences of improved cultivation practices, and the altered social, economic and political circumstances.

This study was therefore undertaken:

- to develop a methodology for assessing the impact of climate change on agriculture in Zambia; and

- to provide information for an analysis of regional climate change impacts in analysis. The country findings will be used to extrapolate to various similar agro-ecological systems on the continent.

Two out of Zambia's total of 72 districts were purposely selected as experimental units for this pilot study. Chongwe (1280m above sea level, 15.25^{o}S and 28.19^{o}E) was chosen because it falls in Zone I, and Chipata (1032m above sea level, 32.35^{o}E and 13.33^{o}S) was selected because it is in Zone II. Both are important agricultural districts and therefore were good candidates on which to test the CROPWAT model. Crop data was obtained from the Ministry of Agriculture headquarters in Lusaka and from the Central Statistics Office in Lusaka, and from the district officials where feasible.

CROPWAT was the tool used to carry out standard calculations for reference evapotranspiration (Eto) and crop water requirements (CWR). This helped in the assessment of production under rainfed conditions, seeing that irrigation is insignificant in these areas. Evaluations were based on a daily soil-water balance. The tool uses the Penman-Monteith method for calculating the reference crop evapotranspiration. Calculations of the CWR were carried out with inputs of climatic, crop and soil data. These data sets were obtained from CLIMWAT, To estimate the CWR the model requires Eto values. These were calculated using the FAO Penman-Monteith equation based on monthly climatic data (minimum and maximum air temperature, relative humidity, sunshine duration and wind speed). Monthly rainfall data was divided into a number of rainstorms each month, and cropping patterns consisted of the planting date, crop coefficient data (including Kc values, stage days, root depth, depletion fraction) and the area planted (0–100% of the total area). A set of typical crop coefficient data files are provided in the program.

Although there is much uncertainty about climate change, adaptive measures that can be applied over a wide range of climate change scenarios, such as the construction of dams and exploitation of groundwater resources, need to be considered for implementation. For example, on the one hand dams can be used for flood mitigation during periods of heavy storms, and on the other they can be used for water storage using prolonged droughts – which have become the rule rather than the exception in the sub-region of late.

Results indicate that, according to the current climate scenario, crop cultivation in the selected districts does not seem to suffer any effect of water deficits. However, as earlier discussed, the various GCMs give varying predictions for future climate. A slight deficit was observed to indicate irrigation requirements towards the end of the growing season, with only 2.86mm being the deficit at the beginning of the season. It is also important to note that there are opportunities for harvesting some of the water and alleviating this deficit. The other opportunity is to plant earlier so as to take advantage of the higher moisture during the peak-growing season. The later planted crops seem to suffer more than the earlier planted ones.

1. Introduction

Zambia is a landlocked country occupying a near central position on the southern African subcontinent and covering an area of 752,620km^2, which is approximately 2.5% of the continent's total area. It shares borders with eight countries; Angola, Botswana, the Democratic Republic of Congo (DRC, formerly Zaire), Malawi, Mozambique, Namibia, Tanzania and Zimbabwe. Although Zambia is tropical, the relatively high altitude of most parts of the country (between 900 and 1,500 m above sea level) permits the production of temperate crops and exotic breeds of livestock.

The country is also endowed with ample water resources comprising seven big lakes, the Kariba Dam (man-made), Bangweulu, Mweru, Tanganyika, Chifunabuli, Walipe and Kampolombo. It is also blessed with four major rivers, the Zambezi, Kafue, Luangwa and Luapula. Zambia has abundant arable land, a good climate and ample water.

1.1 Zambian agriculture

There is consensus in the literature that Zambia's large potential in agriculture remains unexploited. Of a total number of 7.5 million hectares of land, 4.2 million (58%) are classified as medium to high potential for agricultural production and 12% is suitable for arable production although only an estimated 14% of this is currently cultivated (MoAFF 2000).

The Zambian climate is favorable for agriculture production, with abundant arable land receiving 650mm annually in the southern part of the country and 1,800mm in the north. Groundwater resources are also abundant in the Congo/Zaire and Zambezi river basins. The combined irrigation potential for these areas in Zambia is 523,000ha, of which only 46,400ha (9%) is being used, mostly by commercial farmers cultivating sugar, wheat and plantation crops. The majority of agricultural production remains rainfed and therefore production varies according to variations in rainfall.

Zambian agriculture has three broad categories of farmers: small-scale (or subsistence) farmers, medium (or emergent) farmers, and large-scale farmers. Table 1 shows some of their characteristics.

Of the estimated 600,000 farmers, 76% are small-scale farmers. Their farm holdings range from 0.5 to 9 hectares with the average size being two hectares. Emerging commercial farmers account for 20% of the farmers focusing on food and cash crop farming. Their holdings range from 20 to 60 hectares. The commercial farmers (medium and large scale) make up the remaining 4% and their focus is on cash crops with farm sizes that are above 60 hectares. It has been observed that the number of households in the small-scale category has been increasing, while numbers of the medium and large-scale farmers have remained more or less the same.

Although Zambia has a relatively large urban population, approximately 45% of the total population (4.6 million people) are poor people in rural areas who are dependent on agriculture. The share of the population living below the poverty line increased from 70% in 1991 to 75% in 2004, with much higher rates in remoter rural areas. HIV/AIDS has also contributed to this situation, having a drastic impact on skilled labor supply, savings and investment, and ultimately potential growth.

The sector's contribution to real GDP averaged 18% over the past decade, making up 39% of earnings from non-traditional exports, though this has fluctuated significantly mainly due to the dependence on the seasonal rainfall, which is unreliable. Net resource flows into agriculture exceeded mining in the 1995–2001 period, with 232 projects worth US$302 million from Zambian and foreign commitments (excluding official aid-related flows).

Between 1990 and 2000, agricultural growth was around 4.5%, increasing against the industrial sector as a proportion of total GDP. Average growth to 2004 was forecast at 3.2%. This is above the declining population growth rate, which is currently around 2.3%. However, annual fluctuations in productivity vary dramatically (increasing or decreasing by as much as 30%) according to rainfall. Poor farmers dependent on rainfed crops are extremely vulnerable to these fluctuations.

1.2 Agro-ecological zones

In Zambia, farming systems have to a large extent been influenced by the physical and climatic characteristics of the three major agro-ecological zones.

The drought and flood prone valleys of the Luangwa and Zambezi rivers and the western semi-arid plains make up Zone I, covering 42% of the total land area of the country. Zone I is dominated by subsistence crop production of small grains (sorghum and pearl millet), largely using family labor, with the most common farm implements being hand hoes. The use of improved sorghum varieties is quite pronounced, particularly in the southern part of the country. The major constraints on agriculture production in this area are unpredictable rainfall (annual average less than 800mm), recurrent floods, periodic droughts, lack of technical packages, and livestock diseases. This zone also experiences high temperatures during the growing season, which limits the range of crops that can be grown in the area. The combination of all these factors exposes Zone I to a high risk of food insecurity.

Zone II includes most of the Central, Eastern, Lusaka and Southern Provinces and parts of the Western Province and covers 12% of the total land area. It receives between 800mm and 1000mm of rainfall annually and generally has fertile ferrous soils with a high potential for crop production. Zone II is characterized by a maize regime and is the most mechanized and consequently the most commercialized region in Zambian agriculture. Cash crops are grown, the most common being cotton, irrigated wheat and soybeans. The country's most highly valued cash crops, such as spices, flowers and horticultural products, are also produced in this zone. Most of the country's commercial and emergent farmers are found in this zone, and hence it has better infrastructure and services. A good number of the crops here are improved cultivars.

Zone III, representing nearly half of the country, covers the northern high rainfall areas of the Copperbelt, Luapula, Northern and North-Western provinces. The annual average rainfall is always over 1200mm and the soils are generally highly leached and acidic, and therefore relatively unfertile, with low crop production potential. These soils can be reclaimed through liming, which unfortunately is not available in many rural communities. Zone III is largely characterized by a cassava and maize regime, with the northern part of the country also cultivating some finger millet. This zone is similar to Zone I in agricultural production; that is, it is largely dominated by subsistence level of production, farmers here also use hand hoes as farm implements, and crops are grown mainly from local varieties.

1.3 Crop production

There has been a general decline in the total cultivated hectarage. This has been attributed to a number of factors, the most significant of which are the following:

- The cost of farm implements. The 1990s were characterized by full implementation of market policies. This resulted in the total removal of all subsidies on agricultural inputs, with the result that they became very expensive.

- Droughts. These recurred frequently in the first half of the 1990 and made farming rather unpredictable and risky.

- Number of work oxen. This has been reduced largely through the loss of animals as a result of the drought and cattle diseases, which have been rampant.

In Zambia agriculture therefore, as measured by the GDP, has continued to fluctuate significantly from one year to another, as the sector still remains highly vulnerable to climatic and economic variables. Threats of land degradation and desertification have further aggravated the situation.

To determine the ultimate effects of climate change, researchers will need to look at the future extent and effects of land degradation, the quantification of future rainfall variability, the actual response of plants to the combined effects of increased concentrations of CO_2 and elevated temperatures, the consequences of improved cultivation practices, and the altered social, economic and political circumstances.

Therefore, in order to formulate appropriate policies that can minimize the impacts of extreme climatic conditions there is need to assess the impacts of climate change on agriculture. This study was therefore undertaken

- to develop a methodology for assessing the impact of climate change on agriculture in Zambia; and

- to provide information for an analysis of regional climate change impacts in analysis. The country findings will be used to extrapolate to various similar agro-ecological systems on the continent.

2. Methodology

2.1 Sites

Two out of Zambia's total of 72 districts were purposely selected as experimental units for this pilot study. Chongwe (1280m above sea level, 15.25°S and 28.19°E) was chosen because it falls in Zone I, and Chipata (1032m above sea level, 32.35°E and 13.33°S) was selected because it is in Zone II. Both are important agricultural districts and therefore were good candidates on which to test the CROPWAT model.

2.2 Data collection and analysis tool

Crop data was obtained from the Ministry of Agriculture headquarters in Lusaka and from the Central Statistics Office in Lusaka, and from the district officials where feasible.

Chongwe

A cropping pattern of 85% maize, 15% sunflower and 5% groundnuts was used, based on personal communications with the district agricultural officials. Planting dates of 15 December, 15 January and 1 December were used for the three crops respectively. A medium soil was factored into the model.

Chipata

For Chipata, the cropping pattern used was 80% maize, 15% groundnuts and 5% cotton. Planting dates for these crops used were 15 November, 1 November and 15 October respectively. This gave the harvesting dates of 30 March, 21 March and 28 April respectively. As for Chongwe, a medium soil was factored in.

CROPWAT was the tool used to carry out standard calculations for reference evapotranspiration (Eto) and crop water requirements (CWR) (FAO 1992). This helped in the assessment of production under rainfed conditions, seeing that irrigation is insignificant in these areas. Evaluations were based on a daily soil-water balance. The tool uses the Penman-Monteith method for calculating the reference crop evapotranspiration (Monteith 1965).

Calculations of the CWR were carried out with inputs of climatic, crop and soil data. These data sets were obtained from CLIMWAT (FAO 2003). To estimate the CWR the model requires Eto values. These were calculated using the FAO Penman-Monteith equation based on monthly climatic data (minimum and maximum air temperature, relative humidity, sunshine duration and windspeed) (FAO 1992). Monthly rainfall data was divided into a number of rainstorms each month, and cropping patterns consisted of the planting date, crop coefficient data (including Kc values, stage days, root depth, depletion fraction) and the area planted (0–100% of the total area). A set of typical crop coefficient data files are provided in the program.

3. Results and discussion

Chongwe (Table 3)

No irrigation is practiced in this district, so the irrigation requirement was considered as deficit. The total deficit amounted to 111.16mm basically coming towards the end of the growing season, with only 2.86mm being the deficit at the beginning of the season.

It is also important to note that there are opportunities for harvesting some of the water and alleviating this deficit. The other opportunity is to plant earlier so as to take advantage of the higher moisture during the peak-growing season. The later planted crops seem to suffer more than the earlier planted ones.

The above discussion is based on the current status of climate. However, several models are available that give different scenarios for the future. These are shown in Table 2.

Chipata (Table 4)

Looking at precipitation alone, those GCMs (General Circulation Models) that predict increased precipitation may be to our advantage, with only model CCC being the worrying one. However, the climate factors mentioned above are not independent so analysis will have to take into account their interdependencies and correlations with each other. But overall the changing climate will affect crop production and hence there is a need to develop scenarios on which to base mitigation and appropriate policies to tackle these eventualities.

The total deficit represents the irrigation requirement of 2.66mm at the beginning of the season and 0.61mm at the end, a total of 3.27mm, which is very minimal. Therefore, for all intents and purposes, given the current climate scenario, Chipata district does not suffer any effect of water deficits. However, as earlier discussed, the various GCMs are giving varying predictions for future climate.

The results obtained from this study by and large match our observations, suggesting that CROPWAT is a reasonable tool to use to study such works and that it is a logical model. However, the model has one drawback in my opinion – and that is that rainwater is calculated as having fallen in three ten-day periods. This is rarely the case in reality and hence might have somewhat affected the results obtained.

Although there is a lot of uncertainty about climate change, adaptive measures that can be applied over a wide range of climate change scenarios, such as the construction of dams and exploitation of groundwater resources, need to be considered for implementation. For example, on the one hand dams can be used for flood mitigation during periods of heavy storms, and on the other they can be used for water storage using prolonged droughts – which have become the rule rather than the exception in the sub-region of late.

Water withdrawal data at district level was not available (such information is available at basin level, and basins cut across several districts), so comparisons were not possible.

The depletion of vegetation cover in the catchment's area as a result of poor agricultural practices and establishment of human settlements may have accelerated surface runoff. There is therefore a need to encourage good land husbandry practices and it is gratifying to note that the Ministry of Agriculture is doing just that through promoting conservation farming technologies.

4. Conclusions and recommendations

Increasing poor farmers' access to irrigated land could mitigate the effects of unreliable rainfall experienced in the recent past and thus help them produce higher value crops and access marketing channels.

Much of the literature emphasizes Zambia's under-utilized resources that appear to offer the country many alternatives for diversifying the economy away from the mineral sector and increasing agricultural production. Growth in the small-scale agricultural sector would potentially help reduce poverty and improve national economic growth, based on the strong linkages between agriculture and poor people's livelihoods in Zambia, provided that sufficient numbers of the rural poor are actually able to access the benefits of agricultural commercialization.

There would appear to be opportunities for small-scale farmers to diversify from maize into more marketable crops, and this is confirmed by a pattern of declining maize production. There is a trend towards cultivating the more profitable, drought resistant food crops such as sorghum, cassava, millet and tubers that use less chemical fertilizers. There have been considerable increases (20–50%) in the area and production of cassava, groundnuts and millet in the last decade. However, over 70% of households still grow maize as the major staple crop. Increasing use of fertilizer does lead to improved productivity for smallholders, but usage is still less than 15% nationally, with increasing prices making it difficult to afford on a commercial basis.

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Table 1: Characteristics of Zambian agriculture, 1999

Characteristics	Small-scale	Emergent	Large-scale
Number of farmers	459,000	25,230	>4,000
Area / holding (ha)	0.5–9.0	20–60	>60
Crops grown	Food crops	Food/cash crops	Cash crops
Production focus	Subsistence	Commercial/subsistence	Commercial

Source: MoAFF (2000)

Table 2: Temperature and precipitation predictions for Africa for 2100

General Circulation Model (GCM)									
CSIRO		CCSR		HAD3		HAD2		CCC	
T	P	T	P	T	P	T	P	T	P
4.4	0.3	4.3	9.0	4.8	7.1	6.2	9.9	8.1	-15.7

Table 3: Chongwe results

	October			November			December			January			February			March			April			May		
Et_o	59.9	59.6	58.9	57.5	55.7	53.3	50.5	47.3	22.4	37.6	37.9	37.8	37.5	36.8	35.9	34.9	33.6	32.2	30.8	28.4	26.8	25.8	24.9	24.3
K_c	.02	.02	.05	.13	.33	.35	.45	.66	.83	.29	.46	.68	.87	1.07	1.15	1.17	1.19	1.18	1.03	.82	.51	.09	.06	.04
CWR	.31	1.04	3.14	7.22	18.09	18.86	22.41	31.18	18.48	11.03	17.51	25.64	32.72	39.54	41.35	40.88	39.94	37.93	24.04	14.36	2.53	1.60	0.40	0
T.R	0	0.01	1.64	10.28	41.42	55.39	66.65	74.84	39.56	60.44	66.59	69.66	67.52	62.7	55.29	45.57	33.85	20.16	4.21	0	0	0	0	0
E.R.	0	0.01	1.63	8.89	32.62	39.77	44.48	47.19	24.13	39.92	43.72	46.37	46.38	45.03	41.78	36.17	27.94	17.11	3.79	0	0	0	0	0
I.R.	.31	1.03	1.52	0	0	0	0	0	0	0	0	0	0	0	0	4.7	12.01	20.82	27.84	24.04	14.36	2.53	1.60	0.40
Def	.31	1.03	1.52	0	0	0	0	0	0	0	0	0	0	0	0	4.7	12.01	20.82	27.84	24.04	14.36	2.53	1.60	0.40

T.R. = total rainfall; E.R. = effective rainfall; I.R. = irrigation requirement; Def. = deficit

Total deficit: 111.16mm

Table 4: Chipata results

	October			November			December			January			February			March			April			May
Et_o	55.89	56.51	56.42	55.58	54.00	51.70	48.79	23.15	42.62	42.13	41.27	40.06	38.54	36.77		34.85	32.85	30.87	29.00	27.33	25.94	24.91
K_c	0.02	0.02	0.05	0.13	0.33	0.35	0.45	0.66	0.83	0.97	1.14	1.19	1.19	1.19	1.16	1.00	0.78	0.42	0.04	0.04	0.03	0.00
CWR	0.29	0.98	3.03	7.10	18.07	19.11	22.97	32.17	19.10	41.23	48.11	49.22	47.77	45.77	42.66	34.88	25.52	13.04	1.21	0.99	0.58	0.00
TR	0.01	1.64	10.28	41.42	55.39	66.65	74.84	39.56	80.43	85.29	87.66	86.57	81.64	73.12	61.89	48.58	26.04	1.27	0.81	0.34	0.00	0.00
ER	0.01	1.63	8.89	32.62	39.77	44.48	47.19	24.13	48.33	50.20	51.50	51.76	50.63	47.89	43.51	37.12	21.58	1.14	0.74	0.29	0.00	0.00
IR	0.29	0.97	1.40	0.00	0.00	0.00	0..00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.25	0.29	0.00
Def	0.29	0.97	1.40	0.00	0.00	0.00	0..00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.25	0.29	0.00