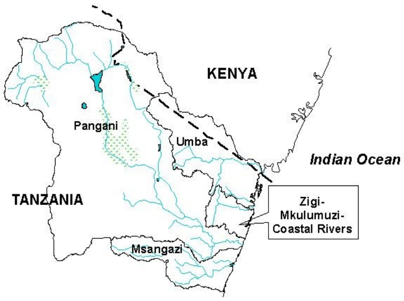
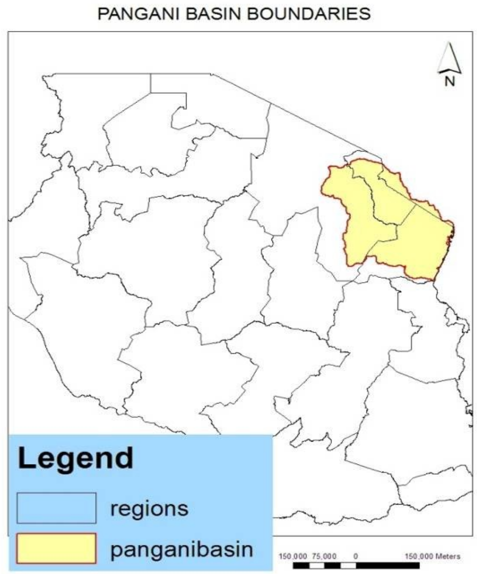
Impacts of Climate





Change on Maize and Beans Production and Compatibility of Adaptation Strategies in Pangani River Basin, Tanzania

Sanga, G.J[1]., Hella, J.P[2]., Mzirai, N[3]., and Senga, H[4].

1. Department of Economics and Statistics, the University of Dodoma (UDOM), P. O. Box 395, Dodoma. E-mail: godysanga2012@yahoo.com. Corresponding author.
2. Department of Agric Econ and Agribusiness, Sokoine University of Agriculture, P. O. Box 3007, Morogoro. E-mail: jp_hella@yahoo.co.uk.
3. Department of Civil and Irrigation Engineering, Arusha Technical College, P.O.BOX 296., ARUSHA. E-mail: nururessa@gmail.com
4. Tanzania Meteorological Agency, P.O.Box 3056, DSM. E-mail: mamaadam@yahoo.com.

Abstract

Climate change present new development challenges particularly in Sub-Saharan countries where the majority of the population depend on climate-sensitive activities such as rain-fed agriculture. Africa's vulnerability to climate change impacts is underscored by the severe droughts experienced recently in the Sahel in 2012 and the Horn of Africa in 2011. All these bring into focus the serious impacts of climate change and compatibility of adaptation as a way of providing sustainable solutions to reduce the vulnerability of the majority of poor Africans. This study employed Ricardian approach to assess the impacts of temperature and rainfall variability on the net revenue from two main food crops (maize and beans) from Pangani River Basin produced primarily under rain fed agriculture. The study also employed the gross margin to assess the compatibility of irrigation adaptation strategy. The results indicate that increase in temperature and decrease in rainfall has decreased the net revenue from maize and beans production and raised rent for irrigated farms particularly in the middle and low altitudes of the basin. Increase in temperature has increased the net revenue from maize and beans production in the upper altitudes of basin. The results clearly demonstrate that climate change have affected the livelihood of the majority of the poor small scale farmers found in the middle and lower altitudes and improved that of farmers living in the upper. They also demonstrate that irrigation is a significant technique for adaptation to climate change in the basin.

Key words: Climate change, impacts, adaptation, compatibility, irrigation.

1. Introduction

Climate change and variability present new development challenges, particularly in Sub-Saharan African countries where the majority of the population depend on climate-sensitive activities such as agricultural production (IPCC, 2007). This has rendered these countries to be more vulnerable to climate change and variability (Kurukulasuriya and Mendelsohn, 2008). In these countries vulnerability to climate change impacts is underscored by the severe droughts experienced in the Sahel in 2012 and the Horn of Africa in 2011(Sarr, 2012). In Tanzania for example, climate variability affects nearly 80% of the population who directly or indirectly depend on rain fed agriculture (Thornton, 2011; WB, 2011). For a significant period of time now the country is experiencing decreasing and increasing trends of rainfall and temperature respectively as well as persistent droughts and floods in many parts (Shemsanga, 2010). These climatic trends have created new burdens for those already poor and vulnerable (Brooks *et al*., 2009). For the most vulnerable groups, exposures to new climatic variability risks coupled with crop failures, food and income insecurity, malnutrition and ill health are ‘the latest in a series of pressures and stresses they are facing’ (Vrieling *et al*., 2013).

The fact that climate is changing and mitigation efforts to reduce the sources or enhance the sinks of greenhouse gases will take time as it involve the diverse global community, regional and country initiatives to adapt to changes are imperative. This is of great concern in developing countries where vulnerability to climate change effects is high due to low capacity to absorb climate change shocks. Adaptation helps farmers achieve their food, income and livelihood security in the face of changing climatic conditions, extreme weather conditions such as droughts and floods (IISD, 2007; De Wit and Stankiewicz, 2006; Kandlinkar and Risbey, 2000). It is believed that small scale farmers can reduce the potential damage by making tactical responses to these changes (Maddison, 2006; Mano *et al*., 2003). However, this will be difficult if climate change effects and compatibility of adaptation mechanisms are taken holistically. Understanding the effects at microclimatic difference and the compatibility adaptation mechanisms used by small scale farmers at these levels is therefore deemed important for finding credible ways to help farmers produce enough for food and income for other household needs.

Maize and beans have been taken as a window through which different responses to climate change can be explored. It is clear that climate change impacts on crop production vary across different areas (Nhemachena and Hassan, 2007; Eid *et al*., 2006; Kurukulasuriya and Mendelsohn, 2007), even though this has been observed at global and national levels. Similarly to maize and beans production in Tanzania, climate change is affecting the production of these crops in various ways. This study is designed to investigate the effect of climate change on the two crops at micro-climatic differences. The study hypothesise that in some areas climate change has favoured production of the two crops and affected it in the opposite direction in others, which in turn affects small scale farmers food and income security. Given the role maize and beans plays to diverse livelihood systems especially food and income security across Tanzania and elsewhere in Sub-Saharan Africa (Haug and Hella, 2013; Helms and Straus, 2009), this study chose the two crops to be the units of analysis. Basing on the two crops the study investigated (i) the relationship between climate variables (rainfall and temperature) and the net revenue from dry land and irrigated Maize and Bean farms in the three areas with different terrain and climatic conditions; (ii) the importance of irrigation as an alternative course of action to mitigate the likely impacts of climate change on Maize and Bean production in Pangani Basin.

The rest of the paper is presented as follows: the next section (2) presents the description of study area, followed by materials and methods describing model and data sources section (3).

The empirical results and discussion are presented in section 4 and the last section (5) presents conclusions and policy implications of the results.

2. Description of the study area

The study was conducted in Pangani River Basin and Pemba Island. The Pangani River basin drains a large catchment in the northeastern part of the country along the border with Kenya, extending from Mount Meru and Mount Kilimanjaro down through the Pare and Usambara Mountain ranges (Figure 1) (PBWO, 1997). The basin has a total catchment area of about 43,650 sq. km with about 3,914 sq. km lying in Kenya (IUCN, 2003). Pangani River Basin is unique in the fact that it begins from the highest peak of Africa, Mount Kilimanjaro (which is 5895 m above sea level) and Mount Meru (which is 4565 m asl) through the Pare and Usambara Mountains to the north and north-east respectively to the low lands of about 900 m asl and 0m asl. The low lands make up about 50% of the basin (Mbonile, 2001).

Figure 1: Pangani River Basin location in Tanzania and Boundaries (Pangani Basin Water Office, 1997).

Population in the basin is characterized by rapid growth and uneven distribution, currently a home to 3.7 million inhabitants (IUCN, 2003). Ninety percent of this population lives in the highlands, leading to a population density of up to 300 people per sq. km, compared to 65 people per sq. km in the lowlands (IUCN, 2003). This rapid population growth, high population density coupled with climate change is posing pressure to the basin natural resources. The basin is well known for persistent water conflicts between farmers and pastoralists, shortage of arable land for agriculture and is also hosting precious natural resources such as wildlife which are important to the economy of the country. Nonetheless, the basin is characterized by in-migration of farmers searching for farmland, water and pasture for livestock.

3. Material and methods

3.1. Analytical framework

The study employed an econometric approach known as Ricardian method, which was applied to assess the effect of climatic variability in the production of maize and beans in the study area. The selection of the two crops based on two major reasons: (1) the two crops are important crops for economic and food security in the study area, and (2) the two crops are sensitive to climate variability. The paper draws heavily on the conceptual contribution and empirical application by Deressa (2005), and Ajetomobi and Ajiboye (2012). There are two major reasons for adopting their conceptual approach: First, is that it is based on the Ricardian approach to assess the economic impacts of climatic variability, and second, is that their frameworks allow for capturing compatibility of farmers initiatives to cope with climatic variability unlike production functions and crop simulation approaches. To simplify estimations, we assumed constant market prices for maize and beans. The model used is based on a set of well-behaved twice continuously differentiable, strictly quasi-concave with positive marginal products production functions of the form:

$$Q_i = (K_i, E), i = 1,2.........., n \quad (1)$$

Where:

Q_i is the quantity produced of good i,

$K_i = K_{i1}, K_{i2},..........K_{ij},........K_{iJ}$ is a vector of production inputs i used to produce Q_i, K_{ij} is the production input $j(j = 1,2,.........., J)$ in production of good i.

$E = (E_1, E_2,........, E_m,.........E_m)$ is a vector of exogenous environmental factors such as temperature, rainfall, and soil characterizing production sites.

Given the factor prices w_i, E and Q, cost minimization gives the cost function as:

$$C_i = C_i(Q_i, W, E) \quad (2)$$

Where C_i is the cost of production of good i and $W(w_1, w_2....w_n)$ is the vector of factor prices. Using the cost function C_i at give market prices, net revenue and profit maximization by farmers on a given site can be specified as:

$$NR = P_i Q_i(K_i, E) - (C_i(Q_i, W, E) + P_L L_i) \quad (3)$$

$$Max\pi = \left[P_i Q_i(K_i, E) - C_i(Q_i, W, E) - P_L L_i\right] \quad (4)$$

Where P_L annual rent is price of land and L_i is the size of land used for production.

Under perfect competition all profits in excess of normal returns to all factors of production are driven to zero as follows:

$$P_i Q_i^*(K_i, E) - C_i(Q_i^*, W, E) - P_L L_i = 0 \quad (5)$$

The main objective of the study is to measure the impact of exogenous changes in environmental variables on the net economic welfare i.e. ΔW. The net economic welfare is the change in welfare induced by or caused by the changing environment from a given state to the other and this is measured either in terms of change in capitalized value of the land or in net farm income. Since in the study area agricultural production in not capitalized, it is merely small scale farming, the study therefore used the net farm income and this was derived as follows:

Consider an environmental change from the environmental state A to B, which causes environmental inputs to change from EA to EB. The change in annual welfare (ΔW) is therefore given by:

$$\Delta W = W(E_B) - W(E_A)$$

$$= \int_0^{Q_B} \left[P_i Q_i(K_i, E) - C(Q_i, W, E_B)\right] e^{-rt} dQ - \int_0^{Q_A} \left[P_i Q_i(K_i, E) - C(Q_i, W, E)\right] e^{-rt} dQ \quad (6)$$

If the market prices do not change as a result of the change in E, the above equation reduces to:

$$\Delta W = W(E_B) - W(E_A) = \left[PQ_B(K_i, E_B) - \sum_{i=1}^{n} C_i(Q_i, W, E_B)\right] - \left[PQ_A(K_i, E_A) - \sum_{i=1}^{n} C_i(Q_i, W, E_A)\right]$$

(7)

Substituting $P_L L_i = P_i Q_i^*(K_i, E) - C_i(Q_i^*, W, E)$ from (5), we get;

$$\Delta W = W(E_B) - W(E_A) = \sum_{i=1}^{n} (P_{LB} L_{Bi} - P_{LA} L_{Ai}) \quad (8)$$

Where: P_{LA} and L_{LA} are at E_A and P_{LB} and L_{LB} are at E_B.

Therefore, the present value of the welfare change is given by:

$$\int_0^{Q_B} \Delta W e^{-rt} dt = \sum_{i=1}^{n} (P_{LB} L_{Bi} - P_{LA} L_{Ai})\, e^{-rt} \quad (9)$$

Other researchers have estimated the value of land used to for production depending on the availability of data (see for example Ajetomobi and Ajiboye, 2012), but this study did not estimate the value of land. Therefore, we used equation nine (9) also used by Deressa (2006) in Ethiopia, Molua and Lambi (2006) in Cameron, and Mano and Nhemachena (2006) in Zimbabwe.

3.2. The empirical model

To assess the economic impacts of climatic changes, we used the econometric approach based on the Ricardian method, which is also based on the theoretical framework described above. As noted in above this study measured the impacts of climate change basing on net farm income, therefore, the dependent variable is the net farm revenue. Following the previous work Deressa (2007), Molua and Lambi (2006) and Mano and Nhemachena (2006), the standard Ricardian model relies on the quadratic formulation of climate variables:

$$NR / ha = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Soil + \beta_4 S + \varepsilon \quad (10)$$

Where: NR / ha is the net revenue per hectare, F is a vector of climate variable, $Soil$ is a vector of soil variable in the three climatic scenarios, S is a vector of socio-economic characteristics of a farmer, and ε is the error term. Both linear and quadratic terms for temperature and precipitation are introduced. The expected marginal impact of a single climate variable on the net farm revenue evaluated at the mean is:

$$E\left[dNR / ha / df_i\right] = b_{1,i} + 2 * b_{2,i} * E[f] \quad (11)$$

3.3. Type of data and empirical analysis

The study used data on maize and beans production costs and prices of the output to calculate net farm revenue, temperature and rainfall data, soil type and farming household characteristics data. The farm level production and farming household characteristics data were collected through household survey which was conducted between 17th and 27th September, 2012 from nine (9) villages categorized into three climatic scenarios. From each village averages of 35 small scale farming households were randomly selected. The villages were purposively selected to represent the three climatic scenarios and the areas which produce the two crops in large quantity. On the other hand farming households were randomly selected from the villages. Data on temperature and rainfall were collected from Tanzania Metrological Agency (TMA) for a span of 51 years and that of soil type were collected from Mlingano Soil Research Institute.

Data analysis preceded by fitting Ordinary least square (OLS) regression model using STATA 10.0 software. To overcome the problems of heteroscedasticity and multicolinearity, a robust estimation of the standard error was undertaken and identified correlated variables were dropped from the model. The marginal impacts of seasonal climate variables were estimated for each of the models.

4. Results and discussion

4.1. Descriptive statistics

The summary statistics of the dataset for the relevant variables of the study presented in table 1indicates that the net farm revenue for dry land and irrigated maize and bean farms in the three areas categorized basing on climatic difference are relatively different. The paper also considered two climate parameters namely rainfall and temperature, and the long rain season which is between February and June. Results in table 1 clearly shows that rainfall and temperature vary across the three areas considered in this study, upper parts of the basin are relatively cooler than middle and lower parts in all the months. Meanwhile, precipitation is relatively higher in the upper parts than middle and lower parts of the basin.

The study also considered the soil type in each area of the basin as it plays a great role in determining the level of net revenue accrued from farms. Soil types were also considered because they are a function of geographical location. Descriptive results indicates that the upper parts of basin area dominated by Lepto crystalline volcanic (LCVC), Lepto volcanic (LV), Feralistic lepto volcanic (FLV), and Brown reddish lepto soil (BRL) soils, while the middle parts are dominated by Brown reddish lepto (BRL), Brown reddish (BR), and Brown reddish crystalline (BRC) soils, and the lower parts by Brown reddish soil (BR) and Lepto sand crystalline (LSC) soils. Equally important, the study considered the size of farms operated by farmers as one of the important determinant of net revenue accrued to farmers in the three areas. Results in table 1 indicate that the average total area devoted to maize and bean production are small ranging from half an acre to three acres, with the upper and middle having the smallest sizes as compared to lower areas of the basin. This suggests that maize and bean production in the area is predominantly small scale especially in the upper and middle part of the basin. Maize and beans are rotated on the same piece of land. The sizes and the farming system used by the upper and middle farmers could be attributed to the fact that in the upper parts land is limited (Mbonile, 2001); therefore, farmers are forced to maximize production on the same piece of land.

Table 1: Descriptive Statistics: Variables for Net Revenue Regression Model

	All climatic scenarios		**Upper**		**Middle**		**Lower**	
Variable	**Mean**	**Std. Dev**	**Mean**	**Std. Dev**	**Mean**	**Std. Dev**	**Mean**	**Std. Dev**
Dry land maize NR/acre	122,268.50	131,237.60	136,050.50	116,465.30	121,795.40	147,557.70	110,815.00	125,288.60
Dry beans NR/acre	6,3742.62	71,640.72	97,609.89	112,792.80	51,311.93	40,472.20	47,295.24	29,207.78
Irrigated maize NR/acre	184,443.80	212,387.00	307,910.40	291,134.30	148,876.00	151,458.40	114,362.00	122,721.30
Irrigate beans NR/acre	157,619.00	198,817.10	253,042.60	307,876.30	131,191.00	108,071.20	102,353.40	98,002.27
February rain	43.35	48.90	54.50	50.86	42.34	45.88	34.74	48.80
March rain	96.78	82.33	104.99	86.09	93.10	86.71	93.48	74.23
April rain	271.57	197.89	469.39	207.97	148.04	102.80	228.35	118.08
May rain	247.35	181.27	373.88	145.65	132.58	151.12	256.84	161.47
June rain	69.21	62.23	96.20	57.82	34.12	48.94	82.77	61.89
Squared February rain	4,263.06	9,724.94	5,528.55	10,669.30	3,878.42	8,515.96	3,565.59	10,028.95
Squared March rain	16,122.88	27,253.17	18,351.96	30,556.39	16,117.87	29,048.99	14,196.20	21,878.63
Squared April rain	112,780.40	163,980.60	263,107.20	221,766.50	32,386.89	48,437.16	65,953.29	69,592.31
Squared May rain	93,936.23	120,008.40	160,769.30	123,973.60	40,203.48	88,513.14	91,793.93	117,144.40
Squared June rain	8,593.60	13,789.77	12,283.59	14,617.45	3,537.76	9,437.55	10,644.06	15,345.91
February temperature	25.21	4.85	20.95	4.08	25.78	5.21	28.31	0.46
March Temperature	25.52	4.47	21.12	4.12	26.18	3.93	28.64	0.57
April temperature	24.13	4.69	20.25	3.89	24.23	5.09	27.38	0.61
May temperature	23.03	3.85	19.10	2.18	23.17	3.77	26.28	0.50
June temperature	21.21	4.85	17.55	2.19	21.05	5.64	24.53	2.95
Squared February temperature	659.11	177.55	455.10	104.37	691.84	151.72	801.95	26.13

squared march temperature	671.03	174.72	463.04	106.30	700.84	128.42	820.36	32.14
Squared April temperature	603.98	168.32	424.94	96.95	612.57	151.59	750.25	33.01
Squared May temperature	545.20	152.77	369.58	61.15	551.15	123.12	691.22	26.38
Squared June Temperature	473.10	166.78	312.99	55.04	474.75	154.27	610.16	112.12
LCVC soil	0.14	0.35	0.23	0.42	-	-	0.20	0.40
LV soil	0.12	0.32	0.40	0.49	-	-	-	-
FLV soil	0.11	0.32	0.37	0.49	-	-	-	-
BRL soil	0.23	0.42	0.23	0.42	0.46	0.50	-	-
BR soil	0.12	0.33	-	-	0.34	0.48	-	-
BRC soil	0.23	0.42	-	-	0.20	0.40	0.47	0.50
LSC soil	0.11	0.32	-	-	-	-	0.33	0.47
Household size	5.02	1.93	5.10	1.92	5.19	1.87	4.78	2.00
Education of the household head	6.92	1.97	7.34	2.64	6.43	1.90	6.06	1.02
Farm size	3.04	2.00	0.50	0.41	1.41	1.24	3.42	1.93
Access to credit	0.30	0.46	0.34	0.48	0.28	0.45	0.30	0.46
Frequency of extension contact	1.65	2.32	0.78	1.03	2.48	2.46	1.53	2.68
Livestock keeping	0.67	0.47	0.65	0.48	0.65	0.48	0.70	0.46
Engaging in non-farm jobs	0.20	0.40	0.18	0.38	0.18	0.39	0.25	0.43

The summary of the personal characteristics shows that on average farmers found in the study area have attained primary education. The statistics also shows that farmers located in the upper parts of the basin have lower frequencies of contact with extension officers as compared to farmers in the middle and lower parts. This could be attributed to the fact that farmers in the upper parts are educated and have relatively better climatic conditions which give them assurance of harvesting from their farm land than those in the middle and lower, therefore, did not required extension services.

4.2. Results from the empirical model

This analysis aimed at testing three hypotheses: first, maize and bean farms net revenue per hectare are sensitive to climate. Second, irrigated and dry land maize and bean farms have different response to climate. Third response to climate differs across microclimatic areas that may vary due terrain and distance from seas level. These hypotheses were tested by estimating the following regression equations: (i) the net revenue per acre for all farms in all area, (ii) the net revenue per acre for dry land Maize and Bean farms in all areas, and (iii) the net revenue for irrigated Maize and Bean farms for all areas. The net revenues were regressed on climate and other control variables (tables 2 to 5). A non-linear quadratic model as specified in section 3.2 equation 10 was chosen for easy interpretation as suggested by Ajetomobi and Ajiboye (2012).

Different net revenues calculated per acre were tested. The net revenue that best fitted the model was the one which defines the net revenue as the gross revenue less total variable cost less cost of machinery and less total cost of labour on various maize and beans farming activities. This definition was therefore chosen as basis for analysis results presented in this paper. The climatic variables were chosen after two trials basin during the main rain seasons in the basin i.e. long rains (late February to May or early June) and short rains (October to December). Results of the first trial had best statistical quality and are therefore reported and discussed in this paper.

Table 2: Determinants of Net Farm Revenue per Acre in Dry Land Maize Farms

	All climatic scenarios		**Upper**		**Middle**		**Lower**	
Variable	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**
Constant	217573.8*	2.82	621505*	6.92	297453*	2.15	-1551883***	-2.20
February rain	241.22*	2.19	2036.84*	2.23	995.50***	1.78	37.25*	2.33
March rain	84.31*	2.94	967.18***	1.67	604.28*	3.98	48.94*	2.53
April rain	44.75*	2.30	703.38*	2.08	67.57*	3.55	283.71	1.34
May rain	58.96*	2.19	494.69**	1.67	635.67*	2.40	89.47***	1.89
June rain	70.25*	2.91	1203.06**	1.75	641.11*	3.69	349.32*	2.35
Squared February rain	0.71*	5.17	9.06*	2.11	7.41*	2.46	4.59*	3.04
Squared March rain	0.12*	1.81	2.47**	1.81	2.37***	1.68	0.27*	2.33
Squared April rain	0.01**	1.99	0.64*	2.13	0.07*	3.90	0.56*	2.14
Squared May rain	0.14*	3.70	0.81***	1.60	0.78**	2.02	0.06*	3.75
Squared June rain	0.71*	7.60	5.21*	3.66	1.03**	1.85	2.62***	1.85
February temperature	-5313.42*	-4.67	-1098881.00*	-3.06	-2908.95**	-2.06	-140386.70*	-2.93
March Temperature	-23761.66**	-1.99	-243369.70*	-5.76	-259828.40**	-1.74	-421017.10*	-9.71
April temperature	-26996.06*	-2.38	-785727.20*	-8.73	-21667.00*	-9.98	-115071.20*	-3.29
May temperature	-15319.83***	-1.93	-53541.25*	-6.52	-260674.90**	-2.51	-93794.14**	-1.95
June temperature	-31378.53*	-4.51	-131515.70*	-2.17	-18932.61***	-1.75	-69902.28***	-1.67
Squared February temperature	-222.61***	-2.02	-28103.17*	-3.31	-7.76*	-3.49	-930.88***	-1.74
Squared march temperature	-448.82*	-4.14	-5730.15*	-2.45	-5324.89*	-6.31	-6875.13***	-1.68
Squared April temperature	-671.22*	-1.81	-19311.17***	-1.68	-531.55*	-3.44	-2030.08*	-3.65
Squared May temperature	-302.41*	-3.24	-2213.75*	-3.59	-5553.90***	-1.63	-2299.30*	-4.05
Squared June Temperature	852.83*	3.89	-116.01*	-2.04	-406.43*	-3.35	-1795.18***	-1.69
LPCV soil	-41140.86***	-1.84	2190.91	0.05	-	-	-	-
LPV soil	35943.11*	2.79	-42053.23	-0.99	-	-	-	-
FLPV soil	8772.75	0.19	-	-	-	-	-	-
BRLP soil	6424.24	0.15	-2678.42**	-1.90	-	-	-	-
BR soil	-58104.19*	-2.00	-	-	-100240.30*	-3.27	-	-
BRC soil	-60544.32***	-1.73	-	-	-133754.70*	-2.60	16128.90**	1.67
LPD soil	-43605.65***	-1.68	-	-			17942.64*	2.06

Household size	-725.09	-0.29	-7715.74***	-1.85	855.02	0.13	-12383.06*	-3.59
Education of the household head	-1624.24	-0.67	-4655.20	0.83	-4283.31	-0.70	-6750.262	-1.08
Farm size	4256.94***	1.76	5887.24*	4.99	15302.68*	3.01	3821.66*	4.63
Access to credit	6281.98*	3.92	45483.51**	1.65	20093.80**	1.72	7465.12*	2.09
Frequency of extension contact	4102.54***	1.83	34629.72*	2.26	2553.38***	1.90	6743.26*	2.62
Livestock keeping	5633.89	0.55	-54884.63***	-1.78	-14499.18*	-3.09	18046.50**	1.66
Engaging in non-farm jobs	8018.63*	3.98	-44149.41**	-1.55	-7369.37*	-2.03	6429.49*	5.59
N	300		88		108		103	
F	2.57*		1.64**		2.42*		4.91*	

Table 3: Determinants of Net Farm Revenue per acre in Dry Land Beans Farms

	All climatic scenarios		Upper		Middle		Lower	
Variable	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**
Constant	35157.09*	5.38	455031.8*	6.90	151665.70*	3.30	3226301*	-4.55
February rain	-140.36*	-2.38	1121.81*	3.17	543.71*	2.92	148.42*	2.70
March rain	13.07***	1.64	583.25*	3.28	121.23**	1.79	179.27*	2.82
April rain	47.89*	3.86	169.95*	4.31	278.32*	2.33	13.10***	1.85
May rain	38.96*	5.27	456.24*	3.45	128.52*	3.37	144.93***	1.94
June rain	36.84*	7.18	680.14*	5.14	961.16*	3.73	231.22*	3.53
Squared February rain	0.38*	9.87	7.57*	2.14	1.55***	1.71	0.26*	2.24
Squared March rain	0.04*	3.39	0.83*	2.83	0.50*	3.00	0.49*	2.73
Squared April rain	0.05**	1.87	0.13*	9.65	0.48**	1.97	0.02**	1.96
Squared May rain	0.05*	2.08	0.52*	4.39	0.13*	4.52	0.23*	2.25
Squared June rain	0.12*	6.32	2.22**	1.96	2.58*	2.12	0.88*	3.25
February temperature	-5870.58*	-4.58	-767075.30*	-2.58	-12745.30***	-1.75	-51834.35*	-2.96
March Temperature	-20740.03*	-2.93	-110929.70*	-2.29	-7570.45*	-2.46	-95221.45***	-1.81
April temperature	-2779.12*	-4.75	-811561.00*	-2.35	-34475.60*	-4.67	-81008.75***	-1.82
May temperature	13617.24*	2.64	-100781.50*	-2.56	-30888.12*	-3.13	-178543.2*	-5.62
June temperature	-440.79*	-2.26	-90247.82*	-3.20	-12649.27*	-2.75	-4984.04*	-2.16
Squared February temperature	-266.98*	-2.83	18955.86*	-2.70	-554.49**	-2.03	-802.69*	-5.39
squared March temperature	-498.96*	-2.15	-3757.43*	-3.12	-632.79**	-2.26	-1537.69*	-2.60
Squared April temperature	-97.10*	-5.50	-20086.18*	-7.15	-1405.02*	-4.94	-1464.80*	-2.32
Squared May temperature	-165.30**	-2.20	-3856.22*	-5.33	-1010.99*	-4.31	-3739.81*	-6.28
Squared June Temperature	-32.21**	-2.33	-3955.05*	-3.27	-539.95*	-3.11	-110.33*	-2.18
LPCV soil	10663.00*	3.39	29144.80	0.76	-	-	-	-
LPV soil	-5436.54*	-3.85	-66081.23***	1.89	-	-	-	-
FLPV soil	9989.05*	4.78		-	-	-	-	-
BRLP soil	15091.59	0.75	-99857.39*	-3.24	-	-	-	-
BR soil	28795.20*	2.31	-	-	25737.84*	2.52	-	-
BRC soil	8149.79*	5.23	-	-	-8120.053	-0.47	-12530.09*	-2.36

LPD soil	3886.02***	1.93	-	-	-	-	-15665.44***	-1.77
Household size	469.63	0.40	-12628.75*	-2.13	912.36	0.42	2140.85	1.31
Education of the household head	463.86	0.40	-2369.82	-0.51	-6552.71	-3.22	10448.36*	3.54
Farm size	1155.15**	604.69	14253.52*	2.28	1087.35	2.22	436.18*	2.56
Access to credit	260.50*	2.05	29902.58*	3.65	11923.65*	2.61	11196.71*	4.72
Frequency of extension contact	2025.86**	1.90	7795.70*	4.73	6587.65*	3.70	1216.57*	2.89
Livestock keeping	-13440.17*	-2.78	-8645.38*	-5.55	-16068.28**	-1.95	16770.96*	2.10
Engaging in non-farm jobs	-8.42*	-2.57	-36154.40*	-9.87	-2315.08*	-2.49	963.56*	5.42
N	300		88		108		103.00	
F	3.12*		2.25*		2.96*		4.91*	

Table 4: Determinants of Net Farm Revenue per acre in Irrigated Maize Farms

	All climatic scenarios		**Upper**		**Middle**		**Lower**	
Variable	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**
Constant	111436.7*	9.19	-4515218*	-4.83	651583.00*	3.60	-68562*	-5.65
February rain	25.97*	2.29	77.39*	4.21	513.26*	3.91	453.00*	4.46
March rain	603.11***	1.74	2386.27*	3.93	350.52*	2.66	78.16*	3.63
April rain	52.66***	1.65	218.61*	3.96	94.31*	7.86	192.06*	3.80
May rain	71.82*	2.95	897.54**	2.01	370.68*	3.18	85.87*	2.90
June rain	424.64*	2.17	800.31*	3.47	692.38*	6.16	187.90*	2.99
Squared February rain	1.54*	2.22	0.89*	4.41	3.93*	2.02	1.21**	1.78
Squared March rain	2.04**	1.96	5.55*	3.38	1.36***	1.61	0.51*	3.06
Squared April rain	0.16***	1.99	0.12**	1.76	0.06*	3.99	0.58*	2.19
Squared May rain	0.01*	2.38	0.70*	3.04	0.49*	4.47	0.03*	2.11
Squared June rain	2.31*	2.52	-2.54*	-4.23	0.98*	2.55	0.71**	1.74
February temperature	-9126.94*	-4.27	-429567.40*	-2.42	-45042.47*	-2.41	-781740.30**	-1.71
March Temperature	-40256.51*	-5.37	-2901488.00*	-5.09	-387540.60*	-2.62	-119579.20***	-1.94
April temperature	-12097.58*	-4.11	-3428538.00*	-4.94	-23573.56*	-2.60	-479206.70*	-7.85
May temperature	-48614.78*	-2.42	-158719.00*	-2.00	-415760.40*	-6.21	-325914.00*	-3.99
June temperature	-33478.42*	-2.61	984469.90*	2.60	-34269.82***	-1.90	-38016.68*	-2.98
Squared February temperature	-365.10*	-2.34	-8924.00*	-3.05	-1590.96*	-2.36	-12984.77**	-1.77
Squared march temperature	-293.38*	-2.91	-62703.82*	-4.84	-8764.23***	-1.74	-3228.32*	-3.91
Squared April temperature	-257.01*	-3.74	-76187.72*	-4.68	-268.26*	-2.26	-7916.13*	-3.56
Squared May temperature	-840.93***	-1.75	-1298.39***	-1.88	-9676.45***	-1.68	-6285.20*	-2.33
Squared June Temperature	-711.23***	-1.76	-31039.42*	-2.97	-755.51*	-4.14	-778.03*	-5.40
LPCV soil	37211.80*	3.35	204821.10*	4.22	-	-	-	-
LPV soil	144234.00**	2.01	-411448.10*	-9.26	-	-	-	-
FLPV soil	559550.00*	6.51	-	-	-	-	-	-
BRLP soil	114931.50	1.47	-400001.60*	-10.20	-	-	-	-
BR soil	206303.60*	2.87	-	-	52635.11**	2.61	-	-

BRC soil	203163.00*	3.15	-	-	8800.731	0.13	172429.30*	4.77
LPD soil	141501.20*	2.14	-	-			110765.10*	3.22
Household size	9253.68**	2.02	44057.30*	5.84	-2848.16	-0.33	5389.45*	0.85
Education of the household head	-6478.73	-1.45	-22797.87*	-3.85	-26964.85*	-3.36	3172.494	0.15
Farm size	1462.77*	3.23	36040.27*	3.07	10278.34*	2.82	5624.88*	3.79
Access to credit	149.68*	-2.82	74295.32*	2.39	20343.37*	4.36	11520.57**	1.74
Frequency of extension contact	2198.75*	2.11	123013.30*	7.65	9366.84*	3.13	958.14*	2.17
Livestock keeping	-18938.14**	-1.96	-5911.13**	-1.88	-48708.27*	-3.95	2139.27***	-1.98
Engaging in non-farm jobs	-41006.03***	-1.85	-123669.30*	-3.07	-24126.89***	-2.11	25590.84*	-3.13
N	300		88		108		103.00	
F	10.43*		15.63*		1.8*		2.10*	

Table 5: Determinants of Net Farm Revenue per acre in Irrigated Land Beans Farms

	All climatic scenarios		Upper		Middle		Lower	
Variable	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**
Constant	-78148.65*	-5.59	-4939133*	-3.43	213170.20***	1.73	5841799*	8.89
February rain	283.96*	2.57	1310.15*	2.76	639.37*	2.15	556.13*	3.18
March rain	466.92***	1.84	3196.35*	3.42	477.94*	2.06	12.67**	1.77
April rain	38.83*	3.07	1138.37*	2.08	217.94***	1.82	106.76*	2.79
May rain	73.40*	2.11	261.83*	2.96	435.15***	1.85	82.55*	2.88
June rain	95.41*	2.63	954.49*	2.21	124.13***	1.81	154.16*	2.68
Squared February rain	1.63***	1.85	4.29*	2.23	3.21**	1.91	3.45***	1.92
Squared March rain	1.35***	1.78	8.77*	3.47	1.14***	1.75	0.10**	1.79
Squared April rain	0.13***	1.84	0.93***	1.90	0.83***	1.81	0.05***	1.96
Squared May rain	0.07*	4.09	0.36*	3.03	0.69*	2.01	0.16**	1.73
Squared June rain	0.27*	2.62	2.32*	2.04	2.73*	2.18	0.87*	3.35
February temperature	-10129.21***	-1.99	-609958.10*	-2.17	-1088.49***	-1.77	-869518.01*	-2.41
March Temperature	-23453.64***	-1.94	-4696930.45*	-5.35	-13259.97**	-1.97	-244980.80**	-1.65
April temperature	-18960.95***	-1.83	-5368639.00*	-5.03	-1024.68***	-1.83	-74512.36*	-2.99
May temperature	-37538.27***	-1.85	-417946.00*	-3.69	-9763.27*	-6.21	-176492.20**	-1.69
June temperature	-2797.96***	-1.86	-370137.50*	-2.02	-8736.35*	-3.82	-2137.65***	-1.60
Squared February temperature	-342.34*	-6.45	-10756.90*	-2.88	-490.77*	-2.12	-15726.57*	-2.39
squared march temperature	-64.73*	-2.30	-107820.40*	-5.40	-508.51*	-2.29	-5256.94*	-2.82
Squared April temperature	-975.79***	-1.74	-122279.90*	-4.88	-229.38***	-1.75	-417.92*	-2.43
Squared May temperature	-628.72***	-1.86	-13361.09*	-2.16	-218.71***	-1.87	-4093.78*	-2.48
Squared June Temperature	-277.26*	-2.91	-11715.65***	-1.93	-280.56***	-1.71	-229.90*	-2.04
LPCV soil	113230.10*	3.03	37150.26	0.50	-	-	-	-
LPV soil	211207.10*	4.03	-232501.20*	-3.40	-	-	-	-
FLPV soil	414435.20*	6.60	-		-	-	-	-
BRLP soil	227480.70*	3.97	-333121.10*	-5.52	-	-	-	-

BR soil	311702.30*	5.93	-		83644.64*	3.06	-	-
BRC soil	267230.70*	5.67	-		84362.04***	1.84	154853.10*	5.42
LPD soil	224483.20*	4.64	-		-	-	128354.50*	4.72
Household size	1008.11	0.30	64142.97*	5.53	-2695.93	-0.46	-1335.16***	-1.87
Education of the household head	-1426.73**	-1.62	3158.54	0.35	-3699.46	-6.72	14413.37**	1.79
Farm size	3014.56*	3.56	61638.21*	3.41	7860.88***	1.74	1321.15*	2.16
Access to credit	17106.85*	3.97	210010.00*	4.40	23022.18*	7.94	14618.31*	2.61
Frequency of extension contact	1154.29*	2.19	27132.70*	5.73	2461.78*	3.26	489.94***	-1.67
Livestock keeping	3244.07*	3.40	-115453.40*	-2.31	-16140.33***	1.79	976.26*	4.11
Engaging in non-farm jobs	-25335.91***	-1.56	-14232.64*	-2.06	-16140.33	-0.57	21242.85*	7.06
N	300		88		108		103.00	
F	6*		7*		2.86*		2.51*	

The overall results from the robust regression models in tables 2 to 5, shows that the net revenues per acre were significant at the 1% and 5% levels of significance. The net revenues from dry land Maize and bean farms were significantly influenced by climatic variables. Also the results clearly show that the net revenues are highly influenced by climatic variables in the lower areas of basin than the upper and middle areas. The hypothesis that the second order temperature coefficient would be negative when temperatures are becoming higher was supported by our results from all farms model and in all areas of the basin. The results indicate that temperature is less harmful in the irrigated farms than dry land farms. These results suggest that the effect of climate change varies not only across the globe but also across micro-climatic differences, which is in line with the findings by Eid *et al*, (2006). The differences seen in the significance of the relations between net revenues and the climatic variables (i.e. rainfall and temperature) across the categorized areas (i.e. upper, middle and lower) is strong evidence supporting this assertion.

In respect of relevance of soil types, the coefficients for the dominant soils in each area significantly affected the net revenue in all farms. Area allocated for Maize and Bean production was significant in all areas suggesting that soil type and area allocated are crucial in determining the net revenue. Even though these finding are in line with the finding by Ajetomobi and Ajiboye (2012) and Chang (2002), but in the study area this can be attributed to the nature of the area where the study was conducted. The area is characterized with dense population and much of the area is dry, therefore, people are concentrated in small area with enough rain and water for irrigation. Households with larger areas had high net revenues than those with small areas, the difference observed on the effect on net revenues, which conform to economic fact that the more resources an economic agent has the more he/she can produce (Asseldonk van and Langeveld, 2007).

On the other hand, the household attributes included (i.e. household size, education level of the household head, access to financial services, frequency of contact with extension officers, livestock keeping and engagement in non-farm jobs) shows an interesting relation in the three areas. Coefficients for access to credit and frequency of contact with extension services were positive and significant in the upper and middle areas for all farms, and they were negative and significant in lower parts of the basin. This suggests that financial service providers and extension officers prefer to provide their services in areas where there is low risk of crop failure (also see Maddison *et al*., 2007). While this is the case with financial and extension services, livestock keeping and engagement in non-farm jobs were negative and significant in all farms in the upper and middle areas and positive in lower areas of the basin. These results suggest that livestock keeping and non-farm jobs are not the preferable options to upland and middle farmers, while are the options to lowland farmers. This could be due to the fact that water and climatic conditions are relatively much better in the upper and middle areas as compared to the lower areas (also see Molua, 2007; Mano and Nhemachena, 2006; Mano *et al*., 2003).

5. Impacts of forecasted climate change on Maize and Bean Revenue in the Basin

In this section we simulated the impact of future climate change scenarios on Maize and Bean agriculture in the basin. In these simulations, the only variables subjected to change were the climate variables (rainfall and temperature); all other factors remained the same. Clearly this will not be the same overtime, but to examine the role of climatic variable on the net revenue accrued from Maize and Bean agriculture and to simplify the analysis we assumed that technology, capital, and consumption trends are constant. To examine the consequences of the climate change scenarios in the basin by 2100 as predicted by Panel of Climate Model (PCM), Canadian Climate Centre (CCC) and Intergovernmental Panel on Climate Change (IPCC) climate models, the study used the econometric models estimated in section 4.2 to predict the likely impact on the net revenue per acre for maize and bean farms in all the three areas of the basin. The PCM predicts a 2^0C increase in temperature and 10% decrease in rainfall (Ajetomobi and Ajiboye, 2012; Washington *et al*., 2000). The CCC predicts a 6^0C increase in temperature and 15% decrease in rainfall (Boer *et al.*, 2000). And the IPCC estimates that by 2100 temperature will rise from 3^0C to 6^0C and rainfall decline by 5-7% or rise between 10-15% (IPCC, 2001).

Having attempted several combinations, in this paper we report 3 scenarios: (i) increase in temperature by 2^0C, (ii) decrease in rainfall by 5%, and (iii) increase in temperature by 2^0C and decrease in rainfall by 5% simultaneously. Concomitantly, we examined if moving from rain fed to irrigated agriculture could be a plausible adaptation strategy in the basin. Simulation results in table 6 shows relatively high decrease in net revenue from dry land farms than irrigated farms in all areas in the basin with the lower areas having higher decrease in both cases. In both cases upper areas appear to be relatively better than middle and lower with maize being not affected n irrigate farms found in the upper areas. In these areas, the net revenue from maize appears to increase in irrigated farms despite an increase in temperature and decrease in rainfall. This could be due to the fact that climate change does not always result to adverse outcomes, in some areas it results into good outcomes (IPCC, 2001). These results suggest that climate change will favor maize production in the high altitudes of Pangani Basin. These results clearly confirm that irrigation is an effective and compatible adaptation option to climate change effects.

Table 6: Impact of Changing Temperature and/ or Rainfall on Dry Land Maize and Bean Revenue in Percentages

Dry Land Farms				
Climate scenario	**Type of crop**	**Location in the basin**		
	Maize	**Upper**	**Middle**	**Lower**
↑2^0C temperature		-6.33	-9.82	-12.20
↓5% rainfall		-8.57	-10.10	-13.50
Both		-11.87	-13.84	-15.96
	Beans			
↑2^0C temperature		-4.51	-9.74	-11.13
↓5% rainfall		-6.52	-11.08	-12.51
Both		-7.21	-14.97	-14.97
Irrigated Farms				
↑2^0C temperature	Maize	3.19	0.62	-1.26
↓5% rainfall		1.60	-1.93	-2.74
Both		1.00	-2.02	-3.63
	Beans			
↑2^0C temperature		6.02	-1.56	-2.20

↓5% rainfall		3.32	-2.44	-3.38
Both		1.22	-5.15	-4.78

6. Conclusion and policy implication

The empirical results from this study provide evidence that climate change is significant to crop production in Pangani Basin. The results have shown that the net revenue per acre is sensitive to marginal change in temperature and rainfall climate variables. The degree of sensitivity varies depending on whether the farm is irrigated or not and also on the location in basin. These results therefore, suggest that irrigation is an effective adaptation measure to reduce negative effects of climate change. However, this can only be effective if the catchment ecosystem is well managed to ensure water availability, irrigation infrastructures and water use regulations are in place and effective, small scale farmers have access to technical knowhow and financial services. Equally important, results show that climate change impacts vary across microclimatic areas (i.e. upper, middle, and lower). This suggest that it is crucial to take into account the climatic differences when conducting research, choosing adaptation strategies, advising farmers on adaptation measures. Finally, given the increasing investment on increasing crop production for making Tanzania self-sufficient in food by 2025, deeper analyses of climate change impact on strategic crops should be encouraged nationwide.

Acknowledgement

This paper was funded by CCIAM project. It is part of a larger study on the Economic Assessment of Climate Change Impacts, Vulnerability and Adaptation in Tanzania: Case of Pangani Basin and Pemba coordinated by Sokoine University of Agriculture (SUA), Tanzania. We are also grateful to all key informants and small scale farmers in Pangani Basin who willingly provided information and shared their views, experience, time and insight with us.

References:

Ajetomobi, O.J., and Ajiboye, A. (2012). Impact of climate change on rice agriculture in Nigeria. CEEPA Discussion Paper No. 54.

Asseldonk van M.A.P.M., and Langeveld, J.W.A. (2007). Coping with Climate Change in Agriculture: A Portfolio Analysis. A paper presented at the 101st EAAE seminar "Management of Climate Change Risks in Agriculture", Berlin, Germany, July 5-6, 2007.

Boer, G., Flato, G., and Ramsden, D. (2000). A transient climate change simulation with greenhouse gas and aerosol forcing: Projected climate for the 21st century. *Climate Dynamics*, 16:427-450.

Brooks, S., Thompson, J., Odame, H., Kibaara, B., Nderitu, S., Karin, F. and Millstone, E. (2009). *Environmental Change and Maize Innovation in Kenya: Exploring Pathways In and Out of Maize,* STEPS Working Paper 36, Brighton: STEPS Centre.

Buys, P., Uwe, D., Craig, M., Thao, T. T., and David, W. (2007). *Country Stakes in Climate Change Negotiations: Two Dimensions of Vulnerability*. The World Bank Development Research Group Sustainable Rural and Urban Development Team.

Chang, C. (2002). The potential impact of climate change on Taiwan's agriculture. *Agricultural Economics*, 27:51-64.

De Wit, M., and Stankiewicz, J. (2006). Changes in surface water supply across Africa with predicted climate change. *Journal of Science,* **311**:1917-21.

Deressa, T. (2007). Measuring the Economic Impact of Climate Change on Ethiopian Agriculture: Ricardian Approach. World Bank Policy Research Paper No. 4342. World Bank, Washington DC.

Deressa, T., Hassan, R., and Poonth, D. (2005). Measuring the impact of climate change on South African Agriculture: the case of Sugar Cane Growing Regions. *Agrekon*, 44(4)

Eid, H.M., El-Marsafawy, S.M., and Oudai, A.S. (2006). Assessing the economic impacts of climate change on agriculture in Egypt: a Ricardian approach. Agriculture and Biological Sciences, 2(6): 316-322.

Haug, R., and Hella, J.P. (2013). The art of balancing food security: securing availability and affordability of food in Tanzania. *Food Sec. Vol*. 5:415-426

Helms, P., and Strauss, J. (2009). *Tanzania Value Chain Analysis.* http://www.iucn.org/themes/wani/pub/SituationPangani.pdf.

Intergovernmental Panel on Climate Change (IPCC) (2001). The report of working group 1 of the IPCC survey for policymakers. Available at: http://www.ipcc.ch/

Intergovernmental Panel on Climate Change (IPCC) (2007). Synthesis report. Summary for policymakers. Available at: http://www.ipcc-wgl-ucar.edu/wgl/wgl-report.htm.

International Institute for Sustainable Development (IISD). (2007). *Community based adaptation to climate change Bulletin*. A Summary of the Second International Workshop on Community-Based Adaptation to Climate Change. IISD Reporting Services.

IUCN Eastern Africa Programme. (2003). *Pangani basin: A situation analysis.* Nairobi, Kenya: IUCN. The World Conservation Union. Available online at

Kandlinkar, M., and Risbey, J. (2000). Agricultural impacts of climate change: If adaptation is the answer, what is the question? *Journal of Climatic Change,* **45**: 529-39.

Kurukulasuriya, P., and Mendelsohn, R. (2007). Endogenous irrigation: The impact of climate change on farmers in Africa. World Policy Research Working Paper 4278.

Kurukulasuriya, P., and Mendelsohn, R. (2008). *A Ricardian analysis of the impact of climate change on African crop land.* CEEPA Discussion Paper 8.

Maddison, D. (2006). *The perception of and adaptation to climate change in Africa*. CEEPA. Discussion Paper No. 10. Centre for Environmental Economics and Policy in Africa. Pretoria, University of Pretoria, South Africa.

Maddison, D., Manley, M., and Kurukulasuriya, P. (2007). The impact of climate change on Africa agriculture. A Ricardian approach. World Bank Policy research paper 4306.

Mano, R., and Nhemachena, C. (2006). *Assessment of the economic impacts of climate change on agriculture in Zimbabwe: A Ricardian approach*. CEEPA Discussion Paper No. 11. Centre for Environmental Economics and Policy in Africa, University of Pretoria.

Mano, R., Isaacson, B. and Dardel, P. (2003). *Identifying policy determinants of food security response and recovery in the SADC region: The case of the 2002 food emergency*. FANRPAN Policy Paper, FANRPAN.

Mbonile, M. J. (2001). Rural population mobility in the Pangani basin, Tanzania. In J.O. Ngana (Ed.), *Water resources management in the Pangani basin: Challenges and opportunities*. Dar es Salaam, Tanzania: University of Dar es Salaam Press.

Mendelsohn, R. (2007). Measuring climate impacts with cross sectional analysis. *Climate Change*, 18:1-7.

Molua, E.L., and Lambi, C.M. (2007). The economic impact of climate change on agriculture in Cameroon. The World Bank Policy Research Working Paper 4364.

Nhemachena C., and Hassan, R. (2007). *Micro-Level Analysis of Farmers' Adaptation to Climate Change in Southern Africa*. IFPRI Discussion Paper No. 00714. International Food Policy Research Institute. Washington DC.

Pangani Basin Water Office (PBWO). (1997). *Pangani Basin Authority annual report.* Tanga, PBWO. Tanzania.

Sarr, B. (2012). Present and future climate change in the semi-arid region of West Africa: a crucial input for practical adaptation in agriculture. *Atmos. Sci. Lett.* vol. 13:108-112.

Shemsanga, C. (2010). The Cost of Climate Change in Tanzania: Impacts and Adaptations. *Journal of American Science*, **6**(3): 182-196.

Thontorn, N. (2011). *Climate Change Financing and Aid Effectiveness*. Tanzania Case Study. [http://www.oecd.org/htm/M0053.htm] site visited 13/9/2012.

Vrieling, A., de Leeuw, J., and Said, M. Y. (2013). Length of Growing Period over Africa: Variability and Trends from 30 Years of NDVI Time Series. *Remote Sens vol.* 5:982-1000.

Washington, W.M., Weatherly, J.W., Meehl, G.A., Semtner Jr, A.J., Bettge, T.W., Craig, A.P., Strand Jr, W.G., Arblaster, J., Wayland, V.B., James, R., and Zhang, Y. (2000). Parallel Climate Model (PCM): Control and transient scenarios. *Climate Dynamics*, 16:755-774.

World Bank (2011). World development indicators. Washington DC: World Bank. http://ddp-ext.worldbank.org/ext/DDPQQ, accessed: September 2013.