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Effects Of Rainfall On Arable Land-Use And Recommendations For Adaptation

Francis Ndamani and Tsunemi Watanabe (PhD)

Kochi University of Technology, Graduate School of Engineering, Japan 185-1 Miyanokuchi, Tosayamada, Kami City, Kochi 782-0003, Japan.

Corresponding Author email: fndamani@gmail.com

ABSTRACT: Though crop production remains the principal source of food and household income in the Upper West Region (UWR) of Ghana, the relationship between rainfall variability and arable land-use appears not to have been investigated. Cultivation of crops is solely dependent on highly sporadic seasonal rainfall. The occurrence of dry spells, droughts and floods in recent times poses adverse effects to arable land-use decisions of crop farmers. The aim of this study is to determine the relationship between annual/seasonal rainfall variability and cropping area dynamics and explore adaptation strategies required to mitigate the effects of rainfall uncertainty on arable land-use. The municipality was chosen because it is ecologically representative of the entire region. Available rainfall statistics and arable land-use data from 1992 to 2012 were obtained from the Wa weather station of the Ghana Meteorological Agency and the Regional Directorate of the Ministry of Food and Agriculture respectively. Correlation analysis was used to determine the relationship between rainfall variability and arable land-use. By using a calculated precipitation median value of 957 mm, the results reveal a highly erratic seasonal and annual rainfall pattern; two years of within median, eleven years of below median and seven years of above median precipitation. The calculated coefficients of variation (i.e. 0.4 - 0.5) of arable land-use reveal high variability in the total area of land put under cultivation of each crop annually. Seasonal rainfall variability was found to be negatively correlated to maize and cowpea, and positively correlated to sorghum, millet and groundnut. These results suggest that arable land-use for maize and cowpea has been negatively affected by seasonal rainfall fluctuations. This study points to the need for agricultural stakeholders to identify/develop and promote/implement appropriate arable land-use strategies in order to mitigate the potential effects of rainfall uncertainties.

Key words: rainfall variability, arable land-use, agriculture seasons, adaptation strategies, soil moisture, stakeholders.

INTRODUCTION

Previous assessments have noted that increasing intensity of drought and floods observed throughout Sub-Saharan Africa in recent years due to climate change will continue to have a negative impact on agriculture across the continent (Easterling et al., 2007). The Intergovernmental Panel on Climate Change (IPCC) (2007) has also projected that rain-fed agricultural production in Africa will decline by up to 50% by 2020. Predicted impacts of climate change relative to current production levels range from −100% to +168% in econometric, from −84% to +62 % in process-based, and from −57% to +30% in statistical assessments (Muller, et. al., 2011). Considering that rain-fed agriculture is a principal method of food production in most parts of rural Sub-Saharan Africa (Cooper et al., 2008), climate change and rainfall variability pose severe threats to crop production and food security.

According to projections by climate change models for Northern Ghana, which includes the Upper West Region, the shift in the onset of the rainy season will continue further in the coming years. These projections indicate that between 2030 and 2039 the rainy season might only start in June or even later in Northern Ghana (Jung and Kunstmann 2007). It is also predicted that the standard deviation for the onset of the rainy season will increase (Laux et al., 2008: 130), which means that not only will it shift but also it will become even more ‘erratic’ (Laube et al., 2012). A similar study conducted in the Upper West Region (UWR) has observed that rainfall in June is highly irregular (Ndamani and Watanabe, 2013).

Majority of people in Upper West Region of Ghana live in rural areas and depend on agricultural activities for their livelihoods. The farming system is based on rain-fed cultivation of crops such as maize, rice, sorghum, millet, groundnut and vegetables (Dietz et al., 2004). The mono-modal rainfall pattern of the region coupled with the exclusive dependence on rain-fed agriculture makes crop production vulnerable to rainfall variability.

Rainfall patterns significantly influence the amount of land cultivated and the type of crops planted by farmers (Veldkamp & Lambin, 2005). Understanding the magnitude and scope of such influence could go a long way in informing adaptation practices adopted by local farmers (Kori et al., 2012). Adaptation by farmers could significantly reduce the negative effects of rainfall variability brought by climate change (Parry et. al., 2009). As such, a comprehensive knowledge of the patterns, distribution, duration and variability of rainfall is essential for year-to-year crop production planning and management. It is also relevant to understand the relationships between arable land-use and rainfall patterns, distribution and variability. This notwithstanding, very few studies have investigated in detail the relationships between rain-fed arable land-use and rainfall characteristics in Ghana.

The aim of this study was to analyze rainfall and arable land-use in the Wa Municipality of Ghana. Specifically, the study has attempted to (i) determine the relationship between annual rainfall variability and cropping area dynamics and (ii) explore adaptation strategies to mitigate the effects of rainfall uncertainty on arable land-use.

MATERIALS AND METHODS

Study area

The study was conducted in the Wa Municipality of Upper West Region (UWR) of Ghana. According to the Ghana Statistical Service (GSS), 2010, UWR is the poorest in the country. The municipality has a landmass of approximately 234.74 square kilometers and exhibits both climatic and agricultural characteristics of the entire region. Wa Municipal lies between latitudes 9°32' N to 10°20' N and longitudes 1°40' W to 2°45' W. It shares borders with Wa West, Wa East, Nadowli and Tuna Kalba Districts of the Northern Region. The geographical location of Wa Municipality on the map of Ghana is represented by the red color in Figure 1.

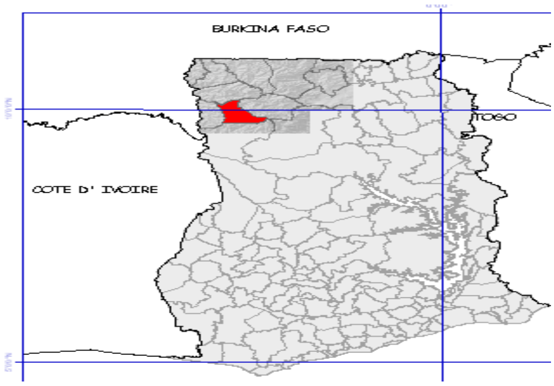

Figure 1. Location of Wa Municipality on the map of Ghana (UNDP Report, 2010).

The GSS 2010 Population and Housing Census puts the total population of the municipality at 107,214 with 71,051 and 36,163 people residing in urban and rural settings respectively. The predominant occupation is agriculture. Crops cultivated include Zea mays, Sorghum bicolor, Echinochloa frumentacea, Oryza sativa, Vigna unguiculata, Arachis hypogaea, Glycine max and Dioscorea rotundata. Livestock and poultry production contribute significantly to household incomes in the municipality.

The vegetation is generally described as Guinea Savanna (Anon. 2002) due its stunted trees, shrubs and short grasses. The most common plant species in the area include dawadawa, (Parkia biglobosa), shea **(**Vetillaria paradoxa), Afzelia Africana. The soils are relatively fertile. According to a UNDP 2010 report, the municipality is basically made up of five different soil series characteristics with varied agricultural potentials: Calcic Vertisols (16.6%), Dystric Leptosols (1.2%), Ferric Lixisols (67%) and Lithic Leptosols (15.2). The greatest influence on the vegetation is the prolonged dry season which last from November to April.

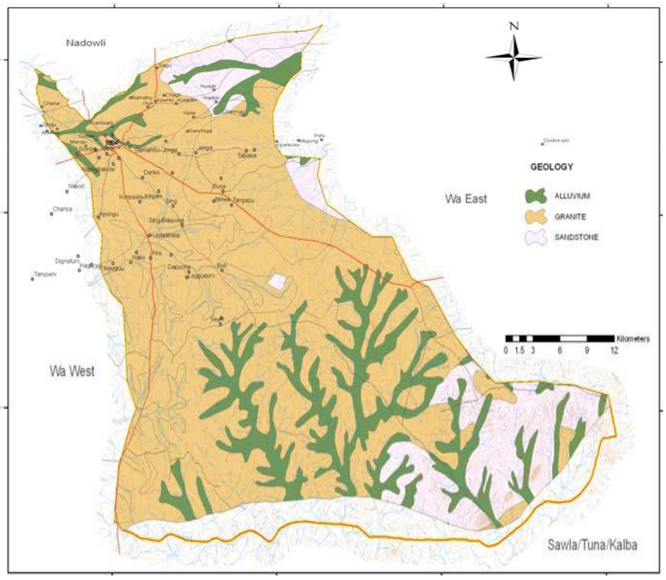

Figure 2. Map of Wa Municipality Geological Distribution (UNDP 2010 report).

The area has only one rainy season every year, from May to October. The mean annual temperature ranges between 27 and 28 °C. The relative humidity is 50–60 per cent and the mean annual rainfall is 1,027 mm. The mean relative humidity of the driest month is less than 30% (UNDP, 2010). In the last 33 years, a twenty year cycle of high and low annual rainfall volumes have been observed in the Lawra district of the region: Annual rainfall totals exceeded 1,200 mm in 1980 and 2000 and fell below 1,000 mm in 1990 and 2010 (Ndamani and Watanabe, 2013).

DATA AND ANALYTICAL METHODS

The study used twenty-one years of rainfall data (1992-2012) obtained from the sole weather station in Wa municipality. Annual data on proportions (i.e. hectares) of land cultivated for each crop was sourced from the Municipal Agricultural Development Unit of the Wa Municipality. Only twenty-one years of data (1992-2012) was available. These two datasets were compared to determine the relationship between rainfall variability and arable land-use. Previous studies have also applied rainfall variability as a predictor to determine similar relations (Ndamani and Watanabe, 2013; Kori et al, 2012; Woldeamlak, 2009; Rugumayo et al, 2003).

Using standard procedure, the mean values and proxy measure of rainfall variability were estimated. Though previous studies have always used Standardized Rainfall Anomaly (SRA), Precipitation Concentration Index (PCI) and Standard Precipitation Index (SPI) as proxy measures, Kori et al (2012) employed absolute precipitation deviation from the normal median value as a descriptor of rainfall variability. This study finds the latter appropriate because it facilitates easier characterization of agricultural seasons as shown in Figure 2. Correlation analysis was used to derive the relationship between rainfall and arable land use. Since only twenty-one years data was obtained for this study, the t-test was used to examine the significance of the observed relationships.

Soil moisture is critical in characterizing agriculture seasons. According to the United States Department of Agriculture (1999), soil moisture regimes are defined based on the levels of the groundwater table and the amounts of soil water available to plants during a given year in a particular region. Soil moisture content is optimal for plant growth, when the water in the large- and intermediate-sized pores can move about in the soil and can easily be used by plants. Soil moisture requirement varies from crop to crop and region to region. Examples are shown in Figures 3 and 10 (i.e. South Africa and Ghana respectively).

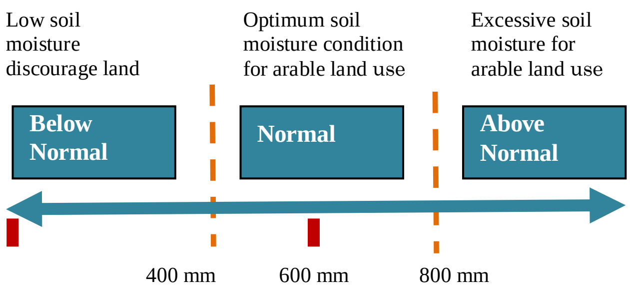

Figure 3. Definition of agricultural seasons of Nzhelele Valley, South Africa (Kori et al, 2012).

RESULTS AND DISCUSSION

Rainfall distribution

Basically, annual rainfall denotes the period between January and December and seasonal rainfall refers to the major rainy season which last from May to October. Understandably, the major crop production season (i.e. land preparation to harvesting) occurs within the seasonal rainfall period. As shown in Table 1, the mean annual and seasonal rainfall determined between 1992 and 2012 were 1,075 mm and 967 mm respectively. A normal rainy season in the Municipality receives between 690 and 1,277 mm of precipitation. The mean value of coefficient of variation (CV) of both annual and seasonal rainfall was 0.14 indicating a moderate variability across the period investigated. 90% of the annual total volume of rainfall occurs within the seasonal period.

Table 1. Statistics of annual and seasonal rainfall of Wa Municipality: 1992-2012

	Mean	Median	Minimum	Maximum	CV
Annual	1,075	1,073	767	1,358	0.14
Seasonal	970	957	690	1,277	0.14

Using a seasonal precipitation median value of 957 mm, the results show a highly sporadic seasonal rainfall pattern throughout the period under review (see Figure 4). The results reveal that precipitation in 1993, 2006 and 2009 fell within the median value. Also, eleven years of below median (i.e. 1992, 1994, 1998, 2001, 2002, 2004, 2005, 2007, 2008, 2010 and 2011) and seven years of above median precipitation was received in the Municipality.

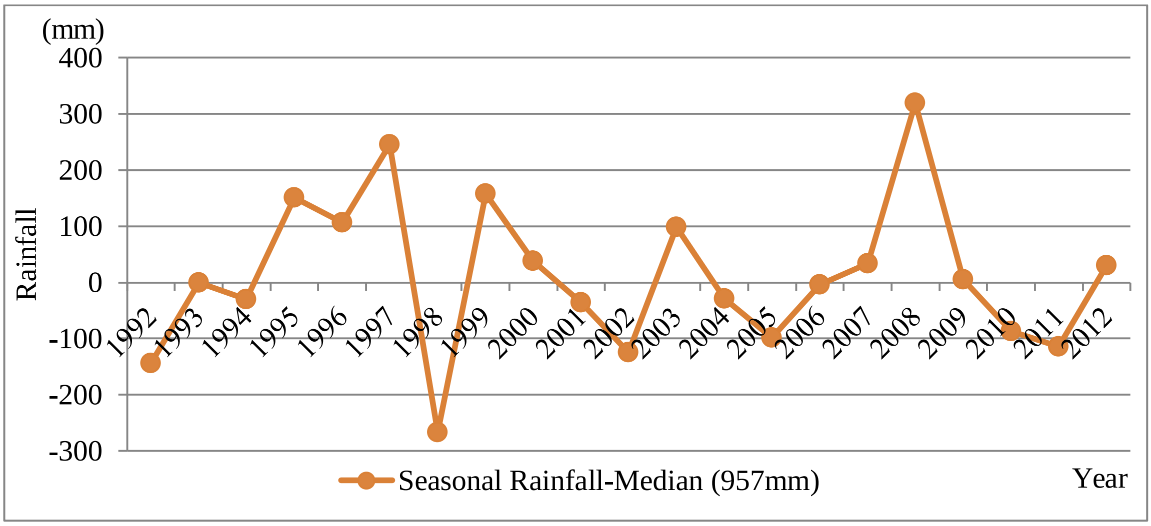

Figure 4. Rainfall variability in Wa Municipality, 1992-2012.

Annual and seasonal trend and pattern of rainfall

Figure 5 reveals that, annually, rainfall volumes fall below 150 mm in July but exceed 200 mm in August and September within the years assessed. As a result, the possibility of occurrence of dry spell and flood in July and August respectively is very high thereby affecting farmers arable land use decisions.

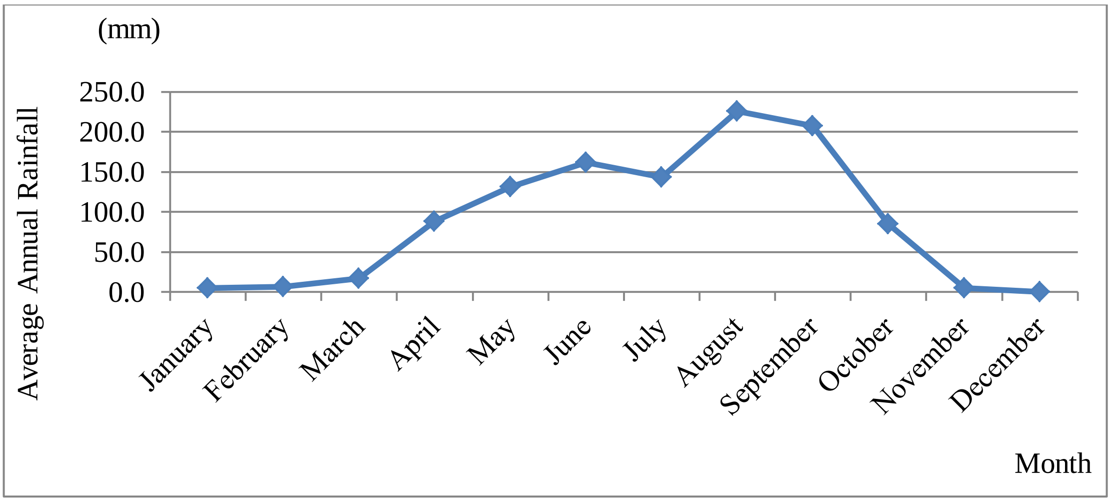

Figure 5. Monthly rainfall trend in Wa Municipality, 1992-2012.

Annual and seasonal rainfall volumes turn to move in the same direction. However, since the off-season period (November to April) also witness some degree of rainfall, the total annual rainfall volumes turn to taper higher than seasonal rainfall volumes. Annual rainfall volumes in 1992, 1998, 2002, 2007 and 2011 fall far below the mean annual rainfall (1,075 mm) of the period studied.

Arable land-use pattern and variability

Sorghum has the largest cropping area with an annual average of 35,188ha. Millet and cowpea are the least cultivated crops with annual average cropped area of 13,596 and 13,082 ha respectively (See Table 2). The calculated coefficients of variation (CV) of cropped area for all five crops investigated ranged from 0.4 to 0.5. These results indicate high annual variability of land put into cultivation of each of the crops.

Table 2. Statistics of arable land-use in Wa Municipality: 1992-2012.

	Hectares (Ha)			
	Mean	Minimum	Maximum	CV
Maize	12,772	5,555	23,000	0.36
Sorghum	35,188	11,611	64,710	0.52
Millet	13,596	2,923	21,300	0.43
Groundnut	28,123	5,345	47,805	0.51
Cowpea	13,082	4,508	30,500	0.50

While sorghum is most widely cropped within 1992 to 2004, groundnut now has the largest cropped area since 2005. Because groundnut is a major cash crop in the study area, it stands to reason that other drivers such as profitability and market demand could be accountable for the situational change since 2005. Since 1995, the arable land put under maize and cowpea cultivation has comparatively been low as shown in Figure 6.

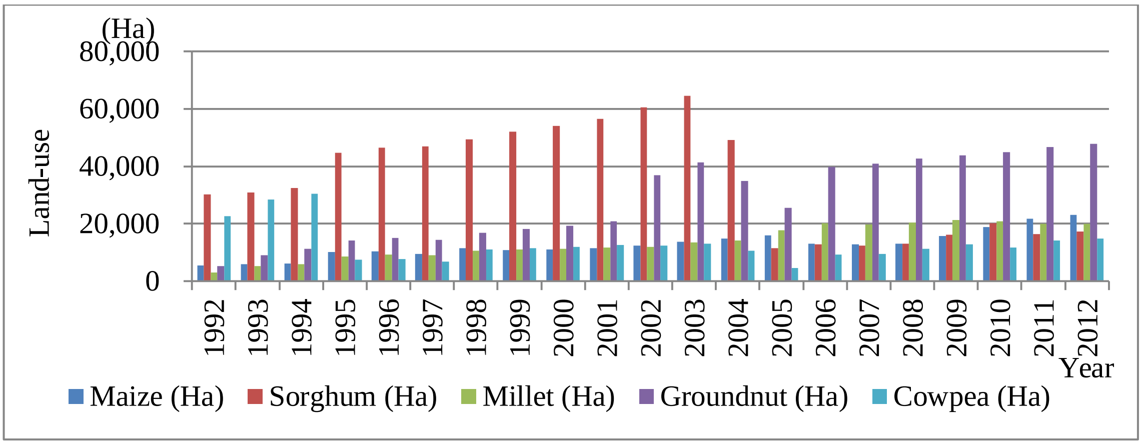

Figure 6. Land-use pattern of crop production in Wa Municipality.

From Figure 7, it can be observed that between 1992 and 2001, the total area of land put under maize, millet and groundnut cultivation fell below the mean annual cropped area (maize=12,772ha; millet=13,596ha and groundnut=28,123ha). The vice-versa can be observed for same crops between 2005 and 2012. In other to boost maize production, the government of Ghana initiated a fertilizer subsidy programme. A pilot phase was carried out between 2006 and 2008. The full scale implementation of the subsidy programme in the study area started in 2009. This fertilizer subsidy programme could therefore be the key factor motivating farmers to increase arable-land for maize production since 2005.

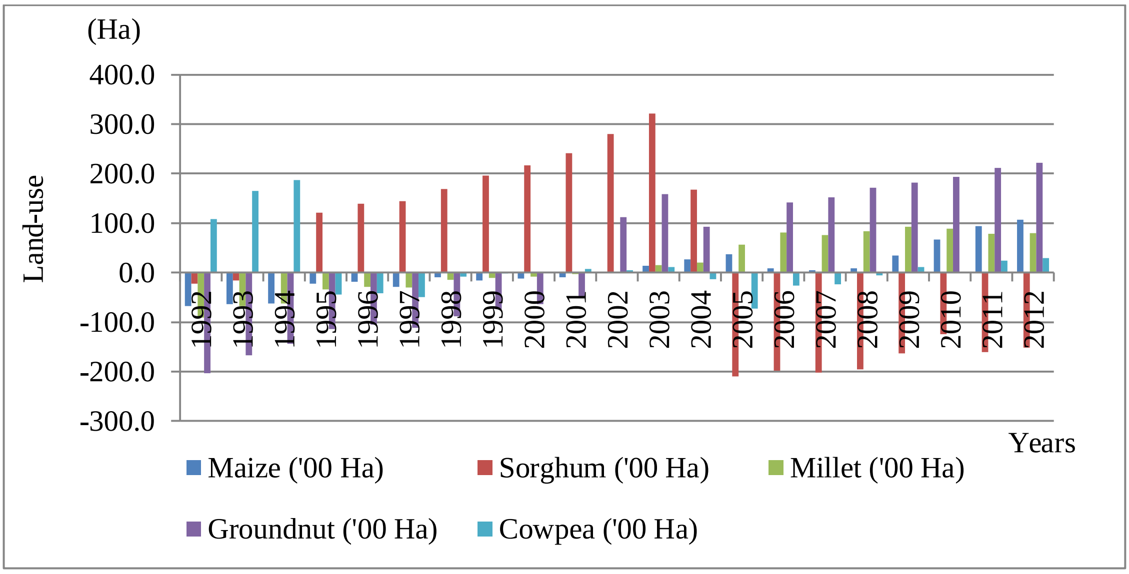

Figure 7. Arable land-use variability.

Because figures for annual volume of crop production were very large, we divided by them 100 to reduce the number of zeros. Thus, '00 Ha is equal to 100 Hectares. For example, from Table 7 above, 300 Ha is equal to 30,000 Hectares.

Relationship between rainfall and arable land-use

The correlation coefficients of arable land-use and the seasonal and annual rainfall volumes are given in Figure 8. The seasonal rainfall duration which is generally same for all crops covers the period from field/land preparation in May/June to the crop maturity/harvesting in October/December. The results of correlation analysis suggest that rainfall variability has led to a decrease in the cropping areas of maize and cowpea on one hand and an increase in sorghum, millet and groundnut on the other. Due to the limited amount of data used, the coefficients were not found to be statistically significant.

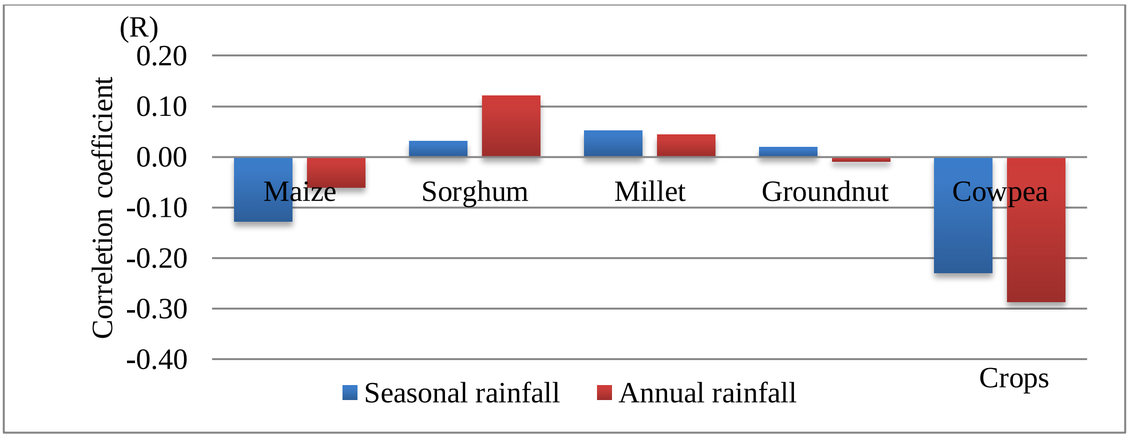

Figure 8. Rainfall and land use relationship in Wa Municipalility: 1992 – 2012.

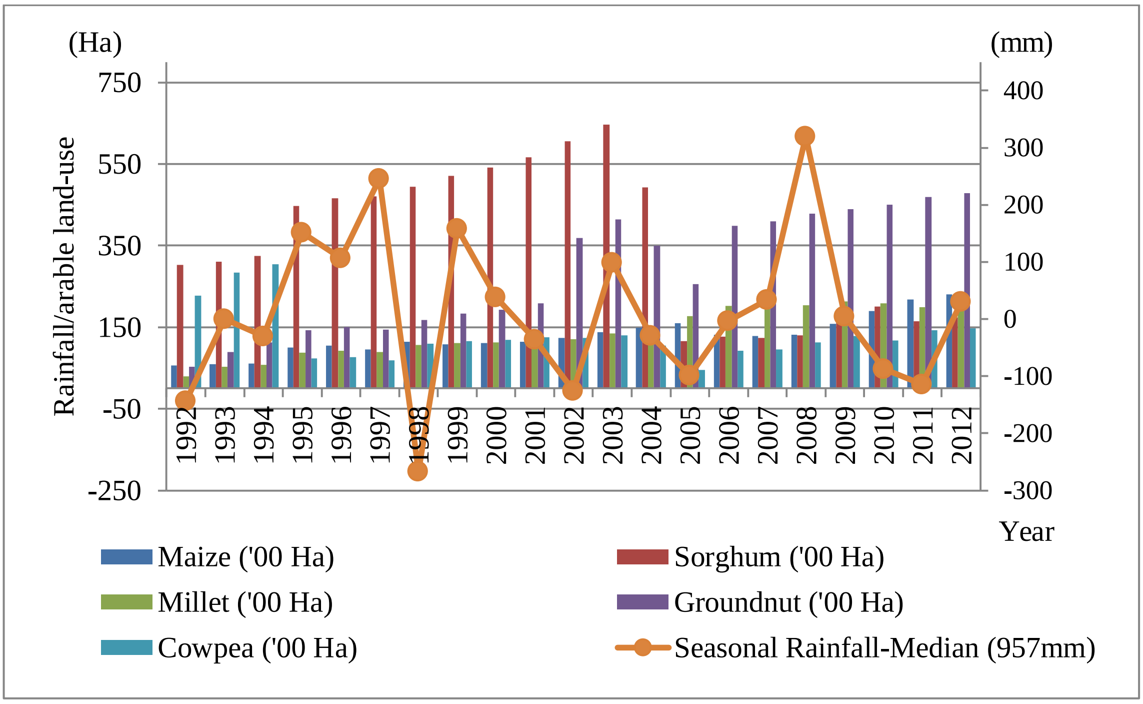

Figure 9. Comparison between rainfall and arable land-use variability; 1992-2012.

Maize (Zea mays)

Maize appears fairly tolerant to dry spells during the vegetative and maturity periods. Ideally, planting should take place within the first two weeks of May or the onset of the big rains. A normal agriculture season for maize cultivation in the Wa Municipality requires precipitation levels of between 500 and 800 mm (FAO). However, it could be observed from Figure 8 that apart from 1992, 1998, 2002 and 2011, all other years received precipitation either far above or below the normal crop water requirement level for maize production. This statistical revelation may well explain why the size of arable land put into maize production has been consistently low over the period studied. However, in other to boost maize production, the government of Ghana initiated fertilizer subsidy programme. A pilot phase was carried out between 2006 and 2008. The full scale implementation of the subsidy programme in the study area was in 2009. This fertilizer subsidy programme could therefore be the key factor motivating farmers increase arable-land for maize production since 2005.

Groundnut (Arachis hypogea) and Cowpea (Vigna unguiculata)

Groundnut and cowpea are generally cultivated as cash crops. Cowpea utilizes soil moisture efficiently and is more drought-tolerant than groundnuts. Unlike groundnuts which require 500 to 700 mm of water, cowpea can grow under rainfall ranging from 400 to 700 mm per annum. Frequency and unreliability of rainfall pose problems to groundnut growth. The most critical moisture requiring period for cowpea is just prior to and during bloom. This happens to coincide with months of June and July where rainfall volumes begin to fall resulting in dry spells. Also, cowpea shows poor tolerance to waterlogging and cold soils (Department of Agriculture, Forestry and Fisheries, South Africa). As seen in Figure 10, the gap between land allotted to groundnut and cowpea production continues to rise since 1994. It must be added that, apart from rainfall anomalies, other drivers such as profitability and market demand could also be accountable for the extensive cultivation of groundnuts.

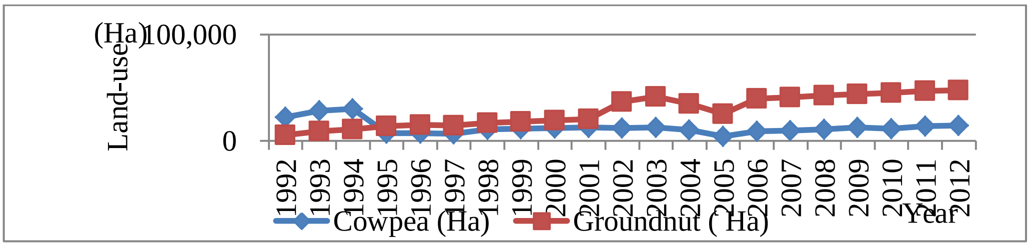

Figure 10. Arable land-use pattern for groundnut cowpea production: 1992-2012.

Sorghum and Millet (Sorghum bicolor and Pennisetum glaucum)

Sorghum and millet are largely used as staple crops in the Wa Municipality. Annually, they constitute the two most extensively cultivated crops. Comparatively, sorghum and millet have lower water requirement than maize, cowpea and groundnut. The relatively high resistance of sorghum and millet to end of season dry spells and droughts gives them a comparative edge over other crops.

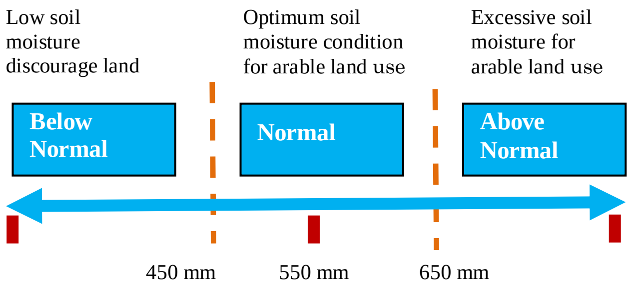

Figure 11. Description of agricultural seasons for sorghum and millet production in Wa Municipality, Ghana.

Suggestions on arable-land-use adaptation strategies under rainfall uncertainty.

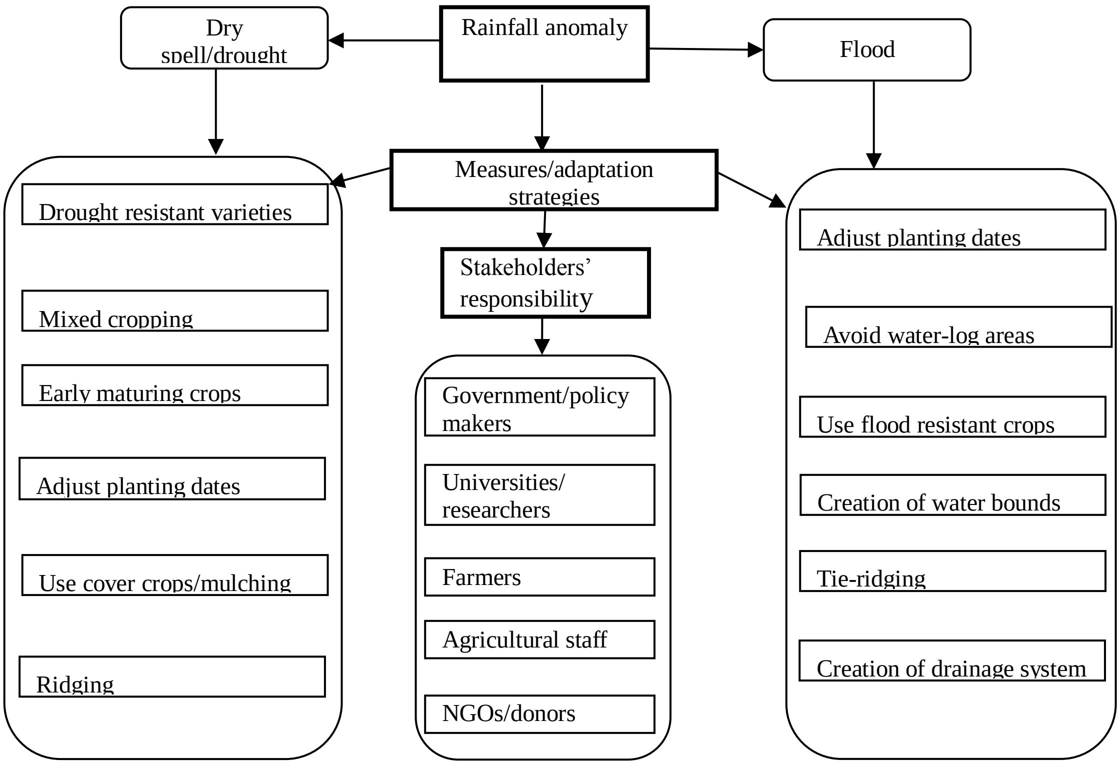

Figure 12. Rainfall anomalies, adaptation measures to land-use and stakeholder responsibility

In drier regions such as Wa Municipality, the annual rainfall pattern is highly erratic as shown in Figure 4. This pattern poses danger of dry spell, drought and floods. To ensure efficient use of arable land for improved crop production under these rainfall anomalies, agricultural stakeholders should develop/identify and implement reliable, resilient and sustainable adaptation strategies. Earlier studies have identified various adaptation and coping techniques associated with drought and floods on agriculture (i.e. Fosu-Mensah et al, 2012, and Mary and Majule, 2009). In occasions of dry spells and droughts, farmers could use strategies such as mulching, changing planting/sowing dates, cropping system (e.g. mix cropping), crop varieties (drought-resistant species) and/or crop type. Water could also be harvested and stored during the peak season for crop watering during periods of dry spell or drought. Depending on farmers' access to irrigation facilities, dry season vegetable production could be a reliable adaptation strategy to rainfall uncertainties. Policies of government, NGOs and donor agencies should target development and promotion of irrigation and water harvesting technologies. Research institutions, universities and agriculture staff should collectively develop and promote drought-resistant, early maturing crop varieties and improved agriculture practices and technologies. The use of flood-prone arable land for crop production should also be avoided.

CONCLUSION

We investigated the relationship between rainfall variability and arable land-use in the Wa Municipality of Ghana over a twenty one year period (i.e. 1992-2012). We also studied the annual and seasonal rainfall patterns in order to identify and propose appropriate land-use strategies/measures to mitigate the effects of potential dry spells, droughts and floods. Using deviations from a calculated precipitation median value of 957 mm, the results show a highly erratic/ variable annual and seasonal rainfall. Generally, rainfall volumes fall below 200 mm in June and rise above 300 mm in July. The estimated coefficients of variation of annual arable land-use for the five crops investigated ranged from 0.36 to 0.52. The high variability of annual land-use revealed by these results suggests that farmers have extreme difficulty in sticking to fixed sizes of cropping area annually. The study reveals that rainfall variability has direct effects on arable land-use. While annual rainfall over the period reviewed was positively correlated with sorghum and millet that for maize, groundnut and cowpea was negative. To ensure proper use of arable land for efficient crop production under rain-fed conditions, this study proposes that agricultural stakeholders should collectively develop and implement sustainable, reliable and resilient adaptation strategies to mitigate the effects of potential rainfall anomalies such as dry spell, drought and flood on crop production.

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