Rainfall Trend, Changes And Their Socio-Economic And Ecological Impacts On The Sumampa Catchment For The 1980-2019 Period

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ABSTRACT

The study investigatedtrend and variability of rainfall in the Sumampa catchment by assessing daily, monthly, annual and decadal changes from 1980 to 2009. Monthly, seasonal and annual data were computed from the daily data series and graphically and statistically analysed to detect trend, changes and variability. The mean daily rainfall for the dry, minor and major seasons increased respectively by 63.9%, 17.57% and 11.84% in the 2000-2009 decade. The mean daily and decadal rainfalls respectively increased by 11.07% and 6.24% in 2000-2009.56.33% and32.44% of rainfall were respectively recorded in the major and minor cropping seasons. The Augmented Dickey-Fuller Test (ADF test) shows statistical evidence of *stationary series* (p = 0.01); the ARIMA model and the Holt-Winters method forecasted maximum amount of rainfall in the month of June and the minimum in January with no general trend of increase or decrease over the ten year period.

Keywords:Variability, Trends, Seasonality, and Forecasting.

1.0 INTRODUCTION

Observational and historical hydroclimatologic data are used in planning and designing water resources projects. There is an implicit assumption, so called stationarity implying time-invariant statistical characteristics of the time series under consideration, in all water resources engineering works. Such an assumption can no longer be valid if the presumed changes in global climate are as a result of the increase of greenhouse gases in the atmosphere. From a more specific perception, for example, floods are considered as an outcome of stationary, independent and identically distributed random process by hydrologists for a long time. Nevertheless, [1] have reported evidence of trends (possibly due to anthropogenic influences) and long-term variability of climate.Rainfall is the limiting factor in the forest-savannah transitional zones. It governs the crop yields and determines the choice of crops that can be grown.

Therefore, a detailed knowledge of rainfall regime is an important prerequisite for agricultural planning. The analysis of rainfall for agricultural purposes must include information concerning the trends or changes of precipitation, the start, end and length of the rainy season, the distribution of rainfall amounts throughout the year, and the risk of dry and wet spells [2].

In spite of having a good rainfall average, the Sumampa catchment intermittently experiences acute problem of water shortage during the dry season. Since the economy of the area depends mainly on agriculture which, in turn, relies on rainfall, the study of changes in rainfall magnitudes and trends is very important for agro-ecological planning. To understand the problem of rainfall and particularly for identification of any trends or persistence in the rainfall series, a climatological study of rainfall in the catchment was undertaken.

The main water sources in the catchment, rainfall, surface and groundwater, have been affected by climate change, deforestation, exploitation of sand and gravel deposits and increasing drought periods and occurrence. Generally, however, much of the catchment receives sufficient rain, but the full potential of this condition has not been exploited. Further resource development is constrained by the fear of increasing erosion risk levels and ecological degradation, technical inadequacy, and budgetary limits. Water demand is ever-increasing due to the formidable effects of population expansion, economic development, and changing life-style of the people as the catchment plays host to one University, two Colleges of Education and four Senior High Schools whose annual enrollments keep increasing and putting variable seasonal, annual and intra-annual pressure on the catchment's water resources.

The Sumampa stream catchment has undergone major anthropogenic changes affecting its land cover for over five decades. These changes, however, have not been quantified in a manner to allow wider scale understanding of the causative factors, their effects and show hot spots that require immediate intervention. The Mampong-Ashanti Municipality has experienced series of droughts since 1980 caused by rainfall failure, rain coming rather late causing short agriculture season or excessive rains which cause damage to properties and affect valley bottom and wetland agriculture.

The objective of this study was to investigate the variability, trend and changes in rainfall in the Sumampa catchment, by detecting trends, annual and decadal changes in the period from1980-2009. The paper looks at the exploratory and statistical data analysis (EDA) on the trend and characteristics of changes in daily, monthly, seasonal and annual rainfall.. Decadal comparisons were made within the period. The challenges and major priorities for future research have been highlighted, and it is hoped that this will promote a better understanding of water erosion processes, agriculture and livelihood and related hydrological issues in the catchment.

2.0 MATERIALS AND METHODS

2.1 Study Area

The Municipality is located in the forest-savannah-transitional zone within longitudes 0.05^o and 1.30^{o}West and latitudes 6.55^o and 7.30^o North, covering a total land area of 2346km^2. It has about 220 settlements with about 70% being rural. [3]. It has a population of 44,380 with a growth rate of 1.6%.

2.2 Hydrology, Climate and Vegetation

The site experiences double maximum rainfall patterns with peak rainfall periods in May-June and September-October and short dry periods between July-August and November-February. The climate is typically tropical, with total annual rainfall between 1270-1524mm with an annual average of 1300mm. Temperatures are uniformly high throughout the year ranging from 25-32^{o}C. The potential evapotranspiration (PET) is estimated at 1450mm per annum. The average humidity during the wet season is typically high (86%) and falls to about 57% in the dry period [4].

2.3 Data Collection

The rainfall data used in this study were obtained from the Ghana Meteorological Services Agency, Accra (MSA). The station is a standard agro-meteorological station in which most climatic data are measured. Continuous daily rainfall data for the station is available from 1980. This 30-year period of data is sufficient to establish a long-term climatology [5]. Monthly and annual data were computed by summing up the daily rainfall data. Annual and seasonal rainfall data were made for the hydrological year from the 1st of March to 28th/29th February. Since the objective of the analysis was to study the variability and changes in rainfall in the catchment, basic statistical analyses were conducted on the annual and intra-annual rainfall data.

Characteristic of many types of hydrologic time series has periodically varying components. The rainfall data was therefore modelled using a linear stochastic model that is commonly referred to as autoregressive integrated moving average (ARIMA) model. In any (p,d,q) model, p indicates the number of autoregressive, q is the number of mobile mean and d is the order of differencing as well as indicating the number of orders needed for attaining the series to a kind of statistical balance. The analysis of initial values of p, d and q was determined by auto correlation function (ACF). By carefully and accurately studying the ACF chart and its components, the general view for presence of time series with trend and its properties was obtained.

Then, it was examined if p and q values, indicating the autoregressive and mobile mean, remain in the model or must be removed from it. It was reviewed whether the residual values, and errors are random and with normal distribution or not to

ensure proper fitness of the model [6]. The model is ARIMA (pdq) (PDQ). Using the multiplicative seasonal ARIMA (SARIMA) model, we have the general notation ARIMA (p, d, q), (P, D, Q)s;
Where:

p, d, q is the non-seasonal part and P, D, Q the seasonal part with p, d, q having their usual meaning and P is the order of the seasonal AR process. D is the differencing of the seasonal process, Q the order of seasonal MA process of the time series, and s is the order of seasonality [6].

2.4 Test for stationarity

The Augmented Dickey-Fuller Test (ADF test) was used to establish stationarity in the data series.

2.5 Forecasting with ARIMA Models

A more statistically sophisticated approach to forecasting is the ARIMA model or Box-Jenkins method. The ARIMA method combines three ideas. First, ARIMA modelling accounts for trend by differencing the series. Instead of modelling and forecasting the series itself, the period-to-period changes in the series were forecasted, and then add up-or integrate the predicted changes to get the final forecast. The second idea in ARIMA modelling is predicting the series by linear combination of its recent past values. The third idea in ARlMA modelling is to take weighted moving averages of past errors. Regression inputs with ARIMA models,could be combined and so regression method was seen as a special case of ARIMA model forecasting. The ARIMA procedure was used to forecast with ARIMA model[6].

2.6 Forecasting with Holt-Winters method

A robust version of the Holt-Winters smoothing techniques was adopted. By downweighting unexpectedly high or low one-step ahead prediction errors, robustness with respect to outlying values was attained. Moreover a simulation study, by [7], shows the robust Holt-Winters method also yields better forecasts when the error distribution is fat tailed. There was only a small price to pay for this protection against outliers, namely a slightly increased mean squared forecast error at normal error distribution. That the proposed robust Holt-Winters method preserves the recursive formulation of the standard method. Again [7] claim Holt-Winters method is of importance for practical forecasting, where outliers frequently occur.

2.7 Exploratory analysis of rainfall characteristics

The major objective here was to graphically analyse the variation in decadal, annual, seasonal, monthly and daily rainfall time series data of the catchment. The understanding of the rainfall dynamics with the help of graphs and simple filtering of the annual rainfall is very crucial for the analysis. From this analysis, input data for a management system would be provided to enable the development of optimal water allocation policies and management strategies to bridge the gap between water needs and obtainable water supply under possible drought conditions in the catchment. On an annual time scale, the analysis helps in the evaluation of the total water budget of the water resources in the catchment. The seasonal rainfall variability was utilized to study the periodicity of the rainfall regime. Monthly rainfall analysis was used in the determination of the crop water requirements whereas the design of flood hydraulic structure and storm water modelling need the analysis of fine resolution rainfall data like daily data [8].

3.0 RESULTS AND DISCUSSIONS

3.1Rainfall characteristics

Rainfall development from orographic or over-mountain impact on air flow occurs when air flows are forced upward. This vertical displacement of air is somewhat analogous to warm air being forced upward in the presence of a cold front. As the air ascends, it expands and cools. As it cools, it may reach a level where temperature and dew point are equal if the absolute water vapour content of the air parcel does not change. At this point water vapour begins to condense into liquid water droplets and the relative humidity is around 100% [9].

3.2 Intra-annual variations

Figures 1 and 2 show intra-annual mean and percentage contributions respectively. Most of the rainfall occur during the major cropping season, March-June, with a sadden decrease in July and August which is related to change of weather regimes following the north monsoon front in West Africa. Relatively high-intensity rainfall is characteristic of the greater part of annual rainfalls. Rainfall magnitudes are high in May-June and in September-October after which the dry season sets in. The major season contributed a mean rainfall of 711.84mm (56.33%) per annum while the minor season contributed 387.71mm (32.44%) per annum. The amount of rainfall varies widely throughout the year and is greatly affected by the Jamase-Nintin topography (Scarp). Rainfall ranges from a minimum of 63.79mm to a maximum of 428.70mm per annum and a mean monthly of 105.31mm. The Major and minor season storms sometimes produce large amounts of rainfall and the resulting streamflow varies annually and seasonally due to changes and expansions in landuse and vegetation cover.

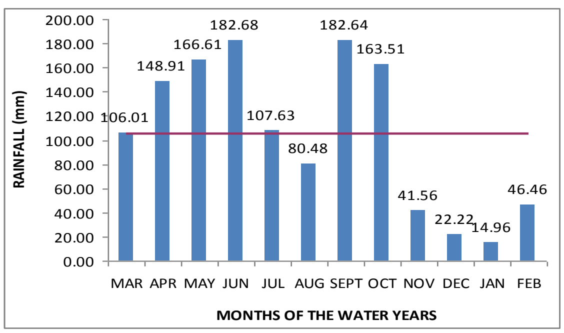

Figure 1: Monthly rainfall distribution (1980-2009)

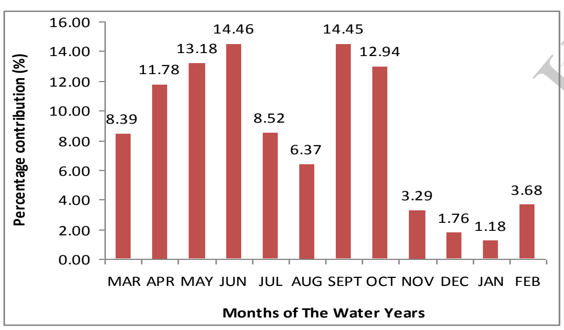

Figure 2: Mean monthly rainfall contributions per annum (1980-2009)

The three decades rainfall analyses show an increase in annual mean rainfall by 4.38% from 1980-1989 to 1990-1999 and 11.1% in 2000-2009. The mean decadal rainfall increased by 6.44% between 1990-1999 and 2000-2009. The 2000-2009 decade recorded 11.07% over the mean for the 1980-1989 period and 5.65% over the period annual mean rainfall (Fig.3).

The wettest month in the catchment, during the period, was June with a mean of 182.68mm and the driest is January with a mean of 14.96mm (Fig.1). The rainfall patterns and variations observed usually have temporal variabilities which affect agricultural production, water supply, the aquatic ecology, and the entire economy of the Municipality. With such high annual and monthly rainfall variability, damage due to extremes cannot be avoided completely but forewarning could be very useful. Sumampa catchment's rainfall regime is characterized by major, minor and dry seasons. Since more than 55% of catchment's annual rain falls in 2-4 months (major season), changes in the major season rainfall can have a profound effect on the hydrologic system and the success of food security programmes. Most of the surface-water runs off and less recharge to the groundwater system occur during the major season when antecedent soil moisture conditions are high and surface storage deficits become minimal.

3.3 Intra-annual changes in mean daily rainfall

The intra-annual and decadal variations in mean daily rainfall can be observed in Fig. 4. All the tree decades follow a similar pattern of variation. The decadal variations are high between all three decades within the major season (wet) but 1990-1999 recorded the wettest major season. The mean daily rainfall, over the period, increased from 3.26mm in 1980-1989 to 3.43mm (5.43%) in 1990-1999 then to 3.65mm (6.24%) in 2000-2009. All three decades show high variation in the major season. The mean monthly rainfall ranged from 63.79mm to 428.70mm during the period (Fig.3).

3.4 Inter-annual variation

One of the most significant climatic variations, in the study area, has been the persistent increase in annual rainfall magnitudes and distribution in the last three decades. Apparently, high oscillation in the annual rainfall values can be observed which reflect the variability and uncertainty in the replenishment of the catchment water resources including the soil. From Figure 3, it can be inferred that in 12 out of the 30 years the annual rainfalls were below the period mean. 146.04% of the mean annual rainfall occurred in the year 2002 where 1845.50mm of rainfall was recorded and 60.58% of the mean occurred in 1982 where 765.5mm was recorded.

3.5 Changes in annual maximum and minimum rainfall

Figure 13 shows the variations in annual maximum and decadal mean maximum rainfalls. It shows a high variation in the two decades (1980-1989 and 2000-2009) and low variation about the period mean. The highest annual maximum rainfall (428.70mm) was recorded in 1989 and the lowest (160.9mm) in 1988. The graph (Fig.13) indicates a wetting trend in a maximum rainfall at a rate of 2.16mm/y (gradient > 0) but weakly correlated with time (R^2=0.0853). The mean maximum for 1980-1989 and 1990-1999 were 0.52% and 0.74%, respectively, lower than the period mean maximum value. However, the 2000-2009 annual mean maximum rainfall was 0.57% higher than the period mean maximum. The decadal mean maximum rainfall increased by 4.38% in 1990-1999 and 11.11% in 2000-2009 (Fig.13). The mean annual minimum rainfall increased by 118.13% in the 2000-2009 decade (Fig.15).

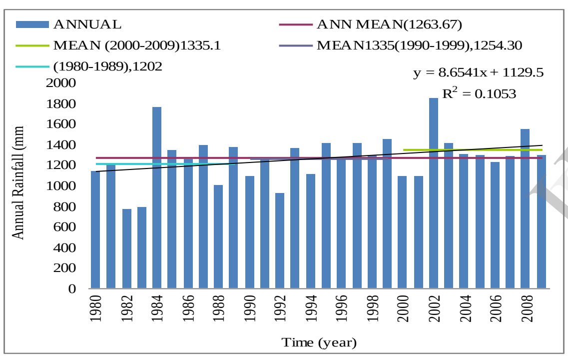

Figure 3: Inter-annual rainfall variations in the Sumampa catchment (1980-2009)

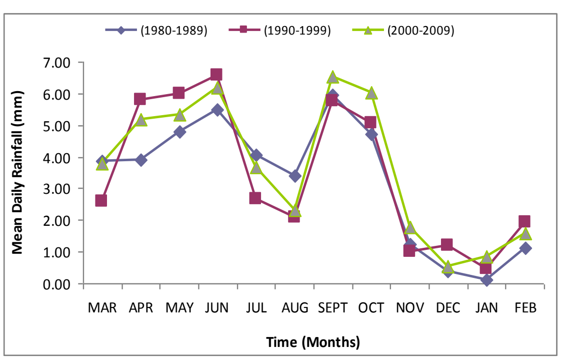

Figure 4: Variation in intra-annual mean daily rainfall over three decades

Table 1: Seasonal changes in mean maximum daily rainfall (mm)

Seasons	Decades 1980-1989	1990-1999	2000-2009
Dry season mean max.	0.72	1.16(61.11%)	1.18(63.89%)
Minor season mean max.	5.35	5.4(0.93%)	6.29(17.57%)
Major season mean max.	5.15	6.29(22.14%)	5.76(11.84%)

Table 2: Changes in Seasonal Rainfall Contributions (1980-2009)

Period (Decades)	Total Seasonal Rainfall (mm)				Period Rainfall (mm)	
	Major season	Change (%)	Minor season	Change (%)	Rainfall	Change (%)
1980-1989	5503.4	45.8	3259.7	27.13	12016.2	31.7
1990-1999	6388.9	50.94	3288.5	26.22	12543	33.09
2000-2009	6234.2	46.69	3836.1	28.73	13351	35.22

3.6 Effects of increased rainfall on the hydrologic cycle of the Sumampa catchment

A key question raised by the increases in rainfall occurring during the 1990-1999 and the 2000-2009 decades over the Sumampa catchment concerns the potential effects on its hydrologic cycle. Projections of climate change for the nation indicates rainfall increases will continue into the future. Water erosion is the most damaging type of erosion nationwide, causing serious environmental deterioration. Against a background of climate change and accelerated human activities in the catchment, changes in natural rainfall regimes have taken place and will be expected to become more pronounced in coming decades. Long-term positive shifts may challenge the existing catchment cultivation systems and eventually alter the patterns of landuse and topography. Meanwhile, specific features of soil crusting/sealing, plant litter and its decomposition, and antecedent soil moisture content(ASMC) is expected to accompany the observed rainfall variability.

3.7 Seasonal changes in rainfall

The mean maximum daily rainfall for the dry season (November-February.) changed from 0.72mm in 1980-1989 to 1.16mm, (61%) in 1990-1999 then to 1.18mm (63.9%) in 2000-2009. For the minor season (Sep-Oct), it changed from 5.35mm in 1980-1989 to 5.40mm (0.9%) in 1990-1999 then to 6.29mm (17.57%) in 2000-2009.The major season's mean daily rainfall changed from 5.15mm in 1980-1989 to 6.29mm (18.12%) in 1990-1999 then to 5.76mm (11.84%) in 2000-2009 (Table 3). There is evidence of increase in the mean daily maximum rainfall in all three seasons (Table 1).

The mean major season rainfall decreased by 6.05% in 1980-1989, increased by 9.06% in 1990-1999 and decreased by 2.06 in 2000-2009 from the period mean.The mean minor season rainfall decreased by 5.83% and 5.0% in 1980-1989 and 1990-1999 respectively and increased by 10.82% in 2000-2009. The total major season rainfall increased from 6,763.90mm in 1980-1989 to 7,214.60mm (6.66%) in 1990-1999, then to 7377.0mm (9.06%) in 2000-2009, a change of 613.1mm. The total rainfall in the minor season increased from 3,641.7mm in 1980-1989 to 4,385.2mm (20.42%) in 2000-2009. The total dry season rainfall, however, dropped from 1610.6mm to 1588.8mm (1.35%) between 1980-1989 and 2000-2009. The seasonal decadal contribution for the major season has increased from 45.8% in 1980-1989 to 46.69% in 2000-2009 and that of the minor season from 27.13% in 1980-1989 to 28.73% in 2000-2009. The total seasonal rainfall contributions per decade for the 30years data series have increased from 31.7% in 1980-1989 to 35.22% in 2000-2009 (Table 2).

The major and minor seasons are becoming wetter and the dry season becoming drier over the decades (Fig.5). The increase in the minor season rains confirms the farmers' perception that the minor season is becoming more reliable for agricultural activities than the major season which sometimes starts late and or ends early, and is, most of the time, concentrated in a period of three to four weeks. The decrease in the dry season rainfall and the increase in the dry months have increased the vulnerability of the catchment's vegetation to annual bushfire. These also account for the high seedling mortality rate observed in all crops in the catchment during the farming periods.

The annual dry season rainfall magnitudes oscillated between 34mm (1984) and 384mm (1990) (Fig.6) with a significant wetting trend at the rate of 1.509mm/y over the period. The wettest dry season occurred in 1990 and the driest in 1984. The 1980-1989 and the 1990-1999 decades show drying trends. The annual minor season rainfall trend is positive (Fig. 7).

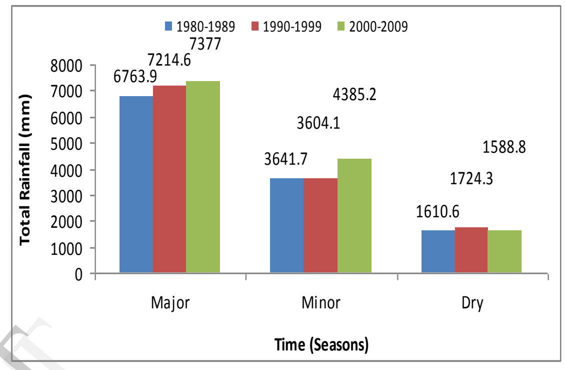

Figure 5: Changes in total seasonal rainfall of the three decades

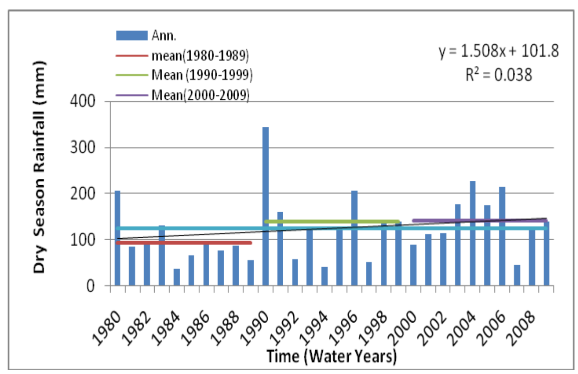

Figure 6: Annual dry season and decadal variations in rainfall (1980-2009)

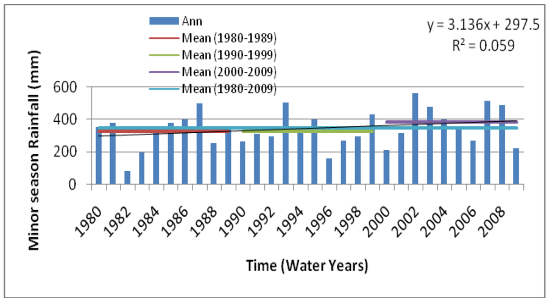

Figure7: Minor season rainfall trend in the 1980-2009

The minor season exhibited a significant wetting trend at the rate of 3.14mm/y during the period, recording a minimum of 85.5mm in the year 2002 and a maximum of 562.3mm in 1982 (Fig.7). The 1980-1989 and 1990-1999 decades recorded means of 325.7mm (5.9%) and 328.85mm (5.0%) respectively below the period mean (346.14mm) while the 2000-2009 recorded 383.61mm (10.0%) above the period mean (Fig.5).

The major season rainfall magnitudes for the period, like the minor season, oscillated between 431.2mm (1990) and 1055.5mm (2002). The wettest major season occurred in 2002 and the driest in 1990 (Fig.8). The mean decade major season rainfall in 1980-1989 decreased by 5.0% below the period mean, 1990-1999 and 2000-2009 increased 1.3% and 3.53% respectively above the period mean (Fig.8).

3.8 Changes in Mean Annual Daily Rainfall

The annual mean maximum daily rainfall (5.03mm) for the period was obtained in 2002 and the minimum (2.10mm) in 1982. The mean decadal daily rainfall graph also shows high annual variations especially in the first two decades and averagely low in the last decade (2000-2009) (Fig.12). The low variation in the daily rainfall creates low antecedent soil moisture deficit and increased erosive forces of runoff which in turn accelerates urban erosion and increases streamflow flashiness. The mean decadal daily rainfall dropped from the period mean of 3.45mm to 3.26mm (5.5%) in 1980-1989, 3.44mm (0.29%) in 1990-1999 but increased in 2000-2009 to 3.65mm (5.8%) (Fig.12).

The mean number of intra-annual rainafll days is shown in Figure 10. Throughout the period, October recorded the highest mesn monthly rainfall of 465mm and January the lowest of 41mm. The mean decadal rainfall days dropped in the last decade (2000-2009) by 5.55% from 1990-1999 and 4.18% from 1980-1989 (Fig. 10). With 2000-2009 recording the highest annual mean maximum (Fig.13) and daily rainfall (Fig. 9) magnitudes and lowest in the mean rainfall days (Fig.11), it can be concluded that the 2000-2009 rainfalls were heavier and of lower frequencies.

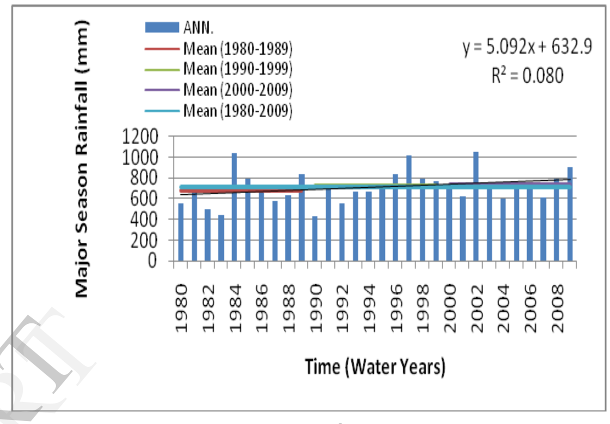

Figure 8: Major season rainfall trend (2000-2009)

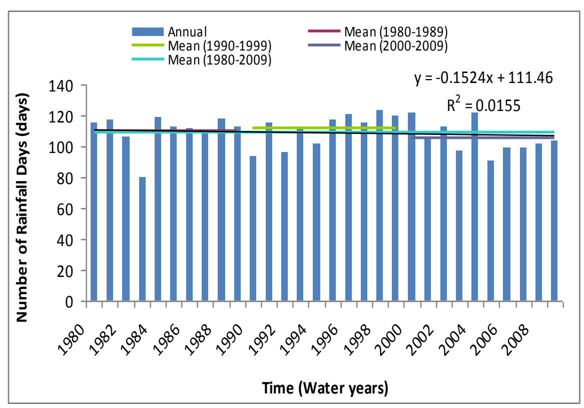

Figure 11: Intra-annaul variation in number of rainfall

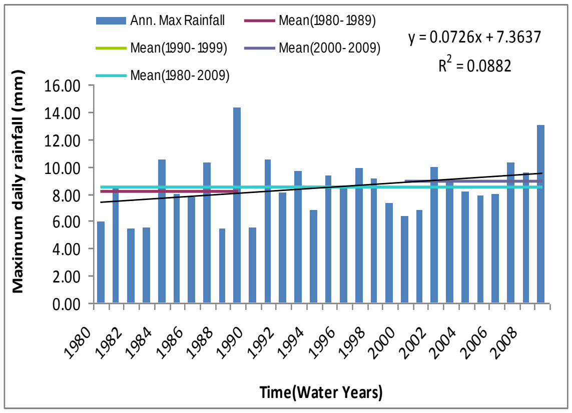

Figure 9: Maximum daily rainfall (1980-2009)

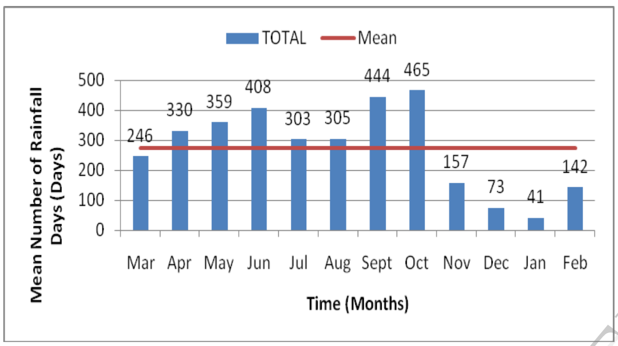

Figure 10: Inter-annual variation in number of rainfall days

3.9 Changes in the number of rainfall days

Average number of days with some rainfall shows the average number of days for each month when a measurable amount (defined as 1mm) of rain falls. This statistic does not imply that it rains throughout the day; it merely shows the number of days in the month when some rain is recorded - a useful indicator of the frequency of rainfall.

The number of rainfall days/y (ie. days with at least 1.0 mm rain) varied considerably during the period (Fig. 10). There is a negative trend in the rainfall days at the rate of 0.152days/y. However, the gradient is not significantly greater than zero (R^2 = 0.0134). There was annual maximum of 124 days (1998) and a minimum of 80 days of rainfall (1983) during the period. The highest (1845.5mm) and the lowest (765.5mm) annual rainfalls occurred in 2002 and 1982 respectively. The highest annual rainfall magnitude and rainfall days did not occur in the same year. This shows the 2002 rainfalls were of higher intensities and/or longer durations. A mean of 108 days, a standard deviation of 11.56 days and

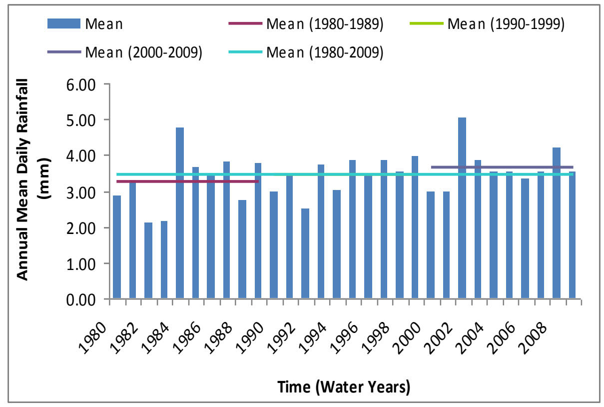

Fig 12. Intra-annaul variation in number of rainfallBetween 1980 and 2008

coefficient of variation of 10.7% were recorded for the period annual data. The mean decadal rainfall days increased by 5.43% from 1980-1989 to 1990-1999 then decreased by 3.27% in 2000-2009 (Fig.10).

3.10 Impacts of rainfall days on vegetation interception capacity

Canopy interception loss, the proportion of incident precipitation that is intercepted, stored and subsequently evaporated from the leaves, branches and stems of vegetation, is a significant and sometimes a dominant component of evapotranspiration from forest stand [10], which is approximated to the differences between incident precipitations measured above canopy, the sum of throughfall and stemflow below canopy [11].The quantitative effects of woodland on water resources are largely dependent on interception loss [12], since tree canopies typically interceptes the majority of rainfall, and control its subsequent evaporation and drainage [13]. The availability of water directly influences the 20 vitality and growth of forest ecosystems by limiting the transpiration (Cui et al., 2005).

The 2000-2009 mean rainfall days dropped by 3.96% from the period mean (Fig.10). The highest canopy interception losses occurred in the year 1998 where the highest rainfall days occurred. Canopy interception losses depend on the storage capacity of the canopy and increases with leaf area and the frequency of rainfall events. The decrease in the number of rainfall days means a decrease in rainfall frequency, interception losses and antecedent soil moisture content in the 2000-2009 farming seasons (Fig.10). This may have accounted for the decreased streamflow, runoff, and recharge in 2000-2009 and might have affected percentage germination and seedling establishment and development.

Intra-annually, the highest monthly rainfall (5,480.50mm) occurs in June and the lowest (448.7mm) in January (Table 2). The highest rainfall days (465days) occurred in October and the lowest (41days) in January (Table 2). This explains why the highest streamflow is recorded in October. The highest rainfall days in October means October rains were of highest frequency, lower in magnitudes and of longer durations. There is a high intra-annual variation in rainfall days (Fig.11) for the period 1980-2009. The number of days increases from March to June and drops in July-August, then rises in September to October. Apart from the dry season months (Dec to February), the other months had rainfall days higher than the mean intra-annual rainfall (wet) days (272.75days). The variation in the mean annual daily rainfall is also high (Figure 12).

In the tropical rain-forest zone, declines in mean annual rainfall of around 4% in West Africa for the period 1960 to 1998 have been reported[11]. There are many different ways in which changes in hydrometeorological series can take place. A change can occur abruptly (step change) or gradually (trend) or may take more complex form. Climate change is often recognized as a progressive trend.

3.11 Changes in seasonal distribution of monthly rainfall

The objective here was to determine if the increase in rainfall appears throughout the year or is concentrated during specific seasons. The mean monthly and the total decade rainfalls for 1980-1989, 1990-1999 and 2000-2009 have been determined. The general pattern of the seasonal distribution of the rainfall in the catchment has not changed significantly in all three decades. However, the seasonal contributions indicate an increase in the minor season and a drop in the major season in 2000-2009 (Table 4). This is reflected in the decadal rainfall magnitudes (Fig.5). The period monthly rainfalls rapidly increased during the major season to a maximum in June, decreased from July to August and increased until September and decreased non uniformly to December and picks up in February (Fig.16).

However, the total seasonal rainfalls increased by 2.0% (16834.10-17170.10mm) in (1990-1999) and 8.4% (17170.10-18618.20mm) in (2000-2009). The changes in the monthly totals of the three decades are represented in Figure 16. In all three decades, the major and minor season months recorded rainfalls above the intra-annual mean. The increase is relatively large in April, May, June, September and October. The number of wet months decreased from 7 to 5 in 1980-1989 and rose back to seven out of twelve months in the last decade (Fig.16).

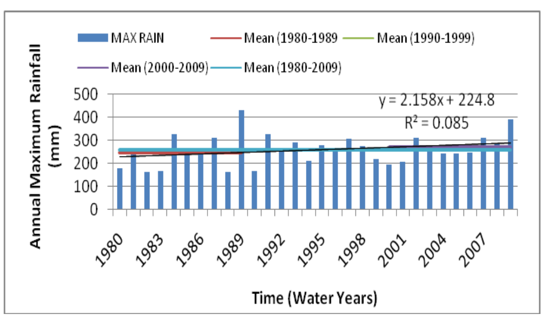

Figure 13: Annual maximum rainfall

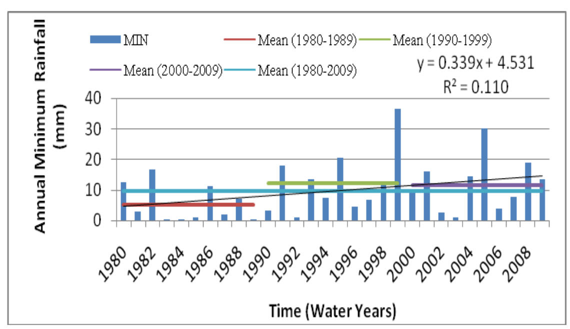

Figure 14: Decade and period mean number of rainfall days

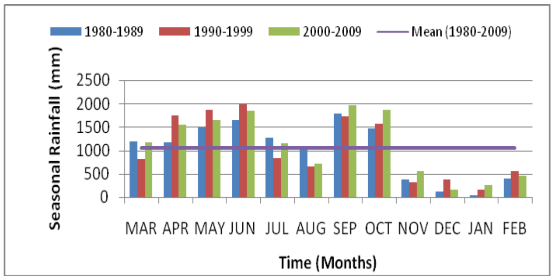

Figure 15: Annual minimum rainfall

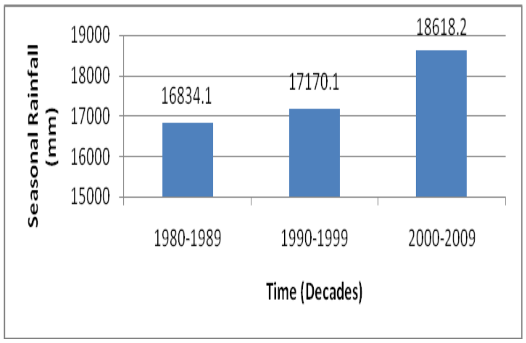

Figure 16: Decadal changes in seasonal rainfall

3.13 Stationarity in Data Series

The Augmented Dickey-Fuller (ADF) test gave the following results:
Dickey-Fuller = -10.2512, Lag order = 7, p-value = 0.01. The reported p-value shows statistical evidence of stationary series (no trend). The fitted model is **ARIMA(1,0,0)(2,0,0)[12]** with non-zero mean.

Rainfall model is

$$Y_t = \mu + \phi Y_{t-1} + \Phi_1 Y_{t-12} + \Phi_2 Y_{t-24} + e_t \quad (1)$$

3.14 Forecasting

Figure 17 shows the observed series and predicted (forecasted) values from the ARIMA model. The forecasted value over a 10-year period from Jan 2010 to Dec 2019 are presented in Figure 17. Based on the forecasted values (Table 5), it was concluded that in the current decade (2010-2019)the maximum amount of rainfall would occur in the months of June. There is no general trend of increase or decrease over the 10-year period, however, in absolute terms the quantity of the amount of rainfall may either increase or decrease. An alternative model, Holts and Winter's method, was proposed to fit the empirical data. The Figure below shows the output of the Holts and Winter's model. For the Holt-Winters method, based on the forecasted values in the Table 6 it could be concluded that in the current decade the maximum amount of rainfall would occur in the month of June. There is a general increasing trend of rainfall over the ten-year period.

3.14 Impacts of Changes in Rainfall Characteristics

Rainfall is a major part of the hydrologic cycle, and is responsible for depositing most of the fresh water on the catchment. All plants need at least some water to survive, therefore rain is important to agriculture. While a regular rainfall pattern is usually vital to healthy plants, too much or too little rainfall can be harmful and even devastating to crops[12]. Determining the exact effects of climate change on crop yield, according to [13] is difficult because changes in technology, fertilizer use, and developmental use of genetically modified foods which could greatly improve the potential for positive crop yield in the area cannot be accurately predicted. However, this study shows that relevant measures need to be taken in order for agricultural yields to continue to meet the needs of the growing catchment population over the coming years as local and global temperatures continue to rise.

The high degree of rainfall variability interspersed with dry spells, when combined with relatively low asset base of the Municipality, especially the rural communities, will restricts crop management strategies and overall crop water productivity. The persistent in general reduction in the number of wet months and increase in the number of dry months have raised concern among the Municipal development planners regarding how to cope with losses due to seedling mortality and crop failure, instances of food insecurity, and increasing scarcity of water resources in the forest-savannah transitional zone.

The major challenge is at the seedlings establishment phase in cash crops production; high seedling mortality rates (30-40%) have been recorded in the cocoa and citrus, 15-20% in oil palm production as a result of prolonged dry seasons (short wet season) during the field survey in 2008/2009. Changes in patterns, trends, frequencies and intensities of rainfall would increase canopy interception losses, exacerbate variation in runoff, infiltration, average antecedent soil moisture contents and groundwater recharge.

As farmers (both small and medium scale) in the Municipality practice rain fed agriculture, they are at high risk of crop failure given the erratic nature and high variability of the rainfall. Most farmers in the catchment practice subsistence agriculture and their ability in achieving yields high enough to ensure household food security hinge on managing their natural resources and the variable rainfall to ensure their crops harness that little soil moisture and achieve high crop yield. Fortunately, for them (farmers) the mean decadal rainfall has increased by 6.44% in the last decade. However, mean sunshine hours, temperature, wind velocity and ET have all increased and these in concert would affect the available moisture content as the dry season extends into the wet season and or starts earlier; midway the wet season and the frequent occurrence of dry spells even in the major seasons.

3.15 Summary and Conclusions

Characterizing the catchment rainfall features and patterns is of great importance in managing and developing the water resources. These conditions informed the carrying out of statistical analysis on the long-term (30y) rainfall data from the agro-meteorological station of Mampong-Ashanti. The analysis conducted focused on the major descriptive and statistical variables of the daily, monthly, seasonal and annual rainfall. Time series of rainfall data were analysed and annual trends and changes reported. Augmented Dickey-Fuller Test (ADF test) shows statistical evidence of *stationary series* (p = 0.01)

The ARIMA model forecasted the maximum amount of rainfall would occur in the month of June and the minimum in January with no general trend of increase or decrease over the 2000-2009 decade was observed while the Holt Winter's method forecasted a maximum rainfall in June with a general trend of increase in 2000-2009 decade.The increase in the daily and annual mean rainfall in 2000-2009 decade and the predicted increase in 2010-2019 decade call for proper urban design and development of infrastructure, introduction and implementation of afforestaion and reforestation programmes, grassing of open spaces in the communities and introduction of integrated soil and water conservation strategies to accommodate the extra rainfall.

Table 3: Basic statistics of rainfall for the 1980-2009 period

Basic statistics	Value (mm)
Min.	0.30
1st Qu.	31.65
Median	92.95
Mean	105.30
3rd Qu.	157.60
Max.	428.70

Table 4: Rainfall model coefficients:

Parameter	Estimate (standard error)
Intercept	107.523(11.335)
ar1	0.132(0.0546)
sar1	0.333(0.0521)
sar2	0.289(0.0528)

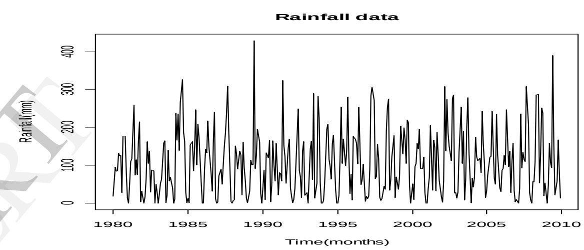

Figure 17: Observed pattern of monthly rainfall data (ARIMA model)

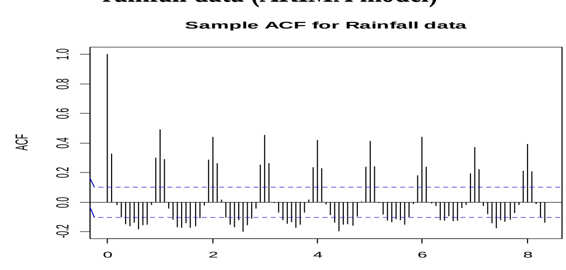

Figure 18: Correlogram of the observed series

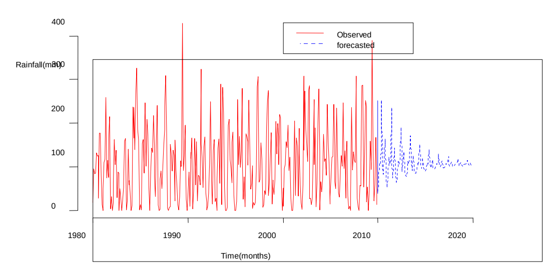

Figure 19: Plot of observed and forecasted rainfall values

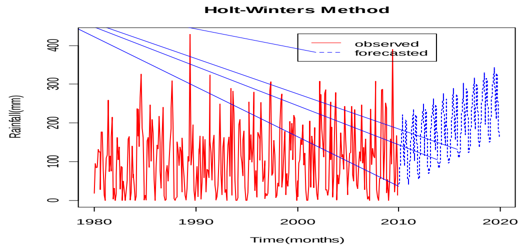

Figure 20: Plot of observed and forecasted rainfall values

Table 5: Predicted rainfall values for a 10-year period (ARIMA model) (2010-2019)

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011	51.562	77.376	121.591	106.326	117.875	235.076	119.600	74.124	100.358	142.281	86.65	64.054
2012	67.058	86.241	111.887	106.099	122.722	190.552	110.611	88.542	110.673	134.106	89.639	78.538
2013	77.250	90.988	112.082	105.836	114.698	170.562	111.092	90.851	105.703	125.406	94.746	84.640
2014	85.050	95.084	109.420	105.683	113.350	151.292	108.727	95.685	106.924	120.168	97.309	90.774
2015	90.550	97.802	108.576	105.557	110.639	139.162	108.063	97.967	105.939	115.953	99.611	94.562
2016	94.602	99.872	107.542	105.47	109.344	129.647	107.174	100.097	105.949	113.056	101.11	97.566
2017	97.51	101.336	106.956	105.407	108.145	123.02	106.687	101.457	105.676	110.892	102.26	99.645
2018	99.64	102.412	106.467	105.362	107.375	118.11	106.273	102.516	105.587	109.347	103.07	101.193
2019	101.177	103.187	106.137	105.32	106.778	114.58	105.996	103.256	105.48	108.217	103.67	102.30

Table 6: **Predicted rainfall values for a 10-year period by Holt-Winters' method**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	31.059	58.612	119.718	168.804	188.351	221.561	123.280	88.755	207.352	201.400	68.138	41.557
2011	44.591	72.143	133.249	182.335	201.882	235.093	136.811	102.287	220.883	214.931	81.669	55.088
2012	58.121	85.674	146.780	195.867	215.412	248.623	150.342	115.817	234.414	228.461	95.199	68.619
2013	71.652	99.204	160.311	209.397	228.943	262.154	163.87	129.348	247.945	241.993	108.731	82.150
2014	85.18	112.736	173.84	222.929	242.475	275.685	177.404	142.879	261.476	255.523	122.261	95.681
2015	98.715	126.26	187.373	236.459	256.10	289.21	190.935	156.411	275.007	269.055	135.793	109.212
2016	112.24	139.797	200.9	249.99	269.536	302.747	204.465	169.941	288.538	282.586	149.323	122.743
2017	125.77	153.328	214.43	263.52	283.067	316.278	217.996	183.47	302.069	296.116	162.855	136.274
2018	139.31	166.859	227.96	277.05	296.598	329.81	231.528	197.003	315.600	309.647	176.386	149.804
2019	152.84	180.39	241.496	290.58	310.129	343.34	245.06	210.534	329.13	323.178	189.916	163.335

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