Effects of Climate Change and Variability on Water Depth of the Tono Reservoir of Ghana

**Abstract**

The study implored the levels of the Tono dam to study the effects of climate change and variability on water resources in the Upper East Region for the purpose of fish culture. The study investigated the relationship between changes in temperature and rainfall on water levels at Tono reservoir and made a seven year projection (2015-2021) about the future of the Tono dam levels using time series decomposition models. The mean depth of Tono was in the range of 3.7m and 8.0m and was suitable for fish culture. The result revealed that day time temperature affects the level of Tono dam negatively by a unit change of -0.0219, night time temperature affected the level of Tono negatively by a unit change of -0.03262 and rainfall positively affected the dam by a unit change of 0.0186. The projection of the dam levels into the future depicted a quadratic trend with a relation yt=-0.7770+0.000791t-0.000004t2. While the linear coefficient depicted an increasing trend, the quadratic coefficient depicted a decreasing trend; however, both increases and decreases were at a very slow pace. It is recommended that the government of Ghana and its counterparts in Burkina Fasso must have a joint monitoring of their water bodies to prevent siltation of the water bodies by farmers who farm along water bodies.

**Key words**

Climate; Variability; Tono; Decomposition; Fish culture; Aquaculture

**1.1 Background of the Study**

Climate change and variability is a long term changes in average weather conditions covering all changes in the climate system, including the drivers of change, the changes themselves and their effects. The global average surface temperature increased by about 0.6ºC during the twentieth century (International Panel on Climate Change (IPCC), 2001) and has led to changes in land and water conditions. The amount of rainfall over space and time is the main driver of water availability (IPCC, 2001) in reservoirs. Warmer conditions directly increase water withdrawals (Frederick et al., 1997) because in a warmer climate, dry season water use for crops is higher because of higher evapotranspiration. Withdrawal and consumption of water change is as a result of climate variability, changes in population, and changes in values (Lettenmaier et al., 1999; Vorosmarty et al., 2000).

In arid and semi-arid central and west Asia, climate variability continues to challenge the ability of countries to meet growing demands for water (Ragab and Prudhomme, 2002). Recent scientific studies have indicated drier climatic conditions for Sub Saharan Africa as opposed to earlier predictions by the IPCC (2012). A combination of increased temperatures and rainfall may lead to the extension of growing seasons (Thornton et al., 2006) and the reverse could be the case if temperature increases and rainfall decreases. Water Resources Commission (WRC) (1999) affirmed that water resources are important and are used in various ways including direct consumption, agricultural irrigation and fishing among others. Water resources provide habitats for aquatic life and moisture for vegetation and terrestrial biota, transporting nutrients between one ecosystem and another (Gleick et al., 2002).

Water is vital for life but its usefulness is limited by climate change and variability. Kuntsmann and Jung, (2005), Andah et al., (2004) and Water Resources Institute (WRI), (2000), have agreed that climate change and variability have effects on Ghana and her water resources. In the specific case of the Upper East Region, the region is vulnerable to drought that affects her water resources. Deforestation which is characterized by the Savanah often makes the lands bare and increase water erosion thereby causing siltation of water resources. This increases the surface area of reservoirs and a corresponding increase in evaporation. Also stagnant water bodies experience a higher increase in temperature and evaporation (Schijven and de RodaHusman, 2005). In addition, the size of a water body is important (Kumagai*et al*., 2003) in the degree of warming of a water body. The management of water resources is a concern for all stakeholders involved (Hagan, 2007) to enhance food security. The research is therefore designed to assess the changes in water levels of the Tono reservoir of the Upper East Region.

# 1.2 Relevance and Statement of the Problem

Assessing the long-term effects of climate change and variability is important in decision making on fish culture. To ensure that the public receives an adequate supply of fish, water resources require periodic monitoring (Gleick et al., 2002). All aquatic organisms deserve some optimum amount of water that is suitable for their survival. The study would therefore inform those who are interested in fish culture about the suitability of the Tono reservoir for fish culture.

The government of Ghana in an effort to ensure food security has introduced the ministry of fisheries and aquaculture development and also the youth in agriculture program. The ministry and the agency in charge for fishery development must know the impact of climate change and variability on water levels to be able to provide technical advice to those who needs it.

To be able to manage the dam efficiently, the management of the Irrigation Company of Upper Region (ICOUR) must know how the dam levels are responding to climate change and variability to be able to regulate the amount of water needed for irrigation. In line with this, many studies have been done and are concentrated on stream flow and hydrological regimes (Arnell, 2004) as an indirect indicator of Climate Change and variability on water resources. Also studies have been done on rivers and water bodies in the Upper East Region on water bodies for the purpose of irrigated farming (Liebe, 2002; Faulkner, 2008; Anayah and Kaluarachchi, 2009; Asante, 2009 and Nakuja et al, 2011). The question is how suitable is the level of Tono dam for fish culture?

The current study implored the levels of the Tono dam to study the effects of climate change and variability on water resources in the Upper East Region. The choice of Tono dam was by convenience because it was the only dam that had adequate available data (2000-2014) for the study. The main objective of the study was to assess the effects of climate change and variability (if any) on water resources in the Upper East Region of Ghana suitable for fish culture. Specifically the study intends to investigate the relationship between changes in temperature and rainfall on water levels at Tono reservoir and to make projections (2015-2021) about the future of the Tono dam levels. To achieve this objectives the following hypothesis were tested.

The hypotheses tested were:

1. H0: Day time temperature is not affecting the Tono dam levels

Ha: Day time temperatures affect the levels of the Tono dam

1. H0: Night time temperature is not affecting the Tono dam levels

Ha: Night time temperatures affect the levels of the Tono dam

1. H0: Rainfall is not affecting the Tono dam levels

Ha: Rainfall affects the levels of the Tono dam

**2.1 Study area**

The study region is the Upper East Region (Figure 1) of Ghana and it is located on the North-East corner of the country between latitudes 10º 30ʹ to 11º North and longitudes 0º to 1º 30ʹ West within the White Volta River Basin (Aquastat, 2005).

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| Figure 1: Map of Upper East region of Ghana |

The region has two international boundaries with the republics of Burkina Faso to the north and Togo to the east. The other boundaries are Northern Region and Upper West Region to the south and west respectively (Ghana Statistical Service (GSS), 2012).The average annual rainfall in Ghana ranges from 800 to 2200 mm and decreases from south to north reflecting the different climatic zones of the country. The Northern Savannah Zone (NSZ) comprising the Guinea Savannah and Sudan Savannah has a uni-modal rainfall pattern with rainfall typically in May to October (Tetteh, 2007). About 85 percent of the entire region falls within the White Volta basin. Also, the Kulpawn River which has its catchment to the south-west of the Region is joined by the Sissile just before its confluence with the White Volta. Besides these, there are other smaller water bodies that give the region a great potential for fishing and irrigation development (Aquastat, 2005). The annual average rainfall of the Upper East Region is 921mm and ranges between 645mm and 1250mm.

The Tono dam is a strategic investment in the Upper East Region of Ghana (Gordon, 2006). The project is multi-purpose such that it involves crop production, fish production and domestic water supply. The Tono project started in 1975 but became fully operational in 1985. The dam has a catchment and reservoir area of 650km2 and 18.6km2 respectively. Tono dam has a volume of 9.26 ×107m3 and a gross project area of 3860 hectares (Gordon, 2006). The dam is operating on the idea of a common resource, the fisheries of the Tono dam and its feeding rivers such as the Yarigatanga River are being exploited by several people and communities (ICOUR, 1995).

**2.2 Methodology**

In this study, based on the objectives of the work, multiple regressions, time series decomposition and trend analysis and forecasting models were employed to model the rate of change, linear relationship and forecasting of the effect of temperature and rainfall on the water resources in the Upper East Region of Ghana. The main objective for using decomposition model is to estimate seasonal effects that can be used to create and present seasonally adjusted values. A seasonally adjusted value removes the seasonal effect from a value so that trends can be seen more clearly. The model is made of additive and multiplicative decomposition models. The additive model is defined as: *Yt = Trend + Seasonal + Random* while the multiplicative model is defined as: *Yt = Trend \* Seasonal \* Random.* In this study, the Maximum Absolute Percentage Error (MAPE), Mean Absolute Deviation (MAD) and Mean squared deviation (MSD) were used to select the model. The model with the least of these values was selected for the modeling (James, 1994).

# 3.0 Results

## 3.1 Preliminary analysis

The Tono dam had an estimated average minimum and maximum depth of 3.7m and 8.0m respectively with the coefficient of variation being 14.57. The data showed an average (Mean) value of 4.9m. The Skewness and Kurtosis estimated to be 2.23 and 5.43 respectively depicted that the data had shifted to the right and was not normally distributed and hence the need to transform the data. As a result Box Cox transformation was performed on the data at the point of fitting the multiple linear regression models to get the relationship between it and the other three variables. The result depicted that, the regression model was correctly fitted with F-ratio of 1226.5, R-square (Adj) of 98.79% and a P-value of 0.0000 with a Durbin Watson statistics value of 1.7743 which confirmed that the data points were now uncorrelated with each other after transformation.

## 3.2 Relationship between Tono dam level, Rainfall, Day time temperature and Night time temperature

The result revealed that, there was a relationship between day time temperature and the depth of the Tono dam in the Upper East Region. In the analysis of variance, F-ratio of 14578.7 with its P-value of 0.000 showed that, temperature was linearly related to the dam level in all the months. It was also seen that, one period (the month of August) was significant at 5% level of significance with a P-value of 0.003 and demonstrated that temperature had no effect on the level of the Tono dam in the month of August. The result revealed that day time temperature affects the level of Tono dam negatively by a unit change of -0.0219 besides the month of August (Table 1). The null hypothesis that temperature had no effects on the Tono reservoir was therefore rejected in favour of the alternate hypothesis that temperature was affecting the dam. The relationship between the level of the dam and rainfall was:

Level of dam= -0.0219 day time temperature – 0.0268 January+0.0256 February+… -0.0237 December

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| Table 1: Regression coefficient of Day time temperature and the Time periods on the dam level

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| --- | --- | --- | --- | --- |
| Variable | Coefficient | SE | T-statistics | P-value |
| Day time temp | -0.0219 | 0.0002 | -120.742 | 0.0000 |
| January | -0.0268 | 0.0207 | 1.236 | 0.1980 |
| February | 0.0256 | 0.0207 | 1.405 | 0.2180 |
| March | 0.0291 | 0.0207 | 1.405 | 0.1620 |
| April | 0.0090 | 0.0207 | 0.433 | 0.6650 |
| May | -0.0185 | 0.0207 | -0.894 | 0.3720 |
| June | 0.0038 | 0.0207 | 0.183 | 0.8550 |
| July | 0.0315 | 0.0207 | 1.522 | 0.1300 |
| August | 0.0621 | 0.0207 | 2.994 | 0.0030 |
| September | -0.0278 | 0.0207 | -1.343 | 0.1810 |
| October | -0.0268 | 0.0207 | -1.293 | 0.1980 |
| November | -0.0375 | 0.0207 | -1.809 | 0.0720 |
| December | -0.2370 | 0.0207 | -1.458 | 0.0632 |

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The general linear regression model of rainfall on the dam level with the dummy variables showed that they were all significant at 5% level with R-square of 76.20% and adjusted R-square of 74.50%. The model displayed an F-ratio of 44.815 with P-value of 0.0000. The rainfall showed an F-ratio of 497.816 with p-value of 0.0000 which is also significant at 5% level. The dummy variables which were significant at 5% level with p-value of 0.0000 had an F-ratio of 10.393. The p-values <0.05 showed that, rainfall was seasonally affecting the dam level by a unit change of 0.0186 (Table 2) in all the months of each year except in the months of April, May and October where the test rejected the null hypothesis. The regression equation of the level of the dam and rainfall was:

Level of dam= 0.0186rainfall+1.1417 January+1.1417 February+…+1.1495 December

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| Table 2: Regression coefficient of Rainfall and Time periods on the Tono dam

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| --- | --- | --- | --- | --- |
| Variable | Coefficient | SE | T-statistics | P-value |
| Rainfall | 0.0186 | 0.0008 | 22.3118 | 0.0000 |
| January | 1.1604 | 0.2610 | 4.4465 | 0.0000 |
| February | 1.1417 | 0.2610 | 4.3785 | 0.0000 |
| March | 0.9883 | 0.2598 | 3.8040 | 0.0000 |
| April | -0.2325 | 0.2527 | -0.9200 | 0.3590 |
| May | -0.4063 | 0.2528 | -1.6076 | 0.1100 |
| June | -1.0340 | 0.2586 | -3.9991 | 0.0000 |
| July | -1.2275 | 0.2672 | -4.5945 | 0.0000 |
| August | -1.9928 | 0.2896 | -6.8809 | 0.0000 |
| September | -1.0159 | 0.2600 | -3.9071 | 0.0000 |
| October | 0.4165 | 0.2540 | 1.6399 | 0.1030 |
| November | 1.0527 | 0.2607 | 4.0374 | 0.0000 |
| December | 1.1495 | 0.2376 | 3.1339 | 0.0000 |

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Night time temperature was well fitted with an F-ratio of 14105.1 and p-value of 0.0000. The time periods also showed significantly well with an F-ratio of 21.5 and p-value of 0.0000. The regression model showed F-ratio of 1186.6 and p-value of 0.0000 with an R-square of 98.83% and an R-square Adjusted of 98.75%. Night time temperature affected the level of the Tono dam (Table 3) negatively by a unit change of -0.03262 besides the months of February, March, May and October all other months were significant at p<0.05. The relationship between the level of the dam and night temperature was:

Level of dam= -0.03262 night time temperature+-0.1467January+1.1417February+…+1.1495 December

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| Table 3: Regression coefficient of Night time temperature and the Time periods on the Tono dam level

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| Variable | Coefficient | SE | T-statistics | P-value |
| Night time temp | -0.0326 | 0.0003 | -118.765 | 0.0000 |
| January | -0.1467 | 0.0211 | -6.913 | 0.0000 |
| February | -0.0415 | 0.0211 | -1.971 | 0.0500 |
| March | 0.0240 | 0.0211 | 1.138 | 0.2570 |
| April | 0.0554 | 0.0211 | 2.629 | 0.0090 |
| May | 0.0344 | 0.0211 | 1.635 | 0.1040 |
| June | 0.0764 | 0.0211 | 3.629 | 0.0000 |
| July | 0.1126 | 0.0211 | 5.346 | 0.0000 |
| August | 0.1535 | 0.0211 | 7.288 | 0.0000 |
| September | 0.0445 | 0.0211 | 2.111 | 0.0360 |
| October | -0.0220 | 0.0211 | -1.045 | 0.2970 |
| November | -0.1389 | 0.0211 | -6.596 | 0.0000 |
| December | -0.1526 | 0.0211 | -5.236 | 0.0000 |

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## 3.3 Model accuracy and selection

Before fitting a model, there is the likelihood that, two or more models will compete hence the need to choose the most appropriate model for the data. The dam level data was deseasonalised to make it stationary and because of that the decomposition model was employed and the model accuracy result revealed that, the additive decomposition model handles the data well since MAPE, MAD and MSD were lower as compared to the quadratic model (Table 4). The data was deseasonalised and the remaining components (the trend and white noise) was modeled by both linear and quadratic trend model and the accuracy measure showed that, the quadratic model best handles the trend line in the data (Table 4).

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| Table 4: Model accuracy and selection

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| **Decomposition models** |
| Model | MAPE | MAD | MSD |
| Additive model | 7.5918\* | 0.0533\* | 0.0064\* |
| Multiplicative model | 7.6049 | 0.0534 | 0.0067 |
| **Trend analysis models** |
| Linear trend | 7.3170 | 0.0533 | 0.0067 |
| Quadratic trend | 7.1645\* | 0.0522\* | 0.0065\* |

\*The best model selected for the data |

**3.4 Trend analysis and projections of the Tono dam level in the Upper East Region**

The analysis on the dam level data was carried out to make projections into the future. Before 2006, there was an increasing trend of the dam but after 2006, the dam showed a decreasing pattern of the dam level with time into the future (Figure 2).

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| Figure 2: Trend analysis of Tono dam level in the Upper East region of Ghana*Trend equation: Yt = -0.777+0.00079t-0.0004t2* |

The projection of the dam levels into the future depicted a decreasing trend with the quadratic relation: yt=-0.7770+0.000791t-0.000004t2 where y is the depth of the water and t is the time in every 3-years. The quadratic aspect of the graph depicted that; measures must be put in place to conserve water in the Upper East Region.

1. **Discussion**

Both day and night time temperatures negatively correlated with the depth of the Tono reservoir and contributed to the decline of the reservoir as temperature increases. Day and night temperatures had negative impacts on the reservoir with coefficients of -0.0219 and -0.03262 respectively. The contribution of day time temperature to the decline of the dam was greater than that of the night temperature because during the day, temperatures are higher ranging between 41.100C and 26.100C as compared to night time temperature which ranged between 29.100C and 13.250C (objective one). During the day transpiration and evaporation are higher as a result of the higher day time temperatures. Human activities such as deforestation and farming along river banks and along the reservoirs resulted in siltation and increase the surface areas of water resources that aggravate evaporation. Also deforestation exposes the land surface and increase run off which may not enter into the feeding rivers.

Rainfall had a positive coefficient of 0.0186 on the fall of the Tono reservoir in the Upper East Region. The average rainfall figures in the region were in the range of 455.50 and 0.00 mm. The contribution of rainfall to the depth of the Tono reservoir with a coefficient of 0.0186 was significant but was not enough to increase the level of water in the dam because of many detractor factors such as temperature, evaporation, transpiration and low or infrequent river flow to the dam. What would increase the level of the dam at Tono reservoir is a continuous flow of water into the dam from rivers which takes their sources in Burkina Fasso. However, these rivers are dry streams and dry up in some periods of the year as a result of human activities largely from Burkina Fasso.

A decrease in the depth of water indicated a decrease in available water for fish. Also since the water is also used for irrigation farming, the impact on catch would be negative in the future when available water is reduced (Boko et. al., 2007) in the Upper East Region who are both fishing and farming. A continuous decrease in the depth of water at Tono could result in drought (Bates *et al*., 2008) because the reservoir increases in water depth only in June, July and August. This implies that fishermen would have to compete with farmers for at least nine months of the year for the water resource for both fishing and farming. A competition for the inadequate water resource would result in both direct and indirect consequences for human livelihoods (Pavel, 2003). A direct consequence is a reduction in the size and quantity of fish and indirectly as in extinction of fish species because some fish species cannot survive in shallow waters. Crop production which was envisaged to take place throughout the year would not be possible because the dam must be shut down to prevent its collapse and also for domestic purposes. The average annual depth of the dam was between 3.7m and 8.0m and was enough for fish culture according to Bernacsek (1984) who suggested that a water level in a reservoir within the range of 2.5-4.0 m is suitable for fish culture.

1. **Conclusion**

An increase in both day and night temperature resulted in a decrease in the Tono dam level and an increase in rainfall resulted in an increase in the depth of Tono dam. However, since rainfall in the Upper East Region was decreasing rather than increasing, the levels in the depth of Tono reservoir would continue to decrease. The decreasing level of the dam was a combination of decreasing rainfall and increasing temperatures in the Upper East Region.

The linear coefficient of the quadratic model depicted an increasing trend while that of the quadratic coefficient depicted a decreasing trend but both increases and decreases were at a very slow pace and so the dam level would have been constant for most parts of the year if water was used for only fishing purposes.

It is therefore recommended that irrigated water should strictly be monitored to avoid wastage. Also damaged channels must also be repaired to reduce channel infiltration. The government of Ghana and its counterparts in Burkina Fasso must establish a joint monitoring team along their water bodies to stop farmers from farming along the banks of water bodies. Deforestation must be discouraged with the enforcement of by-laws and the provision of alternatives for wood fuel and charcoal use. More trees must be planted along the banks of water bodies to reduce siltation of reservoirs due to flooding.

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