Geography and Regional Planning

Changing Flow Regime and its Predictability with Climatic Variability in Aya Basin, South Eastern Nigeria

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Abstract

Explicating the changing flow regime and its predictability by climatic variability for Aya River, the most probable explanatory determinant(s) were identified; while the implications of increasing high and low flows were also highlighted. Data on mean monthly water level, rainfall, Pan Evaporation and temperature were collected from documented sources. Analyses techniques included time series, multiple and step-wise regression. The analyses were based on inter-annual deviations in monthly values and intra-annual deviation during the period of 24 years. That the climatic variables jointly significantly explained the general seasonal pattern of water level regime ($F > p < 0.05$) was identified. This was corroborated by the significance of the explanatory coefficients of two of the variables by the multiple and step- wise regression. Thus monthly deviation in rainfall and evaporation were the most significant predictors of the monthly deviation in water level at the mean intra-annual level. At the yearly intra-annual deviation level, the most probable determinant and significant predictor of the yearly variation in changing flow was rainfall. The trend analyses shows that the maximum flow conditions exhibited a cyclic (oscillatory) pattern (variation), while the low flow exhibited positive (increasing) trend. The implication of random fluctuation in maximum flow for agriculture is increasing vulnerability of the floodplain dependent communities to food insecurity due to unexpected inundation of croplands. In case of the increasing low flow, reduced supply would truncate many domestic chores, while increased pressure on available sources would be heightened.

Introduction

The Aya river system, located between $6^0 27'$N and $6^0 53'$N, $8^0 45'$ and $9^0 15'$E (Fig. 1) in Southeastern Nigeria and spanning across seven local government areas in two states - Benue and Cross River State- has rainfall, which varies between annual total of 1500 and 2000mm, with up four to five months of dry season. Temperature is generally high, having mean monthly of $27\text{-}28^0$C. Evaporation reciprocates the rainfall and temperature regime. The flow regime of a river, which is its seasonal variation in volume during the year naturally, varies from year to year. This is more so that the river system is located within the moist-dry tropics, where hydrological variability is an integral part. Thus changing flow regime, characterized in this paper as the changes in the seasonal (intra-annual) pattern of stream flow (water level) variation during the year, at the inter-annual level, is expected.

Climatic variables such as rainfall and evapotranspiration, are more critical dynamic determinants of stream flow regime. Climate in the sub-humid tropics is naturally variable and unreliable during the year and this unreliability can be reflected at the inter-annual level, hence its manifestation in the flow regime. The seasonality and fluctuation of flow in the Aya basin appears to be increasing in recent times. The cause(s) of this apparent changes call of verification given the value of surface water to the communities.

Although the extent of predictability of water level by the climate system is often accentuated or attenuated by other environmental characteristics of the drainage basin (Marchbanks, 2000, Robertson and Macheso, 1998, Pouraghniaei 2001, Scheeder et al 2002, Tucci and Clarke 1998, and Elkaduwa and Sakthivadivel 1999), any analysis of water level variability must begin by relating this to climate as the first presage at least for planning purpose.

There is yet evidence of the assessment of the influence of intra-annual climatic variability on changing flow regime in the Aya river system. Because of geographical location and high dependence on surface water supply, Utang and Ekpoh (2008) have examined the sensitivity and trend based on annual data values. This work of Utang and Ekpoh (2008), which hinges on mean annual values, does not give a true picture of intra-annual conditions whose understanding for planning water supply. As noted by Elkaduwa and Sakthivadivel (1998), annual values of runoff and even runoff to rainfall ratio give the combine effects of storm runoff and base flow and may thereby conceal the actual changes that occurred in the runoff during the relatively wet and dry periods. To discern changes in the seasonal patterns (flow regime) within the annual cycles is imperative.

In addition, given the seasonality of stream flow, it is natural that the changing flow would be influenced by climatic variables that have a seasonal orientation. A clear assessment of the predictability of stream flow would therefore necessitate the elimination of seasonal influences from the data series. This enables the presentation of the data the way it would look if there were no seasonal effects (Keller and Warrick, 2003). In addition, examining the relationship by working with deviation values would eliminate seasonal influence, as well as standardizing the values since they are not represented using a uniform unit of measurement (Udofia, 2006). Understanding the predictability of stream flow based on intra-annual values devoid of seasonal influences is useful for planning, since it is the intra-annual variation that influences domestic water supply.

This study departs from the analysis of Utang and Ekpoh (2008) and investigates the changes in flow regime based on examination of the changing intra-annual pattern of flow regime, while also emphasizing maximum and low flows. The implication of the later for agriculture and domestic water supply are highlighted.

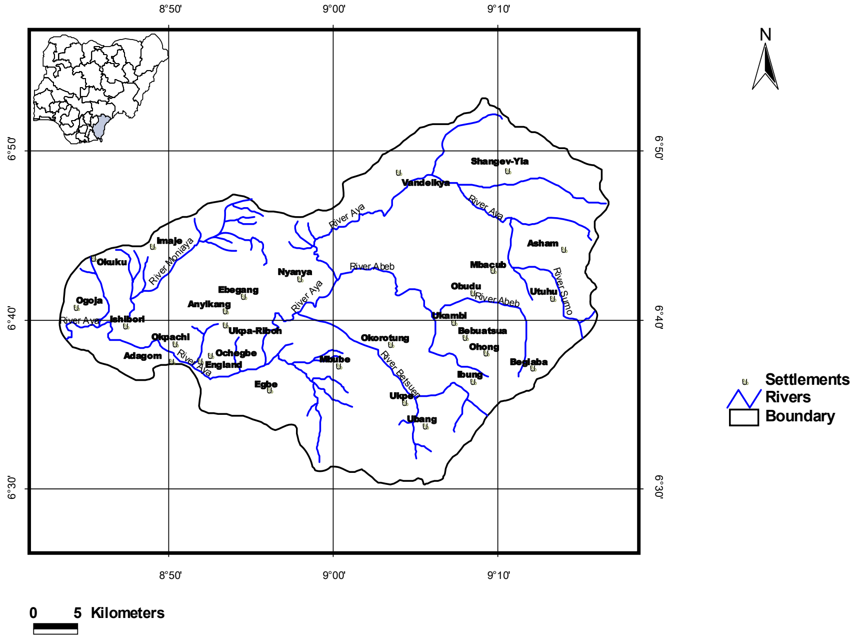

Figure 1: The Aya River System
Insert: Map of Nigeria showing Cross River Basin.

Materials and method of study

The study was empirical and adopted empirical statistical analyses using data of current hydro-climatic variables. Mean monthly rainfall, temperature and evaporation, as well as water level data were used. The data series included mean monthly values derived from the averages of the daily values for each month of the water year (March to February) for twenty four (24) year. The data were collected from two (2) HYDROMET stations, owned by the Cross River Basin Development Authority and one (1) climatologic station, owned by the Nigeria Meteorological Agency (NIMET). Rainfall data based on documented records was obtained from manual rain gauge, while temperature was based on the average from maximum and minimum thermometers in the Stevenson's screen, and evaporation from records using the class A Pan evaporimeter. Water level data was collected from the records obtained using manual metric staff gauge.

The Data as collected from this network of stations were considered adequate enough for practical purposes in hydro-climatological analysis, having been in consonance with the minimum standards of 1-7 rain gauge stations per 10,000 km2, 1 climate station per 30, 000 km2 and 1 discharge gauging station per 30,000 km2 (WMO, 1970 in Wildenhahn, 1984).

Analysis was mainly inferential. Time series analysis was employed to estimate the trend of the data series. In addition, multiple step-wise regression was used to examine the predictability of the changing water level by climatic variables. Since all the variables at the intra-annual scale were likely to be influenced by the season, it was clear that water level would be influenced by the seasonality of the climatic variables. To overcome this natural influence deviation values were used for the regression analyses of the changing flow regime.

Results and Discussion.

Intra-annual hydro-climatic variation: Table 1 show that on the whole, rainfall and evaporation were more variable climatic factors, while water level was equally very unreliable. The mean monthly coefficient of variability indicates that the level of unreliability varies between months and years on the average, based on mean monthly conditions. Although the intra-annual coefficient of variation in Aya River for each year during the period of data ranges between 52.3 and 128.3 %, the mean monthly value was 63.9 % while the mean monthly values range between 23.8 and 93.6 %

These discrepancies (See Table 1) indicate that monthly water level conditions vary between the years. However, June conditions over the period were more unreliable, followed by May and July. June coincides with the second quarter of the rainy season when most floodplain cultivators begin planting flood recession crops such as rice. Thus the unreliable flow in this month as experienced over the years means early planting is at risk as it could be truncated either by reduced or excessive water before the crop is firmly rooted.

Table 1: Mean monthly hydro-climatic series for Aya River, 1982-2006

Month	Rainfall (mm)	Temp^{0}c	Evaporation (ml)	Mean water level (m)	Mean C.V (%)
M	39.7	29.6	5.6	0.62	49.5
A	118.8	29	4	0.33	43.6
M	216.8	27.8	2.6	0.3	59.6
J	260.8	27	2	0.66	93.6
J	271.3	26.4	1.7	1.38	51.6
A	250.1	26.1	1.5	2.37	44.3
S	330.9	26.5	1.9	2.68	32.9
O	258.9	27	2	2.83	27
N	21.09	27.6	3.1	3.39	23.8
D	4.39	26.8	5.2	3.14	24.2
J	8.62	27.4	6.6	1.87	44.8
F	9.13	29.1	6.9	0.97	35
Total	1790		43.1	20.54	529.9
Mean	149.2	27.4	3.6	1.71	44.16
CV (%)	97.3	3.7	54.5	63.9	

C.V = Coefficient of variability

Source: Analysis, 2007 based on data from NIMET and CRBDA

Fig 2 shows the average within year patterns of climatic variables and water level during the period 1981 to 2007. With specifics on rainfall and water level, while the mean seasonal pattern of rainfall is bimodal (July and September) water level has one peak, both parameters however peaking in September. The prominent low flows are in January to April, while the prominent dry months are November to March. A close assessment of the data distribution for individual years shows that this mean pattern does not replicate in all the years. Thus the yearly intra-annual patterns as well as the monthly values vary at the inter-annual scale.

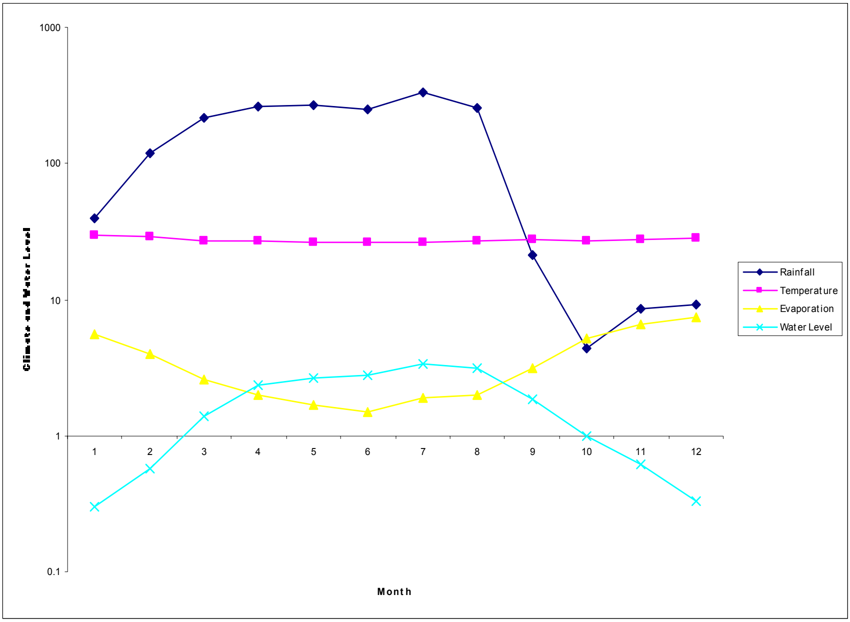

Fig 2: Intra-annual relationship between climatic variables and water level

3.3 Predictability of monthly deviation in inter-annual flow regime by climatic indicators

To understand the underlying causes of the mean intra-annual variation, monthly inter-annual deviation values were analyzed using multiple step-wise regression analyses and these gave the results as shown in equation 1 and 2. The predictability of water level by the climatic variables jointly gave the equation of the form:

$WL = 0.749 + 0.131R + .107T - 0.865E$ (1)

t (3.134) (.548) (.346) (-2.415)

p value 0.014 0.598 0.738 0.042

Rsq = 76.6%; Rsq (adj) = 67.8% F = 8.709; p = 0.007; SE = 0.17633; Mean deviation = 1.18

Where: WL = Water level; R = rainfall; T = temperature; E = evaporation

The coefficient of determination (R square) indicates that the climatic variables jointly and highly (76.6 percent) explained the variability in water level significantly (F > p at 0.05). Given the small standard error of estimate (SE), which incidentally was lower than mean deviation, coupled with significant F and high percent explanation, the model was considered valid and a good fit for predicting water level. The model however reveals that the predictive coefficient of rainfall and temperature were low, while only evaporation had evidence of significant linear relationship with water level (t > p at 0.10). Apart from the fact that the model defied the theoretical, given the positive predictive coefficient of temperature, how can it (the model) be valid and good fit when only one variable linearly and significantly predicted the water level?

One suspicion of the above was the existence of multicollinearity, which according to Keller and Warrick (2003), exists in virtually all multiple regression models. This corroborates WMO (1983), that climatic variables are not truly independent in their influence. To overcome this was to remove the possible redundant variable(s); hence the adoption of the backward step-wise regression analysis.

Since evaporation was already considered a significant predictor of the water level, the first step was to run the analysis without temperature in the model. On this basis, the level of explanation marginally reduced by less than 0.5 percent (equation 2). In addition, the adjusted percentage explanation increased by 3.1 percent. This was significant, valid and a good fit, given F > p at 0.05 and low standard error of estimate. This suggests that the model was more reliable.

$$Y = .805 + 0.136R - 0.772E \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

t (4.795) (0.601) (-3.401)
p 0.001 0.563 0.008
Rsq= 76.2%; Rsq (adj) = 70.9% F = 14.413; p = 0.002; SE = 0.16749; Mean deviation = 1.18

The regression model shows that both rainfall and evaporation significantly predicted water level variation (t > p at 0.10). The new model shows improvement in the level of prediction by rainfall, while the predictive coefficient of evaporation reduced, implying the interaction effects of temperature and evaporation. Generally, while a unit increase in the standard deviation of rainfall increased the standard deviation in water level, evaporation contributed in its decrease.

One the whole, the models show that a unit increases in the standard deviation of evaporation significantly reduced the standard deviation of water level, while rainfall increased the standard deviation on the average during this period of available data used for the study. The evidence of lack of significant linear prediction of flow regime by temperature during the period of the data suggests that temperature was more reliably stable.

Generally, the result of the prediction of water level by the climatic variables over the years, as obtained from the regression model, was a valid and good fit, although the possibility of multicollinearity (inter-correlation between the climatic variables) or chance occurrence of some of the data must have affected the level of explanation. Generally, multicollinearity could have made the tested coefficients to have a small t statistic, hence the wrong inference that there is no significant linear relationship between the monthly deviation in water level and rainfall as presented in model 1.

With collinearity suspected, it is clear, as pointed out by Mather (1979), Johnston (1980) and WMO (1983) that the climatic variables were not truly independent and mutually exclusive. Very little of the intra-annual variation in flow regime based on monthly inter-annual deviation values was thus accounted for by one variable exclusively. However the consistency associated with the relationship between rainfall and evaporation on the one hand and water level on the other justifies that the flow regime was mostly explained by rain fall and evaporation.

Changing intra-annual flow regime and the climatic determinants

An examination of the extent to which changes in the intra-annual deviation in flow over the twenty-four year period were predicted by climatic variability was also carried. Generally the intra-annual flow regime was observed to have varied approximately 49.4 percent as against the 35.8 percent variation based on annual mean values during the same period (table 1). To explore the underlying causes of the changing flow regime and to unravel the most significant predictor of the changing intra-annual flow regime multiple step-wise regression analyses were conducted using the three climatic variables. Despite the evidence that analysis of the overall intra-annual variability was significantly predicted by rainfall and evaporation, this may not be applicable when analyzing changing pattern of intra-annual variation in water level. Analyses results based on joint climatic variables provided the model as shown in equation 3.

WL= 0.325 + 0.638R - 0.009T + 0.001E……………. (3)
t (1.007) (3.649) (-0.055) (0.007)
p value 0.326 0.002 0.957 0.995
Rsq = 40.8%; Rsq (adj) = 31.9% F = 4.591; p = 0.0137; SE = 0.20578;
Mean deviation = 0.629

The result from the analysis shows that approximately 40.8 percent of the changing flow regime was explained by the joint contribution of the climatic variables. This explanation was significant given $F > p < 0.05$. At the same time the model was considered valid and a good fit given the small standard error of estimate. However, only rainfall was observed to have a significant linear relationship with the changing flow regime ($t > p < 0.10$). Intra-annual deviation in rainfall over the years was therefore more variable and unreliable over the years. Thus a unit increase in the standard deviation of rainfall increased the standard deviation of the change in flow regime by 0.638 units. The study corroborates to Utang and Ekpoh's (2008), although this was based on annual mean values rather intra-annual deviations.

The intriguing issue is how the model can be valid and good fit with only one variable linearly related to the flow regime. The possibility of the existence of collinearity was equally suspected; hence the need to remove the redundancies. The first was running the model without temperature. This gave the model as shown in equation 4.

Y = 0.317 + 0.638R + 0.002E……………. (4)
t (1.007) (3.649) (0.007)
p value 0.269 0.001 0.992
Rsq = 40.8%; Rsq (adj) = 35.1% F = 7.228; p = 0.04; SE = 0.20084; Mean deviation = 0.629.

The result indicates that the percentage explanation did not improve much although the adjusted value increased by 3.2 percent. This confirms that temperature did not contribute to the changing flow regime; although its influence must have been attenuated by the other variables. However the model still indicated that only rainfall significantly contributed significantly to the changing flow regime.

To further justify the significant contribution of rainfall, the model was run with only rainfall. The result as shown in equation 5 confirms that rainfall significantly predicted the changing flow regime. The percentage explanation did not change, although the adjusted value increased by 6.2 percent. This implies that evaporation equally attenuated the contribution of rainfall; hence only rainfall evidently had significant influence on the changing pattern of the flow regime during the period under consideration.

Y = 0.317 + 0.639R …………. (5)
t (1.407) (3.892)
p value 0.173 0.001
Rsq = 40.8%; Rsq (adj) = 38.1% F = 15.144; p = 0.001; SE = 0.19622; Mean deviation = 0.629.

In all, temperature and evaporation were reliable over the years and did not contribute significantly to the changing flow regime in Aya River. The unreliable nature of rainfall therefore translated to the changes in seasonal flow regime.

Trends in annual peak and low water level.

Utang and Ekpoh (2008) obtained mean annual trend in the water level of Aya River using regression analysis. The peak and low level trends were not considered. But these are conditions that impact communities more directly. The graphical representations of these, including the regression models, the percentage explanation and test statistics are as shown in figure 2a and b.

Generally, all the models were valid and good fit for estimating mean annual, mean peak and low flow conditions for the twenty four year period of available data. However the small percentage explanation (31%) for the yearly mean peak water level suggests that time was a weak explanation of the nature of peak flow variation. Peak flows were random events, which did not necessarily follow the time trajectory. Thus although the peak flow changed significantly over time, the rate of change was very small compared to that of low flow (53.9%). In addition, the change in peak flow did not follow unidirectional pattern but exhibited irregular /cyclic oscillation. On the other hand, low flow exhibited consistent positive trend.

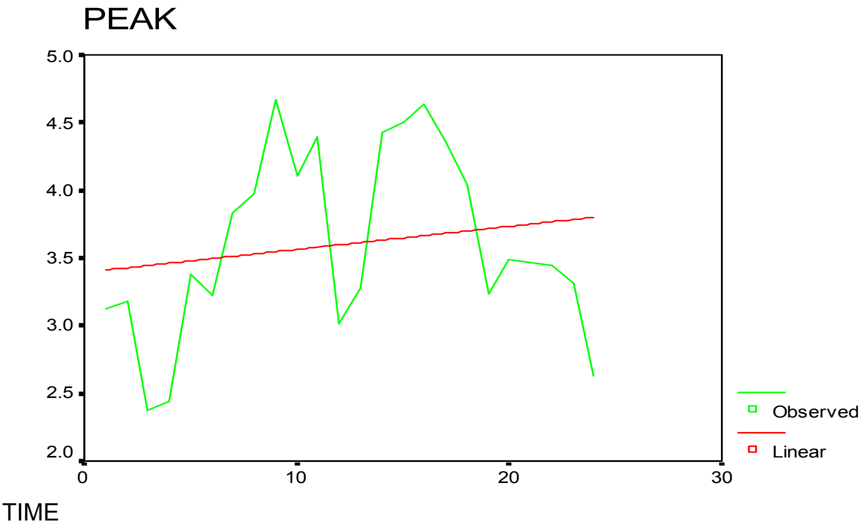

Fig. 2a

$Y = 3.3938 + 0.017t$…………………. (6)

F = 0.71; Sig. F =0.410; RSq = 31%

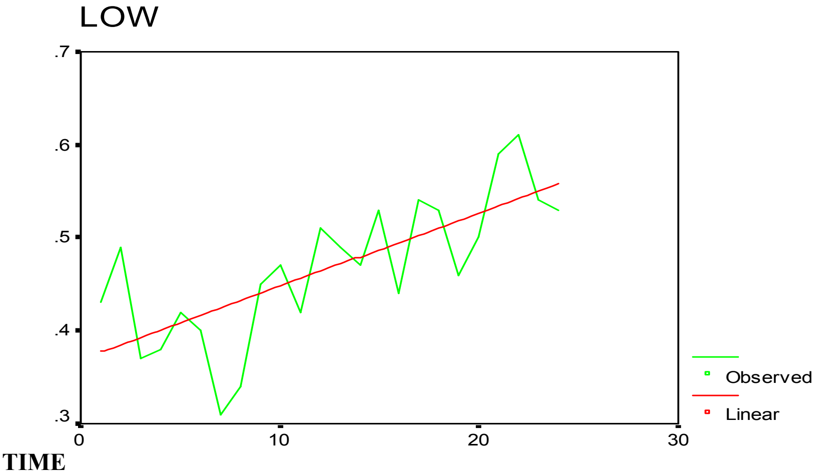

Fig. 2b

$Y = 0.3695 + 0.0078t$…………………. (7)

F = 25.73; Sig. F = 0.00; RSq = 53.9%

Fig 2a and b: Trends in mean peak and low water levels (1982-2005).

Source: Analysis result, 2007

The socio-economic implications of these changes in water level particularly are far-reaching. This is more so with low flow where increasing population would imply stress on available sources and increased demand for surface water during the off season. As noted by Ivey et al (2001), low water levels result in reduction in the amount of water available for use. The likely result is increased conflict with other uses and users due to competition for limited supplies. In addition would be increased cost of development of additional or new alternative or complement sources, such as well drilling and maintenance.

The irregular oscillation of the mean annual peak suggests randomness of peak events these have implications for floodplain ecosystems, partularly agro-based systems Unreliable peak discharge, particularly where the peak flow arrives earlier or later than expected or there is double peak flow has implications for food production as this impacts flood recession agriculture (Adams, 2000). Although the low variability coefficient of peak flow already suggests reliable mean annual peak over the years, this condition may not be same at individual years as double peak flows may occur in some years while unreliable high flows, such as early or late arrival of peak discharges, may be experienced in some years. At the same time the recurrence time for the peak flows above or below mean peak cannot be exactly identified from the oscillatory pattern.

Thus these unusual events are largely unreliable, the dependent communities would be little prepared, being not adapted to the seasonal peak regime. This supports Abler, Adams and Gould's (1977) assertion that where events are rare, people's memories appear to be short and nothing is done to alleviate the problem. Where events are quite frequent, and the hazard is constantly brought to attention of the people, adjustments are nearly always adopted. Inline with Adams (1999) in Adams (2000) valley farmlands can be loss if flood peaks occur in a manner that is as variance with the natural regime that the farmers are already adapted to.

Conclusion

The intra-annual flow regime in Aya is highly variable and unreliable. Although this is significantly a function of the interaction of climatic factors, rainfall is rightly the most probable determinant. Seasonal regime has implication for human activities that depend on water supply from the river. For instance, variable peaks have implications for flood recession agriculture which many floodplain cultivators are adept at, while changes in very low flow conditions affect domestic water supply during the dry season. Changing flow regimes are expected to continue in the future, particularly as climate is projected to experience increased variability, while human activities within the watershed would continue to exacerbate the climatic imprint. Given the changing flow regime of Aya River and its predictability by rainfall, the global climatic scenario as projected, which has the potential of increasing the rainfall regime, would further alter flow regime within the basin. Because this has the potential to alter the established economy that is dependent on supply from the river system, the dependent activities of the rural folk would suffer more monumental effects from changing regime in the future.

The possibility of reduced low flows for example would be reflected in reduced dependency on reliable supply of good quality water, particularly in downstream areas, during periods of less rainfall. Consequent upon this is the fact that the modification of the landscape would accelerate the impact of changes in flow regime, such as changes in the time distribution of runoff with attendant reduction of low flows and increase in high flows. Thus the need for mainstreaming climate change in planning and to protect the critical headwaters and riparian vegetation is imperative.

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