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Rainfall and runoff variability in the southwestern river system of Ghana

Y. OPOKU-ANKOMAH & B. A. AMISIGO
Water Research Institute (CSIR), PO Box M 32, Accra, Ghana

Abstract A number of water resources development schemes including hydroelectric and water supply projects, have been planned in the southwestern river system of Ghana. However, most of the data sets used in the hydrological studies were short and the present study examined the temporal variation and changes in the rainfall and runoff series of the river system. Plots of annual, wet and dry season rainfall and runoff revealed a reduction in magnitudes from 1950–1970 high values to 1971–1991 low values. The changes in the dry season runoff were in particular remarkable. Statistical tests showed that the changes in rainfall and runoff for the two time periods were significant at the 5% level. The flows exceeded 95% of the time can give some indications of low flow dependabilities. Values computed from 1950–1970 and 1971–1991 gave 71 and 17 $m^3 s^{-1}$ respectively. Thus the reliability of using runoff for water resources schemes without impoundment could be very optimistic if only data ending in the seventies are used.

INTRODUCTION

Assessment of surface water resources in a basin for planning and development of water projects is always carried out on the basis of the long-term flow characteristics. Long-term data sets incorporate low and high flows inherent in natural hydrological series and are able to depict the true characteristics of the flows in the basin. Human activities such as deforestation and those associated with the emission of greenhouse gases can have a permanent influence on the climate and long-term data sets may represent different populations of hydrological series. Such changes need to be evaluated for the management of existing water resource systems and planning and development of future ones.

A number of water resources development schemes including hydroelectric and water supply projects have been planned for the southwestern river system of Ghana (Hydroproject Czechoslovakia, 1986). However, the data sets used in the studies were short and most were before the eighties. The present study examined the temporal variation and changes in the extended runoff series and the water resources of the river system. In order to gain a clear understanding of possible changes in the runoff, rainfall series in the basin were also examined.

A couple of studies have been carried out to examine runoff variabilities in West Africa and these include Aka *et al.* (1996) and Lavender & Anderson (1984). Aka *et al.* found a break in the series of annual mean discharges at the beginning of the 1970s for some flows in La Côte d'Ivoire. Lavender & Anderson in their study, however, did not find any declining trend of runoff in Africa but rather a strong periodic fluctuation between wet and dry periods. These studies considered only runoff without rainfall, which might offer some explanation.

STUDY AREA

The area of study covers the southwestern river system in the southwestern corner of the country. Four river basins: Bia, Tano, Ankobra and Pra constitute this river system (Fig. 1). The Pra basin is the biggest and covers an area of about 23 000 km^2 of the total area of the river system.

This river system is in the most humid part of the country with annual rainfall between 1500 mm and 2000 mm. The region receives a large amount of rainfall during the rainy season from moist southwest monsoons. In the dry season, the region comes under the influence of the northeast trade winds or the Harmattan.

The primary vegetation types of the area are the rainforest and semi-deciduous forest. Lumbering is a major activity in the area because of the forest resources. The soils in the region are forest oxysols and forest ochrosols, the latter suitable for agriculture. The underlying rocks of the river system are Birrimian and Tarkwaian. There are good deposits of mineral ores including gold and diamond. The area has potential for development due to its rich natural resources.

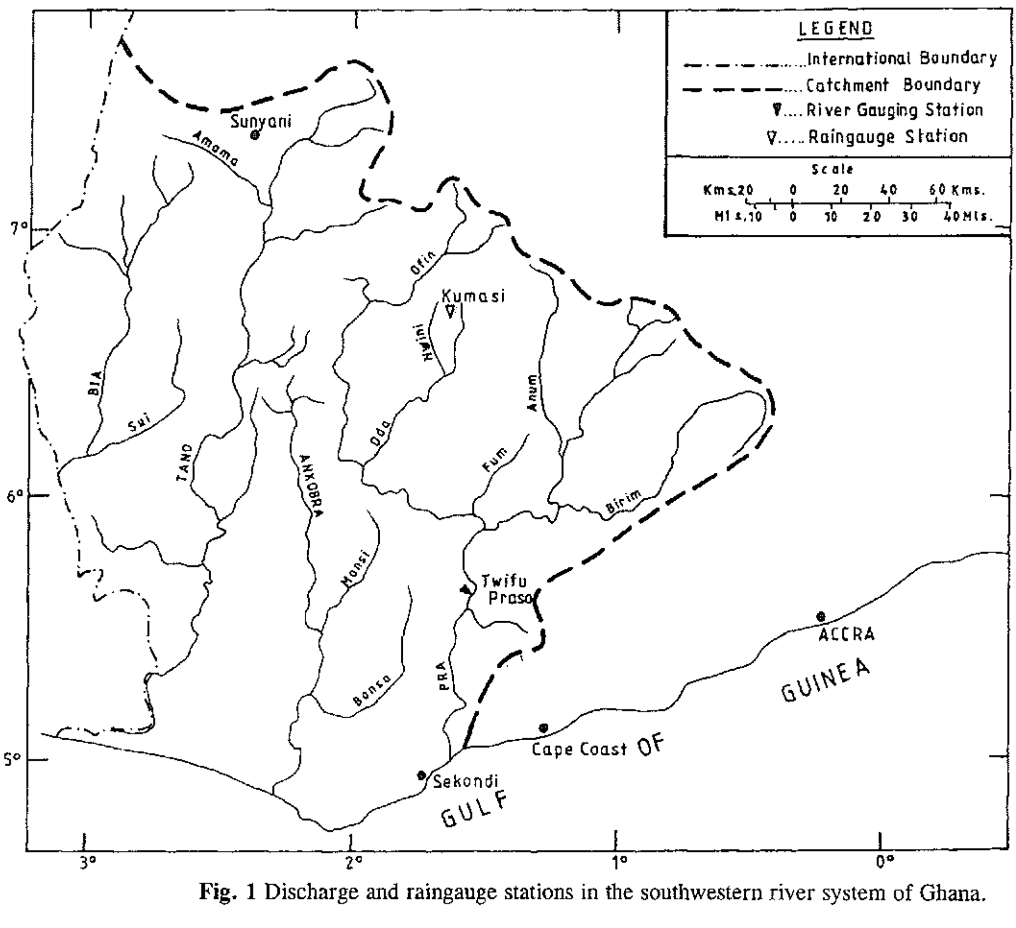

Fig. 1 Discharge and raingauge stations in the southwestern river system of Ghana.

DATA

Two sets of data were used in the study: daily discharges and monthly rainfall totals. Long data sets of good quality are normally required in investigating temporal variations and changes in hydrometeorological data series. Thus daily discharges from Twifo-Praso in the Pra basin and rainfall data from Kumasi synoptic station were used. The available discharge data set for Twifo Praso is from 1951 to 1991 and thus rainfall series of the same length were used for comparison. The rainfall data available is much longer than the period chosen. Only these data sets were used in this study because of the need for long data series with good quality. Missing daily discharge data were estimated from nearby stations where records were available. The daily discharges were further converted to monthly mean discharges.

METHODS

The analyses were carried out on an annual and a seasonal basis. The annual discharges were obtained as averages of monthly discharge for each calendar year. Similarly, the seasonal discharges were obtained as averages over the season. The wet season was taken from May to October and the dry season from November to April of the following year.

For the rainfall series, annual totals and seasonal totals were computed. The series for the discharges and rainfall were plotted together for each case; i.e. annual, dry and wet seasons were plotted together for comparison.

The plotted data series showed a change in the time series around 1970 and thus each of the series was divided into two periods: 1951–1970 and 1971–1991. Statistics on the time series for each of the periods were computed. Two tests of significance on the difference in the means of the divided series were carried out. The first test is a parametric pooled *t*-test, which assumes the underlying distribution to be normal. Moderate departure from normality may not adversely affect the procedure (Hines & Montgomery, 1980). The test statistics, t_0, is computed from the sample means and variances. The sample variances are combined or pooled to estimate the common variance. The degree of freedom for the test statistics is $n_1 + n_2 - 2$ where n_1 and n_2 are the sample sizes of the sub-series whose means are being tested.

The rainfalls and discharges both showed a reduction and thus the test employed was:

$$H_0: \mu_1 = \mu_2$$

$$H_1: \mu_1 > \mu_2$$

where H_0 and H_1 are the null and one-sided alternative hypothesis; μ_1 and μ_2 are the sample means for the 1950–1970 and 1971–1991 respectively.

The second test used was the Wilcoxon two-sample non parametric test. It does not assume any underlying distribution. The method involves ranking the samples or the historical series, followed by computation of rank sums of the two sets of series of which the means are being tested for differences. The test was also applied for a one-sided alternative at a 5% level of significance as in the *t*-test.

RESULTS AND DISCUSSION

The plots of rainfall totals and discharges for the annual, wet season and dry season are shown in Figs 2, 3 and 4 respectively. In each of the plots, a decline in the time series beyond 1970 was evident. The decline observed in each case was however not a continuous downward trend but a change to some mean position.

The statistics computed for the rainfall and the discharges for the 1st and 2nd periods are shown in Tables 1 and 2. The parameters are mean, coefficient of variation (CV), maximum (MAX) and minimum (MIN). The CV is a measure of variability normalized by the mean and is useful for comparing variations in different variables (i.e. rainfall and runoff) and was thus presented instead of the standard deviation.

Figure 2 and the results presented in Tables 1 and 2 for the annual data show that the changes in the annual mean discharges are more severe than the annual rainfall totals. All these changes were found to be significant at 5% level in both tests. Similar results for the seasonal analyses were found for the discharges and rainfall as shown in

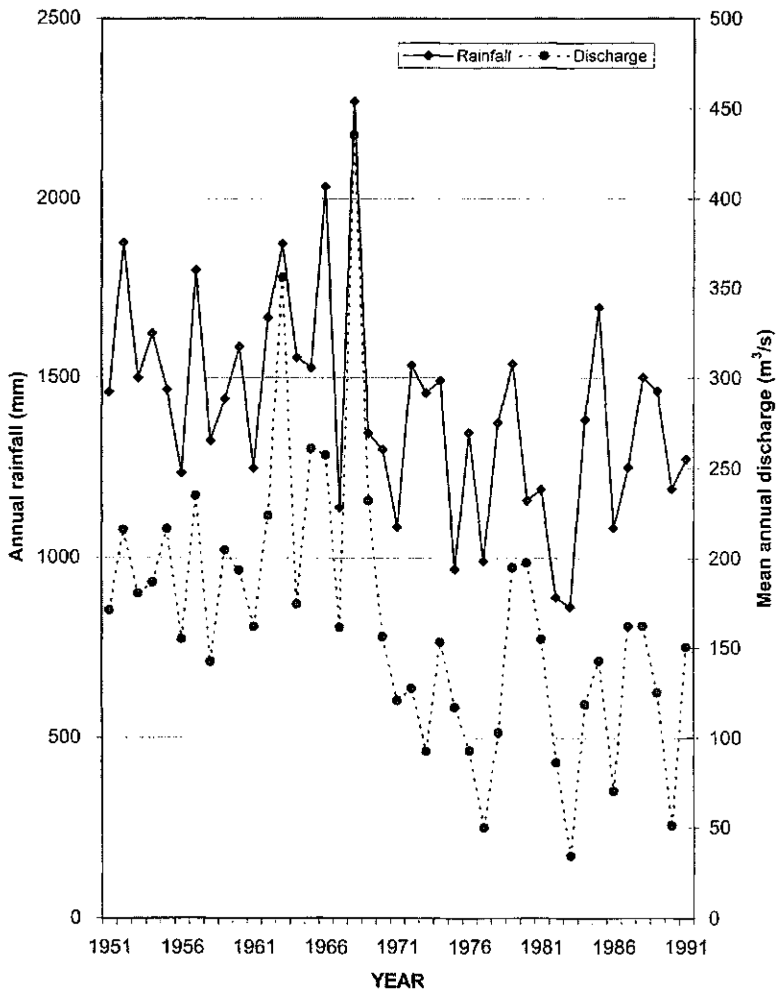

Fig. 2 Annual rainfall and mean annual discharge.

Figs 3 and 4 and in Tables 1 and 2. The t_0 computed ranged between 2.22 and 7.85 and were all greater than $t_{0.05,\,38}$ which is equal to 1.68 (38 is the degree of freedom). Thus, the null hypothesis was rejected and the alternative hypothesis accepted. The t_0 for the dry season flow is 7.85 and it is the most significant.

Comparing the changes in discharges among the seasons (Figs 3 and 4), it is observed that the dry season flows which are more critical to water resources system performance have undergone considerable changes: the second period mean flow is only 37% of the first period for the dry season (Table 2). The flows exceeded 95% of the time for the first and second periods are 71 and 17 $m^3\ s^{-1}$ respectively. Thus low flow dependabilities computed from only the first data set could be very optimistic and misleading. The wet season changes are less, however, they are still significant in magnitude.

The differences in the variances that could be compared by the CV in the two time periods were not quite significant for both rainfalls and discharges for the annual and wet season. However, for the dry season the CV has almost doubled for the rainfall and

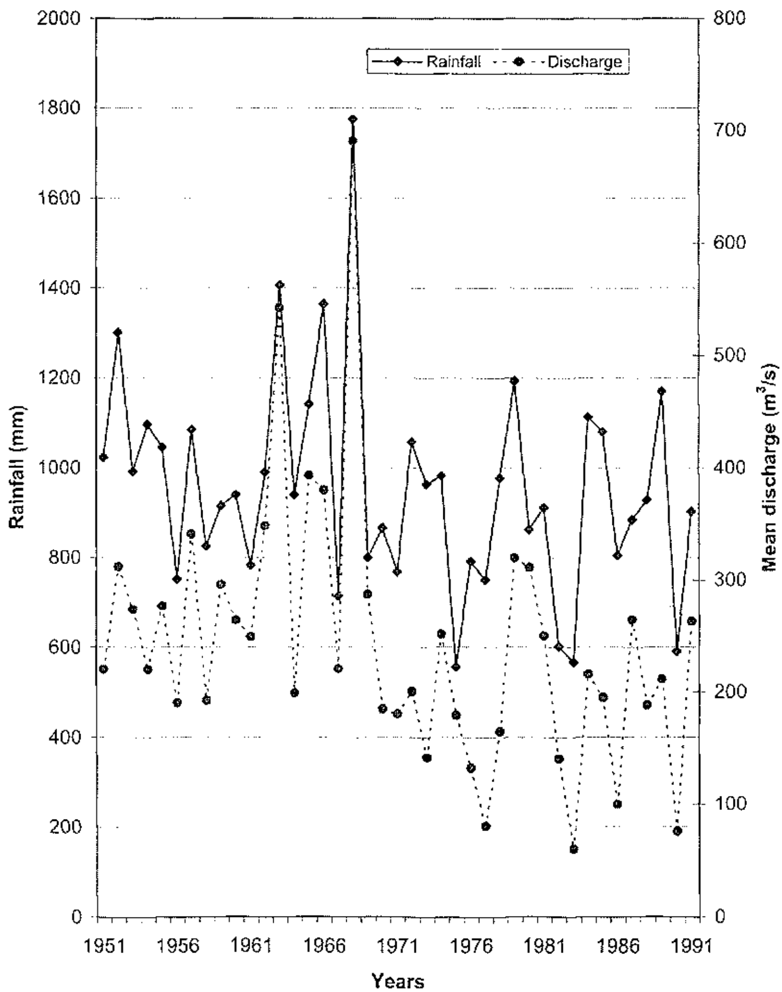

Fig. 3 Rainfall and mean discharge for the wet season.

discharge in the recent period. Thus it is important to note that the discharges in the second period are much less reliable than during the dry season than in the first period.

These changes observed for the discharges and rainfall are all significant whether seasonal or annual but the question is: what is causing these changes? First the changes observed in the discharges and the amount of water resources could be attributed, in a large measure to the changes occurring in the precipitation phase of the hydrological cycle. The reason is that the changes in the rainfalls and discharges are concurrent, although the extent of changes in the latter is more severe. The large decrease in the discharges or runoff as compared to the rainfall must be associated with evapotranspiration, which must be satisfied before runoff. Changes in the land-use practices could also worsen the situation. Further studies will need to be carried out to examine this in detail. The decrease in rainfall amount could be considered as a primary factor causing the decrease in runoff and this is discussed further. This current decrease in rainfall may be assumed to part of a periodic fluctuation normally inherent in climatic data (Lavender & Anderson, 1984). However, the persistence in the current

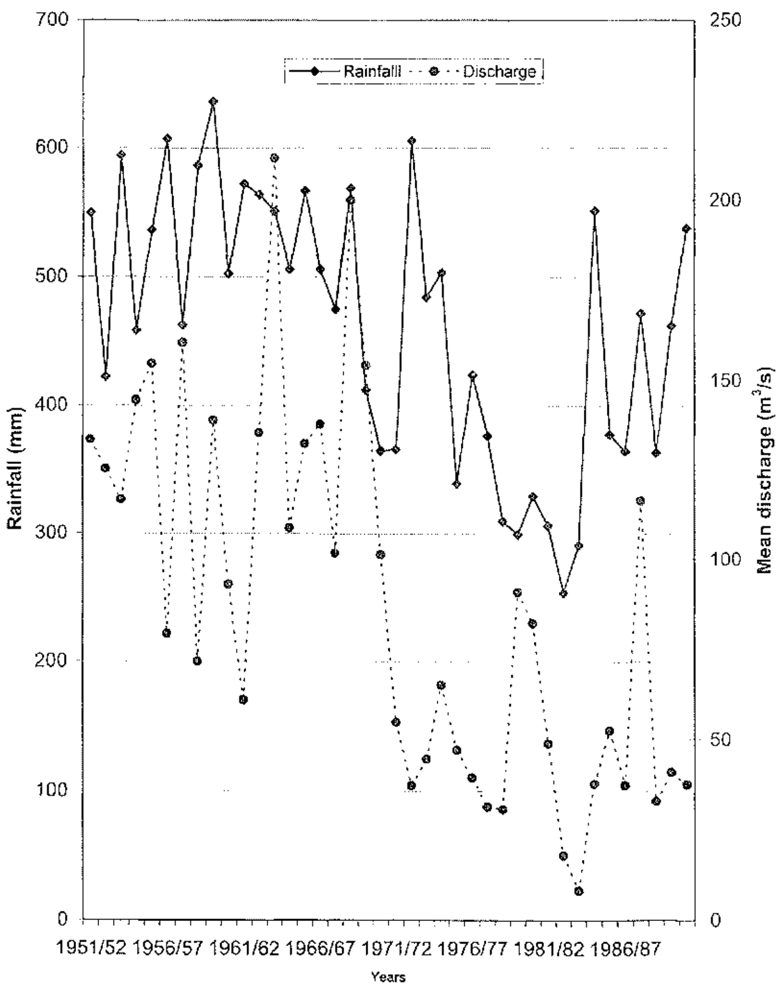

Fig. 4 Rainfall and mean discharge for the dry season.

Table 1 Statistics for rainfall.

		1st Period	2nd Period	2nd Period/ 1st Period (%)
Annual rainfall	Mean (mm)	1563.70	1273.90	81.5
	CV	0.18	0.18	
	MAX (mm)	2270.25	1696.40	
	MIN (mm)	1140.46	864.80	
Wet season	Mean (mm)	1037.55	879.03	84.7
	CV	0.25	0.22	
	MAX (mm)	1774.44	1193.60	
	MIN (mm)	714.25	555.72	
Dry season	Mean (mm)	522.21	400.83	76.9
	CV	0.14	0.25	
	MAX (mm)	636.27	605.54	
	MIN (mm)	364.74	253.50	

Table 2 Statistics for runoff.

		1st Period	2nd Period	2nd Period/ 1st Period (%)
Annual rainfall	Mean (mm)	215.68	119.28	55.3
	CV	0.33	0.38	
	MAX (mm)	435.12	197.54	
	MIN (mm)	141.98	33.81	
Wet season	Mean (mm)	303.97	187.03	61.5
	CV	0.41	0.40	
	MAX (mm)	690.32	320.30	
	MIN (mm)	185.04	59.51	
Dry season	Mean (mm)	127.97	47.60	37.2
	CV	0.30	0.53	
	MAX (mm)	211.43	116.30	
	MIN (mm)	60.90	8.13	

observed dry years since that study with frequent droughts leads one to reject this proposition. Climate change arising out of the increase in emission of greenhouse gases and continuous process of deforestation are more likely to cause the current decrease in mean rainfall and consequently runoff. Ongoing research of the impact of climate change on water resources in Ghana will seek to shed more light on this.

CONCLUSION

The study showed that rainfall and discharge decreased from the 1951 to 1970 mean to a lower mean from 1971 to 1991. Statistical tests showed that the changes in all the means were significant at the 5% level. Further, the decreases observed in the discharges were greater than those observed in the rainfalls.

In the seasonal analyses, the dry season rainfalls and flows were found to be much reduced in the second period of 1971 to 1991. The flows exceeded 95% of the time in the dry season for 1951–1970 and 1971–1991 periods are 71 and 17 $m^3 s^{-1}$ respectively, which are quite different in magnitude. The reduction in dry season flow, which is more associated with the base flow, may be linked to reduction in infiltration of water to groundwater store during rainy season. Less water being infiltrated must be associated with less rainfall amount and high evapotranspiration demand in the hydrological processes.

The reduction in rainfall, which is a primary factor in the reduction of runoff, must be linked to the influence of climate change. The period of reduction in runoff observed in this study is similar to the results of the study in La Côte d'Ivoire with the same humid climatic conditions.

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