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# FLOOD PULSE ALTERATIONS OF SOME RIVER BASINS IN GHANA

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## Abstract
Flood analysis is crucial for designing drainage, managing water quality, assessing the impact on lives and properties among others. The objective of the study was to determine the trends, occurrences and magnitude of floods in Ghana using hydrological data. The study looked at flood phenomenon in Ghana, because flooding has been observed recently as the most common natural hazard in the country. Specifically, the rainfall amounts from selected gauging stations in Ghana and river discharges from the three main river systems namely, Volta (at Bamboi), south western (at Twifu Praso) and the coastal (at Okyereko) river systems in Ghana were considered. Peak streamflows from the selected river systems were also analysed. Flood frequencies were derived using the flow duration curve (FDC), and the high flow frequency (return period) determined to support the analysis. The threshold values above which streamflows are peak flow were estimated from the FDC at 90 per cent probability of non-exceedance for the selected rivers. The results of the analysis showed that increases in the number of occurrence of high streamflows with declining trends of monthly rainfall in the last decade (2000-2010) have been prevalent. This means that rainfall amount is not necessarily the major cause of recent high streamflows (or flood), though there are evidences of direct runoff during rainy season in Ghana. It is, therefore, recommended that as a country, there is the need to improve the drainage systems in the cities, and also provide adequate storage for floods during the rainy seasons. It is further recommended that flood pulse analysis be carried out on a continuous basis as and when new meteorological and hydrological data is available.

## Introduction

Floods in Ghana have become a major environmental problem causing loss of lives and property and displacement of people. Major low-lying areas are subjected to severe perennial flooding which is generally attributed to flaws in drainage design, improper waste management leading to siltation, and reduction in the carrying capacity of drains. Some of the major cities in Ghana which have been severely affected over the years include Accra, Tamale, Bolgatanga, Sekondi-Takoradi and Kumasi. In terms of coastal flooding, areas like Ada, Dansoman-Glefe area (Greater Accra) and Agavedzi-Kedzi area (Volta Region) are most vulnerable (Kankam-Yeboah *et al*., 2011; Kagblor, unpublished).

Despite the commitment to physical infrastructural development such as roads, runoff channels and storm drains constructions to assuage flood effects, the situation never gets better. Flooding and flood damage especially in Accra is a serious issue. (Ludlow, 2009). Flooding in Accra has become a perennial rainfall ritual that does not receive the needed attention any longer, because various interventions in the past had yielded little results. These interventions may be ad-hoc measures, because the cause-effects had not been studied enough to warrant pragmatic interventions. Between 1955 and 1997, an estimated GH¢30,000,000.00 worth of properties were destroyed, 100 lives were lost either during the flood period or after the floods and 10,000 people displaced from their homes (Adinku, 1994).

Due to this preventable loss, the Government of Ghana has implemented major projects (since 2000) to improve drainage systems and address the perennial flooding in the country. Most notable among them include the Korle Lagoon Ecological Restoration Project (Afeku, 2005), and the construction of Odaw river drains at Kwame Nkrumah Circle. In addition, statutory agencies such as the Ministry of Water Resources, Works and Housing (MWRWH), City Engineers of Accra Metropolitan Assembly and Lands Department were established to see to the reduction of the effects of flooding on life and properties (Nyarko, 2000).

The specific objective of the study was to determine the trends, occurrences and magnitude of high streamflows in Ghana using hydro-meteorological data of the three river systems in Ghana. The goals of the study were to (i) use the outcome of the analysis of short-term existing dataset as a tool in predicting preventive, and mitigative approaches that would provide better management options and, (ii) provide scientific data and information to engineers and city planners for proper design and decision making.

## Experimental

*Study area*

The three main river systems in Ghana, i.e. the Volta, south-western and coastal river systems that cover approximately 70 per cent, 22 per cent, and eight per cent, respectively of the total area of the country (Kankam-Yeboah *et al.*, 2011) were studied (Fig. 1). The Volta system consists of the Black and White Volta rivers and the Oti river systems. These three rivers run through Upper West, Upper East, Northern Region, parts of the Brong Ahafo, Ashanti, Eastern and Volta Regions of Ghana. The south-western river system includes the Bia, Tano, Ankobra and Pra rivers. These cut across parts of Ashanti, Eastern, Central and Brong Ahafo Regions of Ghana. Finally, the coastal river system made up of the Ochi-Amissa, Ochi-Nakwa, Ayensu, Densu and Todzie Aka rivers span the Greater Accra, parts of the Central, Eastern and the Volta Regions of Ghana.

*Drainage*

The total annual runoff from all the three river systems in Ghana is estimated to be 56.4 billion $m^3$ of which 41.6 billion $m^3$ is accounted for by the Volta river. The mean annual runoff from Ghana alone is 38.7 billion $m^3$ which is 68.6 per cent of the total annual runoff. The Volta, south-western and coastal systems contribute 64.7 per cent, 29.2 per cent and 6.1 per cent, respectively, of the annual runoff from Ghana (CSIR-WRI, 2000).

*Hydro-meteorological data collection*

Daily mean streamflow data for the period 1980–2008 were obtained from the Hydrological Service Department (HSD) of the Ministry of Water Resources, Works and Housing (MWRWH), Accra, Ghana. These were obtained from two different sources namely, the CSIR-Water Research Institute (CSIR-WRI) and the Ghana Meteorological Agency (GMet) both in Accra. Specifically,

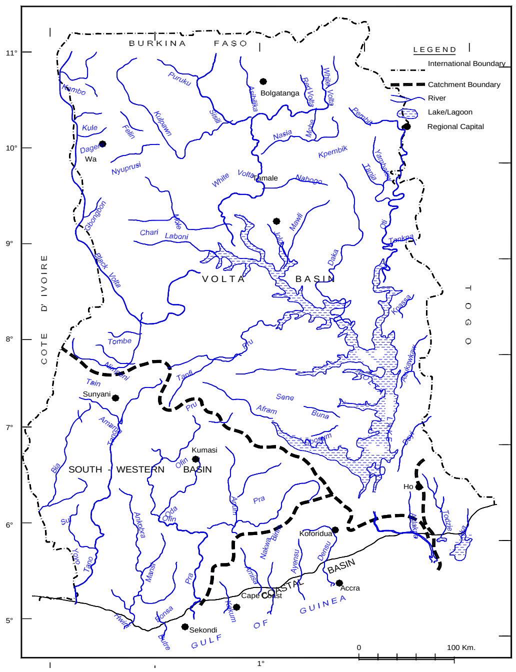


Fig. 1. Main river systems in Ghana

the monthly rainfall figures for Accra collected from CSIR-WRI and the others (Table 1) from GMet were used. Generally, the rainfall data were collected for the periods 1980 – 2008. Except for the south-western river system, due to limited availability of data, rainfall figures for the period 1995 –2008 were used.

*Flood analysis*

The arithmetic mean method was used to compute the monthly mean streamflow values for the river stations for the period 1980 – 2008 to determine the monthly flood situation. On the other hand, the monthly rainfall totals for the period 1980 – 2008 were computed for each synoptic station by summing rainfall values for each month. The mean monthly rainfall for each river system was also computed by calculating the arithmetic mean of the monthly rainfall totals from at least three rainfall stations within the river system. Table 1 shows the selected river flow and rainfall gauging stations used for the analysis.

*Filling-in of missing gaps using correlation coefficient*

Missing gaps in both the rainfall and river discharge data were filled-in using data from synoptic stations with good correlations. Missing streamflow figures for Twifu-Praso, Okyereko and Bamboi stations were filled-in with flow data from Assin Praso, Oketsew and Bui, respectively, because they gave good correlation coefficients.

*Extraction of high streamflows and corresponding rainfall amounts*

Two main methods are used in extracting

TABLE 1

*Selected river flow and rainfall gauging stations of the river systems in Ghana*

| *River systems* | *Selected flow and rainfall gauging stations* | |
|---|---|---|
| | *River flow gauging stations* | *Rainfall gauging stations* |
| Volta | Bamboi and Bui | Tamale, Wa, Navrongo, Bole and Kete-krachi |
| South-western | Twifu Praso and Assin Praso | Oda, Dunkwa-on-Offin and Kumasi |
| Coastal | Okyereko and Oketsew | Accra, Asamankese and Agona Swedru |

high streamflows from the complete streamflow series; the annual maximum series and the peak-over-threshold methods (Chow *et al*., 1988). The former method extracts annual maximum streamflow from the complete flow series, while the latter method depends on a specified threshold above which all streamflows are high flows (Willems, 2007). For long duration streamflow series (about 50 years), the annual maximum series method is most widely used. However, for short duration streamflow series, the use of the annual maximum flows method leads to a lower number of extreme streamflows values, which can result in less accurate flood analyses. In that case, the peak-over-threshold method is used (Willems, 2007). The threshold selection can either be based on physical or statistical considerations.

The peak-over-threshold method was adopted in extracting the high streamflows due to the short duration of streamflow data and missing gaps in the data available. For each extracted high streamflow, the corresponding mean monthly rainfall amount for the period of record was also extracted for the analysis. The threshold selection was based on statistical considerations, where the minimum threshold value above which all flows were high flows, was estimated from the flow duration curve (FDC) using the probability of non-exceedance. The extractions were done using the Microsoft Excel software (by selecting, copying and pasting in new columns the high streamflows that are equaled or not-exceeded 90% of the time; i.e., from 90% to 100% probability of non-exceedance).

*Derivation of river discharge from flow duration curve*

One of the most informative methods of presenting the complete range of river discharges from low flows to flood events is by the use of FDC. The FDC defines the relationship between any given discharge value and the percentage of time that this discharge is equaled or exceeded or not exceeded (Smakhtin, 2001; Mays, 2005). Generally, FDCs may either be calculated as follows: (1) On the basis of the whole available record period (Vogel & Fennessey, 1994), or long-term average annual (Smakhtin *et al*., 1997), or (2) on the basis of all similar calendar months (long-term average monthly FDC) or all similar seasons (long-term average seasonal FDC) from the whole record period (Smakhtin *et al*., 1997).

The period of record for FDC represents variability and exceedance probability of flow over the available period. Vogel & Fennessey (1994) considered FDCs for individual years and treated those annual FDCs in a way similar to a sequence of annual streamflow maxima and annual streamflow minima. This interpretation of the method allows mean and median FDCs to be estimated.

Thus, the FDC was constructed in Microsoft Excel spreadsheet by first arranging the streamflow values in ascending order of magnitude. Then assigning rank numbers to each streamflow value with the lowest flow ranked as 1, and the largest by a value *n*, where, *n* is the total number of records. After that, the probability of non-exceedance for each flow value was calculated. The percentage of time a given streamflow was ‘equaled’ or “not exceeded” (probability of non-exceedance) was computed using;

$$P = 100 \times \frac{r}{n+1} \qquad [1]$$

where $P$ is the percentage of time a given flow is 'equaled' or "not-exceeded" and $r$ is the rank of the flow magnitude. The FDC was finally developed by plotting all ranked flows against their probability of exceedance (for low streamflow analysis), or non-exceedance (for peak streamflow or flood analysis) (Smakhtin, 2001; Mays, 2005).

*Estimation of extreme streamflow and analysis of values*

The return period of high streamflow is an important parameter for studying flood, as it describes the probability of occurrence of extreme events. Flow frequency is normally constructed on the basis of a series of annual (daily or monthly) streamflow maxima, which can be extracted from the available original continuous streamflow series (Smakhtin, 2001). Since the available observed streamflow records are normally insufficient for reliable frequency quantification of extreme event, different types of theoretical distribution functions are used to extrapolate beyond the limits of 'observed' probabilities, and to improve the accuracy of high-streamflow estimation (Smakhtin, 2001).

The mean monthly river discharges for the period of record was sorted in descending order of magnitude, and assigned rank numbers with the largest flow ranked as 1 and the lowest $n$, where $n$ is the total number of records. The streamflow frequency curve was drawn by plotting the river discharge values against the estimated return periods. The recurrence interval of a flow with a certain magnitude (return period) was then computed using;

$$T_e = \frac{n}{r} \qquad [2]$$

where $T_e$ is the empirical return period (in years) and $r$ is the rank of the streamflow magnitude.

A more simplified extreme value analysis was performed on the extracted peak streamflows by using the exponential extreme value distribution. For the probability distribution of the extremes above a threshold in years, the return period was calibrated to observations using;

$$T_c = \frac{n}{t} * \left| \frac{1}{exp(-((x - xt)/\beta))} \right| \qquad [3]$$

where $T_c$ is the calibrated return period (years) based on exponential extreme value distribution (EVD), β is the calibrating parameter and $t$ is the total number of extracted high streamflows used. The number of $t$ selected affects the values of $x_t$ and β .

The accuracy of the estimated distribution parameter was then enhanced using the equation (4):

$$RMSE = \sqrt{\frac{\Sigma_{i=1}^{n} (T_c - T_c)^2}{n}} \qquad [4]$$

where RMSE is the root mean squared error, $n$ is the number of errors and $T_e$–$T_c$ is the difference between the empirical and the calibrated return periods, respectively. In calibrating the parameter of the extreme value distribution, the distribution parameter was then optimised for the value which minimises the RMSE. This was achieved by using the Solver Tool in Microsoft Excel spreadsheet. On the basis of linear regressions in the exponential quantile plots, the design flow for a certain return period was estimated by re-arranging equation (3) as:

$$x_T = x_t + \beta \left[ \text{In}\,(T) - \text{In}\left( \frac{n}{t} \right) \right] \qquad [5]$$

where $\chi_T$ is the estimated design flow at T-years, $\chi_t$ is the threshold value above which all streamflows are high flows, $T$ is the return period in years, $n$ is the period of record (in years), $t$ is the total number of extracted high streamflows used and $\beta$ is the calibrating parameter.

## Results

*Rainfall* versus *river flow regime*

The 28 years time-series plot showing the complete flow duration associated with rainfall (including missing data) for the three river basin system; (the Volta, the south-western and coastal systems) showed varying mean streamflow (Figs 2, 3 and 4). This implies that at the different locations, (Bamboi in the North, Twifu-Praso and Okyereko gauging stations in the south), differences in monthly mean streamflow were observed that ranged from 0 – 5, 270 $m^3\ s^{-1}$ for the Volta system, 0 – 124 $m^3\ s^{-1}$ for the coastal system and 0 – 704 $m^3\ s^{-1}$ for the south-western system.

*Flow duration (FD) of the sampled river system*

Fig. 5 shows the FDs for the three river basin systems sampled. The derived curves were based on the monthly mean streamflow plots at the sampled river stations namely, Bamboi (Black Volta), Okyereko (Ayensu river) and Twifu-Praso (Pra river) over the 30 – year period (1980-2010). Non-exceedance at a probability of 90 per cent, the threshold above which all streamflows are characterised as high flows for each system is noted as 995 $m^3\ s^{-1}$ (Black Volta), 273 $m^3\ s^{-1}$ (Ayensu river) and 30 $m^3\ s^{-1}$ (Pra river). These threshold values represent the peak streamflows for the respective river systems.

*Periodicity of high/peak streamflows of sampled river systems*

Fig. 6 shows the periods (month and corresponding year) in which high/peak streamflows were noticeable for the three river systems. Generally, over the 30-year period sampled, the occurrence and magnitude of high/peak streamflows is noted to be prevalent in the Volta system, followed by the south-western system compared to the coastal system with the least.

In the 1980's streamflows were higher in the south-western river system. However, from 2000 to 2008, there were more frequent and much higher streamflows. From 2000 to 2004 the Volta system recorded the highest streamflow (Fig. 6). The plots of trends of high streamflows in the Volta, south-western and coastal river systems and their corresponding trends of monthly mean rainfall are shown in Fig. 7, 8, and 9, respectively. A decreases in rainfall is associated with increase in streamflow at Bamboi in the Volta river system for the period 1986 - 2003 (Fig. 7). Fig. 8 shows a fairly stable but high streamflow associated with gradually increasing high rainfall in the south-western river system at Twifu Praso for the period 2000 – 2007. In terms of monthly high flows, increases were noted for the coastal river system. Very low monthly rainfall is associated with low streamflow at Okyereko

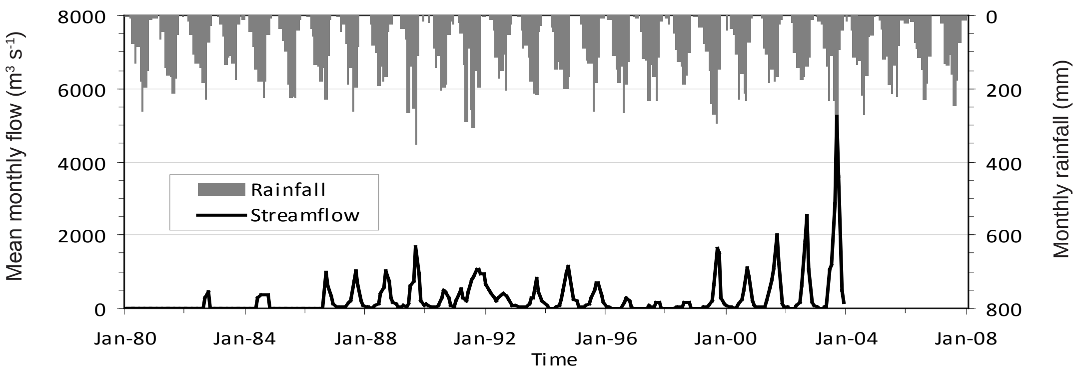


Fig. 2. Mean monthly rainfall and streamflow for the Volta basin system (Black Volta at Bamboi)

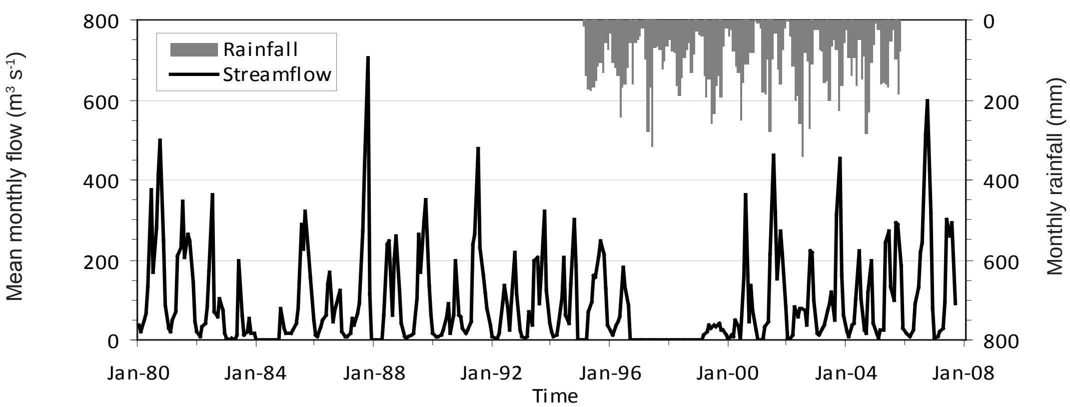


Fig. 3. Mean monthly rainfall and streamflow for the south-western basin systems (Pra at Twifu Praso)

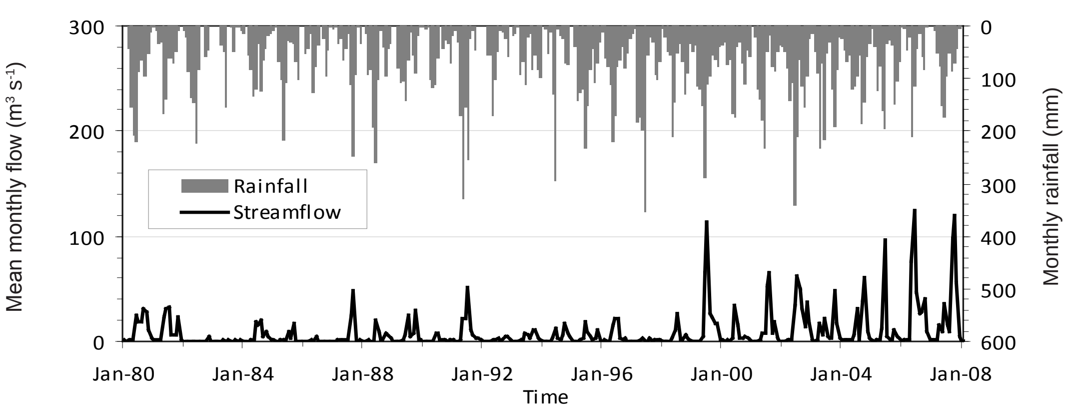


Fig. 4. Mean monthly rainfall and streamflow for the coastal basin systems (Ayensu at Okyereko)

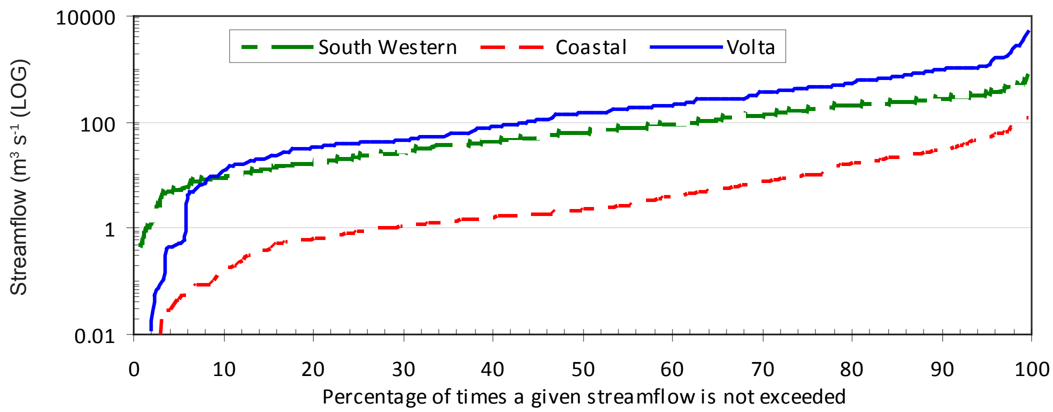


Fig. 5. FDC developed for the three river basin systems in Ghana

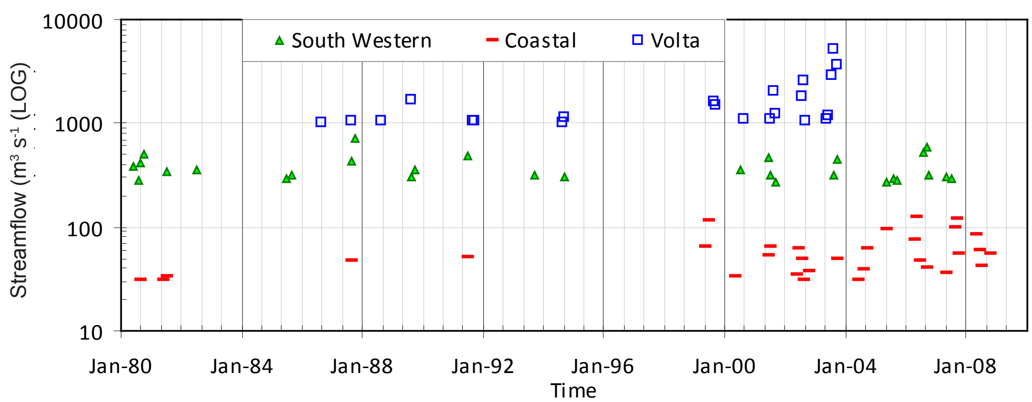


Fig. 6. Magnitudes and occurrences of high streamflows in the river systems of Ghana

for the period 1999 – 2007.

*Flow frequency (return period) curve*

Figs 10, 11 and 12 show the return period plots of streamflows for the Volta, south western and the coastal river systems, respectively. Lack of data availability for certain periods resulted in the differences in the years of study for the three river systems. $t$ is the total number of extracted high streamflows used in the calibration. The number of $t$ selected for the calibration affects the values of $x_t$ and β.

Figs 10, 11 and 12 show the return period plots of extreme (peak) flows, which have been calibrated to $t$ observations and extrapolated based on exponential extreme value distribution (EVD). The value of the root mean square error (RMSE) shows the accuracy of the estimated distribution parameters. From the exponential EVD curves, the chance for a flood with a certain magnitude to occur once in 1, 10 and 100 years have been estimated for the three river systems. These values are shown in Table 2. For example, the return period flows of 650.6 m³

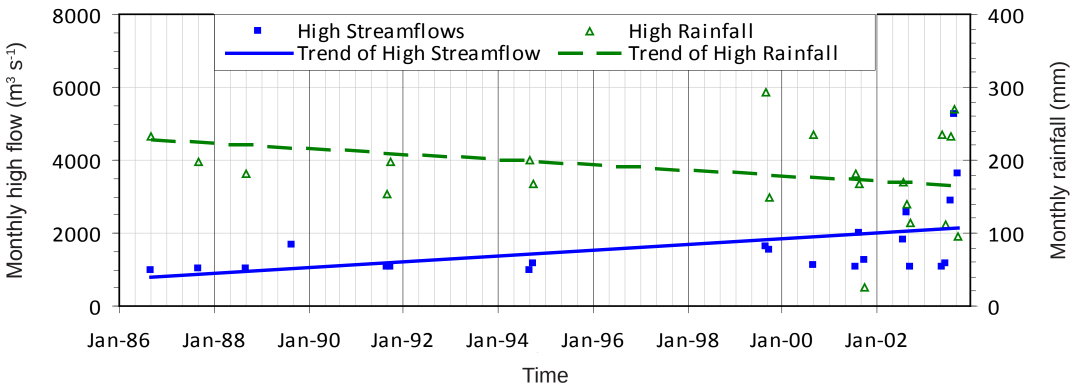


Fig. 7. Trends of high streamflows and corresponding rainfall amount in the Volta river system (Bamboi)

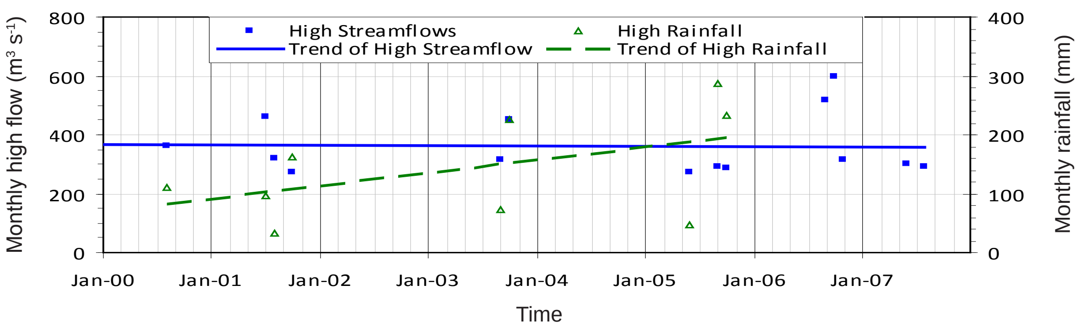


Fig. 8. Trends of high streamflows and corresponding rainfall amount in the South–western river system (Twifu Praso)

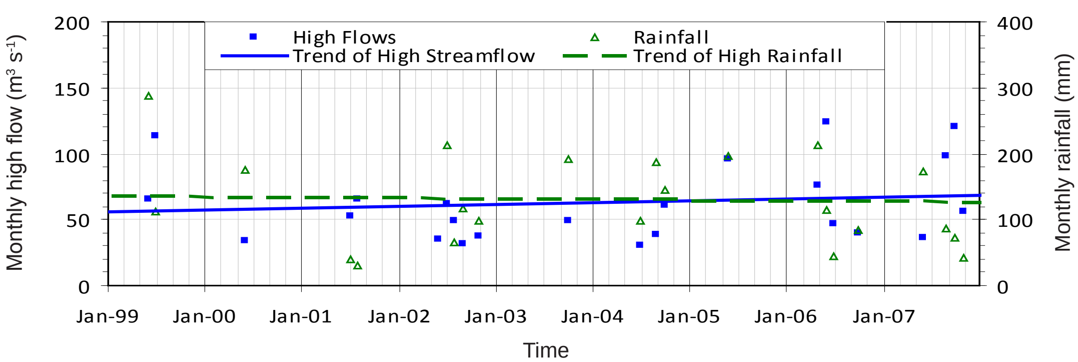


Fig. 9. Trends of high streamflows and corresponding rainfall amount in the coastal river system (Okyereko)

s$^{-1}$ and 6,407 m$^3$ s$^{-1}$ in the Volta river system at Bamboi is likely to occur averagely once every year and 100 years, respectively. Similarly, the return period flows of 296.4 m$^3$ s$^{-1}$ and 36.5 m$^3$ s$^{-1}$ will occur on average once every year in the south-western river system at Twifu-Praso and the coastal river system at Okyereko, respectively (Table 2).

## Discussion

Generally, rainfall is mainly bi-modal in the southern part of Ghana, where the bulk of the three river systems drain. The direct effects on river discharges due to the two-peak flows are separated periods of low flows with long duration. On the other hand, rainfall in the northern part of the country is heavy with short duration. This results in a single high peak flow in the year, especially at the beginning of the season. These contrasting scenarios are illustrated in Figs13, 14 and 15 with mean monthly rainfall totals and mean streamflows for the period 1995 – 2008 for the Volta, south-western and coastal river systems at Bamboi, Twifu Praso and Okyereko, respectively.

Having the uni-modal rainfall pattern, peak monthly rainfall amount of 212 mm in August results in a peak streamflow amount of 1,068.6 m$^3$ s$^{-1}$ in September (Fig. 13).

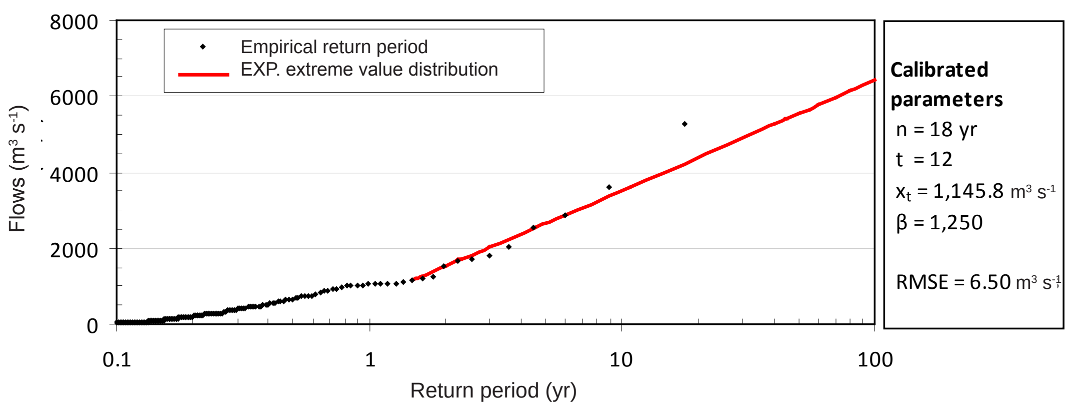


Fig. 10. Return period plots for the Volta river system using streamflow data from the Bamboi station

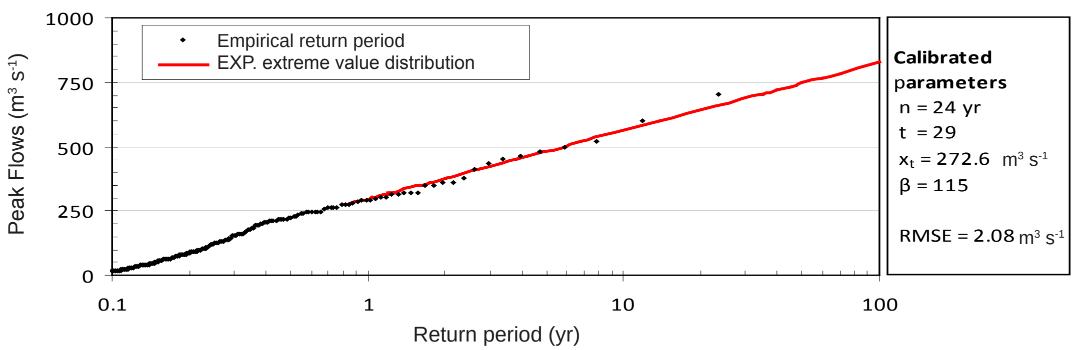


Fig. 11. Return period plots for the south–western river system using streamflow data from the Twifu Praso station

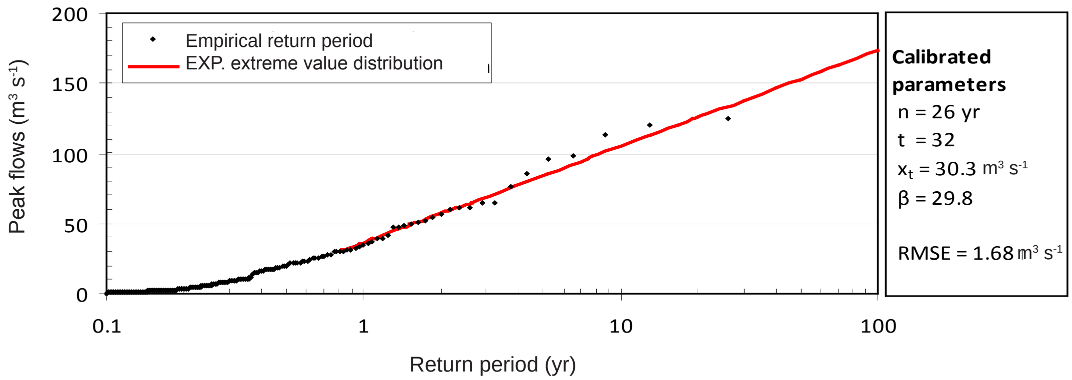


Fig. 12. Return period plots for the coastal river system using streamflow data from the Okyereko station

In the south-western river system at Twifu Praso, the monthly peak rainfall amounts of 206.4 mm in June and 173.5 mm in October resulted in two corresponding monthly peak streamflows of 138.0 $m^3 s^{-1}$ in June and 215.0 $m^3 s^{-1}$ in October, respectively.

At Okyereko in the coastal river system, monthly peak rainfall amounts of 65.5 mm in June and 32.3 mm and October resulted in a direct peak streamflows of 26.7 $m^3 s^{-1}$ in June and 17.6 $m^3 s^{-1}$ in October, respectively.

From the record, the monthly mean high streamflow for the Volta, south-western and coastal river systems ranged from 995 to 5,270 $m^3 s^{-1}$, 273 to 704 $m^3 s^{-1}$ and 30 to 124 $m^3 s^{-1}$, respectively, with average values of 1,684 $m^3 s^{-1}$, 374 $m^3 s^{-1}$ and 58 $m^3 s^{-1}$, respectively (Fig. 5). The highest streamflow values were observed in the Volta river system, whilst high streamflows in the coastal river system showed the lowest peak streamflow.

In terms of the number of occurrences of peak flows, there have been increases in the last decade (2000 – 2010), with the coastal and Volta river systems recording the highest and lowest number of occurrences, respectively (Fig. 6). In terms of the magnitudes, the Volta and coastal river systems recorded the highest and lowest high streamflows, respectively, through-out the period of analysis.

The Volta and coastal river systems at Bamboi and Okyereko, respectively, have shown an increasing trend of high stream-

TABLE 2

*Flood magnitudes with their return period*

| *River systems (stations)* | *T-years flood ($m^3 s^{-1}$)* | | | | | | |
|---|---|---|---|---|---|---|---|
| | *Q1* | *Q2* | *Q5* | *Q10* | *Q25* | *Q50* | *Q100* |
| Volta (Bamboi) | 650.6 | 1,517.1 | 2,662.4 | 3,528.9 | 4,674.2 | 5,540.6 | 6,407.1 |
| South-western (Twifu Praso) | 296.4 | 376.1 | 481.5 | 561.2 | 666.6 | 746.3 | 826.0 |
| Coastal (Okyereko) | 36.5 | 57.2 | 84.5 | 105.1 | 132.4 | 153.1 | 173.7 |

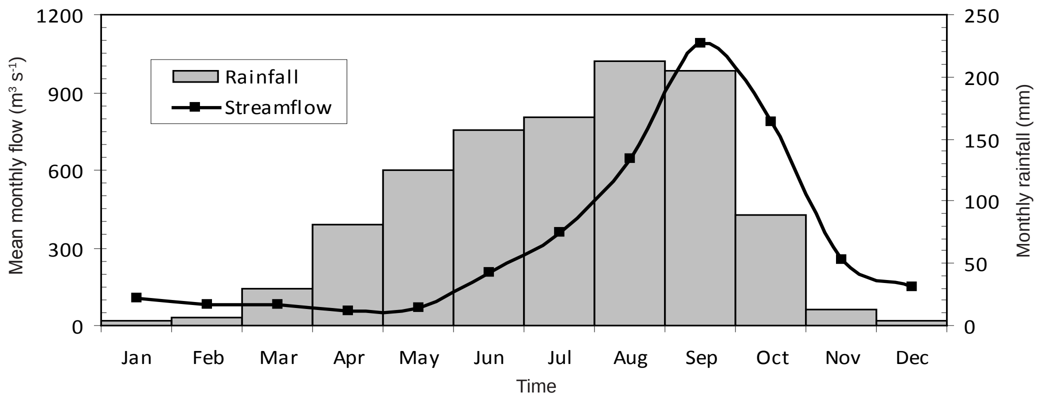


Fig. 13. Mean monthly rainfall and streamflow for Volta river system at Bamboi

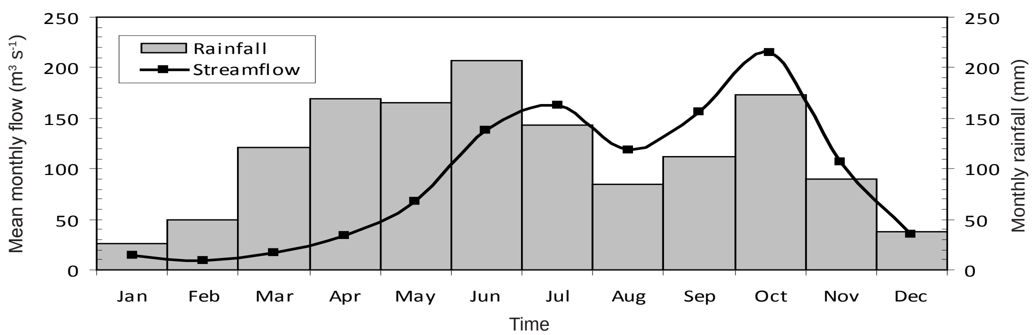


Fig. 14. Mean monthly rainfall and streamflow for south-western river system at Twifu Praso

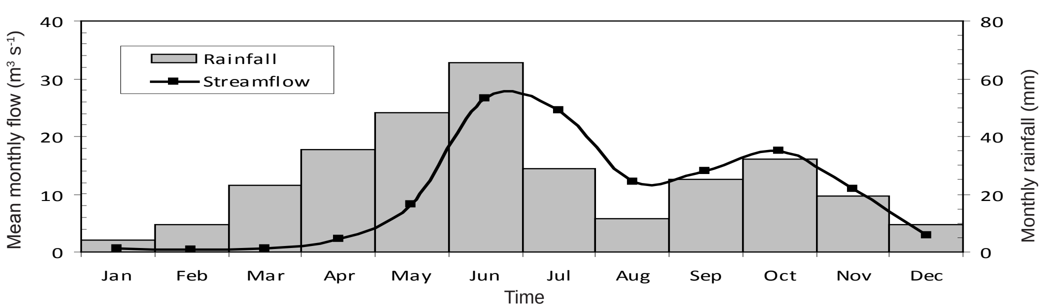


Fig. 15. Mean monthly rainfall and streamflow for the coastal river system at Okyereko

flow, with the Volta river system recording the highest rate of increase of high streamflow over the period of records (Figs 8 and 10, respectively). On the other hand, the Volta and coastal basin systems showed declining trends of monthly rainfall totals. The south-western river system showed almost a no-change in the trend of high streamflows at Twifu Praso (Fig. 9), although the basin showed an increasing trend in high monthly rainfall total for the period 2000 – 2005. This, therefore, suggests that rainfall amount is not the major cause of the recent high streamflows or flooding in Ghana, though there are evidences of direct runoff during every rainy season, especially in the urban areas.

With respect to the recurrence of high streamflow of a certain magnitude, it was estimated from the extreme value distribution that, there is a 100 per cent chance that, peak streamflows of magnitudes 650.6, 296.4 and 36.5 $m^3 s^{-1}$ will occur at least once every year in the Volta, south-western and the coastal river systems, respectively, in Ghana. Similarly, streamflows of magnitudes 3,529, 561 and 105 $m^3 s^{-1}$ have the chance to occur at least once every 10 years in the Volta, south-western and coastal river systems, respectively.

## Conclusion and recommendations

The number of occurrences and trends of high stream flows confirm the increasing number and magnitudes of flooding events in the river systems recently. Even though there are evidences of direct runoff during the rainy season, the study showed that rainfall amount is not necessarily the major cause of the recent high streamflows or flooding. The hypothesis that high streamflow does not lead to flood is not entirely correct, because high streamflows resulting from erratic rainfall leads to flooding, especially in the urban areas. Though heavy rainfall contributes to flooding, the results show that rainfall is not necessarily the major cause of the perennial flooding in the country. The study is also in conformity with findings from other studies (Kabglor, 2010, unpublished), which attributed the major cause of perennial floods in urban areas especially Accra, to drain clogging as a result of siltation, design flaws and improper waste management practices. Thus, the capacity of the drains is reduced, making it unable to hold the incoming high streamflow. This high streamflow then overflows drains and finds its way into homes and farms as flood, destroying lives and properties worth millions of Ghana Cedis.

It is, therefore, recommended that drainage systems in towns and cities be improved to provide adequate storage volumes for run-off water during rainy seasons. City authorities should develop proper waste management and proper land use to reduce erosion. The carrying capacity of drains should be enhanced by de-silting to de-clog them regularly. Flood detection facilities should be provided at vantage points along water courses to attenuate incoming flood waters. Also, studies on flood frequency analysis be carried out on continuous basis as and when new meteorological and hydrological data are available.

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