JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 21 2013

LOW FLOW ANALYSIS OF THE BLACK VOLTA RIVER AT LAWRA IN GHANA

K. Kankam-Yeboah[1]
F.Y. Logah[1]
B. Amisigo[1]
E.O. Bekoe[1]
D. Ofori[1]
J.A. Akudago[2]

[1] CSIR Water Research Institute, Accra, Ghana
[2] Pacific Institute, Oakland, California, USA

A flow duration curve was developed and the minimum flow determined for the Black Volta Basin using mean daily streamflow at Lawra. The result showed that streamflows of 1.24 m³/s and 0.368 m³/s were equaled or exceeded 95% and 99% of the time, respectively at Lawra. Groundwater contribution to streamflows in the basin was very low with estimated baseflow index of 0.01. This may be attributed to the basin being underlain by low permeable aquifers with low storage capacities. The result also showed with 100% probability that streamflow of 0.19 m³/s is expected to occur in the basin at least once every year at Lawra. Various distribution functions including Normal, Lognormal, Weibull, Gumbel and Gamma distributions were fitted to the mean daily low streamflows. The Normal distribution was found to produce the best fit to the low streamflows with NSE equaled to 98.43%. Low streamflow in the basin had a small tendency to produce unusual extreme low flow. The probability of occurrence of low streamflows in the basin was low and daily water abstraction below 1.24 m³/s is considered reliable and sustainable in terms of water supply for domestic, industrial and agricultural uses.

INTRODUCTION

Studies conducted on water resources in Ghana showed that the country is endowed with sufficient surface water resources to serve all its water needs. However, there is the need for a gradual process of development and conservation to make the water available in sufficient quantity and good quality (Kankam-Yeboah, et al., 2004; Gyau-Boakye and Tumbulto, 2006). The assessment of low streamflow is a critical index for a number of water users, especially in areas such as navigation, water supply and agriculture (Passchier, 2004). Statistical analyses are widely applied to derive indices to characterize low streamflow regimes (Longobardi and Villani, 2008).

According to Ries and Friesz (2000), low streamflow statistics indicate the probable non-availability of water in streams during times when conflicts between water supply and demand are most likely to arise. Due to this, low streamflow statistics are needed by the state, regional and local agencies for water-use planning, management and regulatory activities for a variety of water resources application. These activities include (i) developing environmentally sound river-basin management plans, (ii) siting and permitting new water withdrawals, inter-basin transfers and effluent discharges, (iii) determining minimum streamflow thresholds for the maintenance of aquatic biota and (iv) land-use planning and regulation. Low flow statistics are also needed for commercial, industrial and hydroelectric facilities to determine availability of water for water supply, waste discharge and power generation.

Research has been carried out in the past using low flow frequency analysis to characterize low streamflows of major rivers in Ghana (Opoku-Ankomah, 1986; Ontoyin and Opuku-Ankomah, 1992; Okutu, 1978). However, not much has been conducted in the Northern portion of the country where the ecology is savanna and climatic conditions are relatively hotter and dryer and groundwater extraction has increased tremendously over the past two decades (Akudago et al. 2009). This study is to build on what had been done in the past by using updated streamflow data from the Volta River Basin to characterize low streamflows.

Objectives of the Study

The goal of the study was to characterize low flow regime of the Black Volta Basin (BVB) using mean daily streamflows from Lawra. The specific objectives of the study were to:

(i) estimate low streamflow requirements of the BVB using the flow duration curve;

(ii) estimate the base-flow contribution to streamflow so as to determine the importance of groundwater to the flow regimes of the rivers; and

(iii) estimate the recurrent interval of low streamflows in the BVB and identify a suitable probability distribution function that best fits the low streamflow in the BVB.

THE STUDY AREA

The Black Volta Basin (Figure 1) is one of the main river basins in Ghana with a catchment area of approximately 33,302 km². It lies within Upper West, Northern and Brong Ahafo Regions of Ghana, between latitudes 7°17'N and 11°20'N and longitudes 0°58'E and 2°57'W.

Most part of the BVB experiences single major rainy season with monthly totals rising slowly from March until a maximum is reached in August/September. The southern parts, on the other hand, experiences bimodal rainfall pattern with the rainy seasons beginning around March/April

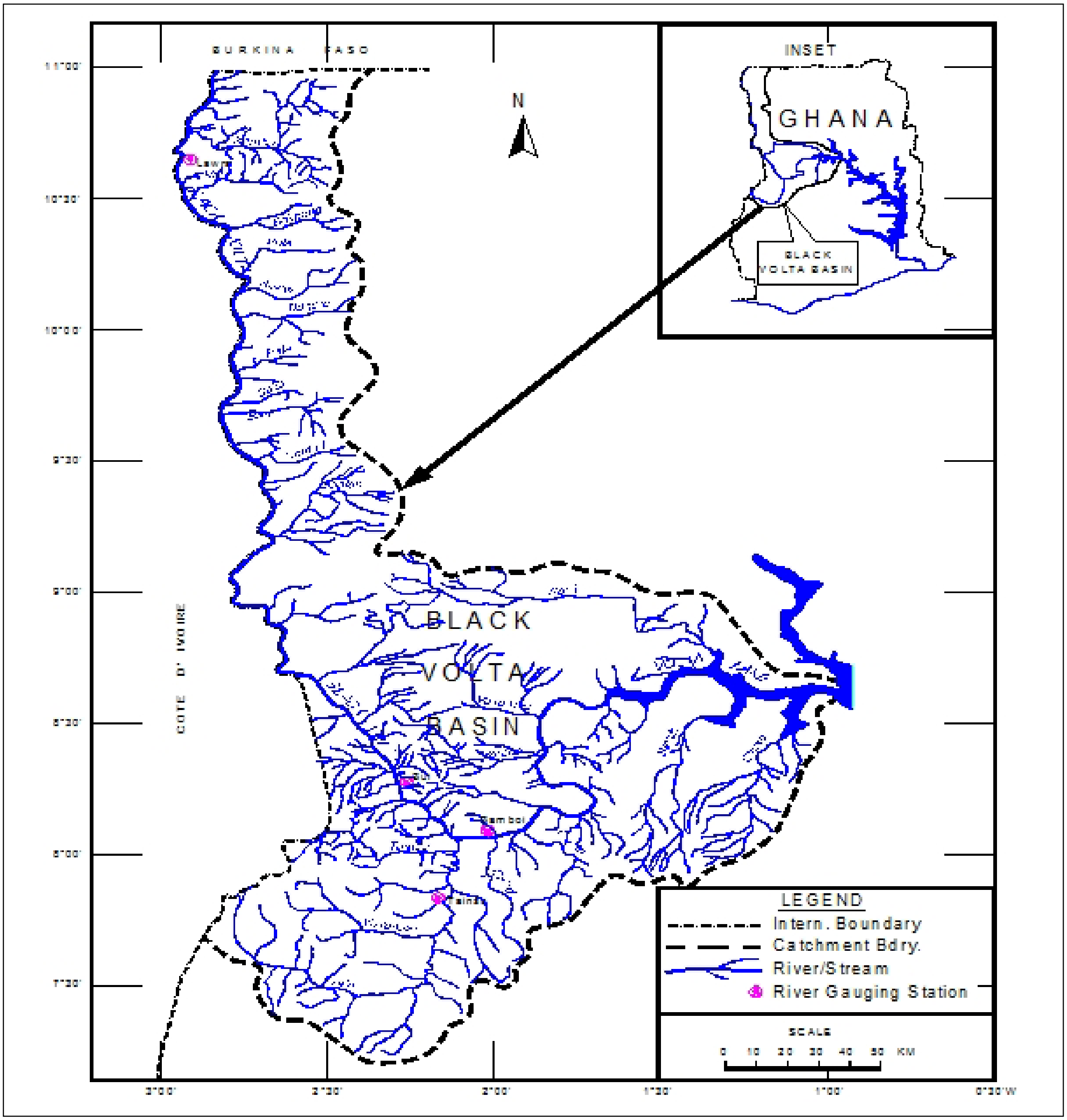

Figure 1. Map of Black Volta Basin.

with peaks in May/June and September/October. The mean annual number of rain days in the basin is between 60 and 120 days. The annual rainfall of the basin varies from about 1,150 mm in the North to about 1,380 mm in the south. Pan evaporation is in the order of 2,540 mm per year, and annual runoff is about 243 m^3/s. This contributes about 18% of the annual total flows to the Volta Lake. Temperature and humidity in the basin varies widely from season to season and from place to place. These values range from 27°C and 60% in the southern parts to 25°C and 77% in the northern parts of the basin, respectively (GWI, 2009).

The basin is mainly underlain by the Birimian, Voltaian, and granite geologic formations and is entirely within the interior savanna ecological zone of Ghana. The vegetal cover is quite open and is dominated by short grasses and "neem" trees (Bekoe et al., 2010).

The BVB is transboundary and is of great economic importance to the riparian countries, i.e. Ghana, Cote d'Ivoire and Burkina Faso. In Ghana, several districts in the Upper West Region rely on the Black Volta River and its tributaries for their water supply needs. Many important agricultural production activities such as cultivation of food crops (yam, rice, maize, legumes, tomatoes and other vegetables) and livestock rearing take place in this basin. There are also numerous small reservoirs for potable water supply, irrigation and livestock watering.

METHODOLOGY

Selection of River Stations with Good Records of Streamflow

The basic data used for the study was the mean daily streamflow data collected at Lawra in the BVB in Ghana. This station was chosen for the analysis because of its relatively good data length and continuity compared to other stations within the basin. This data was acquired from the Hydrological Service Department (HSD) of the Ministry of Water Resources, Works and Housing (MWRWH), Accra, Ghana and was available for the period 1989 – 2009.

The mean daily streamflow data collected at Lawra was plotted and compared with streamflows patterns at Bamboi and Bui stations in the same ecological zone in order to check the quality of the data acquired.

Minimum Streamflow of the Black Volta Basin

The amount of flow needed to sustain the in-stream uses is the most critical determinant of a minimum streamflow. Two main methods have been used in literature to extract low streamflows from the complete flow series: annual minimum series and the peak-over-threshold methods. The former extracts the smallest annual streamflow values from the complete flow series whilst the later specifies a threshold below which all streamflows are low flows (Willems, 2000). For long duration data series (about 50 years of data), the annual minimum series is mostly used for extracting low flows. Historically, designed streamflow between 70% to 99% probability of exceedance are considered sustainable to streamflow (Smakhtin, 2001).

Based on the duration of streamflow data available for the study, the peak-over threshold method was adopted to define the minimum flow of the Black Volta River at Lawra. This value was estimated from the FDC at 95% probability of exceedance.

Estimating Low Streamflow Indices

Depending on the type of data initially available and the type of output information required there exist different methods for estimating low-streamflow indices. These include Flow Duration Curve, Low Streamflow Frequency Analysis and Flow Distribution Functions (Smakhtin, 2001).

Flow Duration Curve

One of the most informative methods of presenting the complete range of river discharges from low flows to flood events is the Flow Duration Curve (FDC). FDC defines the relationship between any given discharge value and the percentage of time that this discharge is equaled or exceeded (Smakhtin, 2001; Mays, 2005). The FDC was constructed by arranging streamflow values in decreasing order of magnitude and assigning rank numbers to each streamflow value with the largest flow ranked as 1 and the smallest n, where n is the total number of records and computing the percentage of time a given flow was equaled or exceeded (probability of exceedance) (Smakhtin, 2001) using the relation below (Willems, 2000):

$$P = 100 * \frac{r}{n+1} \tag{1}$$

where P is the percentage of time a given flow is equaled or exceeded, n is the total number of records and r is the rank of the flow magnitude. The FDC was obtained by plotting *ranked* streamflows against their rank, expressed as the percentage of the total number of time steps in the record.

Low Flow Domain

Streamflows have defined 'upper' and 'lower' bounds. Most fundamental hydrological characteristics define the arbitrary 'upper bound' to low flow hydrology as the mean annual runoff which is the mean value of the available flow time series of annual flow totals. Intermittent and ephemeral streams are characterized by natural extended periods of zero flow which may generally be perceived as the 'lower bound' of low-flow hydrology (Smakhtin, 2001).

Streamflow values at 95% and 100% probability of exceedance were used to define the 'upper' and 'lower' bounds of the low streamflows, respectively.

Mean and Standard Deviation of Low Streamflow

Another way of characterizing low flow of a river is by estimating the mean and standard deviation of the extracted low flows. The *average*(x_1,x_2,...x_n) and *stdev*(x_1,x_2,...x_n) functions in Microsoft Excel were used to estimate the mean and standard deviation of the daily mean low streamflows, respectively.

Baseflow Contribution to Low Streamflow

Base Flow Index (BFI) gives an indication of the volume of groundwater that contributes to streamflow. It may also be defined as the ratio of the discharge which is equaled or exceeded 90% of the time (Q_{90}) to that of 50% of the time (Q_{50}) (Nathan and McMahan, 1990). Flows from the streams during most of the dry season of the year are composed entirely of baseflow and quick flow which represents the direct catchment response to rainfall events. Baseflow contribution to streamflow in the basin was estimated using Equation (2) (Nathan and McMahan 1990).

$$f_b = \frac{Q_{90}}{Q_{50}} \tag{2}$$

where f_b is the fraction of baseflow contributed to low streamflow and Q_{50} and Q_{90} are the streamflows which are equaled 50% and 90% of the time respectively.

Low Streamflow Frequency Analysis

The return period describes the probability of occurrence of extreme events. Low Streamflow Frequency is normally constructed on the basis of a series of annual, or daily or monthly streamflow minima which are extracted from the available original continuous streamflow series (Smakhtin, 2001). Since observed streamflow records are usually 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 low-streamflow estimation.

In developing the low flow frequency curve, the mean daily low river discharges were transformed into high values by using the transformation (X=1/x). The transformed values were sorted in descending order of magnitude and assigned rank numbers with the largest value ranked as *1* and the lowest n, where n is the total number of record data. The recurrence interval of the streamflow with certain magnitude was computed using Equation (3) (Willems, 2000).

$$T_e = \frac{n}{r} \tag{3}$$

where T_e is the empirical return period (in years), n is the total duration of the complete streamflow series (in years) and r is the rank of the low streamflow magnitude.

For the probability distribution of the extremes below a threshold x_t in n periods of years, the return period (T) of low streamflows was calibrated to t low streamflow observations by using the relation (Mirghani et al., 2005; Willems, 1998):

$$T_c = (n/t) * 1/\left[\exp\left(-\left(x^{-1} - x_t^{-1}\right)/\beta\right)\right] \tag{4}$$

where T_c is the calibrated return period (years) based on exponential Extreme Value Distribution (EVD) and β, the calibrating parameter.

The design low streamflow for certain return period (T-years) was estimated by rearranging Equation (4) as (Willems, 2000):

$$X_T = x_t^{-1} + \beta\left(\ln(T) - \ln(n/t)\right) \tag{5}$$

where X_T is the estimated design low streamflow at T-years, x_t is the threshold value below which all streamflows are low flows, T is the return period in years, n is the period of record (in years), t is the number of extracted low streamflows and β, the calibrating parameter.

Flow Distribution Functions

Another index used for characterizing streamflows is the type of distribution that fit the streamflow. Distribution functions are useful in predicting the chance that an extreme flood, drought or other natural disaster will occur. Among the commonly used are Normal, Lognormal, Weibull, Gumbel and Gamma distribution functions. Opoku-Ankomah (1986) fitted various distribution functions to annual streamflows of major Ghanaian rivers and concluded that the Gamma II distribution was generally the better fit to all the annual runoff volumes in the Volta and Coastal river systems and the Pra basin in Ghana.

The probability distribution functions of random function could be described through the use of Cumulative Distribution Function (cdf). Formally, the cumulative distribution function $F(x)$ which is also termed the probability of non-exceedance was defined as the probability of an event (P) that a random variable (X) takes a value equaled to or less than the argument (x) (Loganathan, et al., 1986; Willems, 2000):

$$F(x) = P[X \leq x] \tag{6}$$

Mathematically, the probability of exceedance $F_e(x)$ could be derived from Equation (6) (Loganathan, et al., 1986; as:

$$F_e(x) = 1 - F(x) \tag{7}$$

With the distribution function $F(x)$ identified and substituted into Equation (7), the low streamflows could be modeled based on the various distribution functions.

Normal Distribution Function

A continuous random variable X follows a normal distribution if it has the following probability density function (pdf) (Willems, 2000):

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right] \tag{8}$$

where μ (mean) and σ^2 (variance) are the parameters of the distribution. These parameters can be estimated using the formulas below (Willems, 2000):

$$\mu_x = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{9}$$

$$\sigma_x^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \mu_x)^2 \tag{10}$$

There is no simple expression for the Cumulative Distribution Function (cdf) of normal distribution but it has been evaluated numerically and tabulated for the standardized random variable. In general, the probability of non-exceedance is (Willems, 2000):

$$F(x) = P[X \le x] = P\left[Z \le \left(\frac{x-\mu_x}{\sigma_x}\right)\right] = F_Z\left(\frac{x-\mu_x}{\sigma_x}\right) \tag{11}$$

where $z = (x-\mu_x)/\sigma_x$

The values of $F_z(z)$ could be read from tables. However, in Microsoft Excel, the function $NORMDIST(x,\mu_x,\sigma_x,1)$ could be used to calculate $F(x)$. Substituting $F(x)$ into Equation (7), the probability of exceedance of a normal distribution function was computed as:

$$F_e(x) = 1 - NORMDIST(x,\mu_x,\sigma_x,1) \tag{12}$$

Lognormal Distribution Function

The common parameters used in the lognormal cumulative distribution function are the mean μ *and* standard deviation σ of ln_X using the following formulas (Willems, 2000):

$$\mu_{\ln x} = \frac{1}{n}\sum_{i=1}^{n} \ln x_i \tag{13}$$

$$\sigma_{\ln x}^2 = \frac{1}{n-1}\sum_{i=1}^{n}(\ln x_i - \mu_{\ln x})^2 \tag{14}$$

However the cdf of X could be evaluated using a table of normal distribution or the $NORMDIST(\ln x,\mu_{\ln x},\sigma_{\ln x},1)$ function in Microsoft Excel. From Equation (7), the probability of exceedance of a lognormal distribution function was computed as:

$$F_e(x) = 1 - NORMDIST(\ln x, \mu_{\ln x}, \sigma_{\ln x}, 1) \quad (15)$$

Gamma Distribution Function

The time taken for a number of events t_k to occur in a Poison process is described by the gamma distribution. The time between intervals, t_i (i = 1, 2, 3, …, k), is independent and has exponential distributions with common parameters λ (Willems, 2000; Chow, et al., 1988). The function, t_k is said to be gamma-distributed with parameters k and λ if:

$$f_{t_k}(x) = \frac{\lambda(\lambda x)^{k-1}\exp(-\lambda x)}{\Gamma(k)} \quad \text{for } x \geq 0 \quad (16)$$

The initial guess distribution parameters could be estimated from the mean μ and standard deviation σ using the following formulas (Willems, 2000):

$$\mu_x = k/\lambda \quad (17)$$

$$\sigma_x^2 = k/\lambda^2 \quad (18)$$

The gamma function *Ã(k)* from which the distribution gets its name is equal to *(k – 1)!*, where '*!*' is a factorial and *k* is an integer. The gamma function is widely tabulated as:

$$\Gamma(k, x) = \int_0^x \exp(-u)u^{k-1}du \quad (19)$$

which could be used to evaluate the cumulative distribution function $F_{T_k}(t)$ as (Willems, 2000):

$$F_{T_k}(t) = \int_0^t f_{T_k}(t)dt = \frac{\Gamma(k, \lambda)}{\Gamma(k)} \quad \text{for } t \geq 0 \quad (20)$$

$GAMMADIST(x, \lambda, k, 1)$ function in Microsoft Excel could be used to evaluate the cdf of gamma distribution function. From Equation (7), the probability of exceedance of a Gamma distribution was computed as:

$$F_e(x) = 1 - GAMMADIST(x, \lambda, k, 1) \quad (21)$$

Weibull Distribution Function

The cumulative distribution function for the Weibull distribution is given by the equation (Willems, 2000):

$$F(x) = 1 - \exp\left(-(x/\beta)^\tau\right) \quad (22)$$

where β (shape parameter) and τ (scale parameter) are the parameters of the distribution.

Substituting Equation (22) into Equation (7), the exceedance probability of the Weibul distribution was computed as (Willems, 2000):

$$F_e(x) = \exp\left(-(x/\tau)^\tau\right) \quad (23)$$

The Weibull distribution parameters could be estimated from the mean μ_x and standard deviation σ_x using the relation below (Willems, 2000):

$$\tau = \mu_x \tag{24}$$

$$\beta = \sigma_x \tag{25}$$

Gumbel Distribution Function

The Gumbel distribution is derived from the Generalized Extreme Value (GEV) distribution defined as (Willems, 2000):

$$F(x) = \exp\left[-\left(1+\gamma\frac{x-x_t}{\beta}\right)^{-1/\gamma}\right] \text{ for ã} \neq 0 \tag{26}$$

The distribution for ã = 0 is called the Gumbel distribution. The cumulative distribution function for the Gumbel distribution is given by the equation (Willems, 2000):

$$F(x) = \exp[-\exp(-((x-x_t)/\beta))] \text{ for ã} = 0 \tag{27}$$

where β and x_t are the distribution parameters.

From Equation (7), the probability of exceedance of a Gumbel distribution could be expressed as:

$$F(x) = 1-\exp[-\exp(-((x-x_t)/\beta))] \tag{28}$$

The initial guess distribution parameters could be estimated from the mean *ì* and standard deviation *ó* using the following formulas (Willems, 2000):

$$\mu_x = x_t + 0.577216\beta \tag{29}$$

$$\sigma_x^2 = \frac{\pi^2}{6}\beta \tag{30}$$

Calibration and Validation Data Sets

Streamflow values that were equaled or exceeded 90% of the time were extracted to acquire more data for analysis in this section. The extracted low streamflows were split into two (calibration and validation data sets) after randomizing the data using the *RAND( )* function in Microsoft Excel. This process was to ensure that both the calibration and validation data sets have the same range of low streamflow data.

Choice of Plotting Formula

Literature is replete with various frequency formulas for estimating empirical probabilities which are denoted as plotting positions. Some of the most commonly used ones include Weibull-Gumbel, Chegodayev, Gringorton, Hazen etc. The Weibull-Gumbel plotting position (Equation 31) was used for this study because it has more statistical justification (Chow, et al., 1988) and is the commonly used in hydrological frequency studies (Okutu, 1978).

Weibul-Gumbel formula : $P = \frac{r}{n+1}$ (31)

where P is the probability that a given streamflow is equaled or exceeded, r is the order number of rank and n is the total number of records (Willems, 2000).

Parameter Estimation and Optimization Technique

The accuracy or goodness of the estimated parameters were checked by the use of the Root Mean Squared Error (RMSE) and the related normalization, the Nash–Sutcliffe Efficiency (NSE). These criteria were defined as:

$$\sqrt{(1/n)*\sum_{i=1}^{n} E^2} \quad (32)$$

$$NSE = 100*\left(1-(1/vn)\sum_{i=1}^{n} E^2\right)\% \quad (33)$$

where n is the number of errors, v is the sample variance and E is the difference between the Weibull and the calibrated plotting positions (Willems, 2000).

The estimated parameters were considered satisfactory when NSE is greater than 0.5 (> 50%) and RMSE is close to zero (0) (Moriasi et al., 2007)

RESULTS AND DISCUSSIONS

Figure 2 is a comparison plot between streamflows at Lawra, Bamboi and Bui in the Black Volta Basin, all located in the same ecological zone in Ghana. With respect to data source and the consistencies in flow patterns, the quality of data at Lawra station can be considered good and acceptable for analysis. The mean daily streamflow for the period of record ranged from a minimum of 0.00 m³/s to a maximum of 715.5 m³/s. Figure 2 shows the recurrence of single annual peak flows in the basin which are separated by periods of low flows with long duration. This could be as a result of the mono-modal nature of rainfall in the Northern sector of the country.

The Flow Duration Curve and Minimum Streamflow Requirement

The FDC developed for the Black Volta Basin at Lawra with mean daily flows is shown in Figure

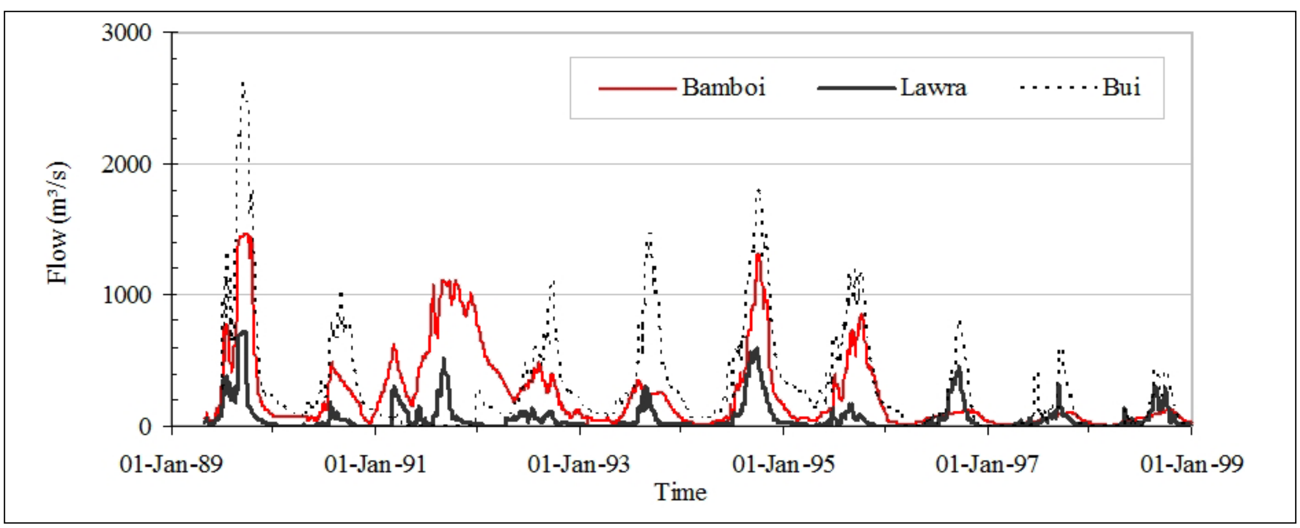

Figure 2. Consistency of flows pattern in the Black Volta Basin (1989 – 1999).

3. The threshold value for the period of record at 95% probability of exceedance corresponded to 1.24 m^3/s. In the most extreme case, streamflow amount of 0.368 m^3/s was equaled or exceeded 99% of the time. The estimated minimum streamflow values from 95% to 99% probability of exceedance are tabulated in Table 1.

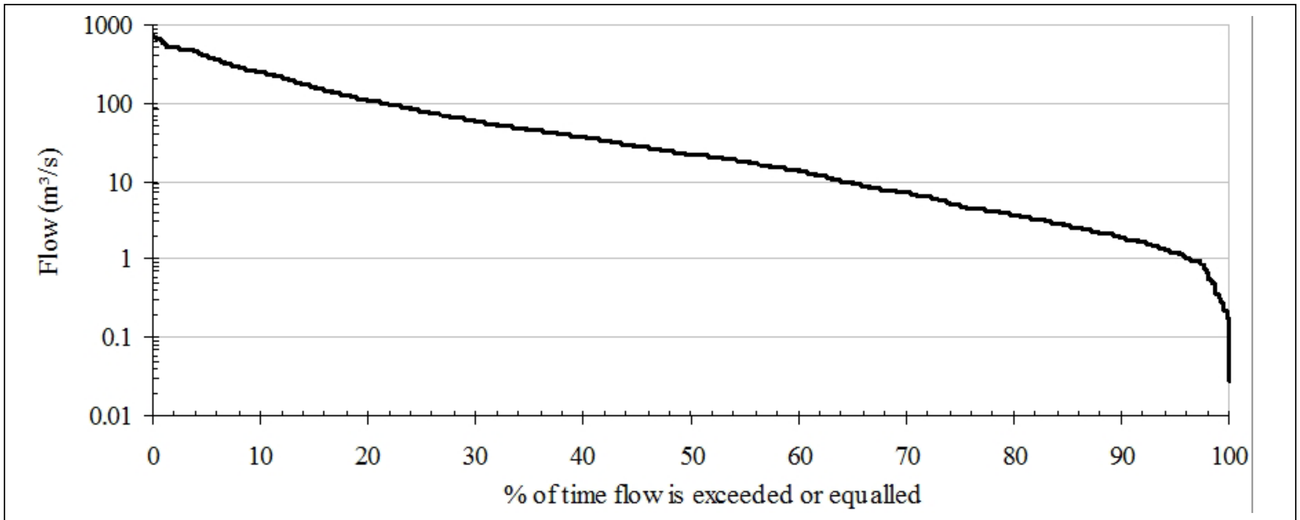

Figure 3. Flow duration curve developed for the Black Volta Basin at Lawra.

Table 1. Estimates of minimum streamflows requirement in the Black Volta Basin.

Probability of exceedance	95%	96%	97%	98%	99%
Streamflow (m^3/s)	1.240	1.055	0.976	0.651	0.368

Baseflow Index

In catchment with high groundwater contribution to streamflow, BFI may be close to one (1) but equal to zero (0) for ephemeral streams. The estimated BFI (0.09) indicated that groundwater contributed approximately 9% to streamflow in the basin at Lawra. This value suggested that groundwater storage within the basin was very low. This might be due to the aquifer material in the basin having low permeability.

Flow Frequency Curve and Recurrence Intervals

The calibrated parameters for the river at Lawra station are tabulated in Table 2. Figure 4 shows the low flow return period plot for the basin at Lawra. The graph also shows the return period plot of extreme low streamflows which have been calibrated and extrapolated based on the exponential Extreme Value Distribution (EVD).

From the exponential EVD, the chance for a flow with certain magnitude to recur at least once in 1, 5, 10, 50 and 100 years have been estimated for the basin using low streamflows at Lawra and tabulated in Table 3. The estimated results showed with 100% probability that streamflow of 0.187 m^3/s would occur at least once every year in the basin at Lawra.

Reliability of the Black Volta River to Meet Future Demand and Supply

Figure 5 shows the comparison plot between the mean river flow pattern, low flow threshold line at 95% probability of exceedance and flow with 1-year return period line at Lawra in the BVB. The result showed that low streamflows in the basin occurs between January and May and that the lowest flow of 712,432 m^3/day was equaled or exceeded 66.73 % of the time at Lawra. This value is 6.65 times and 43.86 times the low streamflow threshold value of 107,136 m^3/day and the 1-year return

Table 2. Data and estimated parameter (β) of the exponential Extreme Value Distribution.

Parameters	
Number of years of data (n)	20
Number of extracted low flows (t)	156
Threshold of low streamflow (x_t), m³/s	0.751
Calibrating parameter (β)	1.94

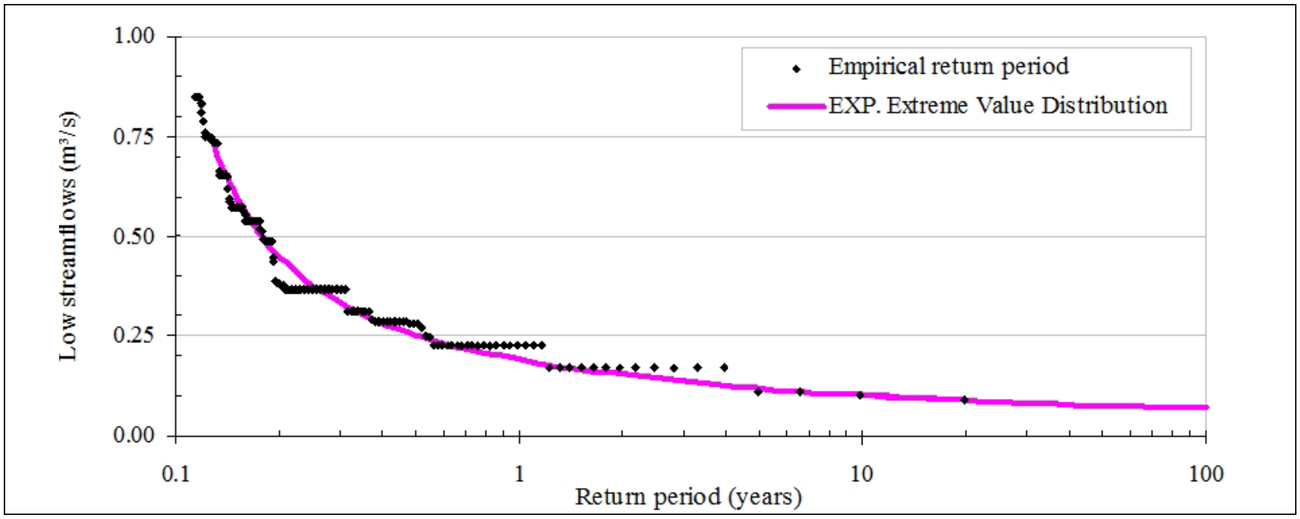

Figure 4. Return period plot for the Black Volta Basin using low streamflows at Lawra

Table 3. Recurrence interval (Return period) and their corresponding low flow values.

Recurrence interval (years)	Minimum flow at Lawra (m³/s)
1	0.187
5	0.118
10	0.102
50	0.077
100	0.070

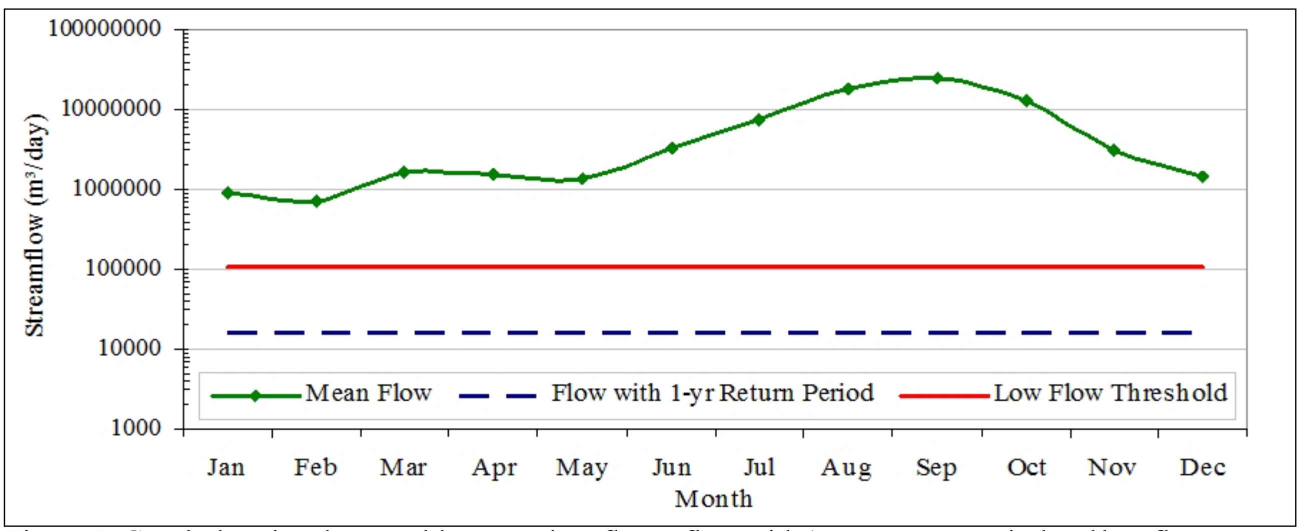

Figure 5. Graph showing the monthly mean river flows, flow with 1-year return period and low flow at 95% probability of exceedance lines in the Black Volta Basin at Lawra.

period flow value of 16,243 m³/day, respectively at Lawra. Given the minimum mean streamflow, the BVB could be considered sustainable and reliable in terms of use for water supply for domestic, industrial and agricultural use if the total abstraction is kept below the threshold value.

Fitting Flow Distribution to Low Flows

Figure 6 shows the plot of the calibration and validation low streamflow data sets with values ranging from 0.0 m³/s to 1.9 m³/s at Lawra. Figures 7 and 8 show plots of the calibrated and validated distributions, respectively fitted to the mean daily low streamflows from the basin at Lawra. Generally, the distribution functions under calibration and validation modes fitted well with the mean daily low streamflows but showed deviations at the extreme ends of the distributions. Apart from the Normal distribution which fitted better at the lower end, all the distributions under calibration and validation modes over-estimated the low streamflows at the extreme ends. This might have given an upper hand to the Normal distribution in the analysis, hence, the highest NSE of 98.43% and the lowest RMSE of 0.044 m³/s as tabulated in Table 4. Table 5 shows the values of the initial estimated and the final optimized calibrated parameters for the respective distribution functions.

CONCLUSIONS AND RECOMMENDATION

The determination and establishment of minimum streamflow is not only important to water users, but also very crucial for planning water supplies, managing water quality, assessing the

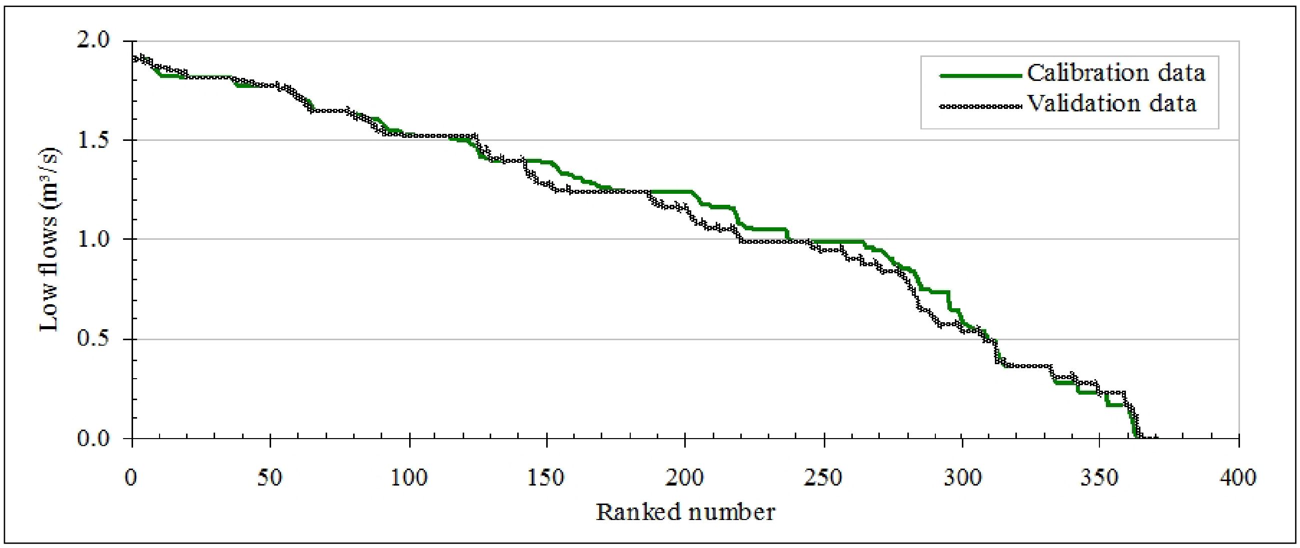

Figure 6. Calibration and validation low streamflow data for the Black Volta Basin at Lawra.

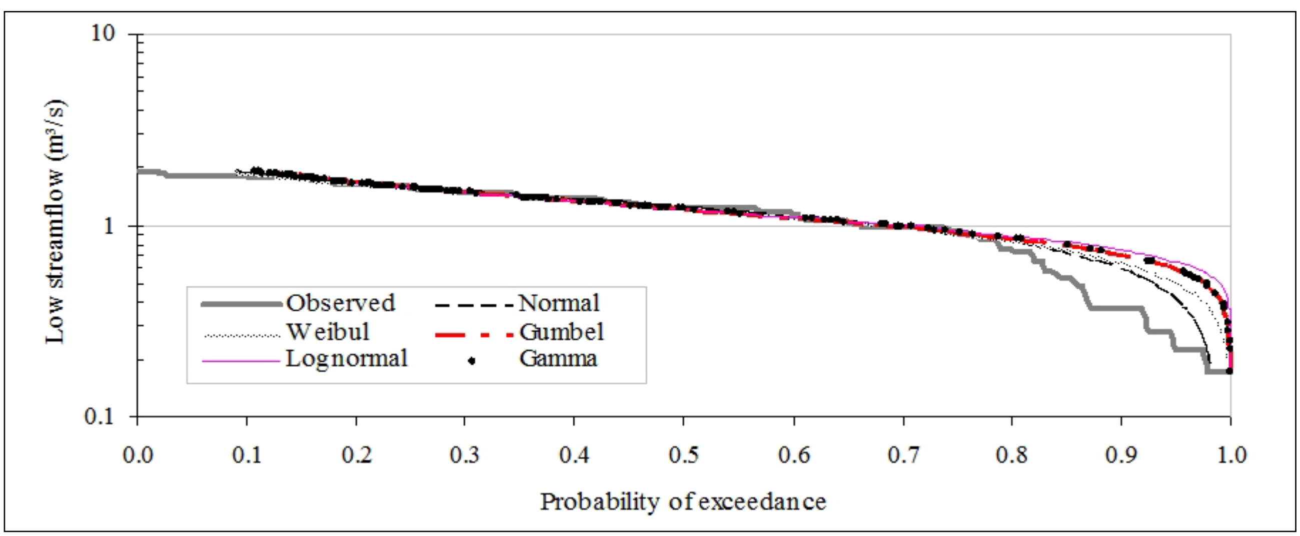

Figure 7. Calibration of distribution parameters using daily low flows from the BVB at Lawra.

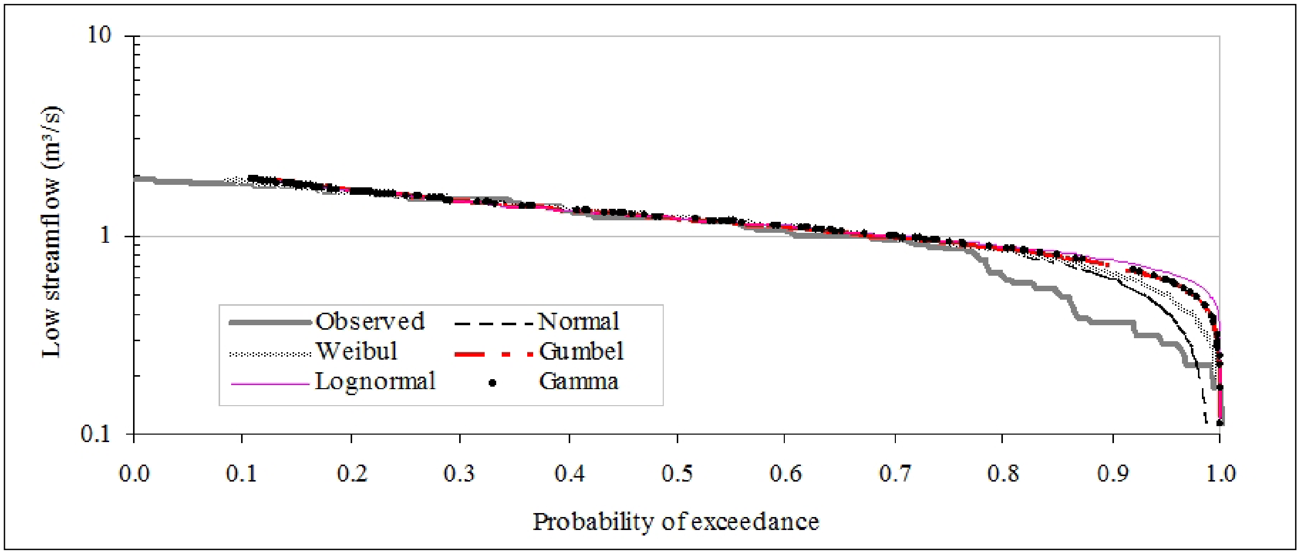

Figure 8. Validation of distribution parameters using daily low flows from the BVB at Lawra.

Table 4. Statistical analysis using NSE and RMSE.

Distribution functions	Calibration		Validation	
	NSE (%)	RMSE (m^3/s)	NSE (%)	RMSE (m^3/s)
Normal	98.43	0.0362	97.74	0.0435
Log-normal	95.89	0.0586	94.56	0.0676
Weibul	97.94	0.0415	96.94	0.0507
Gumbel	92.24	0.0561	94.46	0.0618
Gamma	96.69	0.0526	95.60	0.0608

Table 5. Optimization of calibrated parameters for the distribution functions.

Distribution function	Parameters	Values	
		Initial	Final
Normal	μ_x, (m^3/s)	1.18	1.24
	σ_x, (m^3/s)	0.49	0.50
Log-normal	$\mu_{lnx,}$ (m^3/s)	0.02	0.19
	$\sigma_{lnx\ ,}$ (m^3/s)	0.64	0.38
Weibul	β,(m^3/s)	1.18	1.40
	τ, (m^3/s)	0.49	2.89
Gumbel	β, (m^3/s)	0.15	0.43
	$x_{t\ ,}$ (m^3/s)	1.10	1.06
Gamma	λ, (s/m^3)	10.19	6.74
	K	0.20	0.19

impact of prolonged droughts on aquatic ecosystems, among others. Low flow study is essential since it educates stream user on the desirable minimum flow needed to sustain instream uses.

A streamflow value of 1.24 m^3/s was estimated from the FDC at 95% probability of exceedance as the minimum sustainable streamflow for the Black Volta Basin at Lawra. Groundwater contribution to streamflows in the basin was very low with an estimated baseflow index of 0.09. This may be attributed to storage materials (soil, aquifer) in the basin having very low permeability. The study showed with 100% probability that streamflow value of 0.187 m^3/s is expected in the basin at least once every year at Lawra. Similarly low streamflow of 0.102 m^3/s, 0.077 m^3/s and 0.07 m^3/s are expected to occur at least once in a 10, 50 and 100-year periods respectively, in the basin at Lawra.

Generally, all the distributions under calibration and validation modes fitted very well with the mean daily low streamflows in the basin but the Normal distribution produced the better fit with

NSE equaled to 98.4% and RMSE of 0.04 m^3/s at Lawra. Thus low streamflow in the basin had less of a tendency to produce unusually extreme low flow in the basin at Lawra.

Water abstraction from the basin below 1.24 m^3/s at Lawra is considered reliable and sustainable in terms of use for water supply for domestic, industrial and agricultural use.

Scientific research is data dependent. Forecast for the future is based on historical data or information. It is therefore necessary for the government and relevant agencies to devote adequate resources to set up more monitoring stations to enhance hydrological data collection for research and development activities.

ACKNOWLEDGMENT

We express our deepest gratitude to the Hydrological Service Department (HSD) of the Ministry of Water Resources, Works and Housing (MWRWH) for providing the observed streamflow data used in this study. We are also very grateful to Dr. Philip Gyau-Boakye (Chief Research Scientist) and Dr. Emmanuel Obuobie (Research Scientist) of the CSIR Water Research Institute for thoroughly reviewing the manuscript.

REFERENCES

Akudago, J.A., L.P. Chegbeleh, M. Nishigaki, and A.N. Nukunu. 2009. Estimating the storage and maximum annual yield of the aquifer system in Northern Ghana and the potential for irrigation. Journal of Environmental Hydrology, volume 17, paper 19.

Bekoe, E.O., F.Y. Logah, B.A. Amisigo, and K. Kankam-Yeboah. 2010. Climate variability and change and its impacts on water resources in Ghana, Collaborative Project, UNESCO Cluster Office, Accra, Ghana, pg 37.

Chow Ven Te, D.R.. Maidment, and L.W. Mays. 1988. Applied Hydrology, McGraw-Hill series in Water Resources and Environmental Engineering.

GWI. 2009. Global Water Initiative. A Partnership Funded by the Howard G. Buffett Foundation, http://gwighana.org/?/187/222/Climate Cited August 12, 2012

Gyau-Boakye, P., and J.W. Tumbulto. 2006. Comparison of rainfall and runoff in the humid south-western and the semiarid northern savannah zone in Ghana, African Journal of Science and Technology (AJST), Science and Engineering Series Vol. 7, No. 1, CSIR – WRI, Accra, pp. 64 – 72.

Kankam-Yeboah, K., P. Gyau-Boakye, M. Nishigaki, and M. Komatsu. 2004. Water Resources and Environmental Management in Ghana. Journal of the Faculty of Environmental Science and Technology, Okayama University, Vo1.9, No.I. pp.87-98.

Loganathan, G.V., P. Mattejat, C.Y. Kuo, and M.H. Diskin. 1986. Frequency Analysis of Low Flows: Hypothetical Distribution Methods and a Physically Based Approach. Nordic Hydrology. Dept. of Civil Eng., Virginia Tech., Blacksburg, USA, pp. 129 - 150, http://www.iwaponline.com/nh/017/0129/0170129.pdf Cited June 28, 2012

Longobardi, A., and P. Villani. 2008. 'A Regional Analysis of River's Low Flow Regime'. Department of Civil Engineering, University of Salerno, Italy, http://www.cugri.unisa.it. Cited June 20, 2011

Mays, L.W. 2005. Water Resources Engineering, Civil and Environmental Engineering Department, Arizona State University, Tempe, Arizona.

Mirghani, M., P. Willems, and J. Kabubi. 2005. 'QDF relationships for low flow return period prediction', International Conference of UNESCO Flanders FIT FRIEND/Nile Project – "Towards a better cooperation", Sharm-El-Sheikh, Egypt, 12-14 Nov. 2005, CD-ROM Proceedings, 10 p.

Moriasi, D. N., J. G Arnold, M.W. Van Liew, R. L. Bingner, R. D. Harmel, and T. L. Veith. 2007. Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. Transactions of the ASABE, 50 (3), 885-900.

Nathan, R.J., andT.A. McMahan. 1990. Evaluation of automated techniques for baseflow and recession analysis CSIR-Water Resources Research Institute, 26(26): pp. 1465-1473.

Okutu, W.N. 1978. Low flow characteristics of streams in the South-Western region of Ghana. CSIR-Water Research Resources Institute, Accra.

Ontoyin,Y., andY. Opoku-Ankomah. 1992. 'Apreliminary study on monthly stream flow characteristics of Major River Basins of Ghana'. CSIR - Water Resources Research Institute, Accra.

Opoku-Ankomah, Y. 1986. Annual Streamflow Characteristics of Major Ghanaian Rivers. CSIR-Water Research Institute, Accra.

Passchier, R.H. 2004. Low flow hydrology, Report Q3427, WL Delft Hydraulics, Delft, The Netherlands.

Ries, K.G. III, and P.J. Friesz. 2000. Methods for Estimating Low Flow Statistics for Massachusetts Streams http://pubs.usgs.gov/wri/wri004135/pdf/report.pdf Cited March 26, 2012

Smakhtin, V.U. 2001. 'Low flow hydrology: A review', Journal of Hydrology, pp. 147-186. http://www.sciencedirect.com/science. Cited June 28, 2011

Willems, P. 1998. 'Hydrological applications of extreme value analysis', In: Hydrology in a changing environment, H. Wheater and C. Kirby (ed.), John Wiley & Sons, Chichester, Vol. III, 15-25; (ISBN 0-471-98680-6).

Willems, P. 2000. Statistic for Water Engineering, Chapter 3 on 'Lecture note' on Statistical Analysis of Extreme Values, Katholieke Universiteit Leuven (KULeuven), Leuven, Belgium.

ADDRESS FOR CORRESPONDENCE
Kwabena Kankam-Yeboa
CSIR Water Research Institute
P.O. Box M. 32
Accra, Ghana

Email: kyeb59@yahoo.com