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Estimation of Flow-Duration and Low-Flow Frequency Parameters for the Sumanpa Stream at Mampong-Ashanti in Ghana for the 1985-2009 Period

Richard Kotei[a]*, Wilson AgyeiAgyare[b], Nicholas Kyei-Baffour[c], Thomas Atta-Darkwa[d], Eric TakyiAtakora[e]

[a] *Department of Agriculture Engineering and Mechanization, College of Agriculture Education, University of Education, Winneba, P.O. Box 40, Mampong-Ashanti, Ghana*

[b] *Department of Agricultural Engineering, College of Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana*

[c] *Department of Agricultural Engineering, University of Energy and Natural Resources, Sunyani, Ghana*

[d] *Soil and Water Management Division, Soil Research Ghana Institute, CSIR, Kumasi*

[a]*Email: richstarnaa@yahoo.co.uk*

[c]*Email: atakusgh@gmail.com*

[d]*Email: Thomas.atta-darkwa@uenr.edu.gh*

Abstract

The study examined the characteristics of the *Sumanpa* stream's Flow-Duration-Frequency Curve statistics for a period of 25years (1985-2009) and compared the 1990-1999 and 2000-2009 Flow-Duration-Curves. The high, low and mean Flow-Duration-Curves were also analysed. The discharge records were analysed to develop a general quantitative characterization of the stream's flow variability. Streamflow data was generated from daily stage data using the rating curve model developed at the stream's gauge station. Flow-Duration-Frequency-Curves were developed using the Weibull plotting position and used to analyse the catchment's surface and groundwater storage and stream's flow characteristics. The approach placed the midpoints of the moist, mid-range, and dry zones of the curves at 25th, 50th, and 75th percentiles, respectively. The high zone was centered at the 5th percentile, while the low zone was centered at the 95th percentile. For 95% of the time, the streamflowequalled or exceeded 0.14 m^3s^{-1}, at 5% it equalled or exceeded 45 m^3s^{-1} and at 50% flow equalled or exceeded 5.53 m^3s^{-1}.

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* Corresponding author.

The ratio of Q_{90}:Q_{50} for the period was 7.0%; it dropped from 38.0% in 1990-1999 to 30.0% in the 2000-2009 decades. The mean daily flow for the 1985-2009 (30.1m^3s^{-1}) has exceedance probability of 26% and the normal flow conditions were between 2.79 m^3s^{-1} and 9.9 $m^3s^{-1}$for the period.

Keywords: Flow-Duration-Frequency;Exceedance Probability; Weibull Plotting position; Percentile.

1. Introduction

Understanding both surface and groundwater contribution to streamflows, according to [1], is very important in the planning of catchment water resources management. There are well-established methods for the understanding of the magnitude and dynamics of groundwater discharge. One of such methods, according to [1], is the analysis of the streamflow hydrograph. The aim of analyzing streamflow hydrograph is to separate and interpret the baseflow component, the long-term delayed flow from storage, from quick flow, the short-term response to a rainfall event. In this regard, a multitude of methods have been developed which can be conveniently categorised into four basic approaches; graphical baseflow separation, filtering algorithms, frequency analysis and recession analysis “[1]”.

Daily Flow-Duration hydrographs, according to [2], are appropriately used to depict the daily variability of stream/river flow for both unregulated and regulated conditions which do not have contrasting week-day/weekend flow patterns. The Flow-Duration-Frequency Curve (FDFC) is a graph of the stream discharge plotted against exceedence frequency and is developed by using daily stream/river data collected at the stream’s gauge station downstream. According to [3], it can be used to detect changes in precipitation or landuse in a stream catchment, stream water quality management, hydropower feasibility studies, and in-stream low flow requirement determination. FDFCs, they added, have also been used to evaluate the effects of different climate scenarios on streamflow.

The pressure on water resources in the forest-savannah transitional zone of Ghana is increasing as supply is extended to the expanding settlement and forest landuse changing to more intensive agricultural use coupled with increasing trends in catchment temperature and actual evapotranspiration. With the current population growth (4.2%) and increasing drought length in the Sumanpa catchment, competition over water resources could become more profound. Potable water supplies in and around the catchment are already insufficient to meet the needs of domestic, small scale industrial, agricultural irrigation and the aquatic ecology. To meet future hydrological challenges in the catchment, improved information-based tools are needed to better characterize and manage water resources.

Ashanti-Mampong is the administrative capital of the Mampong Municipal area, with a population of 95,945 and annual growth rate of 4.2% “[4]”. The Sumanpa stream catchment which was once a forest zone is now experiencing a forest-savannah transitional climatic conditions and it is increasingly becoming vulnerable to water scarcity. As more money is invested into water resource development to meet the ever growing demand knowledge about groundwater resources, their trends, changes, extremes and recurrent intervals are critical.

The expansion of agricultural land and urban areas over forest has resulted in increased surface runoff from rainfall events. These expansions have also resulted in reductions in groundwater recharge. Management of runoffs from even minor storms in the catchment is taking an engineering dimension [5]. Unfortunately the catchment's drainage system is not well planned, designed and built as a complete system to adequately manage runoff from higher rainfall events. For an appropriate design of the drainage system, it is essential to understand the changes in storm runoff characteristics from the FDFC statistics due to climate change and rapid uncontrolled catchment development. Even though the Sumanpa stream does not have any interruption of its direct flow by diversion and water harvesting, flows, especially baseflow, may be modified by increasing abstraction for socio-economic and irrigation agricultural activities and exploitation of the catchment's sand, gravel and surface water resources.

It was, therefore, necessary to separate and analyse the baseflow components which have greater influence on the stream's time series flow. Not much study has been carried out on the stream's baseflow characteristics or conditions in recent decades. The objectives of this study were to construct, analyse and interpret the Sumanpa stream's flow-duration-frequency curves, their statistics in order to understand its low and high flow dynamics.

2. Materials and methods

2.1 Study Area

The stream's catchment is located within the forest-savannah transitional zone, Mampong-Ashanti, Ghana, with a population of 44,380 at a growth rate of 4.2% per annum [4]. The catchment relief is 137 m with an area of 38 km^2. The main occupation of the people was agriculture. The major crops produced on a medium scale were are cocoa, oil palm, cassava, yams, maize and vegetables. Dry season agriculture is gaining grounds mainly in the area of vegetables production [6].

2.2 Hydrology, Climate and Vegetation

The combined effects of climatic and geological conditions on the catchment's topography have yielded a drainage pattern characterized by a network of channels and 12 streams. The site experiences double maximum rainfall pattern with the peak periods in May-June and September-October with dry periods between July-August and November-March. The climate is typically tropical, with total annual rainfall between 1270mm-1524mm, giving an annual average of 1300mm. Temperatures range between 25^oC and 32^oC. The potential evapotranspiration (PET) is estimated at 1450 mm/y. The average humidity during the wet season is typically high (86%) and falls to about 57% in the dry period [7].

Flow-duration data were used to statistically characterize streamflow. The flow duration curve, which is the discharge versus percentage of time a particular discharge is equalled or exceeded, was plotted using mean daily discharges and the Weibull plotting position (Equation 1) as follows:

- Mean daily discharges were sorted out and ranked in a descending order and
- Each discharge was assigned a rank value, m, starting with 1 in a decreasing order to n.

The Weibull plotting position is given as:

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

Where,

P is the exceedence probability, ***m*** is the ranking number, in descending order, of all daily mean flows for the specified period of record and ***n*** is the number of daily flows [2].

The area under the flow duration curve according to [2] represents the average daily flow. By this, the ability of the catchment to sustain flow of a particular magnitude for a particular period of time was assessed.

2.3 Streamflow Statistics for High, Low and Normal Flow Years

Streamflow gauge data were compiled to determine high, low and average or normal annual flow years for the catchment. The process to determine and assess streamflow included selection of a potential period of study, determining if the selected period of study satisfactorily represented the long term values and compiling and processing index streamflow gauge data to compare high, low and normal or average stream flow years in the catchment. The "high flow year" designation was assigned to years having total annual gauged flows in the highest 10th percentile. The "low flow year" designation was assigned to years having total annual gauged flows in the lowest 90th percentile during the study period. The "normal or average year" designation was assigned to the remaining years during the study period as described by [1].

2.4 Flow-Duration-Frequency Curve Intervals and Zones

Flow duration curve analysis as published by [1] identifies intervals, which can be used as general indicators of hydrologic conditions (i.e., wet versus dry and severe). Flow duration curve intervals were grouped into broad categories, or zones which provide additional insight about conditions and patterns associated with the impairment. A common way, according to the authors, to look at the duration curve is by dividing it into five zones, as illustrated in Figure 1, representing high flows (0-10%), moist conditions (10-40%), mid - range flows (40-60%), dry conditions (60-90%), and low flows (90-100%).

This approach places the midpoints of the moist, mid-range, and dry zones at the quartiles (25th, 50th, and 75th percentiles, respectively). The high zone is centered at the 5th percentile, while the low zone is centered at the 95th percentile. Ranges, according to [1], can be adjusted, depending on the local hydrology and the relevant water quality issues being addressed. Although five zones are commonly used to derive additional information from FDCs, the number of zones and range of frequency values are decided based on local hydrologic conditions [1].

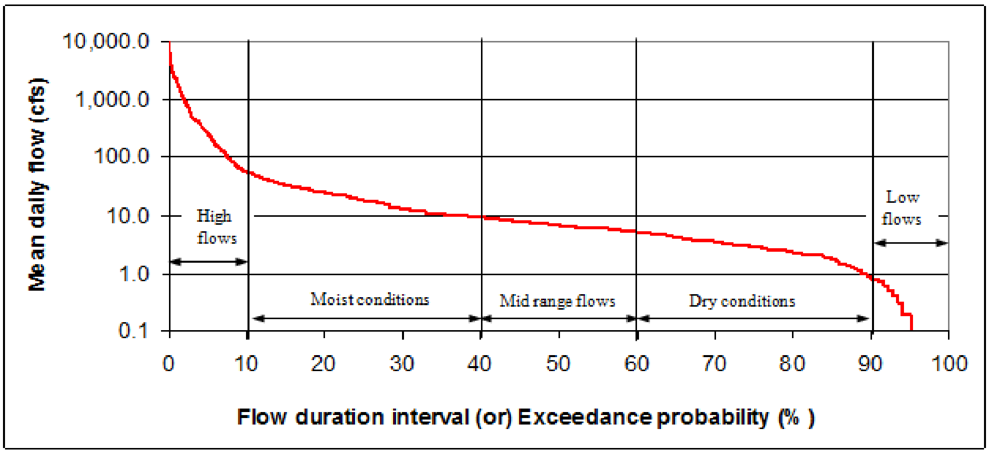

Figure 1: A hypothetical Streamflow-duration frequency curve (FDC) for Sumampa Stream Source: [1]

3. Results and discussions

3.1 SumanpaFlow Frequencies

The FDCs (Figures 2 and 3) are cumulative distribution of *Sumanpa*streamflows of the periods under study; a relationship between any given discharge value and the percentage of time that this discharge is equalled or exceeded. It is normally calculated from available, observed or simulated flow time series. But because the shape of the curve is determined by rainfall pattern, catchment size, shape and physiographic characteristics, land-use type, and the state of water resources development, the primary assumption of the simulation approach is that the effects of all these factors may be built into a FDC priorto the simulation of the actual flow time series [2].

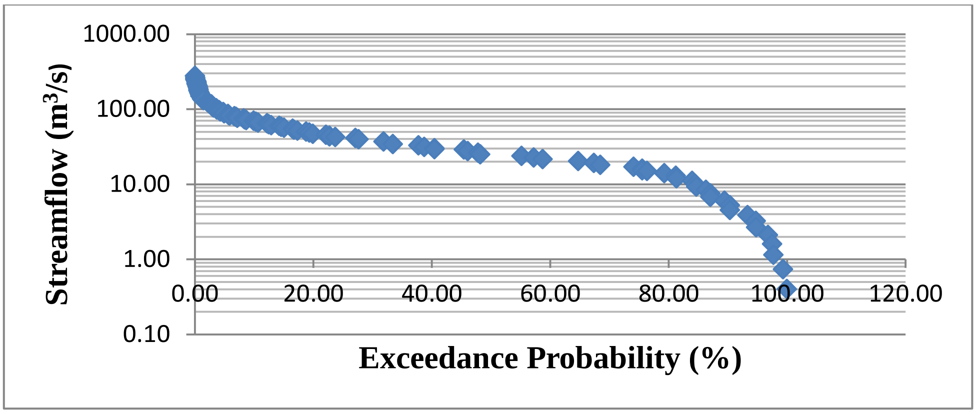

Figure 2: Actual Streamflow-duration curve (FDC) for the Sumampa Stream (1985-2009)

The FDC for the period, 1985-2009, (Figure 2) is very important because by it, the percentage of time that a given flow rate of the stream is equalled or exceeded is determined and is useful for water resource management and future engineering works along the stream. The modelled FDC for the period fits the observed data very well (r^2 =0.99). The 95% dependable discharge at the gauge station, which is the basis for electrical power planning, is 11,439.5m^3d^{-1} (too low). For 95% of the period, flow exceeded or equalled 0.14 m^3s^{-1} (12 096.0 m^3d^{-1}).At the other extreme, i.e. 5% of the time, the flow equalled or exceeded 45.0 m^3s^{-1} (3 888 000.0 m^3d^{-1}) (Table 1).

The part of the period FDC curve below the median flow has a low slope indicating a significant baseflow reflecting continuous discharge from the groundwater storage to the stream [2]. The stream had a mean daily discharge of 1,100,843.0 m^3 with exceedence probability of 28%, and a return period of 4 years for the period under study. The stream's normal flow condition was between 244, 684 m^3d^{-1} (75th percentile) and 1,193,983 m^3d^{-1} (25th percentile). A study of the daily flow duration hydrograph typically indicates a high flashiness of the stream (Figure 3) such that during dry periods, when daily average flows are below the 25th percentile flow mark, a rainfall event will lift the flow into the normal-flow zone, after which they may quickly return to below the 25th percentile flow mark after direct runoff when the rainfall event ceases.

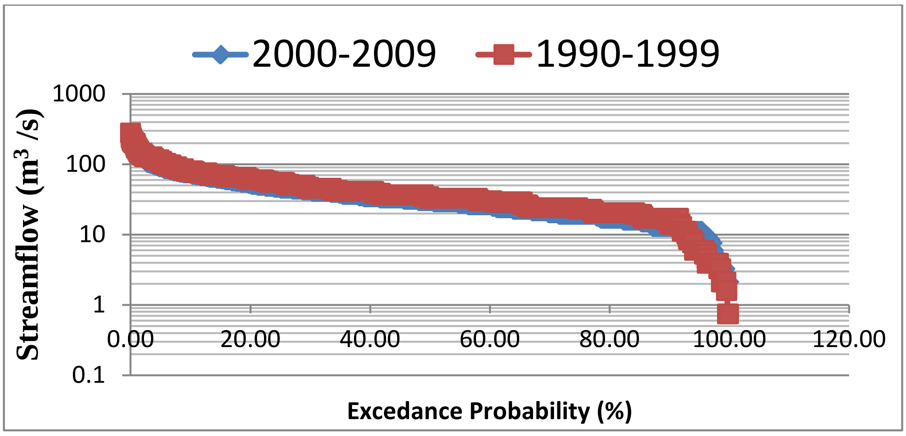

Figure 3: Changes in *Sumanpa*Daily Flows for 1990-1999 Compared to 2000-2009

The steep slope at the high flow zone of the period FDC indicates that high streamflows are highly variable and for the size of the catchment (38 km^2), reflecting high intensity, short duration rainfalls and flashy response to rainfall as a result of rapid changes associated with urbanization (Figure 4). The changes in the stream's flow are not just apparent in the annual flow data; there are also significant changes in the intra-annual flows.

3.2 Changes in the Stream's Decadal High , Normal and low flows

Comparing the flow duration curves for the 1990-1999 and 2000-2009 decades (Fig. 3), the stream dried more frequently in the 2000-2009 decade despite the increasing rainfall trends. Prior to the year 2000, 50% of the days had a discharge greater than 715,331.1m^3d^{-1}. In comparison, since the year 2000 a daily flow of 715,331.1m^3d^{-1} was only exceeded by 42**%** of the time, a situation attributable to decreasing groundwater recharge and increasing length of the dry season. The slope of the curve at the upper end indicates that flood events could be a result of moderate intense and short duration rains and decreasing catchment surface permeability. The steep slope at the lower end of the FDC indicates insignificant natural storage capacity of the catchment, [8]. The managers of the catchment's water resources must introduce intervention early enough to improve the stream's low flows.

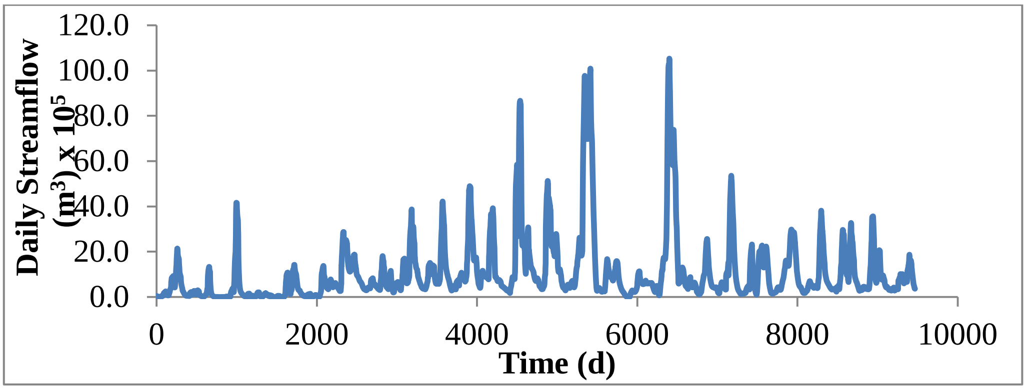

Figure 4: Daily Mean Discharge from the Gauging Station at the Water Works Road's Culvert

The Sumanpa stream is beginning to register significant effects from abstractions in the dry seasons, inimical landuse modifications and regional climate conditions. The almost flat slope between the 25th and 75th percentiles of the FDC (Figure 2) indicates a baseflow dominated perennial stream with insignificant regulatory influence caused by artificial storages and diversions. There is little variation in the stream's flow regime between the 25th and 75th percentiles. This portion of the curve reflects a time series with low flow variability, typical of flow from a permeable catchment, with insignificant anthropogenic influences and a naturalised flow series downstream [2]. For more than 80% of the time, the daily flow varies between 169,291.5 m^3d^{-1} and 1,410,086 m^3d^{-1} but low flows, here, do not substantially change.

The Sumanpa stream has a median (50% exceedance) flow of 484, 852.0 m^3d^{-1} (5.6 m^3s^{-1}) with a return period of 2 years. This means that the median flow, the mathematical "middle" of all measured flow values for the period, is greater than or equal to 484, 852.0 m^3d^{-1}, expected to occur five out of every 10 years. It also means that one-half of all measurements were higher, and one-half of all measurements were lower than 484,852.0 m^3d^{-1} (5.6 m^3s^{-1}). The stream has a 5% exceedence flow of 3,888,106.0 m^3d^{-1}(45.0 m^3s^{-1}).

At 5%, 10%, 25%, 50%, 75% and 90% probabilities, the flow equalled or exceeded were lower in 2000-2009 with a minimum decrease of 14.5% under Q_{10} (Table 1). The ratio of Q_{90}:Q_{50} which indicates the percentage of groundwater contributed to streamflow was 7.0 % during the study period, and dropped from 38.0% in 1990-1999 to 30.0% in 2000-2009 decade. A drop in groundwater contribution to the stream is an indication of decreasing annual recharge, increasing evapotranspiration and to some extent increasing abstraction. The new aquifer contribution is too low to sustain high flows and support socio-economic and ecological activities. The catchment may suffer serious water crisis during prolonged dry seasons which may affect dry season agriculture and its poverty alleviation programmes.

3.3 Impact of Climate Change and Extremes on the Sumanpa Flow

The climate scenarios of the catchment for the study period according to [9] indicated a wetting trend in mean annual rainfalls and rising ambient temperatures which imply an increasing trend in moisture carrying capacity of the atmosphere. Most computer models simulate an increase in extreme daily rainfall as a broad global trend. Observations suggest climate change is altering streamflows in ways that may negatively influence water supply for inhabitants of the Sumanpa catchment as many climate models, according to [10], suggest that these changes will worsen as the climate warms, accentuating the natural variability inherent in streamflows.

The consequences of reduced streamflows in the 2000-2009 decade and changes in the timing of peak streamflows will impact water consumption, agricultural production and economic growth among other vital services. Increases in temperature and variations in precipitation patterns have driven the observed changes in the Sumanpastreamflows during the 1980-2009 period according to [9]. [9]also revealed a decline in the number of rainy days and increase in the frequency and extent of droughts in the catchment. Given the importance of rainfall and evaporation in driving the catchment’s hydrological cycle, the changes in these primary processes (rainfall and ETa) may haveconsiderable effects on the rest of the system’s components (recharge variables); such as changes in the volume and timing of runoff and hence the slope of the high and lowflow parts of the FDF curve [11].

3.4 Impact of Urbanization and Deforestation on the Sumanpa Low Flows

Anthropogenic changes to the landscape of the *Sumanpa*catchment may alter baseflow timing, quantity, sustainability and hence the shape of the Lowflow-Duration-Frequency Curve (LFDFC) at the various flow zones. There is a weir, on the stretch of the stream within the Agricultural Research Station used for experimental irrigation. Apart from direct manipulations, such as water withdrawals from the stream by people living along its banks and subsurface storage, increasing human activities are influencing baseflows timing and quantities by indirect mechanisms associated with changes in Landuse and Land Cover (LULC). The conversion of native vegetation to agro-vegetative covers and artificial surfaces can drastically alter ET_a[12]. Landuse change alters surface permeability characteristics, through soil compaction associated with landuse and addition of impervious surface to the urbanized zones of the catchment. This negative relationship between catchment forest cover and baseflow is attributed to greater interception and water use by mature trees compared with other land cover types [13].

Reference [14] has interpreted that relationship as a suggestion that the catchment management approaches could include deforestation to increase water yield for public uses. However, the gain in streamflow expected to come from deforestation is minimized or nullified by the rapid expansion of impermeable surfaces in the catchment and the current positive trend in ETa. There is a sound theoretical basis and growing empirical evidence that long-term forest conversion reduces baseflows, and specifically low flows, because the intensive soil compaction and increases in impervious surface that accompany landuses decrease infiltration rates and subsurface storage recharge [15].

At 90 % normal and low flow probabilities the flows equalled or exceeded were lower during the 2000-2009 decade indicating a decrease in interflow and groundwater contribution.At the 95 % probability the flow equalled or exceeded increased from 0.47 m^3d^{-1} in the 1990-1999 decade to 1.48 m^3d^{-1} in the 2000-2009 decade indicating a more sustained baseflow, 215% increase, attributable to the positive rainfall trend coupled with increasing deforestation and savanization in the catchment [5].

Urbanization in the catchment has generally increased the size and frequency of floods in the stream. Logging, firewood harvesting, agricultural activities and bushfires together degraded 35.22% of the forest, increased the urban area by 110.46%, increased arable land by 139.20% and increased the area of secondary forest by 104.09% between 1980 and 2009. As a result and coupled with the increase in annual and decadal ET_a, the annual mean flow within the period dropped by 11.25% and the mean decadal major seasonal flow by 36.32% in the 2000-2009 decade.The annual maximum, major season, minor season, dry season and mean decadal streamflow decreased by 8.84%, 36.32%, 3.0%, 14.83% and 3.0% respectively in the 2000-2009 decade. The mean decadal catchment aquifer recharge dropped by 14.05% from 1990-1999 to 2000-2009 [5].

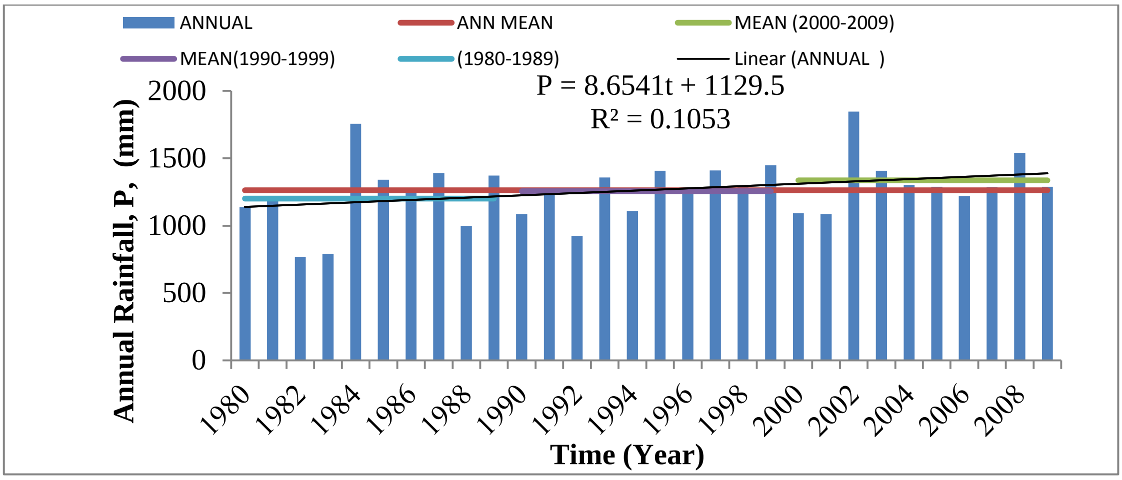

Figure 5: Variation in Inter-Annual Rainfall Over three Decades

Table 1: Period and Decadal Stream Flow (m^3/s) and Exceedance Probabilities (%)

Decade	**Exceedance probabilities (%)**							
	Q_{95}	**Q_{90}**	**Q_{75}**	**Q_{50}**	**Q_{25}**	**Q_{10}**	**Q_{5}**	**$Q_{90}:Q_{50}$**
1985-2009	0.14	0.41	2.79	5.53	9.90	30.45	45.00	7.0 %
1990-1999	0.47	3.16	4.29	8.28	18.12	36.55	60.74	38.0 %
2000-2009	1.48	1.96	3.52	6.61	14.63	31.25	45.39	30.0 %
Change (%)	214.89	-38.07	-17.98	-20	-19.29	-14.49	-25	

The High-flow frequency curve (blue colour) (Figure9) shows the proportion of years when a given high-flow rate is exceeded which is needed in the design of hydraulic structures (culverts) on the stream. This depicts the recurrence interval (in years) that the maximum stream discharge (Figure9) falls above a given rate. The slope of the high-flow region of the maximum discharge graph indicates the stream exhibits low variability in its maximum flows (Figure9). A reconnaissance survey carried out at the beginning of the study revealed a high level of urban erosion (Figures 6 and 7) and the presence, to a large extent, of an impermeable layer in the soil profile in large section of the catchment (Figure 7). The median maximum stream discharge is 77, 841.46 m^3d^{-1} and will be equalled or exceeded in 5 out of 10 years or 50 out of 100 years.

Figure 6: Eroded catchment's top soil exposing impermeable layer in the top soil

Figure 7: Literization at the Mampong market

Figure 8: Gulley Erosion in the Urban-Subcatchment

The mean-flow frequency curve (MFFC) (red colour) (Figure9) shows low variability at its high flow region and that means flows are basically from both surface and groundwater contributions and that abstraction has minimal impact on the stream's normal flow conditions. The Low-flow Frequency Curve (LFFC) (green colour) (Figure9) shows the proportion of years when a given low-flow rate is exceeded. This depicts the recurrence interval (in years) that the stream discharge falls below a given rate and represents its baseflow conditions.

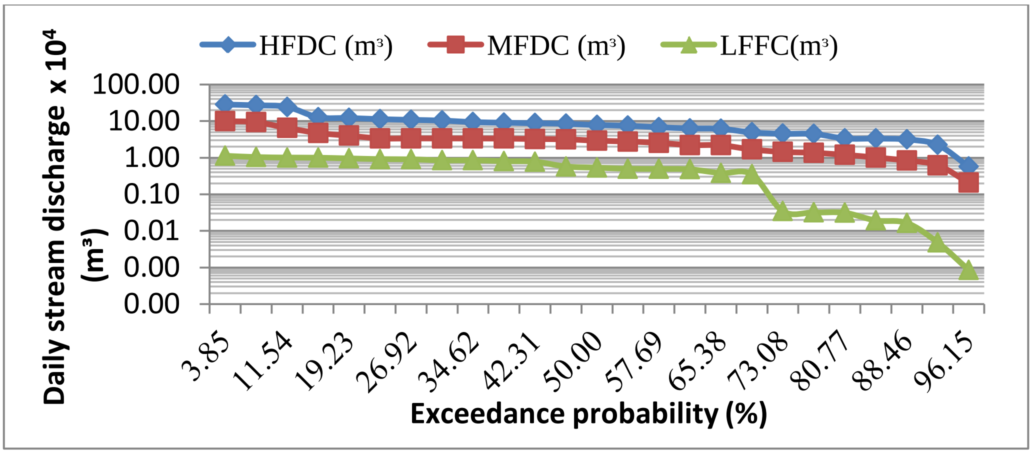

Figure 9: Maximum, mean and minimum annual flow probability curve for *Sumanpa*Stream (1985-2009)

HFDC –High-Flow-Duration Frequency Curve

MFDC- Mean-Flow-Duration Frequency Curve

LFDFC-Low-Flow-Duration Frequency Curve

Low-Flow-Duration Frequency Curve (LFDFC)

The slope of the LFFC, in both the high and normal flow regions of the curve, indicate relatively low variability in the stream's low-flows during the period. Since the stream has no diversions and storage facilities, it could be inferred that the variability is as a result of increasing abstraction for economic, domestic and agricultural uses with vegetable farming increasing along the banks of the stream and its tributaries accounting for the greater effect. Also the water imported into the catchment, from the Kyiremfa Stream, for domestic and small scale industrial uses could contribute to the variations. [5]intimated that, the period (1980-2009) mean monthly temperature has gone up and ranges between 27°C and 28.5°C during the periods of low flows (dry season). The sharp slope at the low region is an indication that low streamflows are exclusively from the aquifer [2] which is highly affected by increasing dry season farming in the catchment. The 50% dependable flow is 3,546.91m^3d^{-1} and this will be equalled or exceeded in 5 out of 10 years. The stream recorded 6 years (24% of the time) of high flow volumes; only 3 years (12% of the time) of low flow volumes and 16 years (64% of the time) of normal flow volumes. The normal flow was between 764.36 m^3 d^{-1} and 1,745.97m^3 d^{-1}.

3.5 Impact of Climate Change and Extremes on the SumanpaBaseflow Conditions

Increase in the catchment's ambient temperature [5] associated with an enhanced greenhouse effect (global), will result in increasing atmospheric water content, due to increases in surface evaporation and the water vapour capacity of the atmosphere [11]. This will lead to an increase in precipitable water in the atmosphere and hence increased annual rainfall and the baseflow conditions. Given the importance of rainfall and evaporation in driving the catchment's hydrological cycle, the changes in these primary processes (rainfall and ETa) may haveconsiderable effects on the system's components; such as changes in the volume and timing of runoff and hence the slope of the high and lowflow parts of the FDF curve [11].

The trends and variability in climate variables in the study area as published by [5] have the potential to impose additional pressure on the catchment water availability, accessibility and demand. Increase in temperature regimes has contributed to increase in ET_a and consequently the rate of water depletion in the catchment. Reduced wet season rainfall, increased temperature and ET_a contribute to significant changes in the shape of the stream's flow-duration-frequency curves in the major season. [16]predicted that the extreme event frequencies and magnitudes will increase even with a small increase in temperature as has been observed in the *Sumanpa* catchment and will become greater at higher temperatures if the trend is not reversed. The impacts of such events may be large under the local scenario and could strongly affect agricultural development. Increased extremes can cause critical hydrological design values or natural thresholds to be exceeded, beyond which the impacts' magnitudes increase rapidly [16].

Coupled with increased rates of ET_a, the potential yield and productivity of crops, especially vegetables, in the catchment will fall in the long-term [17]. In response to the catchment warming, the hydrological cycle is expected to accelerate as rising ambient temperatures increase the rate of transpiration and evaporation from the vegetation and water bodies which will affect the nature of the FDF curve. The catchment is generally becoming warmer and drier and both rainfall and temperatures have been predicted to increase in a more variable manner, with a consequent higher incidence of drought which will affect the slopes of the high and lowflow parts of the FDF curve. This is consistent with [16] climate change report. Since runoff patterns are governed by landuse as well as uncertain changes in rainfall amounts and trends, the catchment runoff is predicted to be more variable with the fast expansion of the impermeable surface areas, conversions of forests and waterlogged lands into agricultural uses.

The climate scenarios for the Mampong-Ashanti Municipality as published by [5] indicate a wetting trend in annual rainfalls over recent decades. Rising ambient temperatures on the other hand imply that the atmosphere will have an increasing trend in moisture carrying capacity, and most computer models therefore simulate an increase in extreme daily rainfall as a broad global trend. Current observations suggest that climate change is altering streamflows in ways that negatively influence water supply for inhabitants of the catchment as many climate models suggest that these changes will worsen as the climate warms, accentuating the natural variability inherent in river flows [10]. The consequences of reduced streamflows in the 2000-2009 decade and changes in the timing of peak streamflows will impact the nature of the FDF curve, water consumption, agricultural production and economic growth among other vital services. Increases in temperature and variations in precipitation patterns are driving the following observed changes in the *Sumanpa*streamflows:

- Mean annual streamflows decreased by approximately 12.3% in the 2000-2009 decade,
- As a result of increased mean temperatures, evaporation in streams, ponds, wetlands and the Ghana Water Company Limited's reservoir is expected to increase "[18]",
- Declines in the number of rainfall days will reduce annual streamflows and pose danger to germination and seedling establishment,
- Increases in the frequency and extent of droughts will also reduce streamflows and irrigation crop

production and will make the vegetation more vulnerable to bushfires.

- Higher temperatures and longer growing seasons will increase domestic and irrigation uses.

4. Conclusions

The Sumanpa Stream's flow-duration-frequency curve was constructed from its daily flow data generated from its rating curve developed at the gauge station using its daily stage data. The statistical analysis indicated that for 95% of the time, the streamflow equalled or exceeded 0.14 m^3s^{-1} and for the 5% it equalled or exceeded 45 m^3s^{-1} and 5.53 m^3/s for the 50% flow. The mean daily flow for the 1985-2009 period was 30.1m^3s^{-1} with exceedance probability of 26% and the normal flow conditions were between 2.79 m^3s^{-1} and 9.90 m^3s^{-1}.The streamflow statistics in this study included annual flow-duration quantiles for the 5th, 10th, 25th, 50th, and 95th percent exceedances. These statistics are of critical interest to the catchment agencies involved in activities such as water-quality regulation, biological habitat assessment, and water-supply planning and management. Low-flow statistics are benchmarks in setting wastewater-treatment plant effluent limits and allowable pollutant loads to meet water-quality standards. A lot more gauging of streams in the catchment is required for future analysis of this desirable parameter.

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