VOL. 5, NO. 2, DECEMBER 2016 ISSN 2305-493X
ARPN Journal of Earth Sciences

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INFLUENCE OF CHANGE IN CLIMATE AND URBAN CHARACTERISTICS ON HYDRAULIC DESIGNS AND DRAINAGE SYSTEM IN MAMPONG-ASHANTI, GHANA

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ABSTRACT

The objective of the study was to explore the challenges imposed by changing climate, rapidly expanding and modifying urban landscape on the hydraulic design of drainage infrastructure in Mampong-Ashanti, in Ghana. Basic approach to designing of urban drainage infrastructure was established through empirical peak runoff method, considering hydrologic input and appropriate design parameters. The Arc view GIS was used to delineate and determine the catchment characteristics and the state of the urban drains was established through observation. The urban sub-catchment has a mean convex slope of 5.65^{o}, a mean slope length of 1.3 km, a relief of 137 m, a mean soil depth of 0.7 m, 48.09 % of impermeable surface, 69.8 % of area located on 7-10^{o} slope class, a 110.46 % increase in urban area and a population growth of 3.3% per annum. It was revealed that: drainage facilities have not been holistically designed and are poorly maintained, the highest rainfall intensity of 60 minutes has increased by 21.0 % with a 1.17 % increase in mean monthly temperature, the city's development does not strictly follow its Master Plan and needs to be reviewed, drainage designs were based on basic hydraulic formulae without critically taking into consideration variance in runoff control variables in a warming environment with rapidly increasing runoff coefficient and that the city's drainage structures would have to be redesigned to match trends in the catchment characteristics.

Keywords: hydrotechnical design, storm water, hydrological data, drainage infrastructure and designed rainfall.

1. INTRODUCTION

Most of the landscapes on the Earth's surface have been significantly altered or are being altered by humans and these have had a profound effect (both positive and negative) upon the natural environment. These anthropogenic influences on shifting patterns of landuse are primary components of many current environmental concerns (Riebsame *et al*., 1994). These changes have become pervasive, increasingly rapid, and can have adverse impacts and implications at local scale drainage systems (Vorosmarty *et al*., 2004).

Urban conditions in developing countries exacerbate drainage challenges; runoff is increased by increasing impermeable urban surfaces and, due to inadequate development control mechanisms and their incompetent enforcement, settlements are constructed with little consideration for storm water drainage (Parkinson, 2002). Currently scientific evidence available indicates that human activities have changed the atmospheric composition resulting in a change in the meteorological processes that define a particular climate. Even though the effects of climate change at the catchment level appear to be gradual, their potential cumulative impact over the service life of drainage infrastructure warrants a change in the basic philosophy of hydrotechnical design (Arisz and Burrell, 2005). Engineers thus have no choice but to consider climate change in their practice in order to adapt and serve the public interest (Lapp, 2005 cited in Arisz and Burrell, 2005).

There is a consensus, today, that urban water systems should be approached in an integrated way. That is, the quantity and quality of the various water resources and the ecology of the catchment should be considered in relation to each other during planning and designing of urban drainage systems. Thus, the introduction of the concept of sustainability has, in the field of urban water systems among others, led to an increased interest for source control and open drainage of storm water within the urban environment (Geldof and Stahre, 2006).

The cumulative effects of gradual changes in hydrology due to climatic change, and the rapid modification of the urban landscape are expected to alter the magnitude and frequency of peak flows over the service life of drainage infrastructure. Potential future changes in rainfall intensity are expected to alter the level of service of drainage infrastructure, with increased rainfall intensity likely resulting in more frequent flooding of storm sewers and surcharging of culverts (Arisz and Burrell, 2005).

In their 2011 publication, Banerjee and Monrella, emphasized on the need to provide proper drainage and sanitation facilities to match up with the ever increasing

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population growth. The increase in the population in the urban sub-catchment and the attendant growth in needs of the residents in both quantity and variety has brought about intensive exploitation of the resources of the catchment. The urban area exploitation has increased to a degree where the resources and facilities may not be able to sustain the growing population, the environment and established development systems may collapse and lead to serious environmental challenges. As the service life of drainage infrastructure (culverts and storm sewer systems) is measured in decades (generally 50 years to 100 years), the cumulative effect of the expected gradual and sudden changes in hydrology are likely significant. The attention of development institutions and Municipal authorities is focused generally on flood risk or water supply rather than storm water drainage network (Banerjee and Morella, 2011).

Some of these infrastructures in Mampong-Ashanti are not properly designed, located and maintained and have therefore lost their designed efficiency. Also, the inadequate integration between the urban road and storm water drainage and rapidly springing up of new settlement around the city can be attributed to natural causes such as increasing trends in intensity and duration of rainfall, long sloping topography with poor soil infiltration and engineering inadequacies. The high and different forms of erosion in Mampong-Ashanti have been conjectured to be caused by rainfall overwhelming the capacity of drainage systems. Some of the drainage facilities have outlived their service lives. There is the need to re-examine the existing infrastructure, runoff control characteristics under the current climate conditions to address drainage challenges in the rapidly expanding urban area.

The objective of the study was to explore the influence of changing climate and urban characteristics on hydraulic designs and drainage system in Mamponh-Ashanti.

The following specific objectives were set toward the achievement of the main objective:

a) To estimate the catchment physical characteristics that affect the design, location and efficiency of the urban drainage facilities,
b) Estimate the catchment's rainfall characteristics in a warming climate,
c) To find out if the designs of the urban infrastructure were based on the use of accepted design methodologies, hydrologic inputs and appropriate design parameters,
d) Examine the technical state of the urban drainage infrastructure through observation and the implications under the new runoff controls of rainfall, landscape modification and urban area expansion.

2. MATERIALS AND METHODS

2.1 Study area

Mampong-Ashanti, the administrative, political and commercial city of the Mampong Municipal area, is located within longitudes 0.05^o and 1.30^o West and latitudes 6.55^o and 7.30^o North (MLGRD, 2006), with an urban area of 5 km^2 (Koteiet *al*., 2013a). The area experiences double maximum rainfall pattern with peak rainfall periods in May-June and September-October and dry periods between July-August and November-February. The climate is typically tropical, with total annual rainfall between 1270 mm-1524 mm, annual average of 1300 mm. The mean monthly temperature is about 25-32^{o}C (MSA, 2006).

2.2 Delineation and characterization of the catchment

Delineation and characterization was carried out using the National Hydrography Dataset (NHD) Watershed, an ArcView (Environmental Systems Research Institute, 1996) extension tool that allows users to delineate a catchment divide in a fast, accurate and reliable manner. A catchment is characterized when vital parameters of its morphology are determined. The Storm Water Management Model (SWMM) 5.0 of the Environmental Protection Agency of the U.S.A. lists a number of factors that would characterize a catchment as required for storm water management as the area: the land size bounded by the sub-catchment boundary (A); remotest overland flow distance; the longest route that runoff will travel before charging the channel. By the time runoff from that remotest point travels to the node of the channel, the channel will be charged by the fullest quantity possible under the prevailing runoff (L); Width: The catchment's area divided by the length of the longest overland flow path that water can travel; Slope: This is the slope of the land surface over which runoff flows or the overland flow path or its area-weighted average; Imperviousness: This is the percentage of the sub-catchment area that is covered by impervious surfaces; Roughness Coefficient: The roughness coefficient reflects the amount of resistance that overland flow encounters as it runs off the sub-catchment surface.

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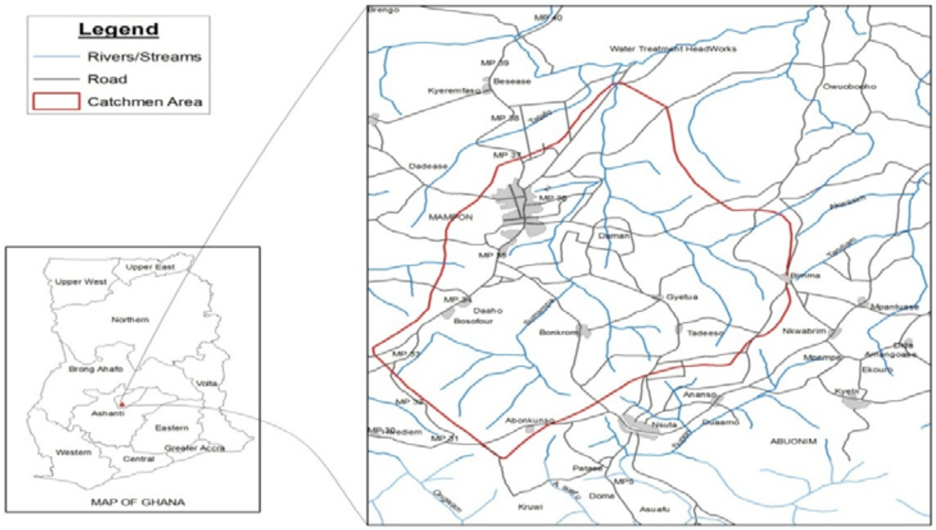

Figure-1. Location of the catchment area of the *Sumanpa* River in the Mampong-Ashanti municipal area(Source: Kotei *et al.*, 2013).

2.3 Geology and Topography

The main geological formation is the consolidated sedimentary formations underlying the Volta Basin (including the limestone horizon) which characterizes the catchment area's ground structure (WARM, 1998). Kotei*et al*. (2013a) classified the catchment slope into 0-2^o, 2-5^o, 5-7^o and 7-10^o classes. The catchment has a maximum relief of 137 m indicating its drainage ability The combined effects of climatic and geological conditions on the catchment's topography has yielded subdendritic drainage pattern characterized by a network of channels and 12 streams (Kotei*et al*., 2013a).

2.4 Basic approach to designing of urban drainage infrastructure

Urban drainage includes the removal of all unwanted water from urban areas; including wastewater and storm water. Greywater, sometimes called sullage, is domestic wastewater predominantly from bath baths, basins and washing machines. Design of storm drainage infrastructure involves the determination of the size of the storm drainage system components required to convey a design flow; while the planning for storm drainage infrastructure focuses primarily on the allocation of land and easements to accommodate this infrastructure, and controlling or limiting the interaction between drainage infrastructures and surrounding development (Arisz and Burrell, 2005). The magnitude of this design flow is selected based on the level of service that a specific piece of drainage infrastructure should provide, and is often defined in terms of the frequency of reccurrence, either as a probability of flow exeedance or a recurrence interval between events of similar magnitude. Once the level of service is selected and the appropriate design frequency is chosen, hydrotechnical design involves the use of accepted design methodologies, considering hydrologic input and appropriate design parameters (Arisz and Burrell, 2005).

Accepted methodologies for the calculation of design flow magnitudes consist of either empirical peak runoff methods, hydrologic simulation models, or statistical methods based on the analysis of hydrometric records. The design method used in the Mampong-Ashanti urban drainage design was generally consisted of the empirical peak runoff method based on parameters that describe the land use upstream of the infrastructure being designed, as well as values of rainfall that are appropriate for the local condition (Arisz and Burrell, 2005).

Approaches commonly used to select appropriate values of rainfall in design of urban infrastructure are the intensity-duration-frequency (IDF) curves, historic design storms and synthetic design storms. IDF curves represent the statistical distributions of extreme precipitation data from a given location, historic design storm generally consist of the most severe historic storm event for a given location, while synthetic design storms are averaged precipitation patterns based on historical precipitation data for a larger area of interest (Arisz and Burrell, 2005).

In the context of the effects of climate change on drainage design, it is important to note that all of the above approaches to the selection of rainfall design data are based on historic climate data and an assumption that there will be no change in climate over the project life. The validity of this assumption, which allows the past environment to be used as an indication of future conditions, is reduced or negated by climate change. The reduction or negation of this fundamental assumption thus has the potential to affect the design of storm drainage infrastructure as well as the associated planning (as planning for drainage infrastructure is a function of its size and location) (Arisz and Burrell, 2005).

The land use parameters are a function of the percentage of the drainage area that is impervious (pavement or roof areas), the soil type, and the vegetation cover. To accommodate the variability in design parameters resulting from these site conditions (both in space and in time), technical and design literature generally present ranges of design parameters rather than single values (Arisz and Burrell, 2005).

2.5 Procedure of data analysis (graphical method)

In this study, IDF curves were developed for the Mampong-Ashanti Municipality for 7 different durations (ranging from 5 to 60 minutes) and 8 different return periods. Data collection and verification was the first step in the process. The data series were obtained as annual maximum series and the following operations carried out: Every storm in a year, from 1980 to 2008, was analyzed to determine the maximum intensities for durations of 5, 10, 15, 20, 30, 45 and 60min. Thus each storm gave one value of maximum intensity for a given duration. The largest of all such values was taken to be the maximum intensity in that year for that duration. Likewise the annual maximum intensities were obtained for all durations in different years.

Maximum intensities were computed from;

$$I = R/ t \text{ (mm/h)} \quad (1)$$

Where *I* is the intensity in mm/h, *R* is the amount of rainfall in mm, and *t* is the duration of rainfall in hours. The maximum intensities determined were ranked in descending order of magnitude such that the largest value was assigned a rank number 1. Return period was then computed using the Weibull plotting position:

$$T= (n+1)/m \quad (2)$$

Where*T* is the return period in years, *n* is the number of items in the sample, and *m* is the rank of the individual items in the sample array. Regression of the intensity values for all the durations against the return periods gave a curve model with *Easyfit*statistical software. Rainfall intensities for varying durations were plotted against the return periods on normal axes using the *Excel* programme (Figures 12 and 13) From the plots, data of intensity against return periods of 1, 2, 3, 4, 6, 7, 11 and 22 years were extracted for each duration. Intensity was then plotted against duration as a function of return period on normal log paper.

3. RESULTS AND DISCUSSIONS

3.1 The characteristics of the urban sub-catchment area

3.1.1 Mean slope length and slope distribution

Slope provides the basis for land capability classification, land use planning and soil conservation needs. The topographic effects on water erosion in RUSLE are accounted for by the LS factor where L is the slope length and the S is the slope magnitude. Erosion increases as slope length increases, and is considered by the slope length factor (L). Slope length is defined by Wischmeier and Smith (1978)as the horizontal distance from the initiation point of overland flow to the point where either the slope gradient decreases enough that deposition begins or runoff becomes concentrated in a defined channel. Slopes in Mampong-Ashanti are generally convex as shown in Figure-2. Under field conditions, effects of slope length on runoff and its erosive force are confounded by the interacting effects of slope gradient, slope shape, depth to bedrock and the changes in soil physical and hydrological properties.

The erosive or destructive power of runoff increases exponentially as its velocity increases. Water, therefore, must not be allowed to develop sufficient volume or velocity to cause excessive wear along ditches, culverts, exposed running surfaces and around building foundations. If, for practical reasons, water velocity cannot be reduced, surfaces must be hardened or protected as much as possible to minimize erosion from high velocity flows. The presence of excess water or moisture during the rainy season within the roadway will adversely affect the engineering properties of the materials with which it was constructed and will cause road erosion. The convex slopes will tend to disperse water as it flowsdownhill to minimise the impact.

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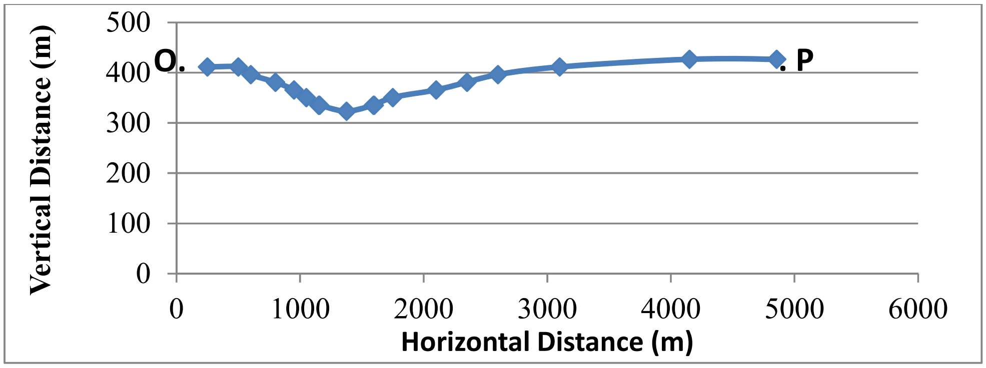

Figure-2. Cross-Section of one of the longest slopes in the catchment (Source: Kotei *et al.*, 2013c).

3.1.2 Population growth, urbanization and impermeabilization

Population pressure and urbanization are two main challenges to water resource, drainage and sanitation facilities management, especially in the city of Mampong-Ashanti. It is essentially characterized by development of new settlements, agro-enterprises and associated infrastructure facilities required for economic and social activities necessary for livelihood of the growing population. Thus, urbanization in Mampong-Ashanti has brought about significant changes in land use with buildings and construction of buildings, roads, pavements, car parks and other facilities and has increased water supply for consumptive use and release of solid and liquid wastes. The urban population has increased from 31,740 (2000) to 42, 244 (2010) (MSS, 2010).There is a higher demand on local natural resources. The natural hydrological processes that prevail in the area have been, therefore, seriously affected due to persistent illegal modifications of the urban landscape. As the catchment population grows at approximately 4.2 % per annum, demands for food, water, shelter, gravel, sand and space for economic activities multiply and dictate the price of land and how they are used. The bcentral part of the urban area, where all the social amenities are concentrated and impermeable surface area very high, is located on the higher grounds of the catchment's convex slope (Figure-2). This naturally gives the catchment efficient drainage system which influences its river's hydrograph (Figure-15).

The impermeable and poorly permeable surfaces together, occupied 69.8% (Table-3) of the urban area as at 2009. This condition impedes infiltration (recharge), promotes high runoff volumes and increases the flashiness of the catchment streams and river. The remaining 22.0% urban area was under fallow, cultivation and grassed areas. The mean depth of the soil profile (0.70 m), increasing network of rills, channels, gullies, ditches and culverts, removal of vegetation and soil, grading of land surface for construction of drainage and road networks with a catchment drainage density of 0.93km km^{-2} (Kotei *et al.*, 2013a) have reduced the distance that runoff must travel through surface and subsurface flow paths into the drainage (stream) network. These promote increased stream peak discharge and changes to the dimensions of the stream channel which limit their carrying capacity to convey floodwaters and promote severe erosion.

Concerns are particularly acute at the mid and downslopes sections of the convex slope due to the uncontrolled extensive development at the summit and mid-slope sections exacerbated by the high population density existing in these areas and the fact that most of the so-called drains, after crossing the Mampong-ahsnati-Kumasi main road discharge their storm waters into the communities (Figures4A, 5B, 6A and B). It is generally expected that urban drainage networks designed for the conditions of the past (over ten years) or present climate will not function as effectively in the future as they do now. The Mampong-Ashanti urban area planners and other stakeholders, backed by law, must develop or adopt new effective plans or processes to ensure that infrastructure services will not be adversely affected by these growing changes through the concept of adaptation.

With this scenario, the river's stage rises more quickly during storms and show double peak river flow hydrograph (Figure-15), with the first small peak having a shorter time of concentration and a sharper peak, from the urban sub-catchment, followed by a second large flow peak which increases steadily, with less sharp peak indicating interflow from all over the catchment. Under sized culverts (Figure-3B) and storm drains (Figure-3A) and designs that have outlived their service lives discharge water on un-tarred and poorly tarred roads (Figure-5) and sometimes diverting them into residential areas causing damage to properties and it is the poor, who are most susceptible and consequently suffer the most (Figure-6A and B). This scenario has led to channel sedimentation and culvert clogging with debris (Figure-4A and B). This and sections of the river channel need to be re-engineered to increase their capacities to convey the high and increasing volume runoffs from the constantly modifying urban sub-catchment landscape characteristics. The local benefits of this approach, according to Konrad (2005), must be balanced against the possibility of increased flooding downstream which would wash away or burry small scale vegetable farms on the flood plains downstream.

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A B

Figure-3. Collapsed storm drain (A) and under sized culvert (B) across the major roads near the lorry park, Mampong-Ashanti.

A B

Figure-4. Silted culvert (A) and a drain (B) at the Methodist JHS and old mechanic shop Mampong-Ashanti.

A B

Figure-5. Gutters outlived their service life, Mampong-Ashanti.

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A B

Figure-6. Buildings threatened by erosion.

Land use practices in the catchment have developed over a long period under different cultural, environmental, political, demographic and social conditions. The hydrologic changes in the river course have also come about as a result of decrease in storage capacities of wetlands along its course through encroachment and increased drainage for dry season agriculture.This leaves long-term hydrologic effects of weakening and subsequently destroying hydraulic structures and widening the river course. Two culverts have been re-designed recently on the Mampong Technical College of Education and Mampong-*Owuobuoho* roads in 2006 and 2011 respectively.The only up-slope natural water storage (Tadiem pond) which stores and gradually discharges storm water into the storm drain has been heavily silted and its vegetation is gradually being replaced by farms (Figure-7).

Figure-7. The Tadiem Pond, Mampong-Ashanti.

Table-1. Sumampacatchment slope distribution.

Slope (°)	**Area** (km^2)	**Percentage** (%)
0-2	13.718	36.1
2-5	7.637	20.1
5-7	3.147	8.3
7-10	13.503	35.5
Total	38.005	100
Mean Slope of the catchment = 5.65° Source; Koteiet *al*., 2013c		

3.2 Climate change effects

Climate change is a statistically significant alteration of the climate variables in terms of distribution in time (amount and intensity) and in space, as well as intrinsic variability in a significantly broad framework of time (IPCC, 2012). Increases in temperature associated with an enhanced greenhouse effect are likely to result in an increase in atmospheric water content, due to increases in surface evaporation and the water holding capacity of the atmosphere. Such a response is liable to lead to an increase in precipitable water in the atmosphere (Douvilleet *al*., 2002). According to IPCC (2012), the volumes of precipitation in extreme events will increase under conditions of a changing climate. With these increases in precipitation magnitude and intensity,

ISSN 2305-493X
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associated increases in runoff, storm water discharges, and flooding are expected.

3.2.1Changes in maximum rainfall intensities and annual mean rainfall

Over 56.0 % of the annual rainfall in Mampong-Ashanti occurs between March and June.One of the most significant climatic variations observed has been the increase in annual mean rainfall magnitudes and distribution in the Mampong Municipal area during the period (1980-2009) (Kotei*et al.,* 2013d) (Figure-8) which is expected to positively influence the urban hydrology, runoff and erosion trends. The increasing annual maximum rainfall magnitudes (Figure-8) and intensity (Figure-9) will increase soil erosion and the impacts will be exacerbated by the values of mean catchment slope (5.56°), slope length (1.3 km), the rapid expansion of impervious surfaces and the lack of technically designed and implemented drainage infrastructure at new urban area. An improved knowledge and understanding of the dynamics of these issues are therefore essential for addressing the challenges regarding integrated river catchment conservation practices and designing of effective hydraulic structures for appropriate and effective sanitation interventions.

The intensities of 60 and 45 minutes rainfalls have increased by 21.00 % (Figure-9) and 29.10 % (Figure-10) respectively between 1990-1999 and 2000-2009 decades. These figures are likely to go up with the trend in monthly mean temperatures (Figure-11). The Municipal mean monthly temperature over three decades has increased by 1.17 % and this has increase, significantly, the moisture carrying capacity of the atmosphere.

The rainfall intensity-frequency curve developed by Kotei*et al*. (2013b) (Figure-11) using 1980 to 2009 data shows maximum rainfall intensities that will last for 60 minutes at return periods of 22 years. This information is critical and can be applied in planning, designing of drainage infrastructure for the new urban areas and re-designing of the existing hydraulic structures to accommodate the catchment-wide integration of drainage facilities and landscape modification. The exceedence probabilities of annual maximum and minimum mean intensities in the catchment respectively can be determined from the developed curves. Normal maximum rainfalls, according to them, will occur between 335.5 mm (25% probability) and 81.9 mm (75% probability). The assessment of extreme rainfall magnitudes is an important challenge in hydrologic risk analysis and design. This is why the evaluation of rainfall extremes, as embodied in the IDF relationship, has been a major focus of both theoretical and applied hydrology (Andreas and Veneziano, 2006).

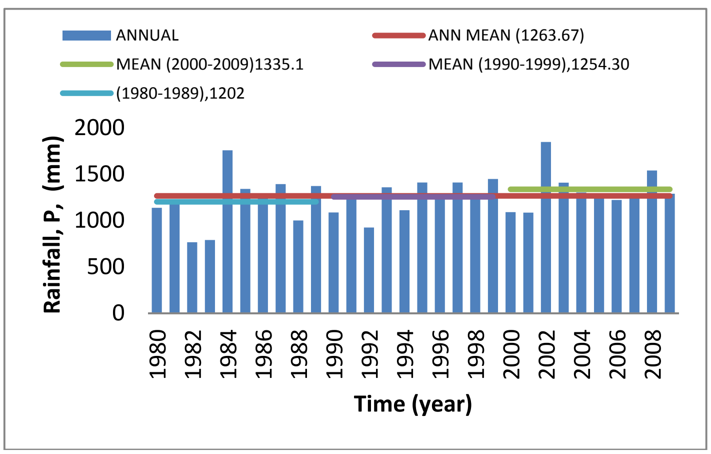

Figure-8. Annual decadal rainfall (1980 to 2009).

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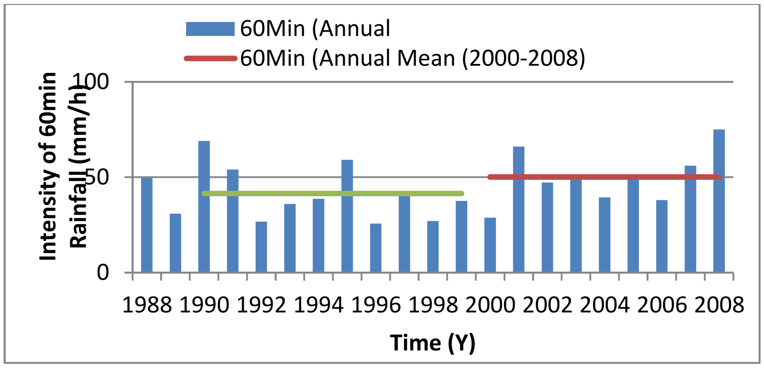

Figure-9. Annual maximum rainfall intensities at 60 minutes duration (1988-2008).

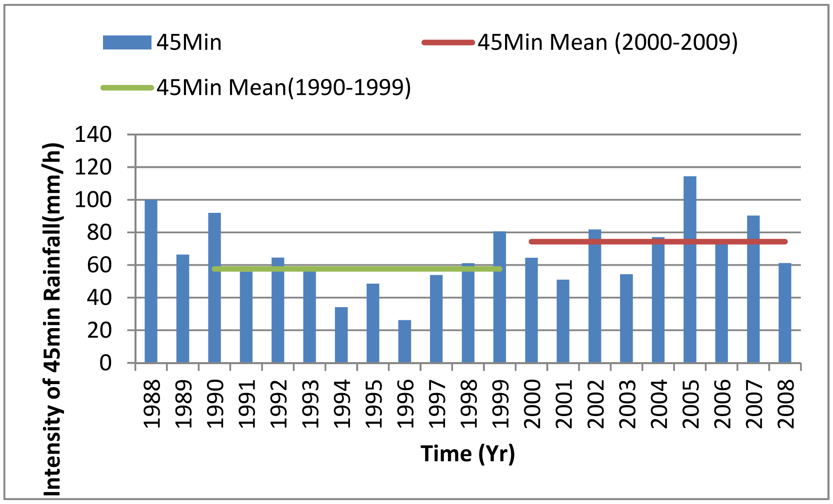

Figure-10. Annual maximum rainfall intensities at 45 minutes duration (1988-2008).

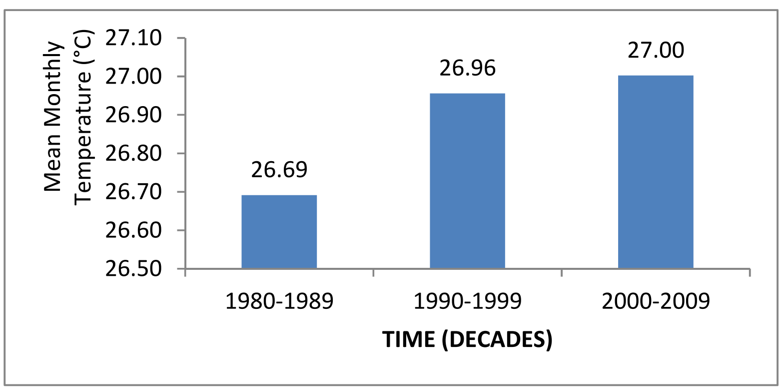

Figure-11. Mean monthly decadal temperature (1980-2009).

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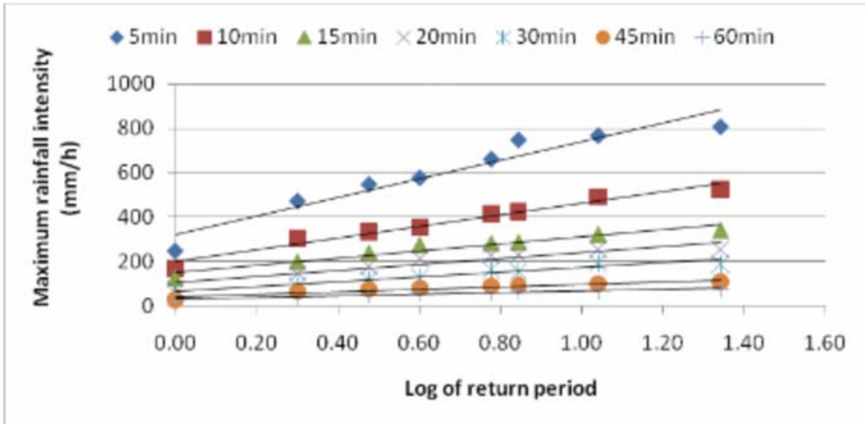

Figure-12. Rainfall intensity-frequency curve (Source: Kotei *et al.*, 2013c).

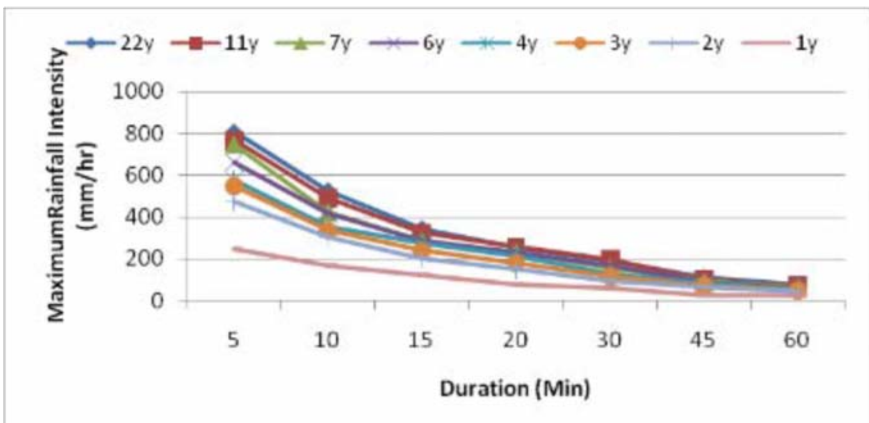

Figure-13. Rainfall intensity duration curve (Source: Kotei *et al*., 2013c).

3.3 Drainage design and planning challenges in Mampong-Ashanti

The main issue in Mampong-Ashanti is developing the city without holistically planning to consider expected developmental changes, the concept of resource conservation and technically implementing its drainage system; drainage and resource conservation challenges are addressed as they occur. The consequences are: new population settlements on unapproved areas and along stream and river banks; increase in flood frequency due to rapid urbanization; degradation of urban areas, including damaging of building foundations, by erosion and sedimentation and water quality impact from wash-load of urban surface and solid waste.

By increasing the urban runoff the river (*Sumanpa*) flow capacity, frequency of flooding and the magnitude of flood peak flows will all increase following the annual unplanned and uncoordinated urbanization and changes in landuse. During the major rainy season, the city experiences events with increasing potentials to cause extensive damage both to properties. The city's development is not strictly following its Master Plan which needs to be reviewed because it does not consider the synergic impact of climate change and rapid urban expansion on drainage flows. The city's engineering department does not have the hydrologic support to cope with these challenges and engineering works are designed without taking potential downstream impacts into account, where built-up areas leave no space into which flow could be diverted during high events, as a means of decreasing peak flows. Besides the failure to plan drainage networks adequately, the municipality encounters many difficulties in enforcing planning, conservation and sanitation legislations.

The Mampong-Ashanti urban drainage system issues have been generated by ad hoc design, planning and implementation of the system augmented by unplanned, uncontrolled and uncoordinated modifications of the urban landscape and the variance created in rainfall distribution patterns as a result of global warming. The drainage structures were designed with basic hydraulic formulae without taking into consideration variance in runoff control variables in rapidly expanding urban area and a warming environment. Almost all the hydraulic structures have failed to serve their purposes. More emphasis has to be made, by engineers, to producing home-grown methods

VOL. 5, NO. 2, DECEMBER 2016 ISSN 2305-493X
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related to the peculiar urban catchment characteristics rather than depending on formulae or assumptions.

As the service life of drainage infrastructure is measured in decades (generally 50 years to 100 years), the cumulative effect of the expected in both gradual and sudden changes in the city hydrology are significant. The urban drainage infrastructure planning and design is further complicated by the hydrologic changes associated with rapid unplanned and uncoordinated impermeabilization (Arisz and Burrell, 2005). The urban sub-catchment had 18.0 % of its surface under fallow and cultivation (undeveloped plot) in 2009. The urban area will have over 87.48 % of impermeable surface when all plots are developed and will significantly increase runoff volumes and velocities and will make the drainage system ineffective (appear undersized). Morgan *et al.* (2004) investigated the hydrological consequences of urban growth and expansion of impervious surface area and found that, while water control infrastructure appeared to attenuate peak runoff, runoff volumes keep increasing making hydraulic structures look undersized. Again, changes in landuse, precipitation timing and magnitude, and water balance dynamics in the future may diverge from historical patterns, and should be considered by the landuse planners and others responsible for urban water and sanitation issues. The city planners and designers of drainage facilities will encounter significant challenges in predicting the hydrological consequences of urban expansion in a changing climate using long-term data sets.

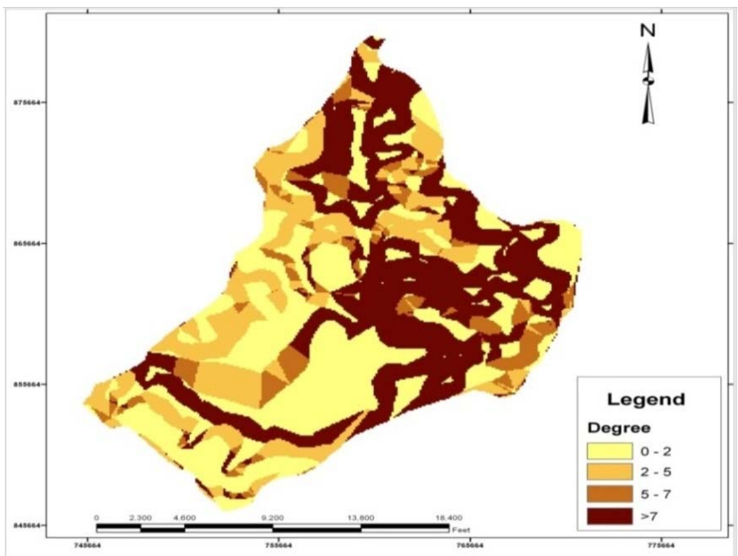

Figure-14. Slope distribution map of the *Sumanpa* catchment area (Source: Kotei *et al.*, 2013c).

Table-2. Landuse Change in the *Sumanpa* catchment Area (1986-2010).

Land cover	**1986**(ha)	**2010**(ha)	**Change** (%)
Settlements	268.58	565.25	110.46
Agricultural	372.49	891.02	139.20
Forest	2997.36	1941.66	35.22
Secondary forest	162.045	330.73	104.09

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Table-3. Land use characteristics in the urban area of Ashanti-Mampong (2010).

Types of land surfaces	**Area** (m^2)	**Percentage** (%)
Impermeable surfaces (roofs, roads, rocky surface etc.)	2328661.10	48.09
Eroded Surfaces (laterites and untarred roads, gravel)	1062740.30	21.75
Fallowed Surface	483342.33	9.89
Grassed Surface (lawn)	215064.56	4.40
Cultivated Surface	378954.66	7.75
Riparian vegetation	373437.05	7.64
Wetland	44800.00	0.92
Total	4886963.00	100

3.4 Changes in the storm hydrograph of the *Sumanpa* stream

Figure-15 shows a double peak storm hydrograph of an event in the catchment. The first peak is dominated by quick runoff from the urban centre through gullies, drains and channels. The resultsare that the catchment river hydrograph typically features higher peak flows during storms, lower baseflows between storms, and more rapid transition from low baseflow to high stream discharge. A cross-section of the catchment's topography (Figure-2) shows a general slope towards the river channel with a mean convex slope of 5.56^o and slope lengths of 1,300 m (1.3 km).Figure-16 shows the trend of composite runoff coefficient in the urban catchment over three decades (1980-2010).

The sharp rise in the runoff coefficient between 2000 and 2010 is an indication of rapidly increasing imperviousness from rapid urbanization and development (increasing drainage network), gravel and sand winning activities, increase in the frequency of bushfires, decreasing forest size and increasing soil compaction. The positive trend in the runoff coefficient means increasing runoff and the river's flashiness. Considering the trend of rainfall between 1980 and 2010 (Figure-2)due to climate change, rapid expansion and improvement of the urban road and drainage network, a mean slope of 5.65^o and a mean slope length of 1.3 km runoff volumes and velocities will increase and accelerate urban erosion even under mild events.

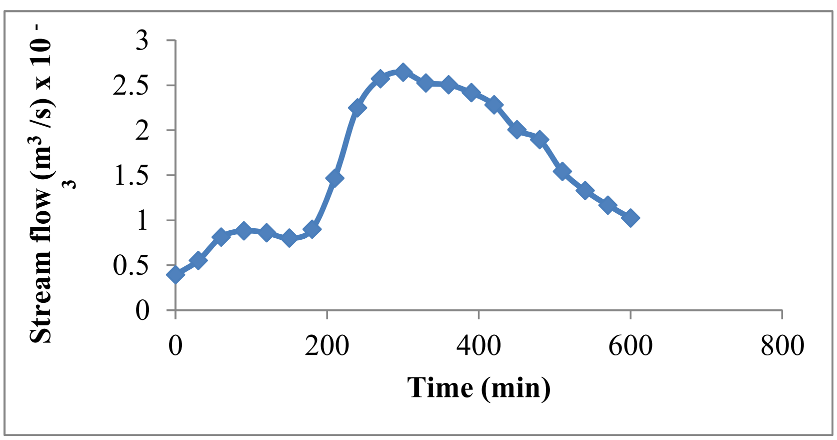

Figure-15. Unit hydrograph of the *Sumanpa* stream constructed from data Collected from the beginning of a storm to over a period of 10hours (Source: Koteiet *al*., 2013c).

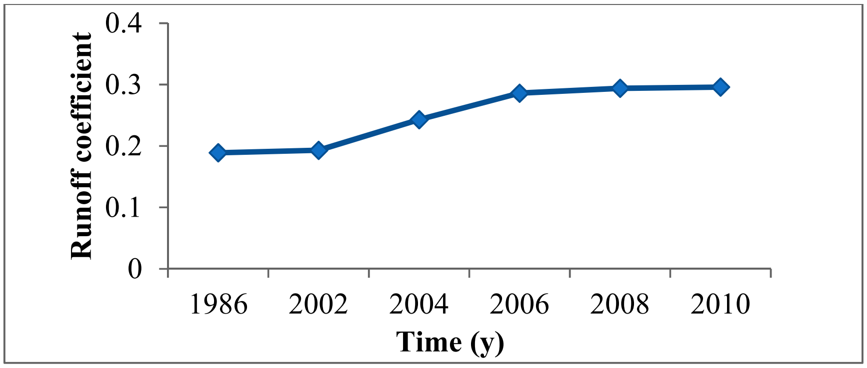

Figure-16. *Sumanpa* catchment runoff coefficient (Source: Koteiet *al*., 2013).

CONCLUSIONS

The urban sub-catchment characteristics of 38 km^2 area, mean convex slope of 5.65^o with mean slope length of 1.3 km, a relief of 137 m, a mean soil depth of 0.7 m, 48.09 % of impermeable surface, 69.8 % of catchment located on 7-10^o slope class, a 110.46 % increase in urban area, decreasing storage capacities of natural storm water storage facilities and a population grow of 3.3% per annum will demand integrated planning and design with climate change adaptive considerations. Drainage facilities are found only along major roads in the central parts of the urban area which discharge their water into uncontrolled channels which discharge into residential areas. The remaining areas have no designed drainage facilities and are therefore not linked up with the existing system.

The maximum rainfall intensities of 60 and 45 minutes have increased by 21.0 % and 29.1 % respectively with a 1.17 % increase in mean monthly temperature and the impacts would be augmented by the current catchment characteristics.

The city's development does not strictly follow its Master Plan which needs to be reviewed because it was designed with basic hydraulic formulae without critically taking into consideration variance in runoff control variables in a warming environment with rapidly increasing runoff coefficient.

In order for investments in Mampong-Ashanti's drainage systems to be effectively utilised and to mitigate urban erosion, downstream flooding and pollution challenges, there is the need to consider a holistic redesigning of its drainage and hydraulic infrastructures and systems. The urban drainage interventions should therefore be based on the concept of source control wherever feasible in order to try to mitigate local challenges within the city.

Again, it is technically always important to define, very well, drainage areas and their boundaries. The urban planners, designers and contractors focus upon technical solutions in a fragmented manner addressing challenges only as they occur with little attempt to predict and put in place preventive programmes in advance.

RECOMMENDATIONS

- The development of Digital Elevation Model for Mampong-Ashanti will help make available physical information and data required to effectively plan and design city-wide drainage system to adapt to the catchment wide climate change scenarios.
- A good information base describing local land use and topography is vital for the calculation of runoff to enable a good evaluation of the existing drainage system performance and for the design of new systems.
- The generation of urban spatial data bank will be necessary to construct base maps, which are essential in the planning process.
- Roof catchment methods of rain water harvesting should be encouraged and supported by government and NGOs to reduce peak flows of runoff that should have entered the drainage system to prolong their service life.
- Designers should combine both hydrological data and local information in determining the drainage challenges.
- Vital information and proper data collection such as water quality of runoff and sediments transport should not be neglected. This could improve the design and sustainability of these drainage channels.

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