Landuse Changes and Their Impacts on the Hydrology of the Sumampa Catchment in Mampong-Ashanti, Ghana

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ABSTRACT

The study determined changes in landuse and cover characteristics and their impacts on the hydrology of the Sumampa catchment. Maps used in the study were prepared by the Arc View GIS dataset. Landuses identified in the area were urban, agricultural and forests. The streamflow was partitioned by means of PART and RORA software programmes. Monthly, annual and decadal streamflow data were generated from daily stage data using the stream's rating curve. Annual vigorous regrowth of the vegetation after lumbering, firewood harvesting, agricultural activities and bushfire coupled with increased mean monthly ET_a were found to be major reasons for the 12.25% decrease in the annual mean streamflow. Also, 35.22% degraded forest, 110.46% increase in urban area, 139.20% increase in arable land area, 104.09% increase in the area of secondary forest and temperature rise of 1.16% were found to be responsible for the increase in daily mean ET_a by 10.2%, and the mean decadal major seasonal flow by 36.32%.

Key words: Delineation, Geographic Information System, Landuse and Urbanization

1.0 INTRODUCTION

According to [1], Landuse and land cover (LULC) are considered as two of the most important components of the terrestrial environmental system. Changes in these components are evidence of impacts of human activities on the regional environment [2]. Most of the landscapes on the Earth's surface have been significantly altered or are being altered by humans in some manner. Human modification of the landscape has had a profound effect (both positive and negative) upon the natural environment. These anthropogenic influences on shifting patterns of landuse are a primary component of many current environmental concerns. LULC change is therefore gaining recognition as key drivers of environmental change [3]. These changes have become pervasive, increasingly rapid, and can have adverse impacts and implications at local, regional and global scales. The global impact of LULC change on the hydrologic cycle may surpass that of recent climate change. Impacts of LULC on subsurface components of the hydrologic cycle are less well recognized, particularly groundwater recharge [4].

Changes in landuse and land cover result in significant hydrologic changes and research has shown that tree canopy can intercept 10-40% of incoming precipitation (commonly 10-20%) depending on factors such as tree species, density of stand, age of stand, location, rainfall intensity and evaporation during or after a rainfall event [5]. Forest degradation, such as logging, annual forest fires and wind damage at the onset of the major season rains in the Sumampa catchment can have major effects upon the canopy characteristics of forest stands and hydrological processes in the catchment. Where forest cover is permanently removed for the purposes of agriculture or urbanization, the hydrologic effects can be more long lasting.

Growing human populations exert increasing pressure on the landscape because according to [6], demands multiply for resources such as food, water, shelter, and fuel. These socio-economic factors often dictate how land is used regionally. Landuse practices generally develop over a long period under different environmental, political, demographic and social conditions. These conditions often vary yet have a direct impact on LULC. A major challenge in agriculture is developing management techniques that ensure high crop production while saving environmental quality. Intensive production of crops with high irrigation input probably represents one of the greatest threats to the quality and quantity of groundwater. In deed, natural groundwater recharge is affected by human activities on the ground surface [6].

Numerous studies according to [7], have investigated the complex relationships between land surface and other components of the climate at the local to global scales, detailing the differences in magnitude of land surface changes in different geographic localities over the Earth. The studies bring to the fore evidence that large-scale LULC changes, particularly in the tropics, generate remote climatic effects of global extent far from where the surface has been directly affected by land-cover changes [8]. [2] also recognized that knowledge about the impact of LULC changes on weather and climate is still limited, especially on the scales that are most relevant for local farmers.

The Sumampa catchment is experiencing intensive activities covering agriculture, urbanization, deforestation and other anthropogenic activities with their attendant impact of reducing the forest areas. The Sumampa stream is one of the three perennial tributaries of Kyirimfa, the main source of surface water for the Ghana Water Company Limited Reservoir at Mampong, even under prolonged drought.. There has never been any hydrological study in the Sumampa catchment to establish trends, variabilities and changes in the stream's flow and prevailing landuse conditions. With the rapidly degrading characteristics of the catchment due to expansion of settlement area and savannaization, including increases in climatic factors, it has become necessary to study the established behaviour of the catchment's water system under the changing external (climatic) and internal (soil and vegetation) conditions and to propose appropriate interventions such as in engineering designs for the catchment.

The Sumampa Stream catchment has, over the last three decades, undergone significant changes in landuse and land cover. Well-developed forest belt in the catchment play an important role in preserving and maintaining water balance. However, the degree of anthropogenic processes in the forested area has reduced it by over 60% over the last four decades [9]. This study comprised the development of landuse and cover maps for the two decades and mapping of spatial extent of the different landuse and land cover classes.

The main objective of the research was to determine the changes in landuse and land cover characteristics and their impacts on the catchment hydrology. Specifically, the study was designed to:

- Quantify geomorphological characteristics,
- Generate various thematic data base in GIS format, derivation of landuse information using remote sensing digital data and
- Determine the impact of landuse and cover change on the flow regime of the stream.

2.0 MATERIALS AND METHODS

2.1 Study Area

The Sumampa stream catchment ($07^{o}04^{'}$N and $010^{o}024^{'}$W) is located within the forest-savannah transitional zone, Mampong-Ashanti, Ghana, with a population of 44,380 and a growth rate of 4.6% . The catchment highlands are at 457m above sea level and the lowlands are at 290 m above sea level at the stream's confluence to the Kyirimfa River near the Ghana Water Company Limited's Reservoir. The catchment, which has an area of 38km^2. The main occupation of the people is agriculture. The major crops produced in the area are cocoa, oil palm, cassava, maize and vegetables. Dry season agriculture is mainly in the area of vegetables [11].

2.2 Hydrology, Climate and Vegetation

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

2.3 The Sumampa stream

The streamflow-gauging station had 37y of stage data with 25y (1985-2009) having continuous records. The stream has a weir, about 6.5m long and 1.5m deep at the Agriculture Research Station where water is lifted for irrigation. There are no significant inter-basin water transfers, industrial and urban wastewater flow augmentation, and/or urban water-supply withdrawals in the upstream drainage catchment. The urban water withdrawals occur in the main River Kyiremfa to which Sumampa is a tributary.

2.4 Geology

The main geological formation is the consolidated sedimentary formations underlying the Volta Basin (including the limestone horizon) which characterize the catchment area's ground structure [13].

2.5 Construction of spatial database

Spatial data were needed in this study for groundwater recharge assessment and modeling. Major spatial data used in this study were landuse, elevation (slope) and rainfall observed at agro-meteorological station. Monthly stage data for the stream were generated from the daily data collected from the Hydrological Department, Kumasi, for the period under research. From daily rainfall and streamflow data, monthly and annual data were computed. The department has its own mechanisms of quality control in data collection.

2.6 Topography

The surface hydrological, topographical and slopes distribution maps of the catchment were prepared from the ArcView GIS dataset. The maps are presented in Figures 1, 2, 3 and 4 respectively. The catchment's slopes were classified into slope classes of 0-2^o, 2-5^o, 5-7^o and 7-10^o. The distribution of the slope classes within the catchment is presented in Table 1. A topographic map (sheet 0702D3) of scale 1:50 000, in feet with a linear scale in metres, published in 1973 by the Survey Department of Ghana was obtained from the Department of Survey in Kumasi, Ghana. It was used to produce digitized copies of Municipal and catchment topographic maps (Figures 1 and 2). The area of the catchment was determined from satellite imagery [14]. The contour maps produced have contour interval of 15m. The highest point in the catchment is 457m and the lowest point is 320m above sea level.

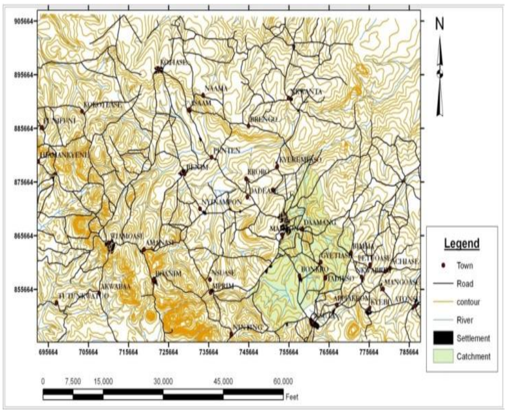

Figure 1 : Topographical Map of Mampong Municipal Assembly Showing the Sumampa catchment.

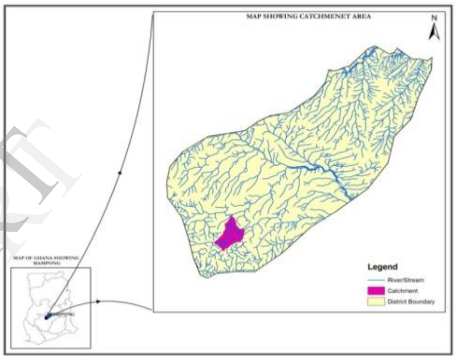

Figure 2: Location of the Sumampa catchment area of the Sumamapa Stream in the Mampong-Ashanti Municipality

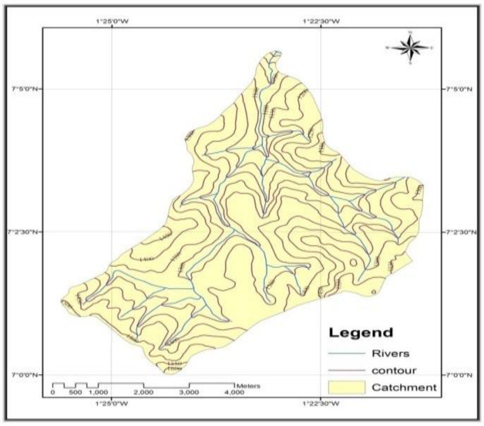

Figure 3 : Topographical map of Sumampa Catchment area.

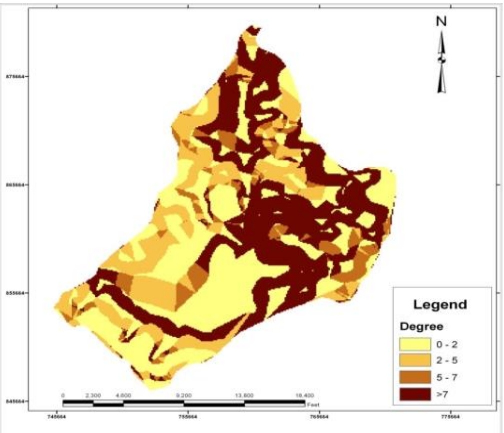

Figure 4: Slope distribution map of the Sumampa catchment area.

3.4 Land use changes in the catchment

From the LULC maps (Figs. 5 and 6) and Table 3, it can be observed that settlement, agricultural and secondary forests lands**,** have expanded.

2.7 Catchment Soil (Bediesi-Sutawa-Bejua Association)

The catchment soil is characteristically deep red sandy loam free from concretions and stones, well drained, friable and has satisfactory water holding capacity. The soil which normally occurs on the upper middle slopes was from the Voltaian sandstone of the Afram plains. It belongs to the savanna Ochrosol class and forms part of the classification. It is classified as *Chromic Luvisol* by the FAO/UNESCO legend [15].

2.8 Reconnaissance Survey

The interaction of groundwater and surface water systems were directly observed in the catchment. A reconnaissance survey was carried out at the initial stages of the research to assess specific locations (hotspots) that warrant further investigation involving more detailed monitoring and sampling.

2.9 Catchment Delineation

National Hydrography Dataset (NHD) Watershed is an ArcView (Environmental Systems Research Institute (1996) extension tool that allows users to delineate a catchment divide in a fast, accurate and reliable manner [14]. The delineated catchment area is shown in Figure 2. The maximum relief of the catchment was estimated by subtracting the lowest elevation from the highest.

2.10 Stage-Discharge Rating Curve (RC)

There is a strong relation between river stage and discharge and, as a result, a continuous record of the stream discharge was determined from the continuous record of stage data [16]. A stage-discharge rating curve (RC) describes a relationship between the water level, a channel cross section and the rate of discharge at that section. The rating curve describes a unique functional relationship between the stream stage and discharge; therefore, it is obtained as a smooth and continuous curve with reasonable degree of sensitivity. Unfortunately there cannot be a unique stage-discharge relationship unless the flow is uniform. And due to stochastic nature of rainfall, river flow is also not uniform. Hence ideal relation to show between stage and discharge is not the truth and it is only for approximation [17].

The stream's stage data were obtained from the Department of Hydrology, Kumasi, for the period 1980-2009. The continuous records of stage were translated into stream discharge by applying the stage-discharge relation obtained from Department of Hydrology, Kumasi. The sufficient number of measured values of discharges when plotted against the corresponding stages gives relationship that represents the integrated effect of a wide range of channel and flow parameters.

Mean daily Sumampa stream stage data were obtained from the Department of Hydrology, Kumasi, from March 1, 1985 to February 28, 2009, that is 25 years period. Changes in landuse and adoption of agricultural best management practices (BMPs) since that time were recently analysed. The work was initiated to determine the changes in in the stream's flow due to landuse changes in the catchment area. In addition, daily flow data generated directly from the stream's rating curve were used to determine and assess annual seasonal and decadal changes in the stream's flow.

3.0 RESULTS AND DISCUSSIONS

3.1 Reconnaissance survey

The survey provided guidance to the parameters that could be measured to quantify connectivity and also to identify the catchment's management issues impacted by the connectivity. The areas assessed were:

- The stream banks and riparian conditions,
- Gravel winning sites (Plates 1A -D),
- Sand winning sites (Plates 2A and B)
- The stream gauge station (Plate 3),
- The agro-meteorological station,
- Wetlands,
- Forest settings,
- Agricultural areas and
- Urban settings and facilities

Plate A1: Old gravel winning site near the Shwidiem-Nsuta road.

Plate 1A: Old gravel winning site turned into dumping grounds near the Sumampa-Offinso divide.

Plate 1B: New gravel winning site near the Sumampa-Offinso divide.

Plate 1C: New gravel winning site near the Sumampa-Offinso divide.

Plate 1D: New gravel winning site near the Sumampa-Offinso divide.

Plate 2A: Old sand Winning Site near the Sumampa gauge station.

Plate 2B: Old sand Winning Site near the Sumampa gauge station.

Plate 3: The Sumampa gauging station near the Ghana Water Company's resevoire, Mampong.

The catchment is challenged with limited physical resources, unpredictable rainfall regime, rapidly increasing populations (at 4.6%), forest degradation and low growth economies. These challenges call for, a proper management and conservation of the catchment's resources. Most of the catchment area is characterized by agricultural land on undulating relief. The main crops on the land, as observed during the reconnaissance survey, consists of maize, yams, cassava, vegetables, small scale oil palm and orange plantations and pockets of teak plantations. The land cover types, besides cultivated lands, were grassland, secondary forest, forest, settlement, gravel and sand winning sites. The Sumampa stream takes most of its water supply from the eastern part of the catchment which has over 90% of its area under fairly good vegetation cover; fallowed, secondary forest and forests areas. Settlement expansion in this part has been slow until 2000. The western part of the watershed has less than 4% vegetation cover with the remaining, 96%, under urban facilities (impermeable and semi-permeable surfaces). It has three temporary storages; the heavily silted Tadiem pond, located near the market, which has a maximum surface area of 1.08ha (2.7acres), an estimated 1.84ha (4.6acres) of swampy area behind the Municipal Mid-Wifery Training College, about 4.56ha (11.4 acres) of wet land between the weir at the demonstration field of the Ministry of Food and Agriculture and the Mampong Technical Training college road, and estimated 2.7acres of wetland along the New Daaman stretch of the stream (areas were taken during the wet season). 35% of the 36.51km stretch of the main stream and tributary banks are engaged with vegetable production under irrigation by the youth. The main stream has a third order segment making the stream a gaining type.

3.2 Catchment Relief (CR)

The catchment highlands, from the topographic map, at 457m above sea level at New Daaman and the lowest point is at 320m above sea level at the confluence to the Kyirimfa River near the Ghana Water Company Reservoir (head works). The highest slope in the catchment measures between 7-10^o. Average slope length was taken from the average of slope lengths from the divide to the main stream bed, from the topographic map. The mean catchment slope obtained from the ESRI GIS Programme is 5.65^o. The catchment slope distribution is shown in Table 1. From theTable, 36.1% of the catchment area was found on slope range of 0-2^o, 20.1% on 2-5^o and 43.8% on 5-10^o. The 5-10^o slope occupying 43.8% of the catchment increases the erosion risk level of the catchment where agricultural and urban landuse are growing rapidly.

Table 1: Catchment slope distribution

Slope (^{o})	Area (km^2)	Percentage (%)
0-2	13.718	36.1
2-5	7.637	20.1
5-7	3.147	8.28
7-10	13.503	35.52
Total	38.005	100

Mean Slope of the catchment = 5.6519^o
Programme used : GIS by ESRI (Environmental Systems Research Institute, 1996).

3.3 Catchment Area, Stream Order and Drainage Density (D_d)

The stream's catchment area was found to be $38km^2$ with a third order stream segment (gaining stream). The total length of stream network was 36.51km and the drainage density was determined to be 0.934km km^{-2}. Based on the work of [18] and [19], arbitrary values of drainage density of 2km km^{-2} and 15km km^{-2} was selected to represent moderate and severe erosion risks. Based on this it could be concluded that the erosion risk level of the Sumampa catchment is below moderate levels. With, approximately, a drainage density of 1km km^{-2} it could be inferred that the catchment's soils have good resistance to erosion and are very permeable minimizing the stream network of the catchment. Figure 2 shows the location of the catchment area in the Mampong-Ashanti Municipality. Figure 3 is a topographical map with a delineated Sumampa catchment in light green colour. A delineated catchment's topographic map is shown in Figure 3.

Figure 4 is the slope distribution map of the catchment area with a slope range of 0-10^o. Figure 6 shows landuse changes in the Sumampa catchment in Mampong-Ashanti from 1986-2010. A histogram of landuse and landuse changes from 1986-2010 is presented in Figure 5.

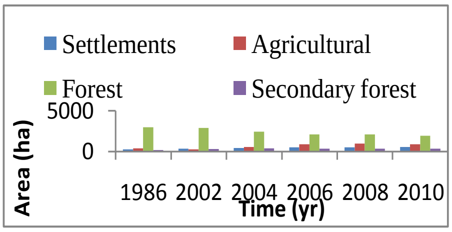

Figure 5 : A histogram of landuse changes from 1986 – 2010

3.4 Land use Changes in the Sumampa Catchment

From the LLC maps (Fig. 6) and Table 3a and 3b, it can be observed that settlement, agricultural and secondary forests lands**,** have expanded by 296.66ha (110.46%), 518.54ha (139.20%) and 168.68ha (104.09%) respectively over the study period. The forest area reduced by 1055.70ha (35.22%) over the same period. Portions of the forest have been degraded into secondary forest by agriculture, annual bush fires and chainsaw operations. Even though there has been some tree planting in response to the call to green the catchment, the rate is slow and inconsistent due to lack of educational incentives. The wetlands are being gradually converted into agricultural use by vegetable farmers. The rate of increase in the urban area means sprawl is also progressing at that rate. The Urban activities have profound effects on groundwater systems because they may alter local climate systems; change the geomorphology; alter the permeability field; and, generally, increase recharge.

3.5 Urban development and catchment hydrology

Urbanization refers to a process in which an increasing proportion of an entire population lives in cities and the suburbs of cities and/or change of landuse from agriculture to human settlements, commercial sectors and industries. Urbanization and population pressure are two main challenges to water resource management, especially in cities of developing countries. It is important to realize that drainage system of the urbanized and urbanizing parts of Sumampa catchment is poorly designed and built as a complete system.

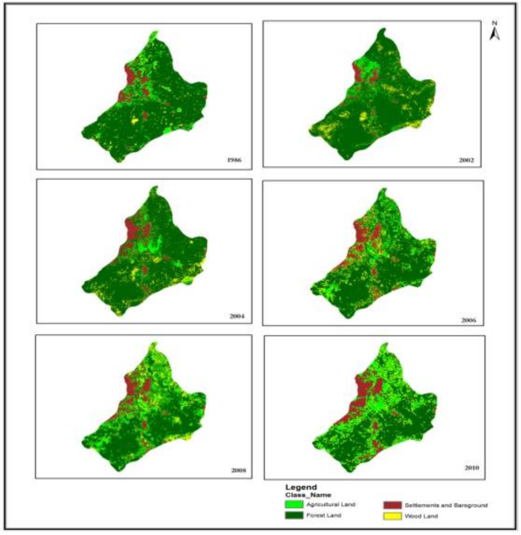

Figure 6: Land Use changes in the Sumampa catchment in Mampong-Ashanti from 1986-2010

For the design of an adequate drainage system, it is essential to understand the changes in storm runoff characteristics with landuse changes. The hydrologic effects of urban development in the Sumampa catchment (small scale basin) are getting greater on the stream. Prior to development, much of the rainfall falling on the catchment, and which are recorded as runoffs, would have been subsurface flows, recharging the aquifer or discharging to the stream network further downstream.

Regarding the groundwater resources it has to be mentioned that urbanization affects both the quantity and quality of underlying groundwater systems [20]. From Table 4, it can be observed that the impermeable surfaces (roofs, tarred roads and pavements) and poorly permeable surfaces (untarred roads and laterite surfaces) occupied 69.84% of the urban area. Fallowed, cultivated and grassed surfaces occupied 22.05%, The area occupied by the impermeable and poorly permeable surfaces is getting larger and would significantly impede infiltration (recharge), promotes runoff and increases the stream's flashiness.

Table 3a: Landuse changes in the Sumampa catchment, 1986-2010

Land Cover	1986 (ha)	2002 (ha)	2004 (ha)
Settlements	268.58	332.19	430.61
Agricultural	372.49	262.78	550.91
Forest	2997.36	2901.83	2453.54
Secondary forest	162.05	301.64	364.23

Table 3b: Landuse changes in the Sumampa catchment, 1986-2010

Land Cover	2006 (ha)	2008 (ha)	2010 (ha)	Change (%)
Settlement	485.62	484.07	565.25	110.46
Agricultue	892.89	947.16	891.02	139.20
Forest	2096.5	2092.5	1941.7	35.22
Secondary forest	331.52	344.23	330.73	104.09

Table 4: Land use distribution within the urban area, 2009

Types of Land Surfaces	Area (Ha)	Percentage (%)
Impermeable/impervious surfaces (roofs, roads, rocky surface and pavements)	232.87	48.09
Eroded Surfaces (laterites and untarred roads, gravel)	106.27	21.75
Fallowed Surface	48.33	9.90
Grassed Surface (lawn)	21.51	4.40
Cultivated Surface	37.89	7.75
Riparian vegetation	37.34	7.64
Wetland	4.48	0.92
Total	488.70	100

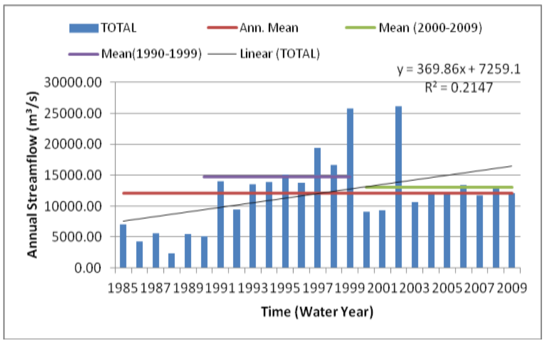

Figure 7: Annual streamflow variation and decadal changes

The annual streamflow variations shown in Figure 7 are primarily driven by anthropogenic factors (landuse change) and seasonal climatic patterns in the catchment. These variations cause intermittent rising and falling of the stream's water levels. These, periodically, produce inundation of the floodplains or the exposure and drying of part of the stream's channel. There is a drop of 11.25% in the mean annual streamflow from 1990-1999 to 2000-2009. The fitted trendline shows a general increase, a positive trend, in the stream's flow during the period. The stream's annual and decadal mean flows decreased by 11.25% and 12.26% respectively as the catchment runoff coefficient appreciates due to increase in impermeable surface area (Fig.15).

The rainfall graph (Fig.11) indicates an increase in rainfall magnitudes over the last two decades. The rainfall in the catchment increased by 2.0% and 8.4% in the 1990-1999 and 2000-2009 decades respectively from 1980-1989. The increase in the mean annual rainfall magnitudes in the 2000-2009 decade (Fig.10) did not reflect in the annual flows in that decade which showed a decline in mean flow. This is attributable to the increase in impermeable surface area as a result of urban expansion and increase in sand and gravel winning areas at the expense of the forest and agricultural lands. Again, indiscriminate lumbering, increased agricultural activities, including increasing dry season vegetable farming, and riparian degradation have also contributed to the decrease in the catchment's surface storage capacity and hence streamflow coupled with incresed ET_a (Fig. 9) due to increase in catchment temperature (Fig. 10), increase in mean annual minimum wind velocity (Fig.12) and decrease in relative humidity (Fig.13).

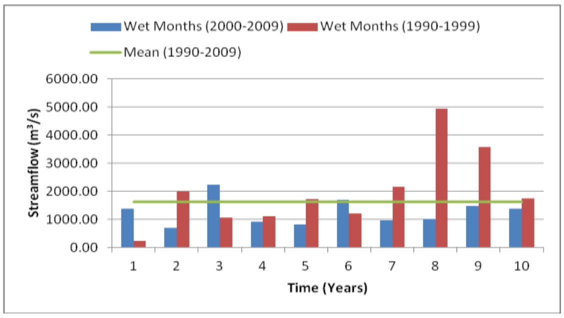

Fig. 8: Variation in major season flows over two decades (1990-2009)

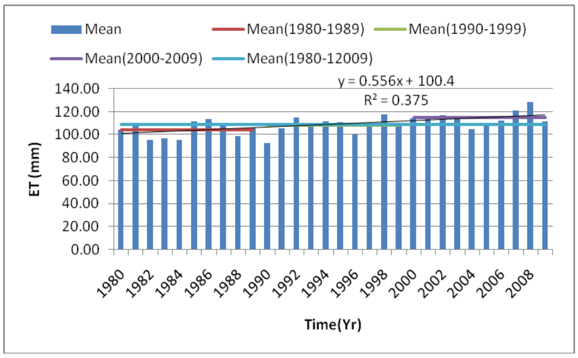

Figure 9: Mean annual vapotranspiration (mm)

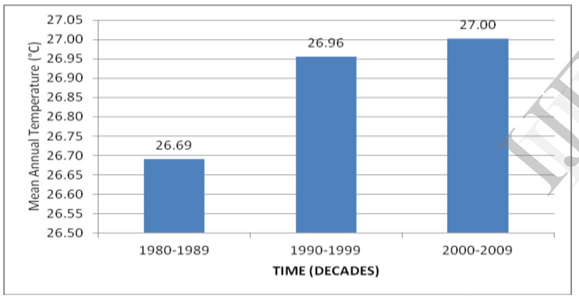

Figure 10: Mean annual temperature (°C)

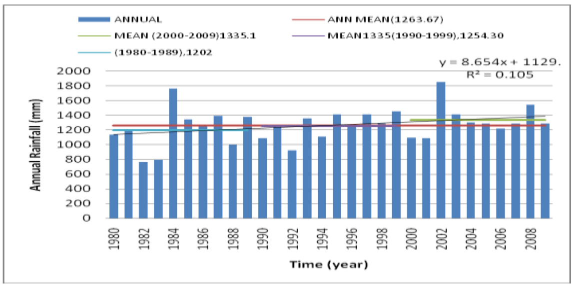

Figure 11: Mean annual rainfall m(mm)

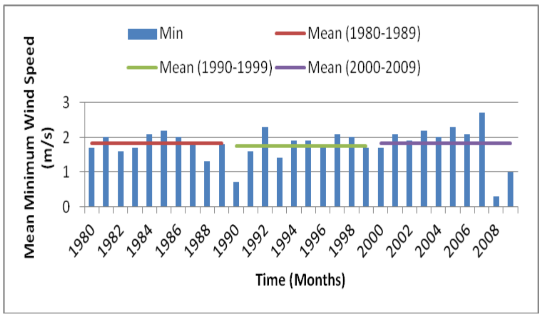

Figure 12: Mean annual wind velocity (m/s)

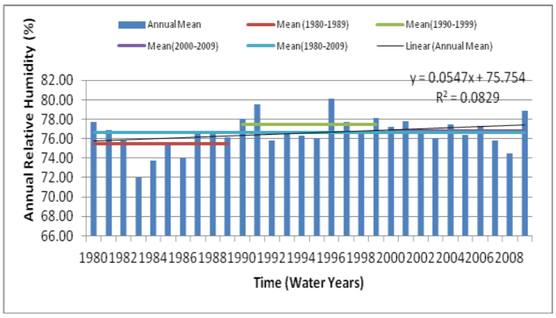

Figure 13: Mean annual relative humidity (%)

3.7 Seasonal and Decadal Changes in Catchment Rainfall and Streamflows

Figure 8 shows variation in annual major season streamflows over two decades (1990-2009). There is a decrease in the major season's streamflows in 2000-2009. During the period, only one year recorded a mean flow above the period mean while 1990-1999 had 6 years with mean annual flows above the period mean. There is a drop in the mean decade major season flow from 19,775.31m^3 to 12,592.99m^3 (36.32%). There is evidence of a drop in annual mean decadal discharge from 3,174.54m^3 in 1990-1999 to 2,785.42m^3 in 2000-2009 representing 12.26%. This decline in streamflow values may be important for planning and management of water resources that must meet increasing municipal, industrial, environmental, and recreational demands in the catchment. The total decadal rainfall and streamflows are shown in Table 2.

Table 2: Decadal rainfall and streamflow magnitudes and their percentage contributions

Elements	Period		
	1980-1989	1990-1999	2000-2009
Total stream discharge (m^3)		379,255,884.0	266,679,172.0
Percentage contribution (%)		58.72	41.28
Total rainfall (mm)	12016.20	12543.00	13351.00
Percentage contribution (%)	31.70	33.08	35.22

3.8 Change in stream's flashiness

A flashy stream is one that exhibits significantly increased flows immediately following the onset of a rainfall event and a rapid return to pre-rain conditions shortly after the end of the precipitation. The R-B Index may be useful as a tool for assessing the effectiveness of programmes aimed at restoring more natural streamflow regimes, particularly where modified regimes are a consequence of landuse/land management practices [21]. The computed R-B Index in Table 5 shows a decrease in the R-B Index by 12.15% from 1990-1999 to 2000-2009. The pathlength has also decreased by 13.88% for the same period. The total decadal stream discharge also decreased by 12.30% in the 2000-2009 decade. The most common effects of changes in landuse and land management are increases in stream flashiness and decreases in baseflow [22].

Table 5: Streamflow flashiness index

Elements	1990-1999	2000-2009	Change (%)
R-B Index	0.107	0.094	-12.15
Pathlength	9791.42	7853.70	-13.88
Total discharge (m^3s^{-1})	96860.03	84949.10	-12.30

The mean soil profile depth of 0.98m, increasing network of gullies, ditches, channels and culverts, removal of vegetation and soil (by erosion), grading of land surface, construction of drainage and road networks with a catchment drainage density of 0.934km km^{-2} 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 stream channel dimension which may limit their carrying capacity to convey floodwaters. These have resulted in the high stream stages recorded in the catchment. With the above scenario, the stream's stage rises more quickly during storms and show double peak discharge rates (Fig.**15**); the first one having a shorter time of concentration and therefore a sharper peak, increases and decreases rapidly, from the urbanised section of the catchment followed by a second rate which increases gradually with a less pointed peak from the forest and agricultural lands.

The changes in streamflow do not only reflect landuse changes, but also storm patterns. The hydrologic effects of urban development in the Sumampa catchment are getting greater on the stream. Culverts that have encroached on in the floodplain (Plates 6A and B) have increased the upstream flooding by damaging and later widening the width of the channel and reducing its resistance to flow. The scenario in Plate 6A and 6B is believed to have been caused by channel sedimentation and clogging with debris, because of undersized culverts constructed at channel section. This and other sections of the channel need to be re-engineered to increase the capacity to convey. The local benefits of this approach, according to [23], must be balanced against the possibility of increased flooding downstream which would wash away small scale vegetable farms on the flood plains downstream.

Plate 6A: One side of damaged culvert on Stream Sumampa on the Owuo Buohoo road.

Plate 6B: Other side of damaged Culvert on Stream Sumampa o the Owuo Buohoo road.

Hydrologically-speaking, the most important impact of the 296.66ha (110.46%) expansion of urban land in the catchment is the percentage increase in imperviousness. Impervious surfaces prohibit infiltration of water to the soil during rainfall events, thus inhibiting groundwater recharge and increasing overland runoff during rainfall events [24]. The results are that the catchment (urban) hydrographs typically feature higher peak flows during storms, lower baseflows between storms, and more rapid transition from low baseflow to high stream discharge. Considering the urban area it is highly reliant upon local aquifers for its municipal water supplies, the reduction in the catchment groundwater recharge is a potentially hydrologically problematic concerning the rate of urban expansion, the mean soil depth of 0.98m, the nature of the catchment topography (concave) with mean slope length of 1700m and slope of 5.65^o. A cross-section of the catchment's topography (Fig. 14) shows a concave sloping towards the stream channel.

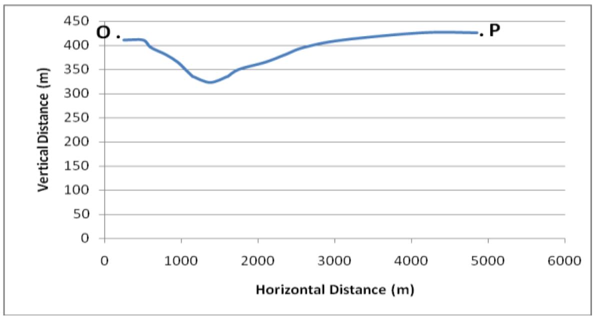

Fig. 14: A cross-section of the Sumampa catchment from the Mampong market to the Agricultural station.

3.9 Impacts of agricultural expansion

Soil compaction, due to agricultural activities, typically increases infiltration-excess overland flow, reduces the size of catchment moisture storage, and induces slower travel time of sub-surface water the stream channel. Overland runoff rarely occurs on simulations observations and soil compaction appears to be the least important factor in water yield dynamics. No evidence was found to support the notion that selected soil compaction conditions alter hydrologic behaviour at the whole-catchment scale [25]. The effects of landuse change on the catchment's seasonal and annual water yields are a net balance of change in the catchment moisture storage size, vegetation pumping effects, and flow regulation. According to [26], tropical forests have higher evaporation from rainfall interception and transpiration than other land-cover types. Consequently, forest-to-crop conversion would reduce pumping effects due to lower ETa rates, releasing more water out into the stream. This assumes that agricultural practices in the catchment do not cause significant soil compaction, which lowers infiltration rate and hydraulic conductivity. The scenario minimizes the effect of urban expansion on the streamflow.

The conversion of native ecosystems to irrigated agricultural production along the streams banks is one of the most widespread landuse change processes in the Sumampa catchment and is one with profound hydrologic impacts of its own. With increasing cultivation of vegetables, cereals and tuber crops, the ratio of bare to vegetated land in the arable areas keeps increasing and reaches a significant level at the germination and growth phases and after bushfires. Under this scenario, large portions of the rainfall are discharged directly into the stream channels, through field channels and gullies, rather than infiltrating into the soil or evapotranspire from the plant surfaces. Conversion of forests to cropland, according to [27], would increase water yield compared to native vegetation. Runoff from the expanding grasslands of the Sumampa catchment during rainfall events, according to [28], is minimal, and anywhere from 20-45% of the rainfall is drained via surface runoff from the croplands. Cropped lands, fallowed croplands and the secondary forests have been evaded by grasses of varied species which keep expanding as a result of the annual bushfires across the catchment. A similar modelling scenario, performed by [28] for a small, lower-mountain catchment whereby 100% of natural grassland was converted to cropland suggested the consequence of such landuse change would be a 50% increase in annual water yield.

The agricultural land, during the study period, increased by 139.20% (Tables 3a and 3b). With such growing size of the agricultural land, the catchment water yield is expected to increase at the expense of groundwater recharge and ETa. However, it must be noted here that the major part of the agricultural land is occupied by small scale plantation crops like orange, oil palm and cocoa most of which have closed canopies and will therefore minimize water yield by maximizing infiltration, rain water interception and ETa. Urban land expansion at the eastern and the western parts of the catchment may lead to lower buffering indicators, higher peak flow, and higher seasonal and annual yields. This is as a result of increased water yields resulting from reduced ETa from increasing area of shallow rooting crops (agricultural expansion) and reducing quantity of intercepted rainfall.

3.10 Predicted impacts of population growth and climate change on the catchment's agro-ecology

Population growth, in general, induces landuse changes, using more land for crop production and in the same process, reducing the size of land occupied by natural ecosystems. In addition, the migration of people from the rural areas to the district capital (Mampong-Ashanti) has converted more agricultural and forest lands into urban landuse. Although these changes do not use water directly, they do have a consequence on the catchment's hydrology. Replacing rangeland with agricultural ecosystems has altered many of the parameters controlling recharge in the catchment. These, basically, are climate, soils, and vegetation [29].

Furthermore, the LULC changes have affected the different hydrological components like interception, infiltration and evaporation, thereby influencing the soil moisture content, runoff generation (both process and volume) and stream flow regimes. Changes in transpiration and infiltration rates, due to the 38.22% decrease in the forest area, have increased runoff generation and recharge. Similarly, the absence of land management, such as soil and water conservation measures in agricultural production would negatively affect the catchment's rainfall partitioning [30].

This type of hydrograph (Fig.15) is known as a storm or flood hydrograph. The shape of the hydrograph varies according to a number of controlling factors in the drainage catchment but it will generally include the following features:

- The baseflow of the river represents the normal day to day discharge of the stream and is the consequence of groundwater flowing into the stream channel,
- The rising limb of the hydrograph represents the rapid increase resulting from high rainfall intensity on increasing imperviousness and surface runoff and throughflows.
- Peak discharge occurs when the stream reaches its highest level of $0.0025m^3/s$),
- The falling-recession limb is as the stream's discharge decreases and the level falls.

It can be observed that the Sumampa stream discharge has a gentler gradient than the rising limb as most overland flow has now been discharged and it is mainly throughflow which is making up the stream water.

The catchment drainage controls influence the way in which the stream responds to precipitation and affects the shape of the hydrograph. The size ($38Km^2$) and the shape, partially round,and relief of the catchment (Fig. 3) are important controls. The large size and partially round catchment dalays large quantity of catchment rainwater to reach the trunk stream. Then, with a mean catchment slope of 5.6529^o and a mean slope length of 1700m, water runs off faster, reaches the stream more quickly and causes a steep rising limb and prolonged heavy rain causes more overland flow than light drizzly rain. The shallow soils, as a result of the presence of impermeable and poorly permeable rock layers between 0.3 and 0.7m below the surface (Plates 7A – D), do not allow more infiltration and so more surface run off occurs to make the rising limb very steep. The increasing catchment impermeability due to urban expansion, increasing exploitation of sand and gravel resources and soil erosion have influenced the shape of the hydrograph. Vegetation interception of precipitation which reduces the amount of water available for overland flow while the large area of impermeable surfaces in the urban areas encourage runoff into gutters and drains carrying water quickly to the nearest channel and or drain.

Plate 7A: An exposed impermeable layer in the Sumampa topbsoil between 0-30cm depth.

Plate 7B: Exposed impermeable layer in the Sumampa topsoil (0-30cm depth)

Plate 7C: Exposed impermeable layer in the Sumampa topsoil (0-30cm depth)

Plate 7D: Impermeable layer in the Sumampa topsoil (30-70cm depth)

3.11 The catchment water yield

The amount and type of vegetative cover is one determinant of water yield of a catchment. The forests produce higher rates of ET_a and interception than do grass or shrub lands, all of which influence the amount of water that is available for direct drainage into the stream or for aquifer recharge [31]. Trees generally have lower surface albedo, higher surface aerodynamic roughness, higher leaf surface area, and deeper roots than other types of vegetation, with each characteristic tending towards an increase in ET_a of water and a decrease in streamflow discharge [21]. These characteristics tend to reduce from November (the beginning of the dry season) and reach minimum at the beginning of the rainy season in March and increase during the re-growth period of the vegetation in the rainy season. This explains one of the reasons for low stream stages during the major season.

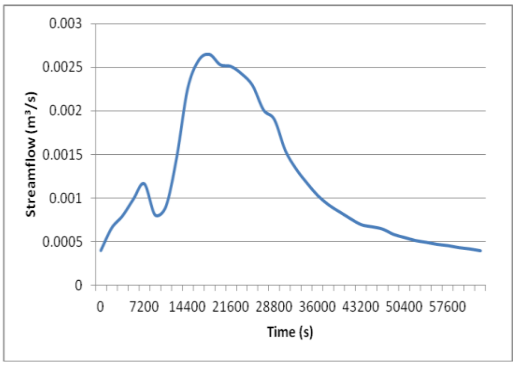

Figure 15: Unit hydrograph of the Sumampa stream constructed from data collected from the beginning of a storm to over a period of 100hours

3.12 Long-term hydrological changes

The removal of the catchment's forest cover leads to decreased interception, ET and increased scaling and crusting and runoff volumes. Research has shown that tree canopy can intercept 10-40% of incoming rainfall (commonly 10-20%) depending on factors such as tree species, density of stand, age of stand, location, rainfall intensity and evaporation during or after rainfall event [5]. The forest disruption in the catchment, such as logging, forest fires (Plates 8A and B) and wind damage, etc., as are common in the catchment, have major effects upon the canopy characteristics of the forest stands and hydrological processes. With the permanent removal of forest cover for the purposes of agriculture or urbanization, including gravel and sand winning (Plates 1A-H and 2A and B), the hydrologic effects are more long lasting [9]. The slow rate of reforestation in the catchment due to increasing chainsaw operations, charcoal production, agricultural activities, prolonged dry season, annual bushfires and absence of soil and water conservation practices, according to [27]is expected to have a long-term increasing trend in the Sumampa flow.

Plate 8: Effect of bushfire in the Sumampa catchment

Plate 8: Effect of bushfire in the Sumampa catchment

When the dense portions of the forests destroyed in fires are allowed to revert to grass or secondary forest, as can be observed in the Sumampa catchment, it promotes higher water yield from these areas (comprising baseflows and flood flows) will be higher than before the fires [33]. The increases in flows, according to him will be approximately equal to that previously lost by canopy interception, i.e., about 2-3 megalitres per hectare of catchment. If tree death does not occur, as occasionally experienced in the study area, recovery of leaf area after fire will occur in 3-5 years. By this time, the understorey is also usually re-established. The canopy stabilises, and the water balance reverts to its pre-fire behaviour. However, where the forest tree species are killed by fire, as it mostly happens in the Sumampa catchment after prolonged drought and bushfire, recovery of leaf area takes a different course. Natural regeneration of the forest occurs, and the re-growing forest is usually far more vigorous than the mature forest it replaces, due in part to access to the pool of nutrients released by the fire. The result, according to [33], is that the re-growth can develop total leaf areas much larger than in the original mature forest. This can occur at age 5-25 years. The denser canopies in re-growth intercept more rainfall and transpire more water than from the unburnt forest. There is significantly less "left-over rainfall" to appear as streamflow, so water yield from re-growth forest catchments will decrease compared to mature forests [33].

3.13 Short-term catchment hydrologic changes

Interception plays a more important role in water balance during rainfall events. The leaves and forest floor leaf-litter capture a considerable amount of water and thus encourage its slow infiltration into the soil. This water (termed sub-surface flow) serves two critical purposes in the catchment’s hydrologic system: it recharges the groundwater supplies stored in aquifers and supplies the return flow of water to stream beds during periods of dry weather [34]. The hydrologic impacts of deforestation have been studied in detail for many decades. In their classic analysis of 94 previous paired watershed studies, [35] found a consistent relationship between forest cover and water yield. According to them, reduction in forest cover, as observed in the catchment, leads to increased stream flow while an increase in forest cover decreased stream flow. According to [27], on average, deforestation increased water yield four-fold compared to loss of grassland and by a factor of 1.6 compared to conversion of shrubland. [36] notes that a few studies have resulted in contradictory findings, though this may be explained by variations in the intensity and extent of soil compaction during logging operations (via road building, skid operations and the movement of heavy machinery). Most case studies originate from smaller watersheds, where water yield variations due to landuse change are easier to quantify as a result of more homogenous weather conditions, soil types and landuse [32].

Currently the reforestation programmes in the catchment has not fully taken off. However, there are pockets of small scale (0.16 to o.8 ha) teak planted areas, small scale oil palm and citrus plantation. The forest regeneration in the catchment is slower, compared to the rate of degradation, and irregular as disturbances from farm activities, charcoal burning, fuel wood harvesting and bushfires continue to keep the forest open and full of regrowing stumps and branches of trees.

3.14 Hydraulic effects

Developments along sections of the stream’s channel and its floodplains have altered the capacity of the channel to freely convey high volumes of water and therefore increased the stream's stage corresponding to a given discharge. In particular, structures that encroach on the floodplain, such as culvert (Plates 6A and B), have increased the upstream flooding by damaging and later widening the width of the channel and reducing its resistance to flow [23].

The scenario in Plates 6A and B is as a result of channel sedimentation and debris clogging, because of undersized culverts constructed at the section. This and other sections of the channel need to be re-engineered to increase the capacity to convey high flow. The local benefits of this approach, according to [23], must be balanced against the possibility of increased flooding downstream which would wash away and or submerge small scale vegetable farms on the flood plains downstream. The above scenarios represent consequences of the catchment's fast urban development. The removal of riparian vegetation at sections of the channel has resulted in widening the few wetlands along the channel reducing the flow velocities and allowing more sedimentation in such areas. The current stream-bank erosion represents an ongoing threat to roads, culverts, and other structures which are difficult to control even by hardening stream banks [23].

3.15 Change in catchment runoff coefficient

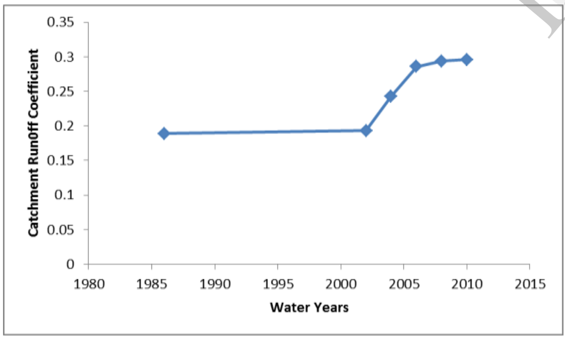

Figure 16: Sumampa catchment runoff coefficient

Figure 14 shows the trend in the changes of the Sumampa catchment's composite runoff coefficient over three decades. The sharp rise in the runoff coefficient between 2000 and 2010 is an indication of rapid urban expansion and development (removal of top soil), increase in gravel and sand winning, increase in the frequency of bushfires, decreasing forest size and increasing soil compaction. The positive trend in the runoff coefficient means rising runoff, decreasing recharge and increasing flahiness.

4.0 CONCLUSIONS

Urban, agricultural, forest and secondary forest uses were identified in the catchment. Logging, firewood harvesting, agricultural activities and bushfires together degraded 22% of the forest and 110.46% increase in urban area, 139.20% increase in arable land and 104.09% increase in secondary forest and temperature rise of 1.16% were noted to be responsible for the increase in daily mean ET by 10.2% , mean decadal ET_a by 4.55%, decreased in mean daily discharge, annual mean flow and the mean decadal major seasonal flow by 12.3%, 11.25% and 36.32% respectively.

Urbanization in the Sumampa catchment has generally increased the size and frequency of floods in the stream. The streamflow information generated would provide a scientific foundation for flood planning and management in the catchment. Because flood hazard maps based on streamflow data from a few decades ago may no longer be accurate today, and floodplain management require current peak streamflow data to update flood frequency analyses and flood maps in areas with recent urbanization. The Municipal stormwater managers can use the streamflow information in combination with rainfall records to evaluate innovative solutions for reducing runoff from the catchment's urban area. Rapid changes in the catchment are attributed to excision of the forests by squatters, logging for timber, charcoal burning and agricultural activities. The changes in land ownership have caused high stocking rates because of the current population drift in the catchment. The effects of the landuse changes to the flow characteristics of the Sumampa stream have been identified as high with high intra-annual and inter-annual variations in peak flows in recent years (2000-2009) and longer base flows. There has also been attenuation of stream hydrographs with time of onset of rains and peak streamflow reduction. If these adverse changes continue the streamflow which supports its riparian communities will be flowing at minimum and even ceasing a few months into the dry season. Sound management options must be arrived at by stakeholders in water development and users of the catchment resources and clearly implemented. The local communities must also be sensitized in sustainable resource reservation techniques.

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