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Re-engineering DEM to extract geomorphologic parameters for flood prediction in Ghana

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Abstract: The study uses GIS and SRTM 90 meter Digital Elevation Model (DEM) to identify streams, watersheds, flood hydrographs, and catchment characteristics such as Bifurcation Ratio (R_B), Stream Length Ratio (R_L), and Drainage Area Ratio (R_A) in Ghana. It was found out that Volta basin occupies 69% land area of Ghana while the second tier of river basins comprising Pra, Ankobra, Tano and Bia occupy 22% of Ghana's land surface; and the rest of the river basins including south eastern coastal river catchments occupying 9%. Furthermore, it was found out that there are 1,797,928 streams in Ghana with the highest stream order being 10 and the total stream length being 907,651 kilometers. The first, second and third stream orders occupy 73%, 21% and 5% of streams in Ghana respectively. Volta basin, with the highest stream order, registered the highest parameter values for Bifurcation ratio (R_B), Stream Length ratio (R_L), and Drainage Area ratio (R_A). Several equations have been developed to help estimation of the parameters from stream numbers. By using the estimated parameters, Nash model was used to estimate unit hydrographs for the major river basins. The results suggest that GIS can be used with a minimal data set of DEM to identify watershed boundaries, streams, and parameters for simulation of the response of ungauged streams to water input in Ghana. Further research is needed to evaluate the effects of using a higher or lower DEM resolution on watersheds parameterization in Ghana.

Keywords: Ungauged streams, Hydrograph, Stream order, Drainage density, Hydrology, Geomorphology

1. Introduction

Ghana, like most tropical countries, is endowed with many streams and rivers (Davies et al., 2008). In this era of climate change, with high level of environmental degradation (Owusu, 2012), tropical countries should be able to account for all available water from their streams. Proper water resource management demands accurate stream flow and climatic data; but most streams in Africa are ungauged (Khalil et al., 2011; Nyabeze, 2005; Symeonakis et al., 2009). These challenges pose an inadequate understanding of the environmental problems; for instance, the lack of understanding in the high level occurrences of flooding in most tropical areas (Dovie, 2010). Another problem inhibiting water resources management in some tropical countries, such as Ghana, is lack of availability of historical water resource data, e.g. rainfall and runoff, for watersheds hydrological modeling. Flood peaks and time of concentration can be predicted accurately in hours, minutes and seconds if there are enough and accurate availability of rainfall and discharge data. Moreover, hydrological processes in a basin are nonlinearly influenced by various climatic, topographic, soils, land use information that requires not only wide variety of geophysical and hydro-meteorological data but also rigorous computational skill for solving the governing equations of a distributed model. Hydrological processes become more complex because it also requires time to time changes in their parameters due to variation encountered with respect to the gradual climatic changes and land use of watersheds. (Rai et al., 2009)

In absence of accurate historical data and lack of computing skills, in the face of changing climate and dynamic land use activities, one approach that can be used to make prediction of runoff in a watershed is the geomorphological parameters which are mostly time-invariant (Rai et al., 2009). Geomorphology of a watershed provides description of topographic features of the drainage surfaces and streams. The relationship between geomorphology and hydrology provides the geomorphologic control on basin's hydrology (Jain and Sinha, 2003). Geomorphology therefore reflects the topographic and geometric properties of the watershed and its drainage channel network (Rai et al., 2009). Quantification of a drainage network of a river basin can therefore provide a significant contribution towards flood management and water logging program (Jain and Sinha, 2003).

Based on geomorphology, Snyder (1938) proposed synthetic unit hydrograph (SUH) approach for an ungauged basin that depends on a catchment area, basin shape, topography, channel slope, stream density, and channel storage leading to a final derivation of the basin stream coefficient by averaging out watershed parameters. Some of the watershed characteristics, summarized in Horton stream laws concept (Horton, 1945; Strahler, 1952, 1957), have been used to develop Geomorphologic Instantaneous Unit Hydrographs (GIUH) for ungauged streams (Rodriguez-Iturbe and Valdes, 1979). Kumar and Kumar (2008) predicted direct runoff from a hilly watershed using geomorphology and stream-Order-Law Ratios. Adib et al. (2010) used several versions of

GUIHs such as geomorphoclimatic instantaneous unit hydrograph (GcIUH-Clark), GIUH-Nash and compared them to Nash-IUH and Clark-IUH on an Iranian catchment with an area of 67.5 km^2. GIUH, modified by Gupta et al. (1980), depends on the watershed characteristics (Horton, 1945) such as Bifurcation Ratio (R_B), Stream Length Ratio (R_L), Drainage Area Ratio (R_A) etc.

Linear Watershed Instantaneous Unit Hydrograph predicts hydrograph ordinates based on decay constant (T*) which depends on Time of concentration of quick runoff (Dingman, 2002). There are several empirical formulas that link Time of concentration (T_c) to catchments characteristics such as drainage area (A_D) (Kirpich, 1940), length of slope, sine of channel slope (S_c), length of the main stream, hydraulic characteristics, and maximum length of flow.

Catchment characteristics are generally grouped into 1) physical characteristics of the drainage basin and 2) channel characteristics of stream network (Rai et al., 2009). Physical characteristics of the drainage basin include drainage area, basin shape, ground slope, and 'centroid' while channel characteristics include channel order, channel length, channel slope, channel profile, and drainage density (Rai et al., 2009).

Several approaches have been used in the literature to determine watershed boundaries and characteristics. Kang and Lin (2009) used the USGS national hydrograph datasets at a scale of 1:24,000 to determine stream orders of a stream network in the East Mahantango Creek Watershed. Adib et al. (2010) combined 1:25,000 topographic map and Arc GIS software through procedure described by Kumar et al. (2002) to delineate watershed boundary and estimate watershed characteristics. Few studies have been done in using only Digital Elevation Model (DEM) to first, delineate watershed boundary; second, to estimate its parameters; and third to estimate a discharge hydrograph from the parameters. Moreover, there is little knowledge on how to use GIS to simultaneously estimate stream parameters for several watersheds at national level; for example for the size of Ghana, in the tropics. Such knowledge will help disaster managers, for instance, to take decisions on several catchments when disaster strikes. The purpose of this research is to develop a Geographic Information System (GIS) model that will use Digital Elevation Model (DEM) to estimate watershed boundary and catchment characteristics for flood prediction of water basins in Ghana. First, all watersheds boundaries in Ghana are estimated with GIS. Second, parameters such as Bifurcation Ratio, Stream Length ratio, Drainage Area Ratio are extracted from the major basins in Ghana i.e. Volta, Pra, Bia, Tano, Densu, and Ankobra. And third the catchment parameters will be applied in a flood prediction.

2. Material and methods

2.1 Study area

Ghana lies within latitudes 4° and 11° 30' north of the equator; and longitudes 1° 12' east and 3° 15' west. The total area of Ghana is 238,533 km^2. Ghana is a tropical country mainly characterized by A and B Koeppen Climatic Classification. Specifically, the country is characterized by humid tropical climates (Af) and tropical wet and dry or savanna climate (*Aw*). There is also an evidence of Koeppen (B) dry climate in the northern part of the country.

2.2 Data input

The main data input of the study include rainfall and Shuttle Radar Topography Mission (SRTM) DEM. The clipped DEM (see Figure 1) has been produced by RADAR remote sensing from SRTM Topography project (NASA, 2004). The SRTM data set, a 90 meter resolution, is a result of a collaborative effort by the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency, as well as the participation of the German and Italian space agencies (Farr and Kobrick, 2000). Without re-engineering, DEM is not useful for the catchment parameterization because there are errors in it (NASA, 2004).

Figure 1: The clipped 90 meter Digital Elevation Model (DEM) of Ghana (NASA, 2004)

2.3 Work flow

In this study PCRaster (Van Deursen, 1995), a higher level GIS language (Karssenberg, 2002), was used to re-engineer DEM. A functional code from PCRaster Environmental Software (Karssenberg, 1996) was written and integrated in this study as a series of equations, in the form of the PCRaster language. A DEM is first imported into PCRaster GIS. The imported DEM is reengineered to remove errors and create a stream network topology called Local drain direction map using PCRaster 'ldd() function' (Equation 2). The spurious peaks of SRTM data were removed by comparing Ghana elevation data and SRTM. If SRTM is extremely higher than the topographical sheet elevation of Ghana, a windowaverage() function in PCRaster was used to replace it with a 3X3 window average. Outflow points map of all the basins in Ghana were then created using PCRaster 'pit()' function. The outflow point map was combined with local drain direction map to create watersheds using PCRaster 'catchment()' function. A stream order map was created from Local drain direction using 'streamorder()' function. And each watershed and its stream order were clipped together using logical functions in PCRaster. PCRaster tabular function 'map2col' was used to strip stream order numbers, lengths, and areas of each watershed into a tabular data. Microsoft Excel was finally used to estimate the parameters. The parameters were transformed with dynamic velocity to derive hydrographs (Figure 2).

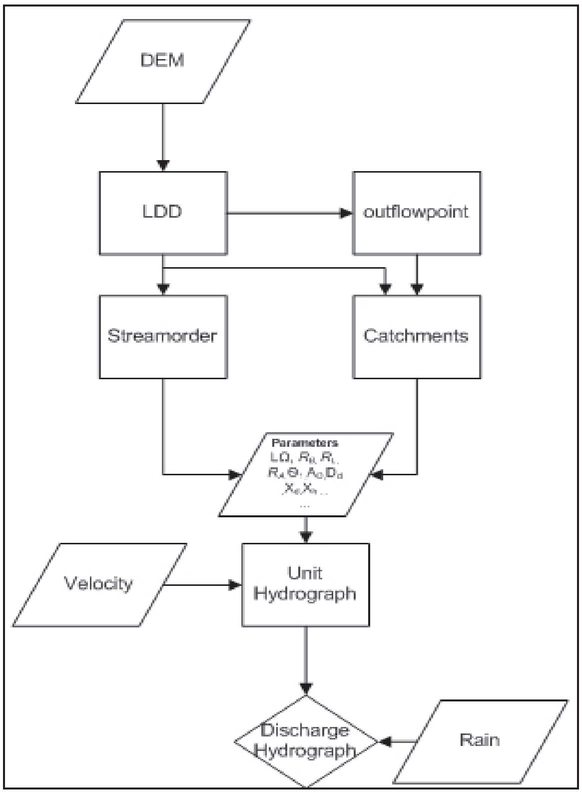

Figure 2: The flow chart of the GIS model

2.4 Data processing

A PCRaster function "lddcreate()" was used to create catchments boundaries and areas (A_D) of Ghana as:

Ldd.map = **lddcreate** (elevation, outflowdepth, corevolume, corearea, catchmentprecipitation) (1)

where elevation is an uncorrected elevation map (from Figure 1), Ldd.map is local drain direction map, and the input parameters "outflowdepth, corevolume, corearea, catchmentprecipitation" are pit removing thresholds that are used in removing errors in the SRTM DEM due to the discretization of elevation surface (Karssenberg, 1996). All pits, volume, area, that were lower than thresholds of "outflowdepth", "corevolume", "corearea" in equation (1) were treated as an error and filled with "catchmentprecipitation". The removal of pits re-engineered DEM so that all the water in the catchment flow through the outflow points as (Karssenberg, 1996):

Ldd2.map=lddcreate(dem.map, 1E35, 1E35, 1E35, 1E35) (2)

where the value "1E35" is the values - for pits, core volume, core areas, and catchment precipitation as in Equation (1) - that remove all the pits and errors on DEM map (Figure 2), except those at the edges of the map or man-made pits such as reservoirs. The edges of Ghana map were assumed to be outflow points of the main rivers leaving Ghana. Rivers were considered flowing to and/or from neighboring boundaries of Ghana such as Burkina Faso in the North; Ivory Coast to the West; Togo to the East; and Atlantic Ocean to the South. The pit map was used to estimate outflow points of the catchments boundaries of Ghana as:
catchment.map=catchment(ldd2.map,pit(ldd2.map))(3)

A PCRaster function "streamorder()" was used to estimate stream order for the whole Ghana as:

streamorder.map = streamorder(ldd2.map) (4)

Drainage parameters such as Bifurcation ratio (R_B), Stream Length ratio (R_L) and Drainage Area ratio (R_A) were evaluated (Rodriguez-Iturbe and Valdes, 1979) according to stream laws of drainage network composition (Horton, 1945; Schumm, 1956; Dingman, 2002:435) as:

$$R_B = \frac{N_w}{N_w + 1}\ ;\ 3<R_B<5 \qquad (5)$$

$$R_L = \frac{L_w + 1}{L_w}\ ;\ 1.5<R_L<3.5 \qquad (6)$$

$$R_A = \frac{A_w + 1}{A_w}\ ;\ 3<R_A<6 \qquad (7)$$

where N_w is stream numbers, L_w is average length of streams, and A_w is an average area of stream order (w). The fraction of watershed (Θ_1) draining directly to first order streams were also estimated based on Dingman's (2002:435) formula as:

$$\theta_1 = \frac{\mathrm{R_B}^{\Omega-1}}{\mathrm{R_A}^{\Omega-1}} \qquad (8)$$

where Ω is the highest order in the watershed. Parameters such as drainage density (D_d), average distance from a basin divide to stream channel (X_d), and average distance that a drop of water travels to a stream in a watershed (X_h) were estimated as (Dingman, 2002:435):

$$D_d = \frac{\sum L}{A_D} \tag{9}$$

$$X_d = \frac{1}{2 \cdot D_d} \tag{10}$$

$$X_h = \frac{X_d}{2} \tag{11}$$

where A_D is an estimated drainage area for each basin, and L is the length of streams draining in a watershed. Rai et al. (2009) established relationship between peak discharge, time to peak of a flood and the parameters (from Equations 5-11) as follows:

$$q_p = 1.31 R_L^{\ 0.43} V / L_\Omega \tag{12}$$

$$t_p = 0.44(L_\Omega / V)(R_B / R_A)^{0.55} . R_L^{\ -0.38} \tag{13}$$

where q_p is the peak flow (h^{-1}), t_p is the time to peak (h), L_Ω is the length of the highest order stream (km), and V is the dynamic velocity parameter (ms^{-1}).

Nash (1957) also established relationship between instantaneous inflow through a cascade of linear reservoirs with equal storage coefficient hydrograph and catchment characteristics as:

$$u(t) = \frac{1}{k\Gamma n} e^{-\frac{t}{k}} \left(\frac{t}{k} \right)^{n-1}, \ \Gamma n = (n-1)! \tag{14}$$

$$n = 2.4 L_\Omega^{\ 0.1} \tag{15}$$

Rai et al. (2009) estimated the storage coefficient 'k' based on catchment parameters as:

$$k = \frac{0.44 L_\Omega}{V} . \left[\frac{R_B}{R_A} \right]^{0.55} R_L - 0.38 \frac{1}{(n-1)} \tag{16}$$

where $u(t)$ is the ordinates of Instantaneous Unit Hydrograph (IUH) (hour-1), t is the sampling time interval (hour), n and k are the parameters of the Nash model. The calculation of Unit Hydrograph Ordinates (UGO) and subsequent prediction of flooding characteristics were based on the calculations of Raghunath (2006, p. 396). Equations 15 and 16 were used to estimate n and k parameters respectively. Then Equation (14) was used to estimate the ordinates of Instantaneous Unit Hydrograph, u(t). The u(t) was multiplied by respective catchment area to derive new u(t). The 2 hour Unit Hydrograph was derived by averaging two successive u(t). Finally, the ordinates of flood water were estimated by multiply 2 hour unit hydrograph by rainfall amount (Figure 2). See Raghunath (2006, p. 396) for more details.

2.5 Model output

The main outputs of the model were maps, tables and graphs. Catchment attributes that were estimated include bifurcation ratio, stream length ratio, drainage area ratio, drainage areas, basin perimeter, longest catchment distance, drainage divides, drainage density, and drainage patterns. The parameters were subsequently used to estimate Geomorphologic Instantaneous Unit Hydrograph (GIUH) and flooding hydrograph.

3. Results

3.1 Watersheds analysis of Ghana

The output of equation (3) identifies all the catchments in Ghana that include river basins such as Volta, Pra, Bia, Tano, Densu, and Ankobra (Figure 3a). Of the estimated total catchment area of Ghana (238,699 km^2), Volta basin occupies 69 % of Ghana's land surface. South western catchments such as Pra, Tano, Ankobra, and Bia and south eastern coastal catchments such as Densu, Ayensu occupy 22% and 9% of land surface of Ghana respectively. The highest stream order in Ghana, based on the 90 meter DEM resolution, according Equation (4), is 10. Out of estimated 1,797,928 streams; first, second and third orders' streams occupy 73%, 21%, and 5% respectively of all the estimated streams in Ghana. The total number of ninth and tenth stream orders is 9 and 2 respectively, with Volta and Pra being tenth order streams (Figures 3, 4a, 7 and Table 1).

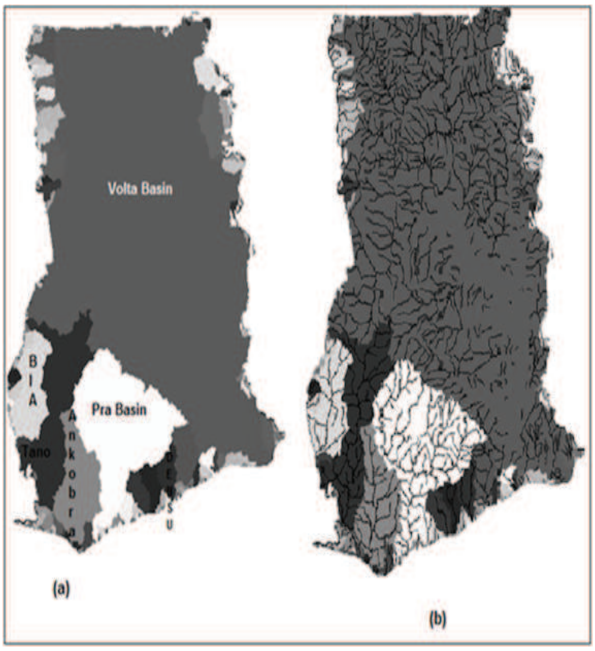

Figure 3: (a) The estimated watersheds boundaries of Ghana and (b) overlay of a digitized river network (Mårtensson et al., 1999) on the estimated watersheds.

The estimated total stream length of Ghana is 907,651 kilometers. Stream length of Ghana decreases with increasing stream order, with orders 1 to 3 possessing 57%, 23% and 10% respectively (Figure 4b). However, average stream length (stream length divided by stream order number) increases exponentially with stream order (ɯ), with R^2 of 0.99. Average stream length can be estimated as:

$$L_{ɯ} = 0.1094e^{0.8251ɯ} \qquad (17)$$

where $L_{ɯ}$ is average stream length (km) of order (ɯ). While average stream length of lower orders 1, 2, 3 are 0.4 km, 0.6 km and 1.2km respectively, higher stream orders 8, 9, 10 have 78 km, 174 km and 675 km length respectively. The distribution of drainage areas among the stream order appears to be uniform with an average of 140,646 km^2 and standard deviation of 13,888 km^2. Stream orders 1 and 10 occupy 140,993 km^2 and 168,581 km^2 respectively (Figure 4c).

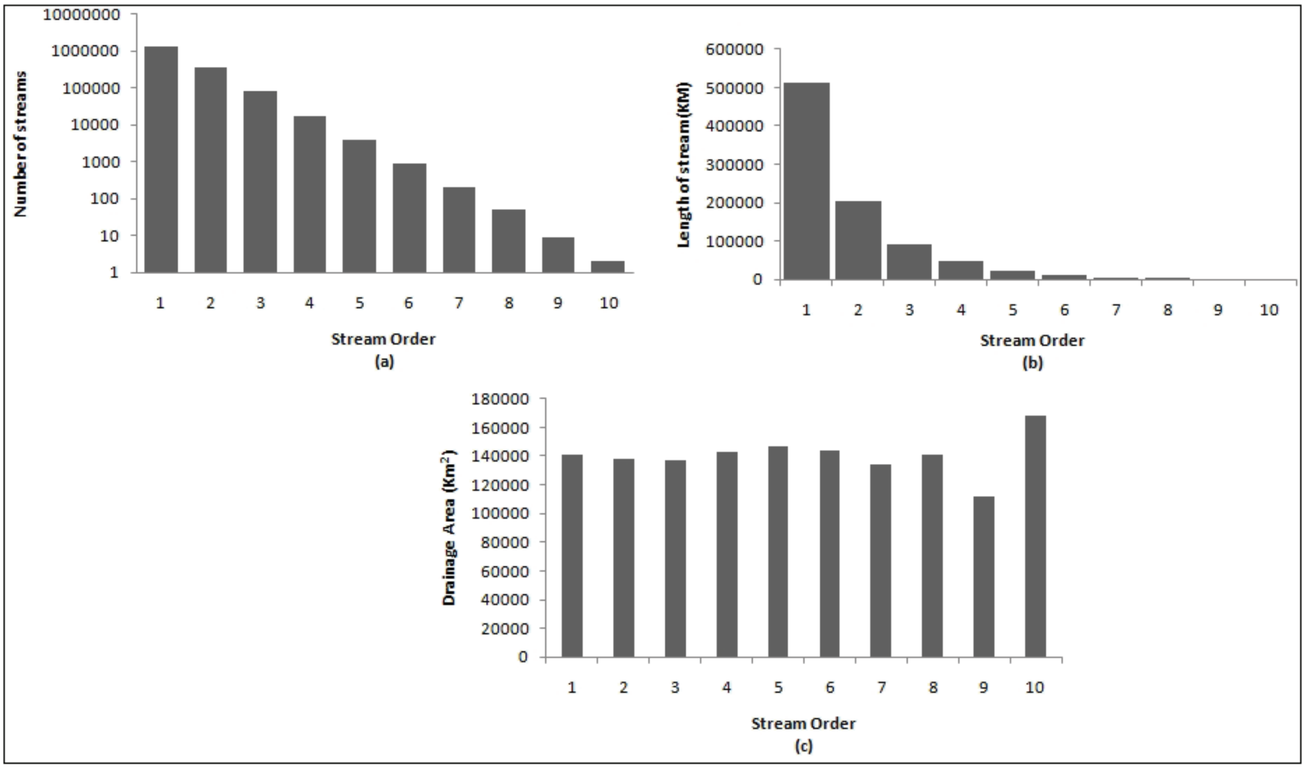

Figure 4: Distribution of (a) stream number, (b) stream length and (c) drainage areas of Ghana

3.2 Stream analysis of Volta basin in Ghana

Out of the total number of 1,193,131 estimated streams in Volta basin in Ghana (located on Figure 3) orders 1, 2 and 3 represent 73%, 21%, and 5 % respectively. The 8th, 9th and 10th order has only 33, 6, and 1 stream(s) respectively. Exponential function that can predict Stream number ($N_{ɯv}$) from stream order (ɯ) in the basin was derived as ($R^2 = 0.999$; see Figure 5a):

$$N_{ɯv} = 5E+06e^{-1.515}ɯ \qquad (18.1)$$

Therefore, bifurcation ratio of Volta basin is [exp(1.515)] 4.55 (Dingman, 2002:434). Stream length of Volta river decreases with order: with orders 1, 2 and 3 possessing 57%, 23% and 10% respectively of the Volta basin. However, average stream length increases exponentially with order, with orders 10, 9, 8 registering 1208 km, 158 km, and 85 km respectively; while orders 1,2,3 measured 0.4 km, 0.6 km, and 1.1 km respectively. Exponential function for prediction of average stream length of Volta river (Lɯv) from stream order (ɯ) was derived as ($R^2 = 0.9767$; see Figure 5b):

$$L_{ɯv} = 0.1021e^{0.8516ɯ} \qquad (18.2)$$

Stream Length ratio of Volta was 2.34 [exp(0.8516)]. The distribution of drainage areas among the stream order in Volta basin appears to be uniform with average of 99,054 km^2 and standard deviation, minimum, and maximum values of 18,660 km^2; 69,501 km^2 and 145,557 km^2 respectively. Exponential curve predicting average drainage area of Volta river ($A_{ɯv}$) from stream order (ɯ) was derived as ($R^2 = 0.9963$; see Figure 5c):

$$A_{ɯv} = 0.0186e^{1.5227}ɯ \qquad (18.3)$$

Drainage area ratio of Volta basin was therefore 4.58 [exp (1.5227)]. The fraction of watershed draining directly into first order streams was estimated to be 0.93 (equation 8). Parameters such as Drainage density (D_d), average distance from basin divide to stream channel (X_d) and average distance that a drop of water travels to a stream (X_h) in Volta basin were estimated as 3.91, 0.128, 0.064 (km) respectively (see equations 8-10).

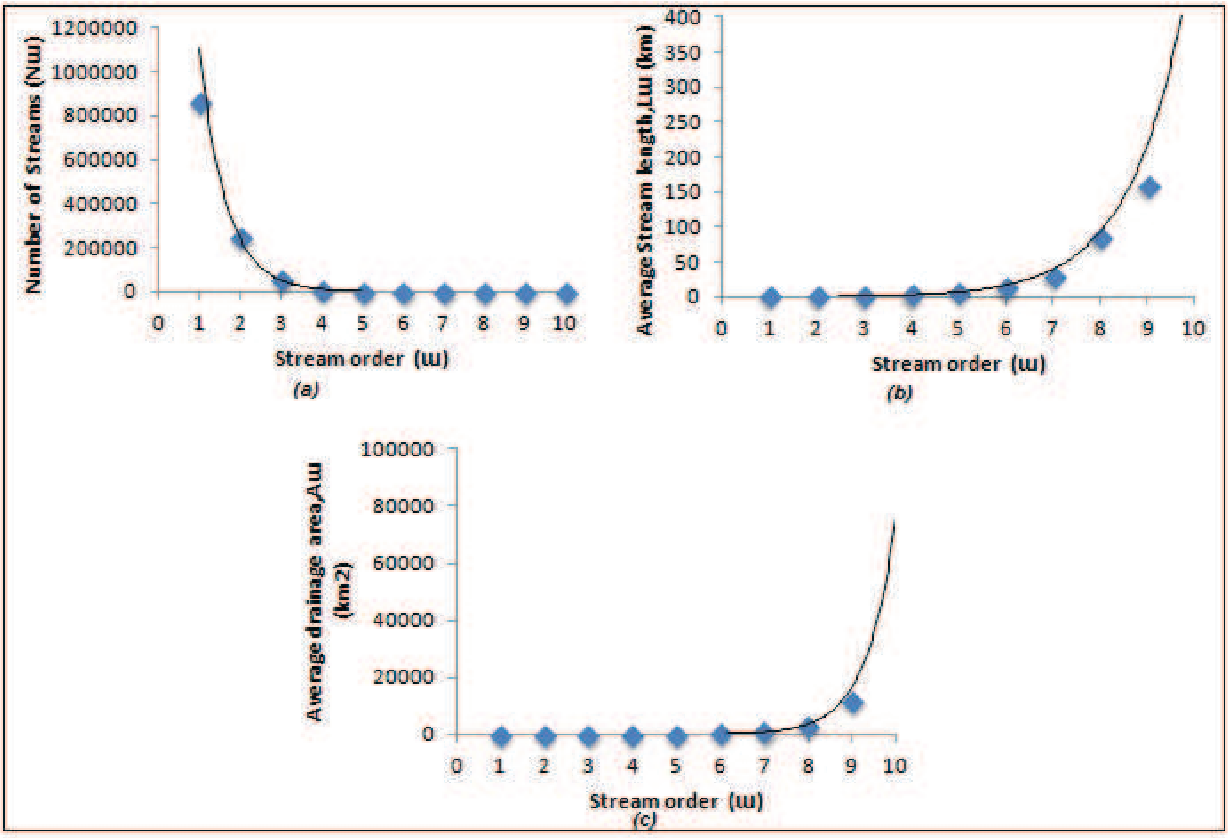

Figure 5: The relationships between stream order and (a) stream number, (b) stream length and (c) drainage area of Volta basin

3.3 Stream analysis of Pra basin in Ghana

In Pra basin (located on Figure 3), out of a total of 186,767 streams, orders 1, 2, and 3 represent 76%, 19%, and 4 % respectively while higher orders 8, 9 and 10 have only 4, 1, and 1 stream(s) respectively. Stream number ($N_{ɯp}$) prediction using stream order of the basin (ɯ) was derived as ($R^2 = 0.9907$; see Figure 6a):

$$N_{ɯp} = 498261e^{-1.412}ɯ \tag{19.1}$$

Bifurcation ratio of Pra basin (R_B) was therefore estimated to be 4.10 [exp (1.412)]. Stream length of Pra river decreases with order: orders 1 to 3 possess 55%, 21% and 11% of the total lengths respectively. Average stream length increases exponentially with order: orders 10, 9, 8 registered 118 km, 178 km, and 142 km respectively, while orders 1, 2, 3 measured 0.3 km, 0.5 km, and 1.2 km respectively. Exponential curve predicting average stream length of Pra river (Lɯp) from stream order (ɯ) was derived as (see Figure 6c):

$$L_{ɯp}= 0.1317e^{0.7597}ɯ \tag{19.2}$$

Stream Length ratio of Pra basin was therefore 2.14 [exp(0.7597)]. The distribution of drainage areas among the stream order in Pra basin appears to be uniform with an average of 15,146 km^2 and standard deviation, minimum, and maximum values of 3,579 km^2; 11,042 km^2; and 23,024 km^2 respectively. Exponential curve predicting average drainage area of Pra river (Aɯp) from stream order (ɯ) was derived as ($R^2 = 0.9939$; see Figure 6b):

$$A_{ɯp} = 0.0226e^{1.4618}ɯ \tag{19.3}$$

Therefore drainage area ratio of Pra basin is 4.32 [exp(1.4618)]. The fraction of first order streams draining into the basin was 0.64. Parameters such as drainage density, average distance from basin divide to stream channel (X_d), and average distance that a drop of water travels to a stream channel in the basin were 3.53, 0.142 and 0.71 respectively.

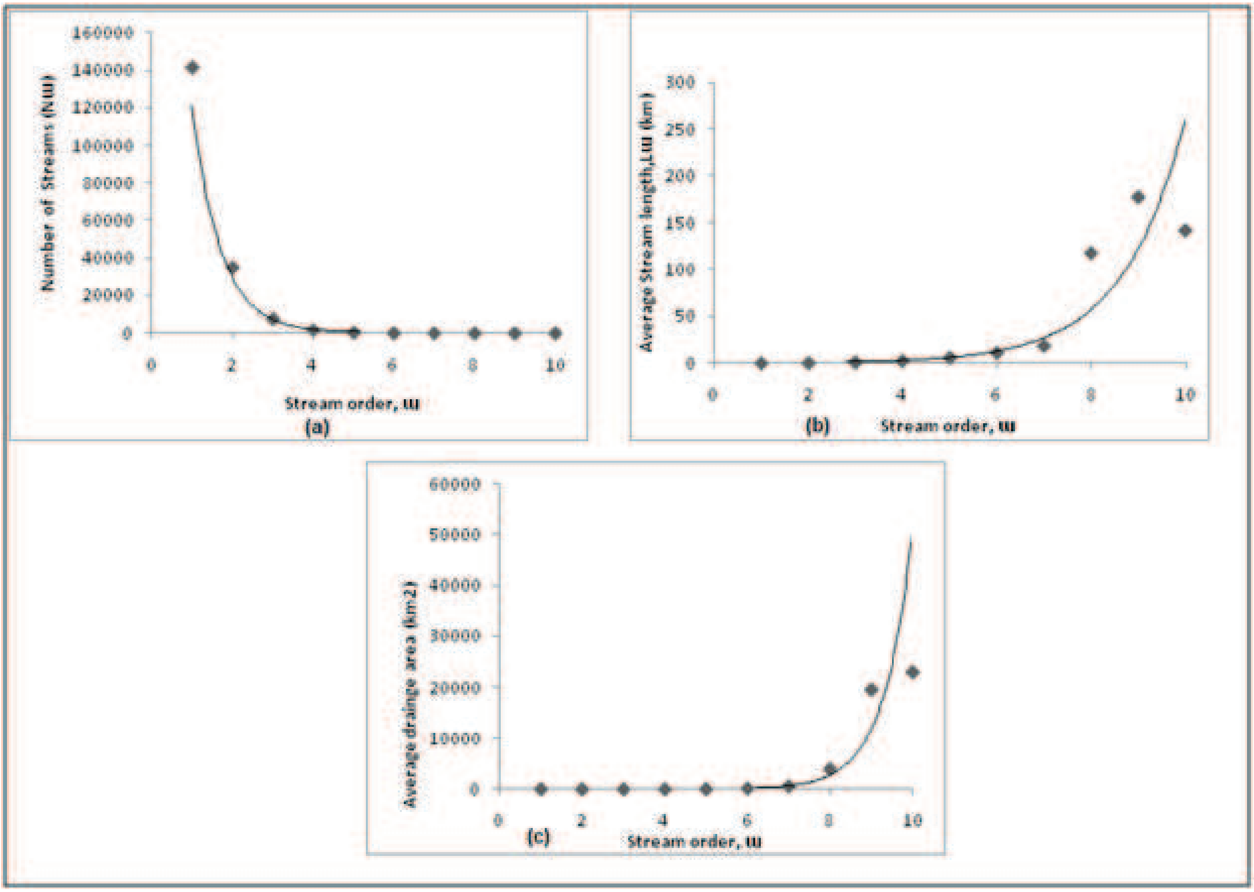

Figure 6: Relationships between stream order and (a) stream number, (b) stream length and (c) drainage area of Pra basin

3.4 Stream analysis of other basins

Watershed parameters for other southern river catchments such as Tano, Ankobra, Bia, and Densu basins are shown in Table 1 and Figure 7. It can be observed that watersheds in Table 1 are ranked by drainage area (A_D) and highest stream order (Ω).

In terms of drainage density (D_d), for instance, basins in Table 1 can be ranked in descending order as Volta, Bia, Tano, Densu, Pra and Ankobra respectively. The fraction of first order streams' contribution to drainage basin (Θ_1) also re-ranks Table 1 into the order of Volta, Tano, Bia, Pra, Densu, and Ankobra.

3.5 The use of catchment parameters for flood prediction

Using the parameters on Table 1 and Equations (14-16) 2-hour unit hydrographs at 3 velocity levels (1, 1.5, and 2m/s) were derived for 4 rivers: Ankobra, Tano, Bia and Densu (Figure 8). The corresponding hydrographs of 2 millimeters of rain are also derived for the 4 rivers in Figure 9. The velocity greatly influences peak discharge, time to peak, time of concentration and total discharge of the rivers.

4. Discussions

In this study watershed boundaries and parameters have been estimated for Ghana using PCRaster GIS and SRTM DEM. Volta basin, southwestern basins and southeastern basins occupy 69%, 22% and 9% of land surface area of Ghana respectively. The first, second, and third stream orders occupy 73%, 21%, and 5% of streams in Ghana respectively. There is a strong spatial variation of watershed parameters in Ghana with Volta basin registering high parameters for stream ratios such as Bifurcation, Stream length and Drainage area. The accuracy of this catchment estimation of water basins in Ghana was validated with an overlay of a digitized river map (Mårtensson et al., 1999) of Ghana (Figure 3b). It can be seen that this model does not only precisely create major river basins such as Volta, Pra, and Ankobra but also the minor river basins that are leaving the country. Moreover, the sum of watersheds areas (238,699 km^2) is only 0.07% higher than the actual total land area of Ghana (238,535 km^2).

There have been some disputes about the exact area and boundary of Ghana in recent years, though.

There are two main challenges with this GIS estimation of catchments in Ghana. First, when there is a major dam on a river, the model estimated the dam catchments instead of the river's. In Ghana, most major dams such as Weija on Densu basin (which supplies Accra half of its water), and Akosombo on Volta basin are however close to the mouths of the river. These dams' catchment estimation can, however, be used to estimate effectiveness of dams to capture most of the water in a basin. This challenge was resolved by increasing the parameters in equation (2) at dams' locations till all the reservoirs are filled. The second challenge on estimating catchment boundaries with GIS is the edge effects or the border problems. Ghana may share the same catchment with neighboring countries but the model treats them as different catchments, because its outlets are leaving the country. For instance, in the north western part of Figure 3, there are many rivers living Ghana to Ivory Coast but they are all part of Volta river basin. The same problems can be seen with borders of Burkina Faso and Togo. The catchment analysis must therefore include all the DEM of the neighboring countries of Burkina Faso, Ivory Coast, Togo and even Mali. The reservoir and edge effects have therefore resulted in production of many small catchments. Mechanically, these challenges can be resolved by merging small catchments with respective larger catchments. Large number of first order streams may be due to the spatial resolution of the DEM. Like the effect of a scale in using topographical map to determine the accuracy of a delineated catchment (Kang and Lin, 2009), increasing or decreasing DEM resolution may change the number of lower order streams. A 90 meter resolution seems not to produce bad results because most streams in tropics are longer than 0.12 km, the length of a cell.

Table 1: Summary of parameters of the major drainage basins in Ghana.

basin	Ω	$L\Omega$	R_B	R_L	R_A	Θ_1	A_D	D_d	X_d	X_h
Volta	10	1208	4.55	2.34	4.58	0.93	164021	3.91	0.128	0.064
Pra	10	142	4.10	2.14	4.31	0.64	23023	3.53	0.142	0.071
Tano	9	334	4.17	2.20	4.30	0.78	14015	3.60	0.139	0.069
Ankobra	9	97	4.05	2.10	4.42	0.49	8608	3.51	0.142	0.071
Bia	8	139	4.66	2.32	4.92	0.69	6148	3.66	0.137	0.068
Densu	8	57	4.11	2.12	4.36	0.66	2669	3.55	0.141	0.070

Legend: Ω is highest Stream order; $L\Omega$ is length of highest stream order; R_B is bifurcation ratio; R_L is stream length ratio; R_A is stream area ratio; $\Theta_{1=}$ fractional contribution drainage basin to first order streams; A_D = drainage area; D_d=drainage density; X_d is an average distance from basin divide to stream channel; and X_h is average distance that drop of water travels to a stream in a watershed.

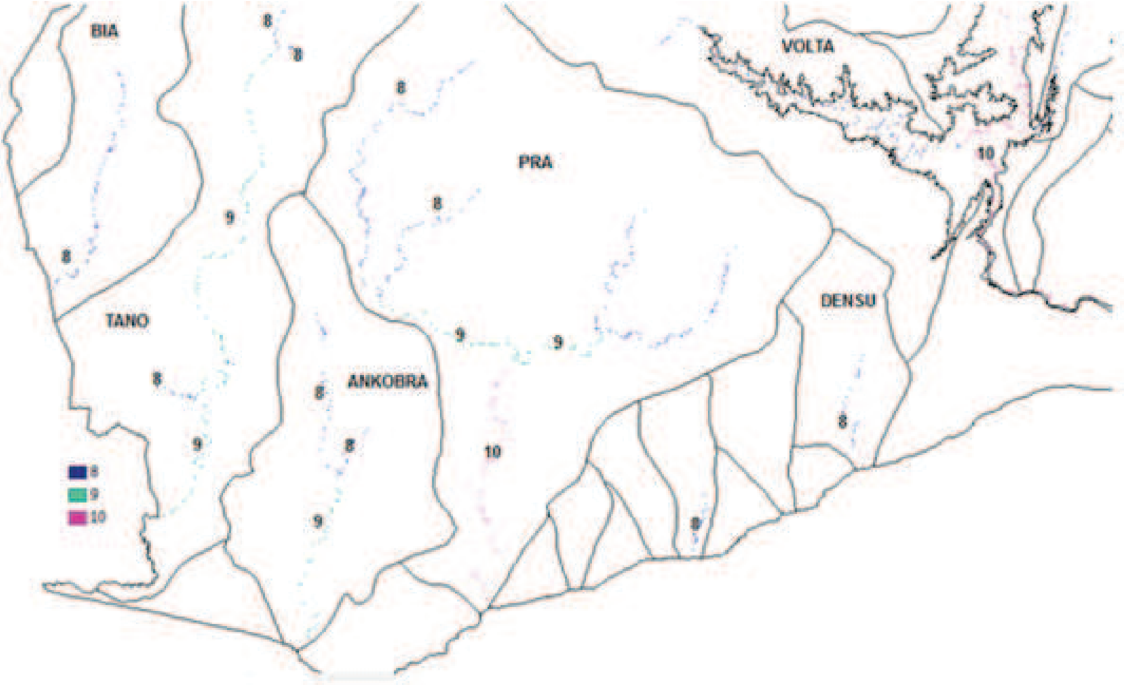

Figure 7: GIS based simulation of stream order in Southern Ghana. Legend: the numbers 8, 9, 10 are stream numbers

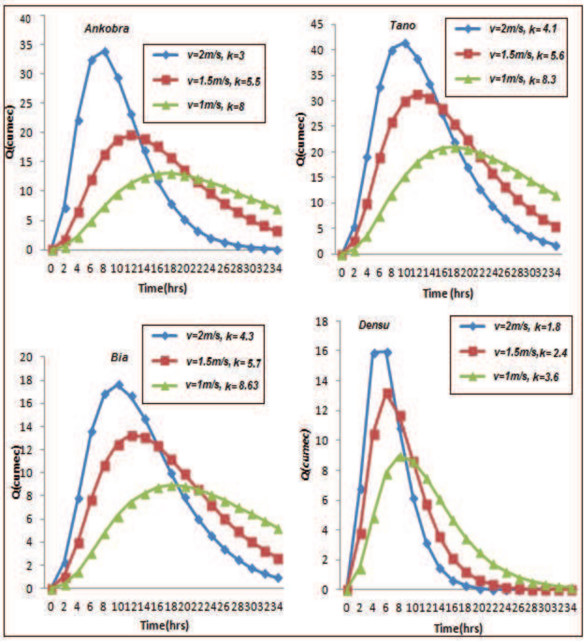

Figure 8: The influence of change of the average stream velocity on the shape of 2 hour GIUH for 4 rivers in Ghana. The parameters on Table 1 and Equations (14-16) were used to derive the unit hydrographs

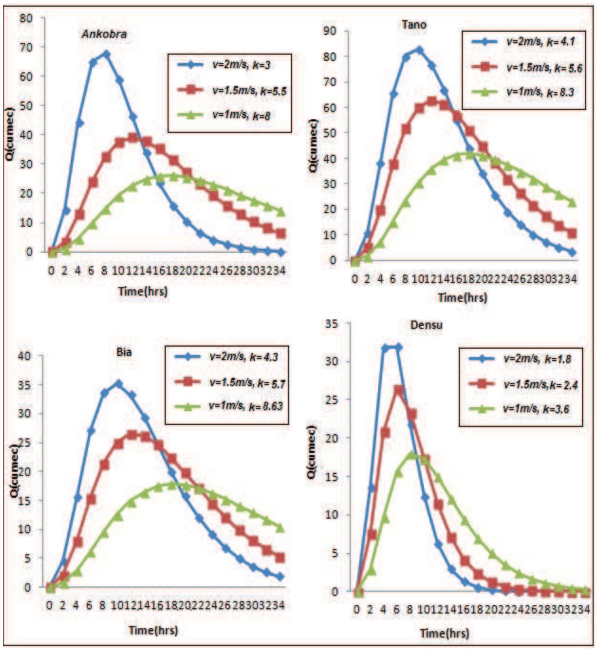

Figure 9: The estimated discharge of the rivers based on the corresponding 2 hour unit hydrograph and 2 mm rainfall. The ordinates of this hydrograph were computed by multiplying the ordinates of the unit hydrograph in Figure 8 by 2 mm of rain

The estimated Bifurcation ratio, Stream Length ratio and Drainage area ratio are within Horton (1945) and Schuum (1956) ranges of $3<R_B<5$; $1.5<R_L<3.5$ and $3<R_A<6$ respectively (see Table 1). It can be deduced that GIS accurately estimates these parameters and they can be used in equations predicting flooding parameters such as time of rising, peak discharge, and time to peak (Adib et al., 2010). Drainage density (D_d), which is the ratio of the total length of streams to total area, indicates the rapidity of stream response to storms (Dingman, 2002). For all things being equal, ranking the basins in Table 1 by drainage density therefore indicates the degree of flood risk among the watersheds in Ghana, with Volta being the highest and Ankobra lowest flood prone basin. Stream Length ratio (R_L), that perfectly correlates with drainage density in Table 1, is directly related to peak discharge (Dingman, 2002).

The length of the highest order stream ($L\Omega$) that determines the Kipich's time of concentration (Kipich, 1940) perfectly matches drainage areas except for Bia basin which was expected to decrease. Flood water will spend more time in travelling in Bia basin than Ankobra basin. The length of the highest order stream ($L\Omega$), as well as Bifurcation ratio (R_B) and Area ratio (R_A), will also more influence peak discharge and time of rising of peak discharge of Bia basin compared to Ankobra basin (Adib et al., 2010; Dingman, 2002).

The fraction of drainage area contribution to first order streams (Θ_1) also re-ranks Table 1 in the order of Volta, Tano, Bia, Pra, Densu, and Ankobra. Most of these first order streams are intermittent, and the catchments will quickly respond to water input. In a scenario where there is climate change or high climatic variability with lower rainfall the higher ranked Θ_1 stream will receive low flows while lower Θ_1 streams will buffer to sustain stream flow. On the other hand, a higher rainfall will easily induce a higher peaked discharge in a higher ranked Θ_1 basins, which will induce flooding (Adib et al., 2010).

The use of the parameters to estimate GIUH and discharges in Figure 9 demonstrates how the parameters can be used in hydrology. If one wants to completely use the catchment parameters without the use of velocity then Nash provides estimation of 'k' with the basin parameters such as length of main stream (L, miles), slope of the basin (S, parts per 1000) and the area (A, sq. miles) as: $k=11A^{0.3}/L^{0.1}\ S^{0.3}$. The parameters can also be estimated with first moment of the IUH about the origin ($t = 0$): $M1 = nk$ *and the* second moment of the IUH about the origin ($t = 0$): $M2 = n(n + 1)\ k2$ (Raghunath, 2006).

5. Conclusion

Arial photographs, survey and mapping are expensive, laborious, time consuming approach of estimating catchment parameters for a wider area such as a large country boundary. Parameters have been estimated at a 90 meter DEM resolution using PCRaster GIS model; it locates all streams in Ghana. Ghana is heavily influenced by Volta basin, covering about 70% of land surface. A 90 meter resolution DEM seems not to produce bad results because most streams in tropics are longer than 0.12 km, the length of a cell. The estimated parameters such as Bifurcation ratio, Stream Length ratio and Drainage area ratio are within the ranges of

Horton (1945) and Schuum (1956) boundaries of $3<R_B<5$; $1.5<R_L<3.5$ and $3<R_A<6$ respectively. The estimated parameters can be used in hydrological models of respective watersheds for production of hydrographs. The derived Equations 18.1-18.3 and 19.1-19.3 can also be used to estimate the parameters when stream number is known of any stream in Ghana. As a higher resolution DEM becomes available, it is recommended that, it should be used with the method provided in this article.

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