Hydrogeomorphic Characteristics of Urban Flood Triggers in Gombe Town, Nigeria as Monitored in 2014

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ABSTRACT: Urban flooding has become a monumental yearly disaster in many of the world's cities and Gombe town in particular. This paper focused on some hydro-geomorphological characteristics that influence flooding in Gombe town. Statistical methods and geographic information techniques were used for the assessment. The result revealed that the highest API of 166.62 mm occurred on the 5/9/2014. The rainfall amount was 92.5mm for a duration 48 minutes, average rainfall intensity was 115.63, stage height (1.42m), average flow velocity (0.98m/s), and instantaneous discharge of 9.47m³/s. This corresponds with the flood disaster that occurred in Gombe town on the same date (5/9/2014). On the other hand, the least API of 18.12 mm occurred on the 18/6/2014. The rainfall amount was 1.2mm for 62 minutes, average rainfall intensity was 1.16, stage height (0.30m), average flow velocity (0.24m/s), and instantaneous discharge of 0.49m³/s. findings also showed that very steep slope covered 2.4537km² (1.78%), steep slope covered 3.60235km² (2.61%), moderate slope (0.735574km² or 0.53%), gentle slope (131.106km² or 94.89%) and flat areas (0.259854km² or 0.19%). The study recommended flood resilience technology, provision of adequate urban drainages and proper storm water management.

Flooding from time immemorial has been the most common and wide spread of both natural and man-made hazards that have unleashed untold fear and hardship on mankind. There are a number of hydrological and geomorphological factors that affect the severity of flood hazard including Antecedent Precipitation Index (API), drainage density, rainfall amount, duration and intensity, stage height, flow velocity and topographic characteristics of the drainage basin. API expresses the moisture condition of the area prior to storm runoff. It is a reliable conventionally accepted index which is crucial in hydro-geomorphological studies and it is considered as the most important soil factor for rapid runoff and flooding (Goudie, 2006; Abaje *et al.,* 2015). Saturated soils obstruct rainfall to infiltrate, resulting in higher runoff regardless of other environmental conditions. Soil moisture can, in fact, control whether a given rainstorm produces a major flood or not due to the non-linear nature of runoff response to rainfall. The drainage pattern of a place plays a major role in assessing hydrological conditions and hence enhances the understanding of urban flood assessment (Abaje *et al.,* 2012). Urban flooding occurs in response to intense rainfall which overwhelms natural or man-made inadequate drainage systems resulting in water flowing overland and ponding in depressions. It is a particular problem in urban areas which are often dominated by impermeable surfaces. The global warming and its effects on climate has increased precipitation and runoff particularly in urban areas leading to environmental hazard such as flooding (Abaje *et al.,* 2016; Abaje *et al.,* 2017). The projection of climate change trends as stated in IPCC (2013) indicates increase in the occurrence of rainfall events both in terms of their intensities as well as frequencies. Such high intensity rainfall events along with the changes in land use patterns, particularly in urbanized areas are expected to have implications on urban flooding (Duan, *et al*, 2016). Recent studies show that contemporary urban areas in developing countries are vulnerable to weather and climate related hazard events such as flooding (Abaje, *et al*, 2017). Anthropogenic activities in the urban environment can enhance the occurrence of flooding. The effectiveness and efficiency of urban drainages rely solely on their ability to evacuate excess runoff to prevent flooding. In urban areas where drainages are inadequate or

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poorly constructed the resultant effect is frequent flooding (Abashiya, 2006). In Gombe town, the drains are either shallow or clogged with refuse dump and are often undermined by excess runoff. The main objective of this paper, therefore, is to examine some hydro-geomorphological characteristics that influence flooding in Gombe town as monitored in 2014.

MATERIALS AND METHODS

Description of Study Area: Gombe town is located between latitudes $10^{\circ}14'10''$N and $10^{0}19'00''$N of the equator and between Longitudes 11° $07'00''$E and $11^{\circ}12'50''$E of the Greenwich Meridian. It is bounded by Kwami LGA to the North, Akko LGA to the Southwest and Yamaltu-Deba LGA to the East as shown in Figure 1. Gombe town has a tropical continental type of climate (Aw) based on Koppen's classification scheme. It is characterized by strong rainfall seasonality with distinct wet and dry season (Abaje *et al*, 2017). The rainfall is concentrated between the months of July and September with a single peak in August. The average annual rainfall total is about 850 mm. The concentration of rain in these three months (July to September) has the potential of increasing the soil moisture condition, reducing infiltration capacity and hence causing flooding (Abashiya *et al*., 2017). The mean maximum monthly temperature is about 35°C while the mean minimum monthly temperature is about 18°C with relative humidity of about 95% in August.

The study area forms part of the sedimentary Upper Benue trough, which is structurally controlled by pre-existing Basement Complex rock consisting of granitic rocks overlain by the sequence of folded Cretaceous sedimentary rocks. These Basement Complex rocks are mainly fine-coarse-grained porphyritic older granites, gneiss, migmatite, gabbros and diorite (Carter *et al,* 1963; Obaje, 2009). The bedrock mainly consists of sandstones of cretaceous age, covered by tertiary and quartenary deposits (Obaje, 2009).
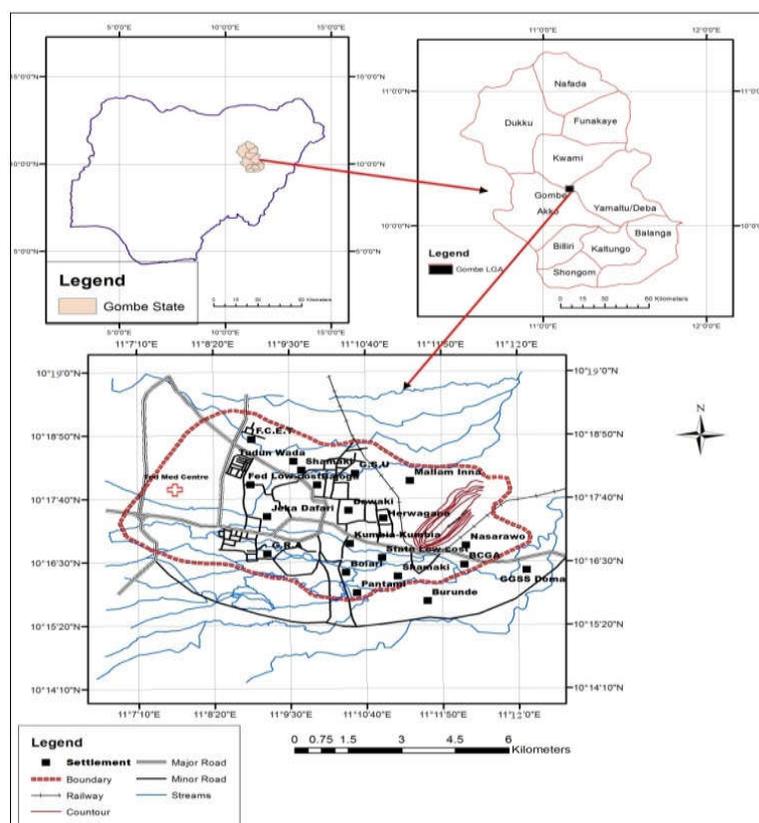
Fig 1: Gombe Town. *Source: Adapted from Ministry of Lands and Survey, Gombe State*

The soils are formed from the intensive weathering of the Basement Complex rocks. They consists of unconsolidated wind-blown or water deposited sand and clay-rich mostly in the southeast of the town along the valley of Pantami catchment (Orazulike, 1992). Soil nutrients except aluminium and iron decrease substantially, this gives the ferric red soils or the Kerri-Kerri formation that have lost the topsoil organic

matter (Amos, Musa, Abashiya and Abaje, 2015). This is attributed to traditional agricultural practices such as slash and burn over the years that has made the soils susceptible to soil erosion which reduced the water holding capacity and increase in surface water flow leading to pluvial flooding. These soils that have been subjected to degradation are mostly nitosols, leptosols, cambisols, or luvisols (Ikusemoran, Didams and Abashiya, 2018). The vegetation is the Sudan savannah type which has replaced the guinea savannah of the 1970s due to anthropogenic activities and climate change with many tree species becoming extinct (Mbaya, 2016).

Data Collection and Analysis: The moisture condition of the area prior to storm runoff was calculated using the API. The API for any day is computed as:

$$API = KP_1 + KP_2 + KP_3 ....KP_n \quad (1)$$

Where: $P_1, P_2, P_3 ....P_n$ = rainfall amount (mm) at different days preceding the storm event, $K_1, K_2, K_3 ......K_n$ = a constant uniformly taken as 0.92 (Bruce and Clark, 1975).

Some storm events were monitored in 2014 to observe the influence of rainfall, stream discharge and antecedent precipitation index on flooding. The velocity-area technique of measuring stream discharge was used, since weirs structures were not possible but rather a graduated bridge-pier along the Pantami catchment and a staff gauge were used to gauge the stage heights. The stream discharge is the direct function of velocity and cross-sectional area of the stream at the point of measurement, given by Gregory and Walling (1973) as:

$$Q = A V \quad (2)$$

Where: Q = is the stream discharge in cumecs; A = is the cross sectional area in km²; V = is the velocity in m/s

The cross-sectional area of the channel at the gauging station was determined by multiplying the channel width by depth. The relevant depth is that measured from water level to the bottom of the channel using a staff gauge. The stream velocity was also determined using the current meter obtained from the department of Geography Gombe State University, Gombe. The flow accumulation map was generated from the flow direction map using a weight factor in ArcGIS environment. The accumulated flow is based on the number of cells flowing into each cell in the output raster. The drainage density is inversely proportional to permeability. The drainage pattern of a place plays a geomorphic role in assessing the hydrological condition and hence enhances the understanding of its influence on flood. The higher the drainage density the higher the runoff and is given by the total stream length per area (km/km²). The drainage network was extracted from DEM and the density map was generated in the ArcGIS 10.5. DEM hydro analysis was then carried out from the ArcGIS 10.5 Software to produce slope map and drainage density map of the study area. Slope map of the study area was developed using two Digital Elevation Model DEM for the study comprising of Shuttle Radar Topographic Mission (SRTM) Version 3 commonly referred to as SRTM DEM (90m) and Aster DEM (30m) data obtained from the NASA's website and National Centre for Remote Sensing Jos were used to provide the most recent elevation information of the study area using Arc GIS 10.5 software.

RESULTS AND DISCUSSION

Hydrological Characteristics of Gombe Town: The result of some hydrological characteristics of Gombe town monitored for the year 2014 is presented in Table 1. A total of 45 storms were monitored during the 2014 rainy season from June to September which conformed with the pattern of rainfall observed in the study area that gradually stabilizes from mid- June and soil moisture condition is also at its peak between June and early September (Tarhule and Woo, 1998). The results show that the least API of 18.12 mm occurred on the 18/6/2014. The rainfall amount was 1.2mm for 62 minutes, average rainfall intensity was 1.16, stage height (0.30m), average flow velocity (0.24m/s), and instantaneous discharge of 0.49m³/s. The highest API of 166.62 mm on the other hand occurred on the 5/9/2014. The rainfall amount was 92.5mm for a duration 48 minutes, average rainfall intensity was 115.63, stage height (1.42m), average flow velocity (0.98m/s), and instantaneous discharge of 9.47m³/s. The highest recorded rainfall of 92.5mm that lasted for 48 minutes given the highest intensity of 115.63 and the highest gauge height of 1.42m, correspond with the flood disaster that occurred in Gombe town on the 5/9/2014. Prior to this date, there were four rainfall storms that occurred on the 25/8/2014, 29/8/2014, 2/9/2014, and 3/9/2014 with rainfall amount of 35.8 mm, 34.4 mm, 12.5mm, and 14.6 mm respectively. This total amount of rainfall (97.3 mm) must have increase the soil moisture condition. When this amount of rainfall is added to the 92.5 mm that occurred on the 5/9/2014, it means that a total of 189.8 mm of rainfall was recorded in just five storms events.

Table 1: Some hydrological Characteristics of Gombe Town (2014). ***Source:*** *Authors' Fieldwork (2014)*

S/No	Date	Mean Daily Rainfall (mm)	Rainfall Duration (minutes)	Average Rainfall Intensity	Stage Height (m)	Mean Velocity (m/s)	Cross-Sectional Area (m²)	Instantaneous Discharges (m³/s)	API (mm)
1	2/6/14	40.6	38	64.11	0.94	0.73	6.39	4.67	37.35
2	6/6/14	5.6	45	7.47	0.34	0.26	2.31	0.60	32.53
3	10/6/14	9.8	70	8.40	0.63	0.47	4.28	2.01	32.98
4	18/6/14	1.2	62	1.16	0.30	0.24	2.04	0.49	18.12
5	21/6/14	16.5	64	15.47	0.76	0.65	5.17	3.36	30.62
6	24/6/14	4.0	52	4.62	0.36	0.25	2.45	0.61	27.85
7	26/6/14	`0.6	32	1.13	0.23	0.22	1.56	0.34	24.17
8	27/6/14	0.7	46	0.91	0.24	0.23	1.63	0.38	22.94
9	30/6/14	9.1	68	8.03	0.66	0.56	4.49	2.51	26.97
10	2/7/14	2.9	95	1.83	0.28	0.27	1.90	0.51	25.73
11	5/7/14	6.1	98	3,74	0.41	0.35	2.79	0.98	26.14
12	8/7/14	72.4	78	55.69	1.24	0.78	8.43	6.58	92.76
13	9/7/14	1.5	54	1.67	0.34	0.28	2.31	0.65	86.84
14	11/7/14	13.2	47	16.85	0.42	0.32	2.86	0.92	86.70
15	16/7/14	5.6	35	9.60	0.32	0.26	2.18	0.57	62.74
16	18/7/14	82.0	93	52.90	1.38	0.82	9.38	7.69	135.1
17	21/7/14	8.5	25	20.40	0.56	0.43	3.81	1.64	113.7
18	28/7/14	10.8	28	23.14	0.36	0.25	2.45	0.61	74.23
19	30/7/14	12.1	41	17.71	0.48	0.34	3.26	1.11	80.39
20	30/7/14	0.8	32	1.50	0.26	0.21	1.77	0.37	74.76
21	31/7/14	11.5	80	8.63	0.46	0.33	3.13	1.03	80.28
22	3/8/14	5.5	34	9.71	0.32	0.24	2.18	0.52	68.01
23	11/8/14	26.0	75	20.80	0.72	0.76	4.90	3.72	60.90
24	14/8/14	13.2	64	12.38	0.47	0.37	3.20	1.18	50.63
25	15/8/14	10.7	26	24.69	0.58	0.46	3.94	1.81	57.28
26	16/8/14	5.2	45	6.93	0.34	0.26	2.31	0.60	57.90
27	18/8/14	6.2	68	5.47	0.38	0.28	2.58	0.72	55.21
28	19/8/14	5.5	62	5.32	0.31	0.24	2.11	0.51	56.29
29	20/8/14	0.9	46	1.17	0.27	0.23	1.84	0.42	52.69
30	21/8/14	6.6	58	6.83	0.39	0.27	2.65	0.72	55.08
31	22/8/14	8.9	35	15.26	0.43	0.38	2.92	1.11	59.57
32	25/8/14	35.8	67	32.84	0.80	0.73	5.58	4.07	82.19
33	29/8/14	34.4	61	33.84	0.80	0.72	5.44	3.92	93.28
34	2/9/14	12.5	36	20.83	0.46	0.33	3.13	1.03	79.32
35	3/9/14	14.6	91	9.63	0.49	0.34	3.33	1.13	87.57
36	5/9/14	92.5	48	115.63	1.42	0.98	9.66	9.47	166.6
37	7/9/14	1.1	25	2.64	0.31	0.24	2.11	0.51	142.1
38	13/9/14	35.4	46	46.17	1.12	0.76	7.62	5.79	121.5
39	15/9/14	2.2	32	4.13	0.28	0.21	1/90	0.40	105.1
40	16/9/14	2.6	71	2.20	0.29	0.20	1.97	0.39	99.30
41	20/9/14	15.1	58	15.62	0.54	0.41	3.67	1.51	86.24
42	21/9/14	29.2	92	19.04	0.76	0.69	5.17	3.57	108.5
43	22/9/14	9.6	43	13.40	0.65	0.52	4.42	2.30	109.4
44	27/9/14	15.8	69	13.74	0.68	0.48	4.62	2.22	87.94
45	29/9/14	41.5	59	42.20	0.96	0.74	6.53	4.83	116.1

Flow Accumulation: The flow accumulation map of Gombe town is presented in Figure 2. The result of flow accumulation is a raster of accumulated flow to each cell, as determined by accumulating the weight for all cells that flow into each downslope cell. While output cells with high flow accumulation constitute areas of concentrated flow that can be used to identify drainage channels, output cells with a flow accumulation of very low to zero are local topographic highs that can be used to identify ridges. The Flow accumulation operation determines the number of pixels that naturally drain into outlets. The operation can be used to find the drainage pattern of a terrain.

Drainage Density: The drainage density map of Gombe town is presented in Figure 3. The drainage density of a geographical area has an inverse relationship with permeability; the higher the drainage density the lesser the amount of infiltration which increases the amount of runoff leading to flooding. In the study area, the drainage density varies from 0.00km/km² to 0.54km/km² (total length of the drainages per km²). There are six classes in the drainage density and the highest class with 0.54-0.43 km/km² or 36% is the most significant in terms of runoff generation and triggering of flooding while lowest class with 0.09-0.00 km/km² or 5% is the least significant for runoff contribution.

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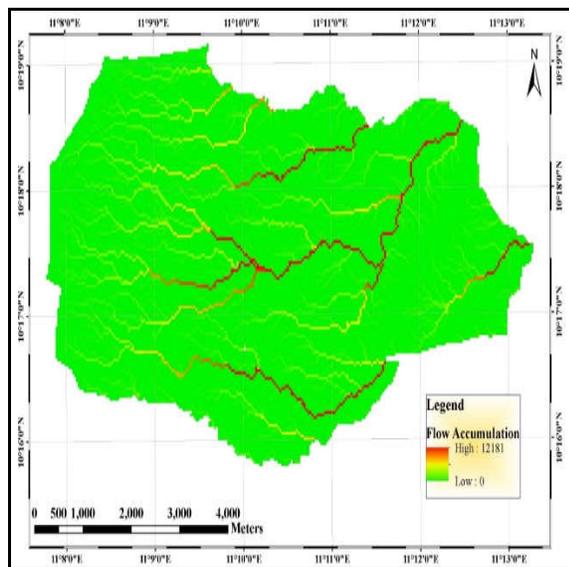
Fig 2: Flow Accumulation Map of Gombe Town **Source:** Authors' GIS Analysis (2016)
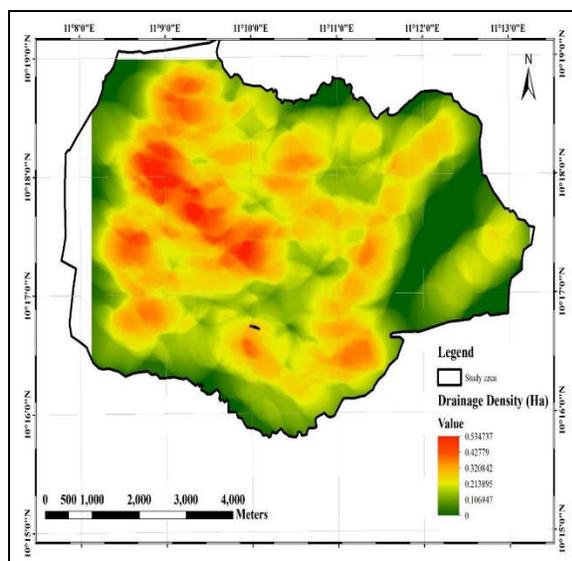
Fig 3: Drainage Density Map of Gombe Town **Source:** Authors' GIS Analysis (2016)

Slope Morphology: Figure 4 shows the slope morphology map of Gombe town which has five classes namely: very steep, steep, moderate, gentle and flat. Their areas and percentages were also calculated using ArcGIS 10.2 software tool convertor. The results show that very steep slope covered an area of 2.4537km^2 or 1.78%, steep slope (3.60235km^2 or 2.61%), moderate slope (0.735574km^2 or 0.53%), gentle slope (131.106km^2 or 94.89%) and flat areas (0.259854km^2 or 0.19%). The slope is the ratio of runoff to infiltration with inverse relationship. It is the change in height verses change in horizontal distance. Hence the steeper the slope the greater the runoff and

the lower the infiltration. The result indicates that gentle slope has the highest area of 131.106km2 or 94.89% and flat areas have the least 0.25985km2 or 0.19%. These two areas occupy a total of 131.36585km^2 or 95.08%. This implies that 95.08% of Gombe town is low lying. These are areas that are more liable to flooding because of low velocity of runoff, flow water finding its way to the streams ponding and water-logging causing urban flooding.
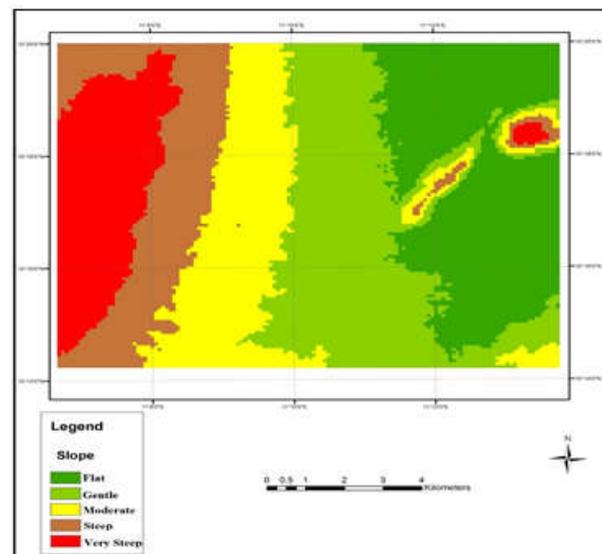
Fig 4: Slope morphology Map of Gombe Town
Source: Authors' GIS Analysis (2016)

Conclusion: Urban flooding occurs in response to intense rainfall which overwhelms natural or man-made inadequate drainage systems resulting in water flowing overland and ponding in depressions. The results of the study revealed that initial soil moisture condition, rainfall amount, intensity and duration, drainage density and topographical characteristics are crucial factors that trigger urban flooding. Observation of the API show a rhythm which followed the rainfall regime of the area during the period of study.This study recommends proper flood resilience technology and urban storm water management. Besides structural measures aiming at a reduction of the probability of flooding, the adoption of non-structural approaches for urban flood mitigation is important. Urban planning guidelines and flood management strategies should, therefore, be part of an integral approach to the problem of flooding for any appropriate authority concerned in Gombe State such as Gombe State Ministry of Lands and Survey and Urban Town Planners.

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