TERTIARY EDUCATION TRUST FUND

ENGINEERING

A MORPHOMETRIC STUDY OF FIVE SELECTED DRAINAGE BASINS IN CENTRAL NIGERIA

Sule, B. F. and Bilewu, F.O.
Department of Water Resources and Environmental Engineering,
University of Ilorin, Kwara State, Nigeria.

Corresponding Email: bilewuk@yahoo.com
Manuscript Received:04/03/2016 Accepted:30/03/2016 Published: March, 2016

ABSTRACT

The physical parameters of a watershed have been shown to influence the hydrological response of the watersheds to storm events. They are useful in geo-hydrological, flood risk mapping, neo-tectonic and landform studies most especially in the many ungauged basins across the world. In the developed parts of the world, there are usually gauged basins nearby which can be used in ungauged basin predictions. In the less developed parts of the world, gauged basins are few and far between while accurate and reliable topographical maps of many basins are scarce. This makes flow predictions using basin morphometry an important subject in these areas. A morphometric study of five selected basins in central Nigeria was carried out. The results show that all the basins have elongated shape, are not compact and have low drainage density indicating moderate runoff potentials. Low stream density and high constant of channel maintenance affirm that the basins have a high permeability. The hypsometric curves show that a large part of the basins are at a low relief which is typical of the Guinea savannah found in central Nigeria. The implications of these results are critical in management decisions of sustainable use of these basins to improve rural livelihoods.

Keywords: *Basins, Morphometry, Topography, Ungauged, Predictions*

INTRODUCTION

Basin Morphometry basically describes the process of measuring the external shape and physical dimensions of landforms in a watershed. Morphometric properties of a basin affectsto a large extent its hydrological responses to flood and drought (Biswas, 2014). The concentration time, which characterizes the speed and intensity of the basin's response to a rainfall event, is influenced by the different morphometric characteristics. Analysis of some basins in different parts of the world exist in literature (Pisal *et al.,* 2013; Golekar *et al.,* 2013; Nageswara *et al.*, 2010; Nanda *et al*,., 2014; Koshak and Dawod, 2011; Nongkynrih and Husain, 2011; Pingale *et al.,* 2012; Al-Saud, 2009; El-Bayomi, 2010) and in Nigeria (Eze and Effiong, 2010; Ajibade *et al*., 2010; Aisuebeogun and Ezekwe, 2013).

Morphometric properties of basins has been applied in geo-hydrological studies (Hajam, 2013), flood hazard mapping (Diakakis, 2011), neo-tectonic studies (Jacquesa, 2014), changing pattern of landforms (Ward, 2007) and to appraise the hydrological potential of ungauged basins (Ezemonye and Emeribe, 2013).

Runoff from a drainage basin is influenced by various physiographic and climatic factors. Climatic factors are natural occurrences usually outside man's influence. While the physiographic factors may be influenced, they generally vary only with respect to geological time and may thus be constant. Relevant basin characteristics that influence runoff include the Catchment Area, Basin Shape, Slope, geology, altitude, drainage density and stream density among others.

Quantitative assessment of hydrological variables such as precipitation, evaporation, infiltration and run off, and their use in water balance studies or in the problems of design and forecasting will only be rational when they are applied to an area with well-defined boundaries or a drainage basin. A basin is defined as the area drained by a stream or a system of connecting streams such that all the surface run off originating in this area leaves the area in a concentrated flow through a single outlet (Reddy, 2008).

This research sought to draw conclusions on the hydrological responses of some selected basins in central Nigeria based on their morphometric characteristics and make generalizations if possible.

MATERIALS AND METHODS

Five basins were selected based on the availability of their topographical maps to a scale of 1:50,000 and to achieve some spread in central Nigeria. The basins were delineated manually and used to obtain GIS maps of the basin. The chosen basins are shown in Table 1.

Table 1: Selected Study Basins and Control Points

SN	Basin	Control Point	Latitude (°N)	Longitude (°E)
1.	Oyun	Offa	8.15	4.72
2.	Asa	Ilorin	8.50	4.55
3.	Gongola	Dindima	10.22	10.15
4.	Taraba	Gassol	8.52	10.46
5.	Katsina Ala	Sevav	7.43	9.25

The basin area is the area of a closed curve obtained by projecting the catchment boundary onto a horizontal plane whileother parameters were calculated based on methods described by Authors listed in Table 2. ER values close to 1.0 are typical of regions of very low relief (Nageswara *et al.,* 2010). The Shape Factor (SF) is the inverse of the elongation ratio. The Unity Shape Factoris the ratio of the basin length to the square root of the basin area. Drainage Density (DD) is the total length of all stream channels per unit area of the basin. Ruggedness Number (RN) is a product of basin relief and drainage density. The Drainage Texture (DT) is the ratio of the total number of streams of all orders to the basin perimeter. Quantitative description of Drainage Texture is difficult and qualitative expressions such as coarse, medium and fine are usually applied (Matsuda, 2004).

Table 2: Morphometric Parameter Calculation Methods

SN	Parameters	Reference
1.	Circularity Ratio (CR), Elongation Ratio (ER), Stream Density (SD)	Reddy, 2008
2.	Compactness Coefficient (CC), Form Factor (FF)	Suresh, 2008
3.	Bifurcation Ratio, (BR)	Chow *et al.*, 1988
4.	Fitness Ratio (FR), Wandering Ratio (WR), Hypsometric Curves	Seth *et al..*, 1998
5.	Watershed Eccentricity (WE), Sinuosity Index (SI), Infiltration Number (IN)	Pareta&Pareta, 2011

RESULTS AND DISCUSSIONS

Some primary physiographic parameters of the basins under study are listed in Table 3 while other characteristics are in subsequent Tables. All the basins have Fern leaf shapes. With this shape, the times of concentration are long since the tributaries are of varying lengths. The discharges from the catchments are thus distributed over a long period. The shapes of the drainage basins as defined by the various parameters are given in Table 4 and the values obtained for the FF indicated that the basins are elongated and have flatter peak flows for shorter duration. The values of the FF will normally vary from zero (highly elongated shape) to unity (perfect circular shape) (Mishra *et al.,* 2011). The CR obtained for the basins indicated that the Taraba basin is relatively the most circular in shape, since nearness to unity is indicative of a round basin. The CR's indicated that the basins are elongated in shape, have low runoff and a high possibility of permeable soils. This is further confirmed by the Elongation Ratios (ER). The classification index for the ER's is shown in the Table 5 (Pareta and Pareta, 2011).The Compactness Coefficients in Table 4 shows that the basins are not very compact. Values around unity are indicative of better compactness. The Unity Shape Factors for the basins are far above 1.0 which is a further confirmation that they are elongated. All these shape parameters are descriptors of peak discharge. The Shape Factor is negatively correlated with peak discharge. The average slopes of the basins are in Table 6.The DD is a useful numerical measure of landscape dissection and runoff potential. While it is a result of interacting factors controlling surface runoff, it also influences the water output from the drainage basins (Malik *et al.,* 2011). The DD obtained in the basins are less than 2. These are categorised as low DD. Watershed are grouped into four categories on the basis of DD as in Table 7. The obtained low DD in Table 8 suggests that the basins have a high percentage of permeable sub soil and substantial vegetative cover (Nageswara *et al.,* 2010), are resistant to erosion (Reddy, 2008) and runoff from the catchment can only be moderate (Raghunath, 2008). Overland flow in these basins is predominant and the resulting hydrograph has a slowly rising limb (Subramanya, 2002).

Table 1: Some Primary Physiographic Parameters of the River Catchments

S/N	Parameter	Oyun	Asa	Gongola	Katsina Ala	Taraba
1.	Area (km2)	87.2	872.9	10,537.3	11,718.4	19,590.3
2.	Perimeter (km)	52.8	152.6	469.3	665.0	600.5
3.	Average width (km)	5.8	18.5	72.1	65.6	86.1
4.	Total Relief (m)	119.8	121.9	1100.0	1400.0	1300.0
5.	Main Channel Length (km)	21.6	59.0	135.3	187.5	240.8
6.	Upper Contour Elevation (m)	396.0	488.0	1675.0	1800.0	1500.0
7.	Lower Contour Elevation (m)	290.0	381.0	455.0	100.0	120.0

Basin Relief

Basin relief parameters are given in Table 9. Drainage Texture (DT) for the basins is low (<2.5). This is indicative of a very coarse soil texture. DT has been classified into five different Textures as in Table 10.

The Ruggedness Number (RN) indicates the structural complexity of the basin terrain. Basins having high RN are susceptible to erosion (Bagyaraj&Gurugnanam, 2011). The values obtained for the basins under consideration show that the Taraba river basin may be more susceptible to erosion than the others.

Table 2: Shape Parameters of the Basins

S/N	Parameter	Oyun	Asa	Gongola	Katsina Ala	Taraba
1.	Form Factor	0.23	0.33	0.41	0.33	0.48
2.	Circularity Ratio	0.40	0.47	0.60	0.33	0.68
3.	Elongation Ratio	0.41	0.59	0.72	0.65	0.78
4.	Compactness Coefficient	1.57	1.45	1.29	1.73	1.21
5.	Shape Factor	2.44	1.68	1.38	1.54	1.28
6.	Unity Shape Factor	2.75	1.89	1.56	1.73	1.44

Table 3: Classification Index for Elongation Ratios

ER Value	Basin Description
0.9 – 1.0	Circular
0.8 – 0.9	Oval
0.7 – 0.8	Less Elongated
0.5 – 0.7	Elongated
< 0.5	More Elongated

Table 4: Slope Parameters of the Basins

Parameter	Oyun	Asa	Gongola	Katsina Ala	Taraba
Average Slope of Main Channel (%)	0.615	0.303	0.420	0.733	0.106
Slope of Hydraulic Grade line (%)	0.475	0.242	0.483	0.901	0.111
Relative Relief (%)	0.230	0.080	0.165	0.253	0.030

Table 6: Length Comparisons for the Basins

Parameter	Oyun	Asa	Gongola	Katsina Ala	Taraba
Drainage Density (Km/Km2)	0.313	0.286	0.34	0.316	0.292
Average Length of Overland Flow (Km)	3.19	3.50	2.94	3.16	3.42

This is however in relative terms only as the values for all basins are low. The Constant of Channel Maintenance (CM) depends on the rock type, permeability, climatic regime, vegetative cover and relief as well as the duration of erosion.

Table 7: Relief Parameters for the River Basins

Parameter	Oyun	Asa	Gongola	Katsina Ala	Taraba
Drainage Texture	0.83	1.2	0.785	0.386	0.712
Ruggedness Number	0.0407	0.0744	0.323	0.269	0.465
Constant of Channel Maintenance (Km2/Km)	3.19	3.50	2.94	3.16	3.42
Stream Density	0.066	0.071	0.084	0.063	0.068
Bifurcation Ratio	3.0	4.7	5.22	3.0	2.5
Fitness Ratio	0.38	0.40	0.394	0.345	0.391
Wandering Ratio	1.16	1.01	1.15	1.23	1.05
Sinuosity Index	1.04	1.08	1.08	1.12	1.04
Watershed Eccentricity	0.46	0.55	0.58	0.69	0.55
Infiltration Number	0.021	0.020	0.029	0.020	0.020

The obtained values in Table 9 are significant. It shows that they are under little structural disturbance and less runoff conditions. These conditions include high permeability, gentle basin slopes and low surface runoff. Lower values of this constant may be favourable to a higher runoff. The low stream density obtained for the basins is to be expected. This is indicative of a highly permeable upper geology, low relief and high vegetative growth. Values of 3.0 and above are considered as very high (Bagyaraj&Gurugnanam, 2011).

Table 8: Classes of Drainage Textures

Drainage Texture	Description
<2	Very Coarse
2 – 4	Coarse
4 – 6	Moderate
6 – 8	Fine
>8	Very fine

Source: Pareta&Pareta, 2011

Bifurcation Ratios (BR) obtained in the analysis indicates some similarity in morphometry. The long narrow basin with high BR is expected to have attenuated flood – discharge periods. It has also been noted that low BR is an indication of a higher risk to flooding in some parts of the basin (Eze and Efiong, 2010). The basin shape analysis also shows that the rivers do not meander or wander much. This is based on the Wandering ratios and the Sinuosity Indices for the rivers as in Table 7. Of the rivers under consideration, the Katsina - Ala River has wandered more. The areas of high relief are not much in the basins. This is typical of the Guinea Savanna which is predominant in central Nigeria. Rivers having a Sinuosity of 1.5 and less are called "Sinuous" while above 1.5, they are considered as "meandering".

Infiltration rates indicates that the Gongola basin has relatively higher infiltration tendencies. For the same rainfall event and area, the Gongola river basin is likely to have a lower runoff than the others. It must however be noted that the values are low and thus the basins are likely to have high infiltration and low runoff.

Hypsometeric Curves describes the distribution of the basin area relative to height and the output obtained for each basin is shown in Figures 1to 5.

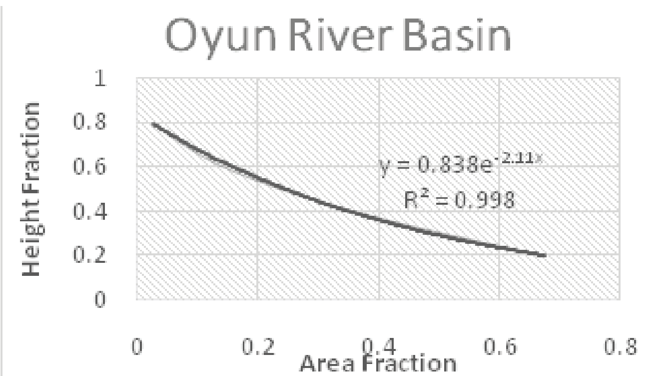

Figure 1: Hypsometric Curve for Oyun River Basin

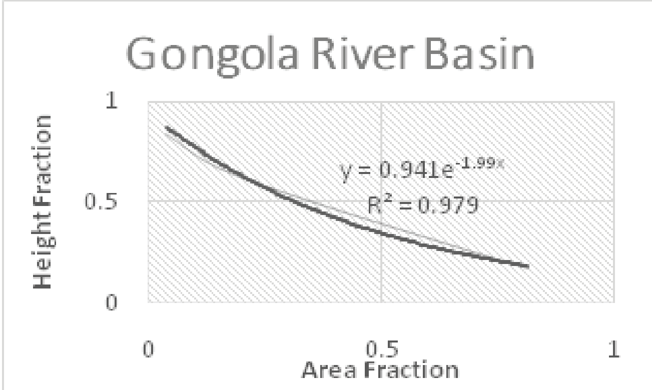

Figure 2: Hypsometric Curve for Gongola River Basin

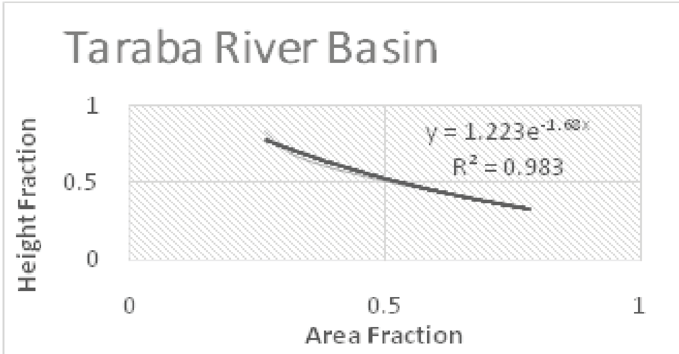

Figure 3: Hypsometric Curve for Taraba River Basin

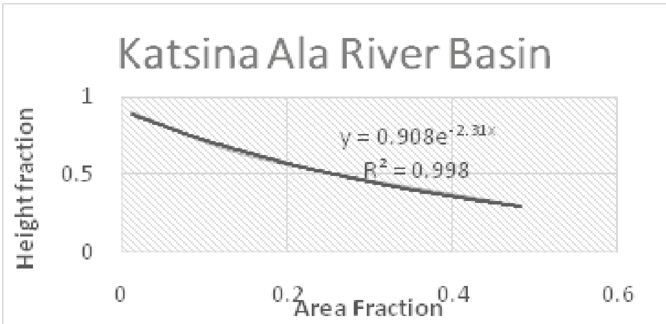

Figure 4: Hypsometric Curve for KatsinaAla River Basin

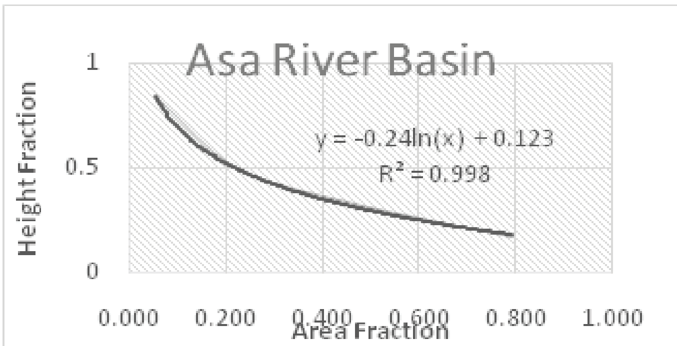

Figure 5: Hypsometric Curve for Asa River Basin

The curves in all cases are concave in form. This indicates that a large part of the basins are at relatively low relief and will typically be associated with more old terrain. Some materials have been eroded from higher parts of the basin and deposited at the lower parts or removed completely from the basins. There may also have been an extensive erosion in the basins which widens the upland valleys. As this happens the part of the basin at low relief increases while the part of the basin at high relief decreases. It can thus be concluded that erosion may be an issue in some of the study basins.

CONCLUSION

Apart from a few characteristics like the Ruggedness Number, all the basins show a similar morphometry. This is an indication that the landforms and geology of central Nigeria do not vary much from location to location and the difference in the conversion of rainfall into runoff from basin to basin will depend more on land use and vegetative cover rather than on the relief properties. The hypsometric curves also show an inclination towards a similar erosion pattern and process in the basins. A complete topographical map of many basins in Nigeria are very difficult to obtain and in most cases dates back to the sixties. This study encourages the use of the properties of nearby basins where the map of a basin of interest is non-existent as has been shown above by the closeness of the characteristics of the Asa and Oyun River basins that share a common boundary.

REFERENCES

Aisuebeogun, A. O., Ezekwe, I. C. (2013). Application of Basin Morphometry Laws in catchments of the South-Western Quadrangle of South-Eastern Nigeria., *Frontiers of Earth Science*, Volume 7, Issue 3, Pp 361-374.

Ajibade, L. T., Ifabiyi, I. P., Iroye, K. A., Ogunteru, S. (2010).Morphometric Analysis of Ogunpa and Ogbere Drainage Basins, Ibadan, Nigeria.*Ethiopian Journal of Environmental Studies and Management*, Volume 3, No 1, Pp 376 – 380.

Al-Saud, M. (2009).Morphometric Analysis of WadiAurnah Drainage System, Western Arabian Peninsula. *The Open Hydrology Journal*, Volume 3, Pp 1 – 10.

Bagyaraj, M., Gurugnanam, B. (2011).Significance of Morphometry Studies, Soil Characteristics, Erosion Phenomena and Landform Processes Using Remote Sensing and GIS for Kodaikanal Hills, A Global Biodiversity Hotpot in Western Ghats, Dindigul District, Tamil Nadu, South India. *Research Journal of Environmental and Earth Sciences*, 3 (3), Pp 221 – 233.

Biswas, A., Majumdar, D. D., Banerjee, S. (2014). Morphometry Governs the Dynamics of a Drainage Basin: Analysis and Implications.*Geography Journal,* Volume 2014, Pp. 1 – 14.

Chow, V. T., Maidment, D. R., Mays, L. W. (1988).Applied Hydrology.McGraw Hill Book Company. ISBN 0-07-100174-3, New York, USA.

Diakakis, M. (2011). A Method for Flood Hazard Mapping Based on Basin Morphometry: Application in Two Catchments in Greece.Natural Hazards, Volume 56, Pp 803–814.

El-Bayomi, G. (2010).Morphometric Analysis in Esna Basin, Using Remote Sensing and GIS Techniques. US – Egypt Workshop on Space Technology and Geo-information for Sustainable Development, Cairo, Egypt, 14 – 17 June, 2010.

Eze, E. B., Effiong, J. (2010). Morphometric Parameters of the Calabar River Basin: Implication for Hydrologic Progress.*Journal of Geography and Geology,* Volume 2, No 1, Pp 18 – 26.

Ezemonye, M. N., Emeribe, C. N. (2013): Appraisal of the Hydrological Potential of Ungauged Basin using Morphometric Parameters.*Ethiopian Journal of Environmental Studies and Management,* Volume 6, No 4, Pp 376 – 380.

Golekar, R. B., Baride, M. V., Patil, S. N. (2013). Morphometric Analysis and Hydrogeological Implication: Anjani and Jhiri Basin, Maharashtra, India.Archives of Applied Science Research, Volume 5, No 2, Pp 33 – 41.

Hajam, R. A., Hamid, A., Bhat, S. (2013). Application of Morphometric Analysis for Geo-Hydrological Studies Using Geo-Spatial Technology: A Case Study of Vishav Drainage Basin.*Hydrology Current Research*, Volume 4, Issue 3, Pp 1 - 12.

Koshak, N., Dawod, G. (2011).A GIS Morphometric Analysis of Hydrological Catchments within Makkah Metropolitan Area, Saudi Arabia.*International Journal of Geomatics and Geosciences*, Volume 2, No 2, Pp 544 – 554.

Malik, M. I., Bhat, M. S., Kuchay, N. A. (2011). Watershed Based Drainage Morphometric Analysis of Lidder Catchment in Kashmir Valley Using Geographical Information System.*Recent Research in Science and Technology,* Volume 3, (4), Pp 118 – 126.

Matsuda I. (2004). River Morphology and Channel Processes.*in Fresh Surface Water, [Ed. James C.I. Dooge], in Encyclopaedia of Life Support Systems (EOLSS),* Developed under the Auspices of the UNESCO, EOLSS Publishers, Oxford ,UK, [http://www.eolss.net]

Mishra, A., Dubey, D. P., Tiwari, R. N. (2011). Morphometric Analysis of Tons Basin, Rewa District, Madhya Pradesh, Based on Watershed Approach.*Earth Science India*, Volume 4 (III), Pp 171 – 180.

Nageswara R. K., Swarna L. P., Arun, K. P., Hari K. (2010).Morphometric Analysis of Gostani River Basin in Andra Pradesh State, India Using Spatial Information Technology. *International Journal of Geomatics and Geosciences,* Volume 1, No 2, Pp 179 – 187.

Nanda, A. M., Ahmed, P., Kanth, T. A., Hajam, R. A. (2014). Morphometric Analysis of Sandran Drainage Basin (J & K) using Geo-spatial Technology.Earth Science India, Volume 7, No 2, Pp 55 – 66.

Nongkynrih, J.M., Husain, Z. (2011).Morphometric Analysis of the Manas River Basin using Earth Observation Data and Geographical Information System.*International Journal of Geomatics and Geosciences,* Volume 2, No 2, Pp 647-654.

Pareta, K., Pareta, U. (2011).Quantitative Morphometric Analysis of a Watershed of Yamuna Basin, India Using ASTER (DEM) Data and GIS.*International Journal of Geomatics and Geosciences,* Volume 2, No1, Pp 248 – 269.

Pingale, S. M., Chandra, H., Sharma, H. C., Mishra, S. S. (2012).Morphometric Analysis of Maun Watershed in Tehri – Garhwal District of Uttarakhand using GIS. *International Journal of Geomatics and Geosciences*, Volume 3, No 2, Pp 373 – 387.

Pisal, P. A., Yadav, A. S., Chavan, A. B. (2013). Morphometric Analysis of Bhogavati River Basin, Kolhapur District, Maharashtra, India. *IOSR Journal of Mechanical and Civil Engineering* (IOSR-JMCE), Volume 6, Pp. 1 – 8.

Raghunath, H. M. (2008).Hydrological Principles.*New Age International (P) Limited.* ISBN 81-224-1825-2, Delhi.

Reddy, P. J. R. (2008). A Textbook of Hydrology.*University Science Press*, India.

Seth, S. M., Ramasastri, K. S., Rao, S. V. N. (1998). Representative Basin Studies: Morphometric Analysis of Suddagedda Basin, Andra Pradesh.P*ublished by the National Institute of Hydrology*, Jal VigyanBhawan, Roorkee – 247 667, India.

Subramanya, K. (2008).Engineering Hydrology.Tata McGraw *Hill Publishing Company Limited of New Delhi,* India.ISBN 0-07-462449-8.

Suresh, R. (2008).Land and Water Management Principles.*Standard Publishers Distributors*, Delhi, India. ISBN 81-8014-107-1.

Ward, J. V. (2007): Changing Patterns of Land Use and Basin Morphometry: Impacts on Stream Geomorphology in the Illinois River Basin, Northwest Arkansas, 1941—2004, *University of Arkansas,* USA.