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Article in *International Journal of Image and Data Fusion* · November 2019

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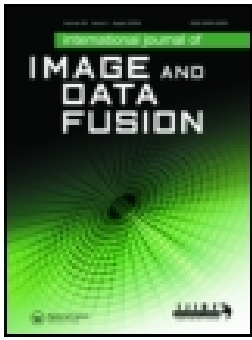
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To cite this article: Adedayo Oreoluwa Adewole, Felix Ike & Adebayo Oluwole Eludoyin (2019): A multi-sensor-based evaluation of the morphometric characteristics of Opa river basin in Southwest Nigeria, International Journal of Image and Data Fusion, DOI: [10.1080/19479832.2019.1683622](https://doi.org/10.1080/19479832.2019.1683622)

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ARTICLE



A multi-sensor-based evaluation of the morphometric characteristics of Opa river basin in Southwest Nigeria

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ABSTRACT

Studies have shown that many river basins in the sub-Saharan Africa are largely unmonitored, partly because they are poorly or totally ungauged. In this study, remote sensing products (Landsat, Advanced Spaceborne Thermal Emission and Reflection Radiometer; ASTER and Shuttle Radar Topography Mission; SRTM) that are freely available in the region were harnessed for the monitoring of Opa river basin in southwestern Nigeria. The remote sensing products were complementarily used with topographical sheets (1:50,000), ground based observation and global positioning systems to determine selected morphometric characteristics as well as changes in landuse/landcover and its impact on peak runoff in the Opa river basin. Results showed that the basin is a 5th order basin whose land area has been subjected to different natural and anthropogenic influences within the study period. Urbanisation is a major factor that threatens the basin with degradation and observed changes, and the threats are expected to become worse if restoration is not considered from some tributaries. The study concluded that commentary use of available remote sensing products in the region will provide an important level of decision support information for management and monitoring of river basins.

ARTICLE HISTORY

Received 3 April 2019

Accepted 11 October 2019

KEYWORDS

River basins monitoring and management; remote sensors; morphological characteristics; digital elevation models

1. Introduction

A river basin is an area that is drained by tributaries to a single outlet. It is the basic unit of hydrological studies and forms a landscape element, which integrates all aspects of the hydrologic cycle within a defined area (Wagener et al 2004). Through the ages, humans have interacted with rivers and their basins to make them serve their interests better. However, the carrying capacity of the river basins often varies, partly because of the effects of climate, anthropogenic influences and certain catastrophic events (Wang et al, 2018). While concerns for river basins have increased in many developed countries, many activities within river basins and their effects on water resources and the general environment have grossly overlooked in water-related policies in many sub-Saharan countries (Woodhouse 2003, Baker 2006, Rebelo *et al.* 2010). The United Nations' Millennium Development Goals Report (2012) hinted that 40% of the sub-Saharan Africa (SSA)'s

population are without access to improved sources of water supply. Also, whereas studies (e.g. Skinner and Bruce-Burgess 2005, Gurnell *et al.* 2016) have also shown that wetland restoration and drainage management require accounting and understanding of key drainage processes, there is apparently no known effort for restoration or management of most river basins in the SSA; more specifically, none in the Nigerian Policies for water resources, other than political statements and promises.

In Nigeria, as typical of many of the SSA countries, a significant link exists between poor basin management and water insecurity. For example, except for the recent efforts of the Food and Agriculture Organisation of the United Nations (FAO) to inventorise remotely sensed water information for different parts of West Africa in the Water Productivity through Open access of Remotely Sensed-derived Data (WaPOR) programme (Dieulin *et al.* 2019), there is no fully developed database for drainage systems in the region. Specifically, in Nigeria, existing studies have shown that drainage basins are poorly studied, and that existing studies are more of disjointed bits with little or no relevance to management. In fact, Akindele and Adebo (2004) criticised the duplication of activities of the Basin and Rural Development Authority and Ministries of Water Resources in the country, suggesting that such duplication caused unnecessary political interferences and managerial problems that have 'permeated the nations' socio-political, economic and cultural institutions. Consequently, the objectives of the River Basin Authorities (Nigeria's River Basins Development Authorities Act No. 35 of 1987) have never been accomplished. Studies (e.g. Beven *et al.* 1984; Kendall and McDonnell 2006; Sheriff *et al.* 2016, Eludoyin *et al.* 2017) highlight the importance of management, pollution and land use change on drainage basin morphology. Most of these studies also show the need for detailed understanding of basin morphometry, regardless of the location of the basin. Whereas most studies on sites located in technologically advanced countries reveal the substantial decision-support information, majority of studies from less developed countries have appeared in local journal outlets (based on Google Scholar search as of November 2018), often exhibiting too generalised information.

Recent records of population and urban growth intrusion into drainage basins, globally, have rekindled the concerns for drainage basin protection, restoration and management (Whalen *et al.* 2002, Sivapalan *et al.* 2003; Muhar *et al.* 2018, Festin *et al.* 2019). Despite the growing concerns for improved understanding of drainage basins, it is not certain that the morphometric features of most streams and rivers in the SSA will be adequately accounted for, due to data problems. This is partly because the technology and data required to assess the morphometric features of drainage basins are either very expensive or unavailable for most researchers that are based in the region (Whitehead and Robinson 1993, Altbach 2004, Teferra and Altbachl 2004). In most of the existing studies of small and large rivers in Nigeria, researchers have been concerned with water quality analysis, land cover analysis and land use change assessment over certain river basins (e.g. Ajibade *et al.* 2010, Eze and Effiong 2010; Adediji and Jeje 2004, Adediji 2005, Ogunkoya 2012, Orunoye *et al.* 2016, Orewole 2016, Ibitoye *et al.* 2016) while extensive configuration of relatively medium to large river basins is rarely undertaken. On the other hand, it has been argued that results from water quality observations as well as land cover/use change assessment may be difficult to comprehend without adequate understanding of the form of the drainage basins. Whereas studies from other parts of the tropical regions have emphasised the usefulness of improved models, including the

Système Hydrologique Européen (SHE/MIKE SHE; Bormann and Dieckkrüger 2003), Soil and Water Assessment Tool (SWAT; e.g. Yang *et al.* 2008, Kumar *et al.* 2017a, 2017b, Kumar and Lakshmi 2018) and Topographical (TOP) model (Coulthard *et al.* 2013, Gumindoga *et al.* 2014), very few studies are focused on medium-large size drainage basin morphometry in the Nigerian environment. Key to improving the understanding of drainage basin processes is the investigation of drainage morphometry, hence this study.

Specific objective of this study is to harness the freely available map and remote sensing products in the area for the monitoring of an important but vulnerable river basin in southwestern Nigeria. It also intends to demonstrate a complementary use of topographical map and handheld global positioning systems (GPS) to determine changes in landuse/landcover and runoff over period of study, and as well, determine selected morphometric characteristics of the river basin. These are important since the approach to achieving this study can be adopted for most of the drainage basins in the country. For such documentation of the drainage forms and characteristics, management decision can be enhanced. Landsat sensors appear to most accessible to Nigerian-based geospatial researchers, and recently digital elevation models (DEMs), particularly ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer and SRTM (Shuttle Radar Topography Mission) are prominent among many others. A complementary use of these products (including global positioning system's signals) is what is termed as a 'multi-sensor' s approach in this study.

1.1. Study area

The Opa river basin lies between 7°26'N, 7°35'N and 4°24'E, 4°39'E, in the southwestern region of Nigeria; a tropical country in Africa. The river basin is one of the most utilised sub-basins in the Ogun-Osun river basin. The basin covers communities in three local government areas – Ife central, Ife East and Atakumosa – that are characterised by varying levels of urbanisation. In the rural areas, residents of villages clear the surrounding areas of the basin for farming purposes while the portions of the basin in the built-up section are influenced by urban activities; some streams are open dumpsites for household and commercial wastes while courses of others are either purposefully or unintentionally reshaped by human activities. Within the river basin is a 116 km²wide impoundment, named Opa Reservoir that was created in 1980 to provide raw water for treatment and subsequent uses for research, laboratory, agriculture, recreation and domestic purposes in Obafemi Awolowo University, Ile-Ife (Akinbuwa and Adeniyi, 1996). The University's main campus covers about 11,350 ha with student population that have increased from about 35,000 in 2012 to more than 50, 000 in year 2019 (University's Annual Reports). Population within the basin area were about 644, 375 as at 2015.

The basin's elevation ranged 186–647 m with almost 0–15% slope, except for the north-eastern part that is dominantly steep (42.4–100%). Analysis of the aspect of the basin area shows relatively contrasting levels of topography that suggests an undulating relief or influence of different landuse/cover systems in the basin (Figure 1).

The climate of the region belongs to the Koppen's *Af* climatic class that is characterised by heavy rainfall (231.8–206.0 cm in the area) and tropical rainforest vegetation. Mean minimum temperature varies from 23.0 to 25.8 °C while average maximum varies as 28.8–33.8 °C. Dominant soil in the basin is the Alfisol soil series with the ferruginous tropical

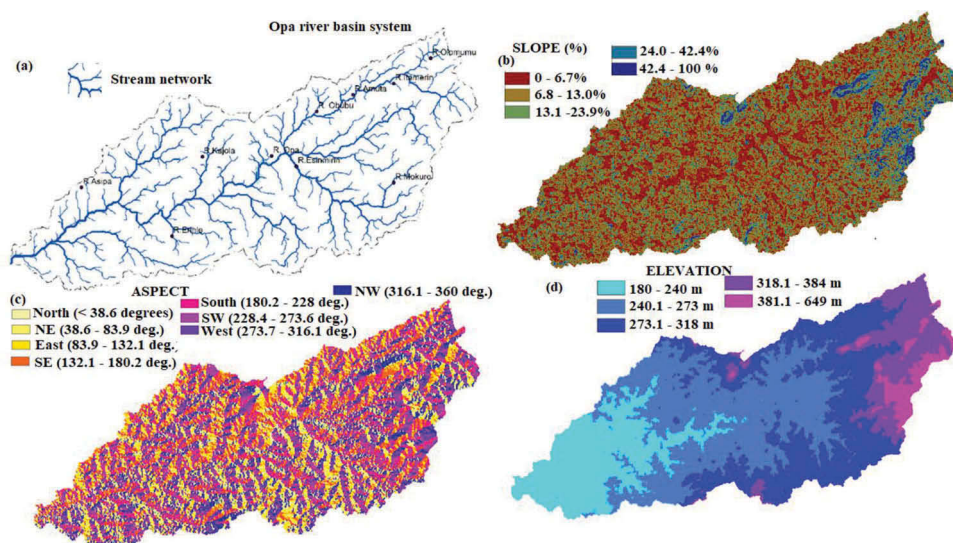


Figure 1. Streams network, topographical aspect and slope of the Opa river basin in southwest Nigeria.

overlay, which is associated with the underlying basement complex geology. The soil belongs to the Egbeda and Iwo soil association or *Oxic tropaudoalf* soil series of the United States' Department of Agriculture (USDA) system. The basin is ungauged, and this explains why it is difficult to monitor the dynamics in the hydrological processes within its system without the use of remote sensing approach. Adequate monitoring of the basin is important to its sustainability, and the sustenance of livelihoods in the region.

2. Materials and methods

2.1. Data

Data used for this study included the freely available Landsat imageries (Thematic Mapper of December, 1986; Enhanced Thematic Mapper plus Landsat 7 of December 1999 and March, 2002 and Operational Land Imager/Thermal Infrared Sensor Landsat 8 of January, 2016) for evaluating the changes in land use/cover in the basin. The essence of the land use/cover change was to speculate changes that have occurred in the basin area within the period for which data were available. Landsat imageries on the other hand, lack the topographical (height/depth) dimension that may allow them to be used to evaluate the changes in the morphometric attributes, hence the decision to use the 3-D DEM data. The DEM data that were used were considered suitable based on their availability and free access were the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Shuttle Radar Topographic Mission (SRTM). They were preferred because their use can facilitate repeatability and replicability of this research. Whereas ASTER data occurred at 15 and 30 m spatial resolution, and available for 2011, SRTM data occurred in the 30 m resolution, and was made public in 2014 was considered suitable for the study.

All the data were downloaded from the archive of the United States Geological Survey (USGS) (<https://landsat.usgs.gov>).

Furthermore, sheets of available topographical maps (1:50,000) covering the study area in 1965 were obtained to help in the georeferencing of the imageries and DEMs. Although the data have previously been georeferenced, studies have advised the need to perform a local georeferencing to ensure data quality assurance. As topographical maps in Nigeria were based on the aerial photography mission of 1962 in country, information on the maps was not used for further assessment. Rainfall records, covering the study period were obtained from a meteorological station within the university campus, and were used to estimate runoff rates. The study area was also visited with a handheld Global Positioning System (Garmin Etrex 10 model, ± 3 m precision) to obtain existing benchmarks that could be identified on the imageries, and were used with the information from the maps for georeferencing in ArcGIS software (version 10.4). The software (ArcGIS) was preferred because it was available under the ArcGIS Desktop Software for Students programme of the Environmental Systems Research Institute (ESRI) in Nigeria.

2.2. Data analysis

The Landsat imageries and DEMs were first processed for geometric (through georeferencing), and radiometric (through filtering) errors to correct for locational misplacement and noises, as advised in the literature (e.g. Das *et al.* 2016). The DEMs were thereafter run through windows-driven *filling operation* on ArcGIS software. *Filling operation* filters DEM data, and grants values (based on specified method of interpolation; in this case, the average within neighbouring cells) to void areas or cells with extreme values (using *data sinks* or *spikes* procedure; Wood, 1996). The Landsat imageries were classified into different landuse/cover types, based on Anderson (1976)'s land cover classification scheme with supervised classification procedure (Eludoyin and Iyanda, 2018). Analysis of the level of accuracy of the classification of the imageries showed the tendency for the 1999 imagery to be less accurate than others, given the 80% overall accuracy ($K_c = 0.75$) compared with 88% overall accuracy ($K_c = 0.84$), 92% overall accuracy ($K_c = 0.9$) and 86% overall accuracy ($K_c = 0.82$) for the 1986, 2002 and 2016 imageries, respectively. The DEMs were analysed for selected drainage morphometric characteristics described in Table 1. Stream order and length were respectively calculated based on the hierarchal order length of the stream while the other selected variables were determined by computing the respective formula presented in Table 1.

Furthermore, peak runoff rates were determined as described in Eq. (1) (Pendke et al, 2018).

$$Q_{peak} = \frac{0.0208 \times A \times Q_d}{T_p} \quad (1)$$

Where,

Q_{peak} = Peak runoff rate, m^3s^{-1}

A = Catchment area, ha (derived from Landsat imagery for the year)

Q_d = Runoff depth, cm

T_p = Time to Peak, h, $= 0.6T_c + T_c^{1/2}$

T_c = Time of concentration, h; and

$T_c = 0.0195X K_c^{0.77} X K_c = (L^3/H)^{0.5}$

Table 1. Information on selected morphometric parameters and equations used to derive them in this study.

S/No	Morphometric Parameters	Calculation Formulae	References
1.	Stream Order	Hierarchical rank	Strahler (1964)
2.	Stream length (L_u)	The length of the stream	Horton (1945)
3.	Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$ L_u = total stream length of order u N_u = total number of stream segments of order u	Strahler (1964)
4.	Stream length ratio (R_L)	$R_L = L_u/(L_u - 1)$ L_u = total stream length of order u $(L_u - 1)$ = total stream length of next lower order	Horton (1945)
5.	Stream frequency (F_s)	$F_s = N_u/A$ N_u = total number of stream segments of order u A = Area of the basin	Horton (1932)
6.	Drainage density (D_d)	$D_d = L_u/A$ L_u = total stream length of all orders A = Area of the basin	Horton (1932)
7.	Drainage texture (R_t)	$R_t = N_u/P$ N_u = total number of streams of all orders P = perimeter of the basin	Horton (1945)
8.	Bifurcation ratio (R_b)	$R_b = N_u/(N_u + 1)$ N_u = total number of stream segments of order u $(N_u + 1)$ = number of segments of next higher order	Schumm (1956)
9.	Form factor (R_f)	$R_f = A/L_b^2$ A = area of the basin L_b^2 = square of the basin length	Horton (1932)
10.	Elongation ratio (R_e)	$R_e = 2\sqrt{(A/\pi)}/L_b$ A = area of the basin $\pi = 3.14$ L_b = basin length	Schumm (1956)
11.	Circularity ratio (R_c)	$R_c = 4\pi (A/P^2)$ A = area of the basin $\pi = 3.14$ P = perimeter of the basin	Miller (1953)
12.	Relief ratio (R_h)	$R_h = H/L_b$ H = total relief of the basin L_b = basin length	Schumm (1956)
13.	Length of overlandflow (L_o)	$L_o = 1/(2D)$ D = drainage density of the basin	Horton (1945)
14.	Relative relief (R_r)	$R_r = 100H/P$ H = total relief of the basin P = perimeter of the basin	Schumm (1956)
15.	Slope average (S_a)	$S_a = L_b/H$ L_b = basin length H = total relief of the basin	Schumm (1956)

3. Results

3.1. Temporal changes in the drainage basin characteristics

Figure 2(a-b) presents the results of the supervised classification of the Landsat imageries for 1986, 1999, 2002 and 2016. The basin environment was increasingly affected by human activities over the years. Numbers of farmlands and proportions of built-up areas appear to have increased by more than 200% between 1999 and 2002. In 2016, built-up areas also increased, although at a lower rate than the earlier period. Conversely, the waterbodies increased in extent, between 1986 and 1999, but decreased thereafter (Table 2). The results of trend analysis that was carried out to determine the future of the

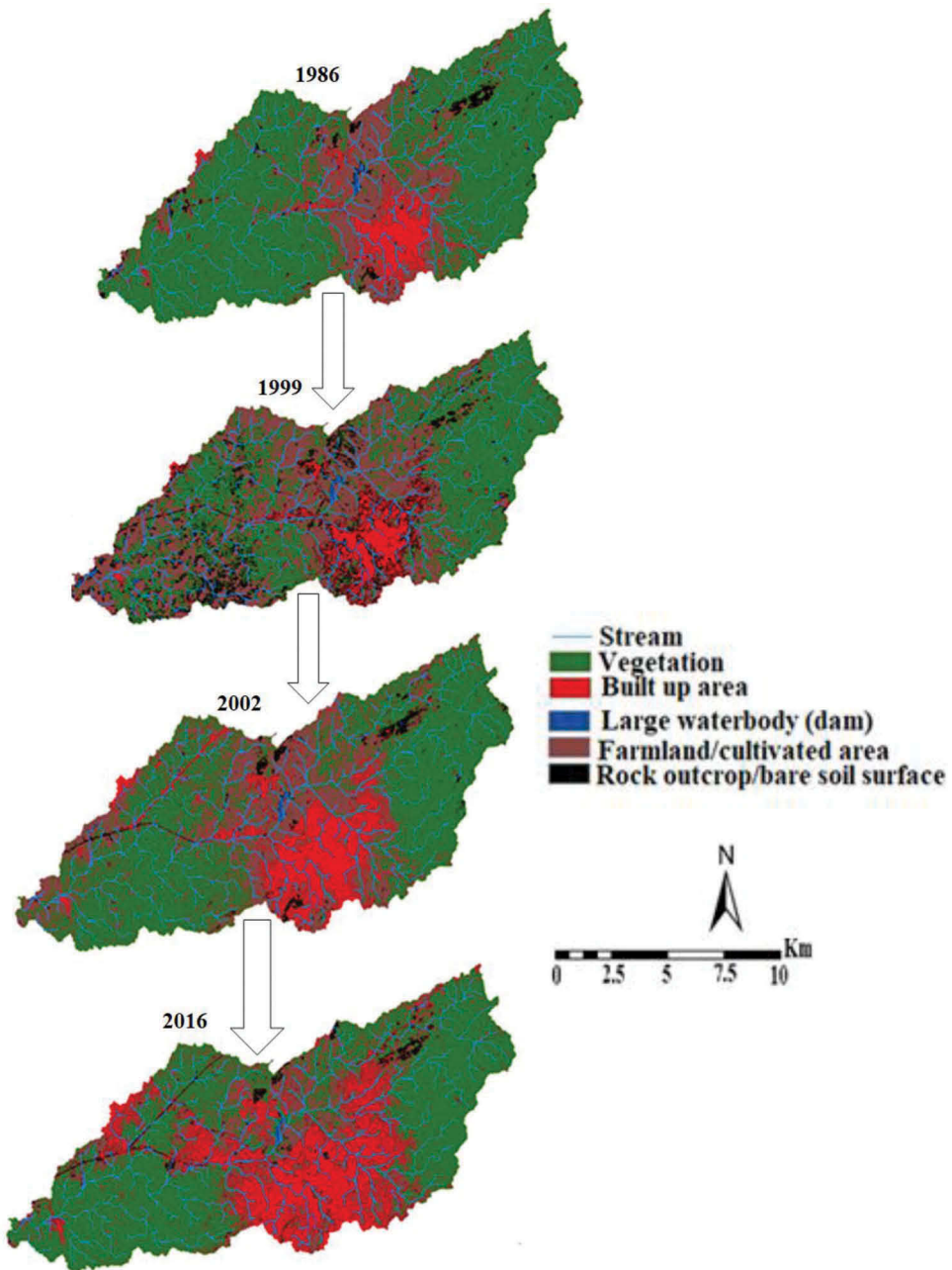


Figure 2. Landcover change over Opa river basin in southwest Nigeria between 1986 and 2016.

changes in the land use/cover types indicates that whereas the built-up area will increase over time ($b = 1.1$, $R^2 = 0.7$), vegetation ($b = -1.2$, $R^2 = 0.6$) and water bodies ($b = 0.01$, $R^2 = 0.1$) will decrease. Field observations showed that many of the headwater streams, their channels and forms have also been altered by construction of buildings and farm-land activities in many portions of the basins. Ogunkoya (2012) has also implicated

Table 2. Percentage change and linear trend (regression) of area covered by selected landcover in the basin area within the study period.

Year	Vegetation	Built-up	Waterbody	Farmlands	Rock outcrop /Bare surface
Change from 1986 to 1999 (%)	−24.6	−34.2	31.3	49.2	284.8
Change from 1999 to 2002 (%)	4.0	227.9	−14.3	−10.1	−73.7
Change from 2002 to 2016 (%)	−2.8	68.0	−2.8	−20.1	47.5
Linear regression	$2541.5 - 1.2x$	$-2164.2 + 1.1x$	$-1.1 + 0.01x$	$-99.0 + 0.1x$	$-43.5 + 0.03x$
R ²	(0.6)	(0.7)	(0.1)	(0.01)	(0.03)

increasing human activities as cause of siltation of parts of the Opa reservoir. Evidences from the imageries suggested that urbanised part of the basins are characterised with more streams whose flow have been altered or whose channels have been diverted.

In addition, analysis of the basin area and stream length delineation as well as the peak runoff rates for the period between 1986 and 2016 suggested that whereas the peak runoff rate and time of concentration were comparatively higher in 2016, the other attributes (basin area and stream length) were lower in 2016 (Table 3). It is perceived that the higher rate of runoff in 2016 could be due to the conversion of previously vegetated part of the basin to built-up area and open surfaces.

3.2. Comparative analysis of SRTM and ASTER data for the study area

Results of slope and elevation SRTM and ASTER data (both 30 m) classified the edges of the imageries differently. Whereas mean elevation ($\pm$ standard deviation) from the ASTER image is 270.3 ± 48.4 m, SRTM was slightly greater (276.9 ± 48.9 m). In terms of the slope, the SRTM data revealed relatively lower mean value (218.2 m) than the ASTER's (375.9 m). Also, ASTER data revealed more frequencies of first – to fourth-order streams (44, 10, 7 and one respectively for the first-, second-, third- and fourth-order in excess of what was obtained with SRTM). Both ASTER and SRTM, nonetheless showed that the drainage pattern in the study area is dendritic, which studies have argued to indicate relatively homogeneous texture and insignificant level of structural control by its geology (Wandre and Rank 2013, Gebre *et al.* 2015, Orunoye *et al.* 2016). On the other hand, ASTER 15 m expectedly showed finer distribution of the pixels than was ASTER 30 m, due to the difference in the spatial resolution. ASTER 15m also showed more information at the upper and lower ends (up to 0–6% and 37–100%, respectively) than ASTER 30m data.

3.3. Morphometric characteristics

The SRTM, which was used to delineate the morphometric characteristics because it was more recent than the ASTER data. The results showed that the river basin was

Table 3. Comparison of selected drainage variables in Opa river basin between 1986 and 2016.

Drainage variables	Unit	1986	2016
Length of Stream	km	67.61	65.57
Area of Drainage Basin	ha	23,638	23,600
Time of Concentration	h	5.31	5.33
Peak Runoff Rate of Basin	$\text{m}^3 \text{s}^{-1}$	461.76	536.63
Peak daily rainfall	mm	33.3	39.7

characterised by 331 first-order, 68 second-order, 13 third-order, 2 fourth-order and one fifth-order streams, using the Strahler (1964)'s ordering system. Drainage density varied as 0–2.87 km; and this describes the drainage basin as generally coarse (Aravinda and Balakrishna 2013, Gebre *et al.* 2015). Pockets of fine density occur, however, around Kajola, and Mokuro that are sub-urban area and around Ile-Ife, one of the most urbanised settlements around the basin (Figure 3). Basins with coarse density are known to be prone to high rates of soil infiltration dominance of saturation overland flow, and possibility for groundwater recharge (Kant *et al.* 2015). Low drainage density also suggests that the basin is characterised by permeable subsurface material and good vegetation cover that often results in increased infiltration capacity.

Furthermore, stream frequency (ratio of total number of streams in a basin to the basin area) were between 1.45 and 2.24, and considered as relatively high, whose implication is that dominant sphere has been exposed (Pandey *et al.* 2007). Texture ratio, the total number of stream segments of all orders per perimeter of that area, ranged as 0.1–1.45. Wailker and Nilawar (2014) categorised the drainage's texture ratio of the range of the study area as 'low in nature'. In addition, Form Factor, defined as the ratio of basin area to square of the basin length, varied from 0.1 to 0.52, and this suggests that the basin is elongated. In parts of the basin with form factor value being greater than 0.38, Horton (1932)'s study on drainage characteristics suggests that such portions are likely to experience larger peak flows within shorter duration, than basins with a lower factor. In order word, the basin tends to experience a diverse range of peak flows. In terms of the circulatory ratio (i.e. ratio of the area of the basin to the area of circle having the same circumference as the perimeter of the basin; Thornbury 1969) the drainage basin exhibited 0.1–0.36 ratio. The value of the ratio, by interpretation, suggests relatively high channel storage and low sediment yield–delivery ratio in parts of the basins and high

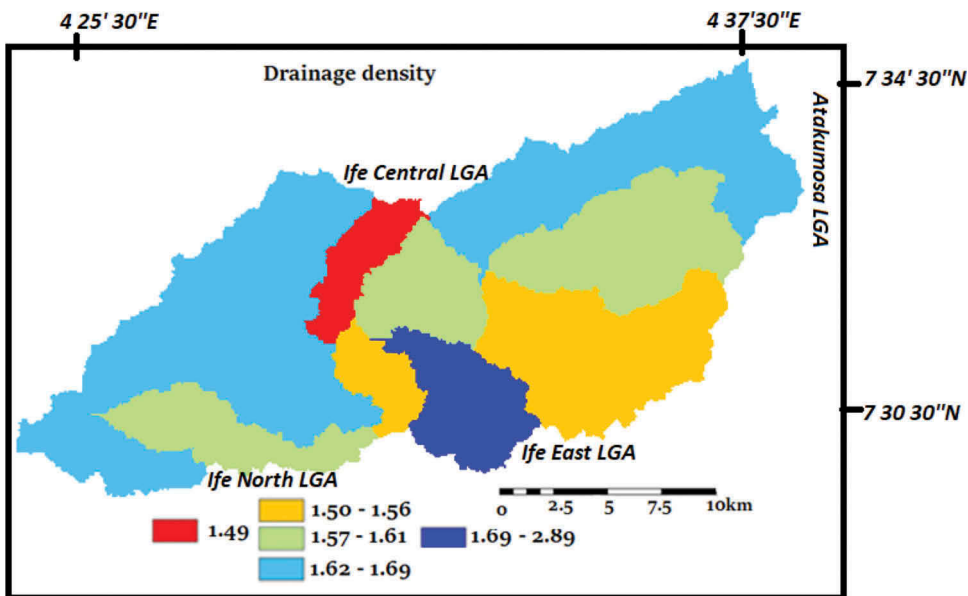


Figure 3. Drainage density of the study area (source: the SRTM data).

discharge at some other locations in the basin. In general, when compared studies elsewhere, including the observations of Nigam et al (2017) in India, the results from the study area indicated an anthropogenic influence on a natural drainage basin ecosystem. Elongation ratio (i.e. the ratio of the diameter of a circle of the same area as that of the basin to the maximum length of the basin; Schumm 1956) varied as 0.47–0.81, suggesting that the basin's landform may be 'associated with high relief and steep ground slope' (Strahler 1964). This result was affirmed by the undulating relief observed in the topographical maps.

3.4. Temporal changes in drainage characteristics

A comparison of the digitised 1962 topographical map sheets, 2011 ASTER GDEM and 2014 SRTM of the river basin showed that (i) the number of streams, basin length as well as number of headwater streams (first order streams) were comparatively lesser in the map than either ASTER or SRTM DEMs of the latter years – i.e. 2011 and 2014, respectively (Table 4); and that (ii) more headwater streams existed in the 2011 ASTER GDEM than in the 2014 SRTM DEM data (Figure 4).

Factors such as technological advancement in sensor capacity, clearance of land surface that can expose the water bodies to remote sensing detection, intentional disturbance of the drainage systems through farming activities and construction works are principal reasons that may have caused the observed changes in the drainage properties. The features that were mapped in the topographical sheets were processed from the aerial photographs (Balogun 1987, Ufuah 2003). When compared to the DEM data (which are largely multi-spectral), the aerial photographs were panchromatic (black and white) and was vulnerable to miscalculation of the geographical features they contain. According to Shan and Lee (2005), the potential for misclassification of spectrally similar features, such as buildings and roads, due to limitations on image spatial resolution and low image contrast as obtainable in panchromatic images is an important limiting factor of the usefulness of topographic maps. Also, Christophe *et al.* (2005) noted that the quality of geographical features tends to vary with the processes of vectorisation or rasterisation.

Furthermore, the results of the comparison of the ASTER and SRTM imageries suggest that the number of headwater streams declined between 2011 and 2014. Freeman *et al.* (2007) identified chanelisation, diversion through pipes, impoundment and burial, among other activities that are capable of modifying the fluxes between upland and downstream's ecosystems may eliminate the small river segments that make up the headwater drainage system. Studies on selected headwater streams in the basin (Ogunfowokan *et al.*

Table 4. Comparison of selected drainage characteristics in topographical map and DEMs.

Parameters	1962 Topographical map	2011 ASTER	2014 SRTM
Stream Order	1	65	375
	2	15	82
	3	4	19
	4	2	3
	5	1	1
Total length of streams	102.5	421	378.1
Basin area (sq. km)	198.5	250.8	236.2
Basin perimeter (km)	74.5	93.7	82.2

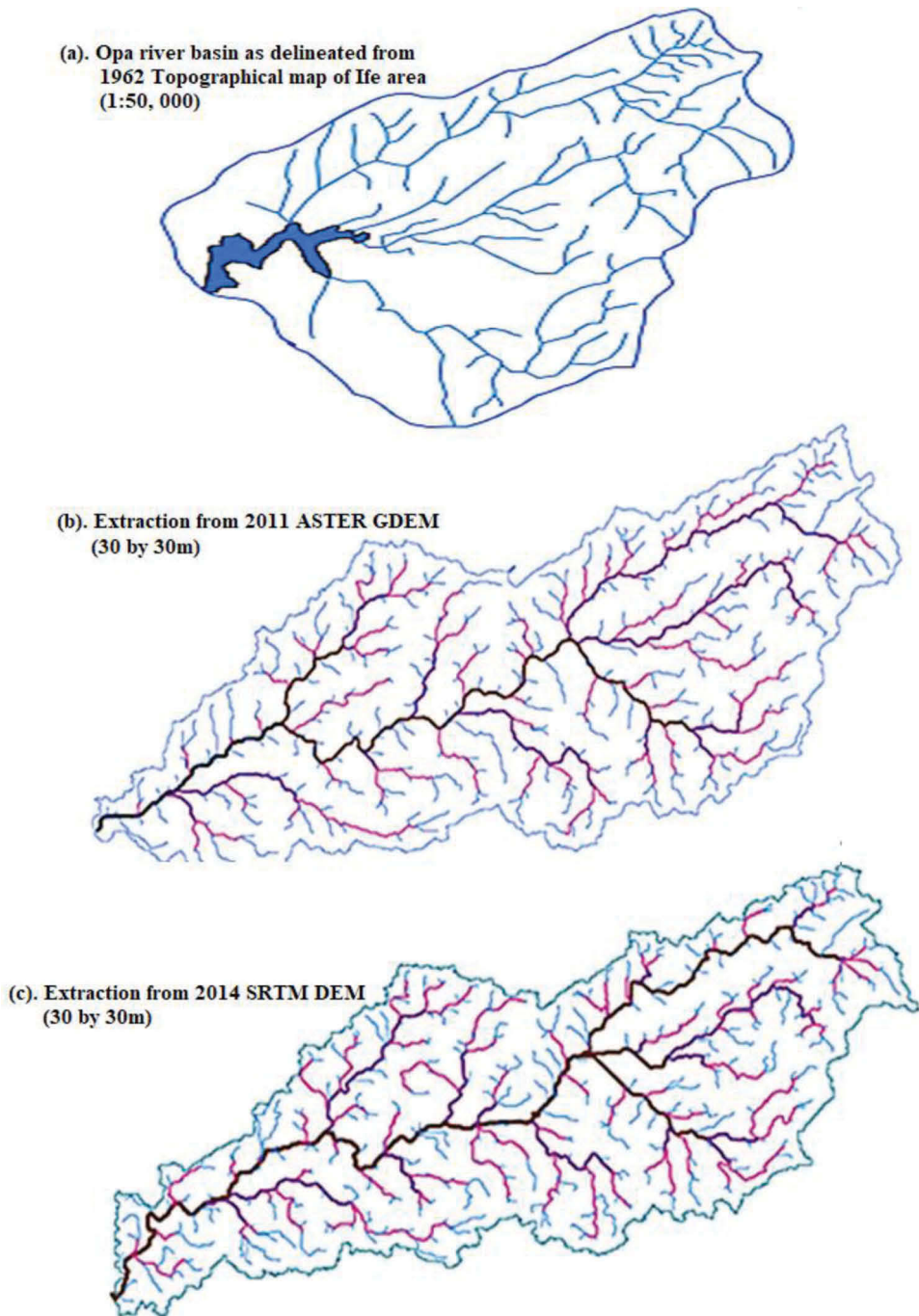


Figure 4. Variations in the streams segments in Opa river basin as extracted from topographical map and selected DEMs.

2009, 2013, Eludoyin 2014) have shown that they were exposed to pollution through agricultural activities as well as domestic and commercial waste disposal into the channels. Researchers have raised concerns that both wastes and agricultural activities are

threats to wetlands, and that the threats tend to increase as population and urbanisation increase (Dunne and Leopold 1978, Dubrovsky *et al.* 2010, Edwards *et al.* 2015, Sholtes *et al.* 2018), as observed in this study.

3.5. Hydrological implications

Length of overland flow, determined as the length of the runoff rainwater on the ground surface before it gets concentrated into definite stream channels, varied between 0.75 and 1.45. The pattern exhibited in the distribution of the values depicted slightly heterogeneous pattern; and the contrast was more obvious around Ife-East. The value range obtained suggests that most part of the stream exhibited relatively slow response, which can be attributed to the dominance of saturation-excess overland flow rather than the Hortonian or infiltration-excess overland flow. This is rather unexpected as the study area is within a tropical region. What was unexpected is the display of the infiltration excess in some regions that were hitherto covered by forest; a situation which indicated that the areas have been opened to the severe influence of runoff. In addition, as built-up increases, there is a need to control the rate at which impervious layers are created if the basin area will be sustainable in the near future. Also, areas with dominance of built-ups exhibited shorter duration of flow length than vegetated areas, providing further explanation into the influence of urban growth within the basin area.

Furthermore, based on the results of bifurcation ratio, which ranged between 1.0 and 7.91, and showed spatial fluctuations – being low in the western area and high at the central and north-eastern parts of the basin area – indicates the possibility of geological influence on drainage in the latter areas, where the value was more than 5.0. In addition, values computed for the stream length ratio (0.6–66.8) indicated significant spatial contrasts in the basin.

4. Discussion

The use of the dataset acquired from different remote sensors (GPS, Landsat MS, ETM+, OLI/TIRS, SRTM DEM and ASTER GDEM) in this study has demonstrated that multiple sources of remote sensing can be used complementarily to provide explanation and decision support systems to a variety of field-based research work. In this case, land use/cover around a basin were evaluated for the period within which data were available. The Landsat sensors used in this study provided opportunities for temporal assessment; albeit at a medium size (28–30 m) resolutions. Although the research would have provided more insights into further issues if they had been in much higher resolution (e.g. at <10 m spatial resolution), but that does not suggest that the freely available Landsat data are useless for similar study. Cost is often a major challenge of remote sensing research in many parts of the SSA, and in this, Landsat has provided a chance. Similarly, the use of STRM and ASTER data was made prominent in this study for spatial analysis. These DEMs data were not used for determination of temporal variations for which the Landsat data was found useful. Subsequently a complementary use of these data proved to supply better explanations than would have been if one of the sensors was not used. Information from the GPS sensors, with available topographical maps were used to georeferenced the image data.

The relative changes in the morphometric analysis of the drainage basin when ASTER DEM and ASTER DEM indicate the possibility of great response if researchers in the SSA will explore its use and encourage its use. The results show that an adoption of either of the sensors with product of a different sensor can be more prone to geometric errors than when data were derived from different resolution of same sensors. Studies which have compared ASTER and SRTM argued that differences may occur due to variations in their mission specifications (Nikolakopoulos et al., 2006). Subsequently, it can be argued that the geometric errors may have been occasioned by the fact that the sensors have certain unique characteristic that makes it more suitable for one purpose than for the other.

5. Conclusion

This study combined data from topographical maps, GPS surveys and data from multi-date Landsat data and DEMs to characterise an important (to livelihood) river basin in Nigeria, SSA. The study indicated that the comparative advantages of each data source could be harnessed when they are used complementarily to solve a problem. In general, multi-sensor approach to solving location-based environmental problem can be cost effective and at the same time provide valuable research results for environmental management.

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References

- Adediji, A., 2005. Reservoir sedimentation: the case or the Opa Reservoir catchment, South western Nigeria. *South African Geographical Journal*, 89, 123–128. doi:10.1080/03736245.2005.9713835
- Adediji, A., and Jeje, LK, 2004. Land use and sediment delivery ratio in opa at the basin, south-by western nigeria. *Tropical Agriculture*, 83, 133-140.
- Ajibade, L.T., et al., 2010. Morphometric analysis of ogunpa and ogbere drainage basins, Ibadan, Nigeria. *Ethiopian Journal of Environmental Studies and Management*, 3 (1), 13–19. doi:10.4314/ejesm.v3i1.54392.
- Akinbuwa, O., and Adeniyi, I.F., 1996. Seasonal variation, distribution and interrelationships of rotifers in opa reservoir, nigeria. *African Journal Of Ecology*, 34 (4), 351-363.
- Akindele, S.T. and Adebo, A., 2004. The political economy of river basin and rural development authority in Nigeria: A retrospective case study of Owena-River basin and rural development authority (ORBRDA). *Journal of Human Ecology*, 16 (1), 55–62. doi:10.1080/09709274.2004.11905716.
- Altbach, P.G., 2004. Globalisation and the university: myths and realities in an unequal world. *Tertiary Education & Management*, 10 (1), 3–25. doi:10.1080/13583883.2004.9967114.
- Anderson, J.R., 1976. A land use and land cover classification system for use with remote sensor data (Vol. 964). US Government Printing Office
- Aravinda, P.T. and Balakrishna, H.B., 2013. Morphometric analysis of vrishabhavathi watershed using remote sensing and GIS. *International Journal of Research in Engineering and Technology*, 2 (8), 514–522. doi:10.15623/ijret.2013.0211077.
- Baker, A., 2006. *Land use and water quality*. Encyclopedia of hydrological sciences. Wiley. doi: 10.1002/0470848944.hsa195.

- Balogun, O.Y., 1987. The directorate of overseas surveys and mapping in Nigeria. *The Cartographic Journal*, 24 (1), 3–14. doi:[10.1179/caj.1987.24.1.3](https://doi.org/10.1179/caj.1987.24.1.3).
- Beven, K.J., et al., 1984. Testing a physically based good forecasting model (TOPMODEL) for three UK catchments. *Journal of Hydrology*, 69, 119–143. doi:[10.1016/0022-1694\(84\)90159-8](https://doi.org/10.1016/0022-1694(84)90159-8)
- Bormann, H. and Diekkrüger, B., 2003. Possibilities and limitations of regional hydrological models applied within an environmental change study in Benin (West Africa). *Physics and Chemistry of the Earth, Parts A/B/C*, 28 (33–36), 1323–1332. doi:[10.1016/j.pce.2003.09.008](https://doi.org/10.1016/j.pce.2003.09.008).
- Christophe, E., Léger, D., and Mailhes, C., 2005. Quality criteria benchmark for hyperspectral imagery. *IEEE Transactions on Geoscience and Remote Sensing*, 43 (9), 2103–2114. doi:[10.1109/TGRS.2005.853931](https://doi.org/10.1109/TGRS.2005.853931).
- Coulthard, T.J., et al., 2013. Were rivers flowing across the Sahara during the last interglacial? Implications for human migration through Africa. *PloS One*, 8 (9), e74834. doi:[10.1371/journal.pone.0074834](https://doi.org/10.1371/journal.pone.0074834).
- Das, S., Patel, P.P., and Sengupta, S., 2016. Evaluation of different digital elevation models for analyzing drainage morphometric parameters in a mountainous terrain: a case study of the Supin–upper Tons Basin, Indian Himalayas. *Springer Plus*, 5 (1544), 1–38. doi:[10.1186/s40064-016-3207-0](https://doi.org/10.1186/s40064-016-3207-0).
- Dieulin, C., et al., 2019. A New 60-Year 1940/1999 monthly-gridded rainfall data set for Africa. *Water*, 11 (2), 387. doi:[10.3390/w11020387](https://doi.org/10.3390/w11020387).
- Dubrovsky, N.M., et al., 2010. The quality of our nation's waters—nutrients in the nation's streams and groundwater, 1992–2004. *US Geological Survey Circular*, 1350 (2), p. 174.
- Dunne, T. and Leopold, L.B., 1978. *Water in environmental planning*. USA: Macmillan.
- Edwards, P.J., Schoonover, J.E., and Williard, K.W., 2015. Guiding principles for management of forested, agricultural, and urban watersheds. *Journal of Contemporary Water Research & Education*, 154 (1), 60–84. doi:[10.1111/j.1936-704X.2015.03188.x](https://doi.org/10.1111/j.1936-704X.2015.03188.x).
- Eludoyin, A.O., 2014. Land use around headwater streams in a semi-rural environment in the humid tropics. *International Journal of Water*, 8 (1), 82–100. doi:[10.1504/IJW.2014.057789](https://doi.org/10.1504/IJW.2014.057789).
- Eludoyin, A.O., et al., 2017. An evaluation of the hysteresis in chemical concentration–discharge (C–Q) relationships from drained, intensively managed grasslands in southwest England. *Hydrological Sciences Journal*, 62 (8), 1243–1254. doi:[10.1080/02626667.2017.1313979](https://doi.org/10.1080/02626667.2017.1313979).
- Eludoyin, A.O., and Iyanda, O.O., 2018. Land cover change and forest management strategies in iife nature reserve, nigeria. *Geojournal*. 1–18.
- Eze, B.E. and Effiong, J., 2010. Morphometric parameters of Calabar river basin: implication for hydrologic processes. *Journal of and Geology*, 2 (1), 18–26.
- Festin, E.S., et al., 2019. Progresses in restoration of post-mining landscape in Africa. *Journal of Forestry Research*, 30 (2), 381–396. doi:[10.1007/s11676-018-0621-x](https://doi.org/10.1007/s11676-018-0621-x).
- Freeman, M.C., Pringle, C.M., and Jackson, C.R., 2007. Hydrologic connectivity and the contribution of stream headwaters to ecological integrity at regional scales. *Journal of the American Water Resources Association*, 43 (1), 5–14. doi:[10.1111/j.1752-1688.2007.00002.x](https://doi.org/10.1111/j.1752-1688.2007.00002.x).
- Gebre, T., et al., 2015. Analysis of watershed attributes for water resources management using GIS: the case of chelekot micro-watershed Tigray, Ethiopia. *Journal of Geographic Information System*, 7, 177–190. doi:[10.4236/jgis.2015.72015](https://doi.org/10.4236/jgis.2015.72015)
- Gumindoga, W., et al., 2014. Predicting streamflow for land cover changes in the Upper GilgelAbay River Basin, Ethiopia: A TOPMODEL based approach. *Physics and Chemistry of the Earth, Parts A/B/C*, 76, 3–15. doi:[10.1016/j.pce.2014.11.012](https://doi.org/10.1016/j.pce.2014.11.012)
- Gurnell, A.M., et al., 2016. A multi-scale hierarchical framework for developing understanding of river behaviour to support river management. *Aquatic Sciences*, 78 (1), 1–16. doi:[10.1007/s00027-015-0424-5](https://doi.org/10.1007/s00027-015-0424-5).
- Horton, R.E., 1932. Drainage basin characteristics. *Trans. Am.Geophys, Unon*, 13, 350–361. doi:[10.1029/TR013i001p00350](https://doi.org/10.1029/TR013i001p00350)
- Horton, R.E., 1945. Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. *Geological Society of America Bulletin*, 56, 275–370. doi:[10.1130/0016-7606\(1945\)56\[275:EDOSAT\]2.0.CO;2](https://doi.org/10.1130/0016-7606(1945)56[275:EDOSAT]2.0.CO;2)

- Ibitoye, M.O., Aboyeji, O.S., and Adekemi, S.O.A., 2016. Spatio-temporal analysis of landuse dynamics in Upper Opa catchment, Southwestern Nigeria. *Ethiopian Journal of Environmental Studies & Management*, 9 (6), 780–792.
- Kant, S., Meshram, S., Dohare, R., and Singh, S., 2015. Morphometric analysis of sonar sub-basin using srtm data and geographical information system (gis). *African Journal Of Agricultural Research*, 10 (12), 1401–1406.
- Kendall, C. and McDonnell, J.J., 2006. *Isotope tracers in catchment hydrology*. United Kingdom: Elsevier Publications, 847.
- Kumar, B. and Lakshmi, V., 2018. Accessing the capability of TRMM 3B42 V7 to simulate streamflow during extreme rain events: case study for a Himalayan River Basin. *Journal of Earth System Science*, 127 (2), 27. doi:10.1007/s12040-018-0928-1.
- Kumar, B., Lakshmi, V., and Patra, K.C., 2017a. Evaluating the uncertainties in the SWAT model outputs due to DEM grid size and resampling techniques in a large Himalayan river basin. *Journal of Hydrologic Engineering*, 22 (9), 04017039. doi:10.1061/(ASCE)HE.1943-5584.0001569.
- Kumar, B., Patra, K.C., and Lakshmi, V., 2017b. Error in digital network and basin area delineation using d8 method: A case study in a sub-basin of the Ganga. *Journal of the Geological Society of India*, 89 (1), 65–70. doi:10.1007/s12594-017-0559-1.
- Miller, V.C. 1953. A Quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee, Proj. NR 389–402, Tech Rep 3, Columbia University, Department of Geology, ONR, New York
- Muhar, S., et al., 2018. Restoration in integrated river basin management. In: Schmutz S. and Sendzimir, J. (Eds), *Riverine ecosystem management*. Cham: Springer, 273–299.
- Nigam, G.K., Tripathi, M.P., Ambast, S.K., Kumar, L., and Khalkho, D., 2017. Morphometric analysis of seonath river of chhattisgarh using remote sensing and geographical information system (gis) technique. *Journal Of Soil and Water Conservation*, 16 (3), 251–259.
- Nikolakopoulos, K.G., Kamaratakis, E.K., and Chrysoulakis, N., 2006. Srtm vs aster elevation products. comparison for two regions in crete. Greece. *International Journal Of Remote Sensing*, 27 (21), 4819–4838.
- Ogunfowokan, A.O., Obisanya, J.F., and Ogunkoya, O.O., 2009. Assessment of chemical quality of three streams under different agricultural land systems in Obafemi Awolowo University Ile-Ife, Nigeria. *Toxicological & Environmental Chemistry*, 91 (5), 847–872. doi:10.1080/02772240802615066.
- Ogunfowokan, A.O., Obisanya, J.F., and Ogunkoya, O.O., 2013. Salinity and sodium hazards of three streams of different agricultural land use systems in Ile-Ife, Nigeria. *Applied Water Science*, 3 (1), 19–28. doi:10.1007/s13201-012-0053-2.
- Ogunkoya, O.O., 2012. *All Rivers run into the sea; yet the sea is not full*. Inaugural Lecture Series 256. Ile-Ife: Obafemi Awolowo University, 103 p.
- Orewole, M., 2016. Application of geospatial technology in watershed delineation and extraction of hydrologic characteristics in Opa Catchment, Southwestern Nigeria. *Journal of Geography, Environment and Earth Science International*, 8 (2), 1–9.
- Orunoye, E.D., et al., 2016. Drainage basin morphometric parameters of River Lamurde: implication for hydrologic and geomorphic processes. *Journal of Agriculture and Ecology Research*, 5 (2), 1–11. doi:10.9734/JAERI/2016/22149.
- Pandey, V.K., Pandey, A., and Panda, S.N., 2007. Watershed management using remote sensing and GIS – a case study of Banikdih watershed (Eastern India). *Asian Journal of Geoinformatics*, 7 (1), 3–16.
- Pendke, M.S., Sreenivasan, G., Bhuibhar, B.W., Kadale, A.S., and Khodke, U.M., 2018. Impact of morphometric parameters and change in land use on peak runoff rates of pingalgarh watershed using geospatial techniques. *Journal Of Agricultural Engineering*, 55 (1), 72–81.
- Rebello, L.M., McCartney, M.P., and Finlayson, C.M., 2010. Wetlands of Sub-Saharan Africa: distribution and contribution of agriculture to livelihoods. *Wetlands Ecology and Management*, 18 (5), 557–572. doi:10.1007/s11273-009-9142-x.

- Schumm, S.A., 1956. Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. *Bulletin of the Geological Society of America*, 67, 597–646. doi:[10.1130/0016-7606\(1956\)67\[597:EODSAS\]2.0.CO;2](https://doi.org/10.1130/0016-7606(1956)67[597:EODSAS]2.0.CO;2)
- Shan, J., and Lee, S.D., 2005. Quality of building extraction from ikonos imagery. *Journal Of Surveying Engineering*, 131 (1), 27–32.
- Sherriff, S.C., Rowan, J.S., Fenton, O., Jordan, P., Melland, A.R., Mellander, P.E., and Huallachain, D.O., 2016. Storm event suspended sediment-discharge hysteresis and controls in agricultural watersheds: implications for watershed scale sediment management. *Environmental Science & Technology*, 50 (4), 1769–1778.
- Sholtes, J.S., et al., 2018. Managing infrastructure in the stream environment. *Journal of the American Water Resources Association*, 54 (6), 1172–1184. doi:[10.1111/1752-1688.12692](https://doi.org/10.1111/1752-1688.12692).
- Sivapalan, M., et al., 2003. IAHS decade on predictions in Ungauged Basins (PUB), 2003–2012: shaping an exciting future for the hydrological sciences. *Hydrological Sciences Journal-Journal Des Sciences Hydrologiques*, 48, 857–880. doi:[10.1623/hysj.48.6.857.51421](https://doi.org/10.1623/hysj.48.6.857.51421)
- Skinner, K.S. and Bruce-Burgess, L., 2005. Strategic and project level river restoration protocols—key components for meeting the requirements of the Water Framework Directive (WFD). *Water and Environment Journal*, 19 (2), 135–142. doi:[10.1111/j.1747-6593.2005.tb00561.x](https://doi.org/10.1111/j.1747-6593.2005.tb00561.x).
- Strahler, A.N., 1964. Quantitative geomorphology of drainage basins and channel networks. In: V.T. Chow, ed. *Handbook of applied hydrology*. New York: McGraw-Hill, 439–476.
- Teferra, D. and Altbachl, P.G., 2004. African higher education: challenges for the 21st century. *Higher Education*, 47 (1), 21–50. doi:[10.1023/B:HIGH.0000009822.49980.30](https://doi.org/10.1023/B:HIGH.0000009822.49980.30).
- Thornbury, W.D., 1969. *Principles of geomorphology*. 2nd ed. New York, USA: Wiley and Sons.
- Ufuah, M.E. (2003). Non-revision of 1: 50,000 topographic maps and its implications for sustainable development in Nigeria. In *Proceeding of the 21st International Cartographic Association Conference on Cartographic Renaissance* (pp. 2579–2589). Durban, South Africa, 10 - 16 August 2003.
- Wagener, T., Wheeler, H., and Gupta, H.V., 2004. *Rainfall-runoff modelling in gauged and ungauged catchments*. London: World Scientific. Imperial College Press, 231 p.
- Wailker, M. and Nilawar, A., 2014. Morphometric analysis of a drainage basin using geographical information system: a case study. *International Journal of Multidisciplinary and Current Research*, 2, 179–184.
- Wandre, S.S. and Rank, H.D., 2013. Assessment of morphometric characteristics of Shetrunji River basin using remote sensing and geographical information system (GIS). *African Journal of Agricultural Research*, 8 (18), 2003–2015. doi:[10.5897/AJAR2013.7031](https://doi.org/10.5897/AJAR2013.7031).
- Wang, Z., Zhong, R., Lai, C., Zeng, Z., Lian, Y., and Bai, X., 2018. Climate change enhances the severity and variability of drought in the pearl river basin in south china in the 21st century. *Agricultural and Forest Meteorology*, 249, 149–162.
- Whalen, P.J., et al., 2002. Kissimmee River restoration: a case study. *Water Science and Technology*, 45 (11), 55–62. doi:[10.2166/wst.2002.0379](https://doi.org/10.2166/wst.2002.0379).
- Whitehead, P.G. and Robinson, M., 1993. Experimental basin studies—an international and historical perspective of forest impacts. *Journal of Hydrology*, 145 (3–4), 217–230. doi:[10.1016/0022-1694\(93\)90055-E](https://doi.org/10.1016/0022-1694(93)90055-E).
- Wood, J., 1996. The geomorphological characterisation of digital elevation models (Doctoral dissertation, University of Leicester)
- Woodhouse, P., 2003. African enclosures: a default mode of development. *World Development*, 31 (10), 1705–1720. doi:[10.1016/S0305-750X\(03\)00140-2](https://doi.org/10.1016/S0305-750X(03)00140-2).
- Yang, J., et al., 2008. Comparing uncertainty analysis techniques for a SWAT application to the Chaohe Basin in China. *Journal of Hydrology*, 358 (1–2), 1–23. doi:[10.1016/j.jhydrol.2008.05.012](https://doi.org/10.1016/j.jhydrol.2008.05.012).