Environmental Technology & Science Journal [ETSJ]

VOLUME 6 No.1 JUNE 2015

ISSN NO: 2006-0459

PUBLISHED BY:
School of Environmental Technology (SET),
Federal University of Technology,

P.M.B. 65 MINNA, NIGER STATE
E-mail: etsjournal2006@yahoo.com

Environmental Technology & Science Journal (ETSJ)
Volume 6 No.1, June, 2015. ISSN-2006-0459

Published by:
School of Environmental Technology (SET),
Federal University of Technology,
P.M.B. 65, MINNA, NIGERIA
E-mail: etsjournal2006@yahoo.com
ISSN: 2006-0459

Table of Contents

MAPPING SURFACE HYDROLOGICAL PATTERNS IN THE SOUTHERN PART OF NIGER STATE FROM DIGITAL ELEVATION MODEL

ZITTA, N.; ODUMOSU J. O; AJAYI O. G. and OPALUWA Y. D.
Department of Surveying and Geoinformatics,
Federal University of Technology, Minna.
Corresponding Email:xietass@yahoo.com

Abstract
Determination and mapping of the morphometric parameters of a drainage channel is an essential task for water quality assessment, flood modelling and flood prevention; since these parameters affect catchment flow pattern and eventually drain-basins. The SRTM Digital Elevation Model covering Southern Part of Niger State was used to determine the drainage channels, drainage basins and topographic wetness index (twi) around the study area as a surrogate to flood vulnerability in the area. The results obtained from the study identified Shiroro drainage basin (1104.045 Km^2) and Mashegu / Borgu (151.516 Km^2) as the largest and smallest basins respectively in the study area. It also pointed out the possibility of flood in certain Local Government Areas (areas with high wetness index such as Paikoro, Chanchanga, Borgu and Mashegu).

Keywords: Morphometry, Topographic wetness index, Flooding, QGIS

Introduction

The problem of flooding in recent times has received much attention by government and environmental scientist. Considering its severe and devastating effects on lives and properties, flooding is the most frequent form of natural disaster in Nigeria. Though most cases of flood inundation have occurred in the Southern Western and Eastern parts of the country, the North Central region has also recently witnessed her own share of the menace; with flood occurrences in Kogi, Nassarawa and Benue States.

In a bid to mitigate flood occurrence, the importance of locating natural runoff flow routes and documenting them in map form for sustainable planning and development of the urban and rural areas cannot be over emphasized (Chukwuocha and Igbokwe, 2014). These natural drainage channels serve as runoff paths along which water bodies flow on the topographic surface. Once the drainage channels are determined, other hydrological parameters such as catchment area, catchment slope, catchment height and drainage basin can efficiently be delineated. These hydrological parameters therefore serve as indices for efficient design and building of reliable state-wide flood prevention structures and environmental-friendly urban designs. A flow transport channel is principally a function of surface topography and gravity. While it is not the interest of this research to investigate gravimetric impact on natural drainage patterns, the concept of topography in drainage path delineation is herein considered; which requires that a digital elevation model (DEM) of the study area be acquired. Recent advancement in remote sensing technology have improved the methods and processing for developing hydrological models (both graphically and mathematically) to mitigate flood disaster. As remote sensing precisions and accuracies have improved over the years, Digital Elevation Models (DEMs) have gone from 30 – 100 meter resolution to 1 – 5 meter resolution presently for most parts of the Earth's Land Surface (Wallis et al, 2009). Besides, the global-extent coverage and easy on-line accessibility of high precision DEM's are beginning to give its use great popularity and relevance in large scale regional projects and researches. Terrain analysis based on digital elevation models are therefore being increasingly used in hydrology (Wilson and Gallant, 2000). Ajibade et al, (2010) conducted morphometric analysis of the Ogunpa and Ogbere drainage basins in Ibadan based on data derived from a topographic map of the study areas. The study further revealed that morphometric properties of Ogunpa drainage basin are likely to induce high magnitude flood compared to morphometric properties of Ogbere drainage basin. Also, Rao et al (2009) integrated GIS and remote sensing to demonstrate the dynamic equilibrium in the geo-hydrological characteristics of four sub-water sheds of Agra district. This research however used the SRTM 30 arc seconds DEM for Southern Nigeria (Path 189, Row 53) to determine the channel flow patterns, drainage basins and topographic wetness index for the southern part of Niger State in North Central Nigeria.

Process description

Demarcation of Channel Networks
Generally, developing a flow model and mapping the channel network from a gridded Digital Elevation Model follows a now-well- rehearsed procedure (Wallis et al 2009) of (1) filling Sinks (2) computing flow directions and (3) computing the contributing area draining into each grid cell; all which are well described in details by Odumosu et al (2014). The pour point method of pit removal was used for filling the sinks while the Rho 8 method was used for computing the flow direction.

Determination of Drainage Basins:
A drainage basin or watershed is an extent or an area of land where surface water from rain and melting snow or ice converges to a single point at a lower elevation, where the waters join another waterbody, such as a river, lake, reservoir, estuary, wetland, sea, or ocean (www.wikipedia.com). Determination of Drainage basins is fundamentally done using the Strahler's technique (Strahler, 1957; Hajam et al, 2013) wherein the conglomerate of $1^{st} - 4^{th}$ order streams (drain channels) are linked together to form a basin as shown in Figure 1.

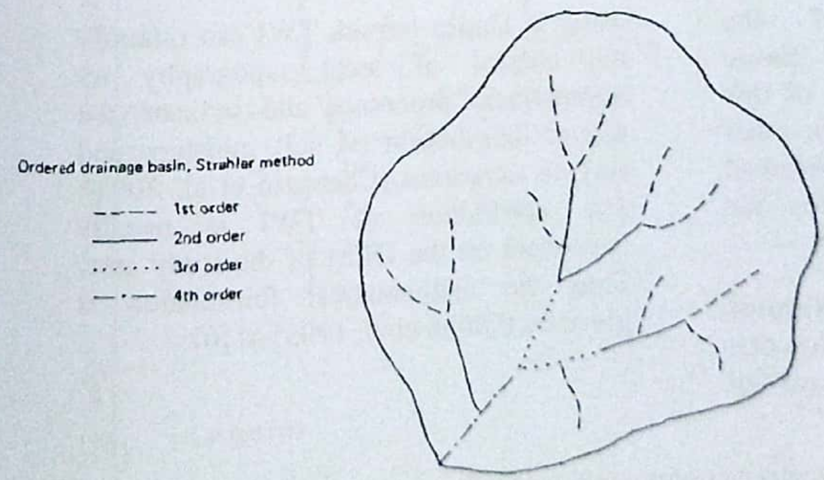


Figure 1: Ordering of Drainage channels in stre*ams*. Adapted from Morisawa (1964)

Mathematical Formulation of Algorithm:

The mathematical formulations used for the execution algorithm is as given by Hajam et al (2013)

$$Stream\ Number\ (N_u) = R_b{}^{s-u} \quad [1]$$

$$Mean\ Stream\ Lenght\ (\bar{L}_u) = \bar{L}_1 R_L{}^{u-1} \quad [2]$$

$$\text{Basin Area}\ (\bar{A}_u) = \bar{A}_1 R_a{}^{u-1} \quad [3]$$

$$\text{Total Stream Length}\ (\textstyle\sum L_u) = \bar{L}_1 R_b{}^{s-u} R_L{}^{u-1} \quad [4]$$

$$\text{Stream Gradient}\ (\bar{S}_u) = \bar{S}_1 R_s{}^{s-u} \quad [5]$$

Where: $N_u = No\ of\ Streams\ of\ order\ u$

$R_b = bi-furcation\ ratio$

s = Highest order of the basin

$\bar{L}_u = mean\ stream\ length\ of\ order\ u$

$R_L = Stream\ Length\ Ratio$

$\bar{A}_u = mean\ area\ of\ basin\ of\ order\ u$

$R_a = basin\ area\ ratio$

$\sum L_b = total\ Stream\ lengths\ in\ a\ basin\ of\ order\ u$

$S_u = mean\ gradient\ of\ stream\ of\ order\ u$

$R_s = stream\ gradient\ ratio.$

These properties are called the morphometric properties of the basin. While we have limited the scope of this study to delineation of basin area, the other mophometric properties herein obtained can be further used to determine the hypsometry of the water channel.

Computation of Topographic Wetness Index (twi): Based on the assumption that topography controls the movement of water in slopes terrain, TWI can quantify the control of local topography on hydrological processes and indicate the spatial distribution of soil moisture and surface saturation (Chengzhi et al, 2005). The calculation of TWI is usually dependent on the DEM of the study area. Thus the mathematical formulation is given by (Quinn et al, 1995) as [6]:

$$TWI = \ln \frac{a}{\tan b} \quad [6]$$

Where: *a* is the upslope contributing area per unit contour length

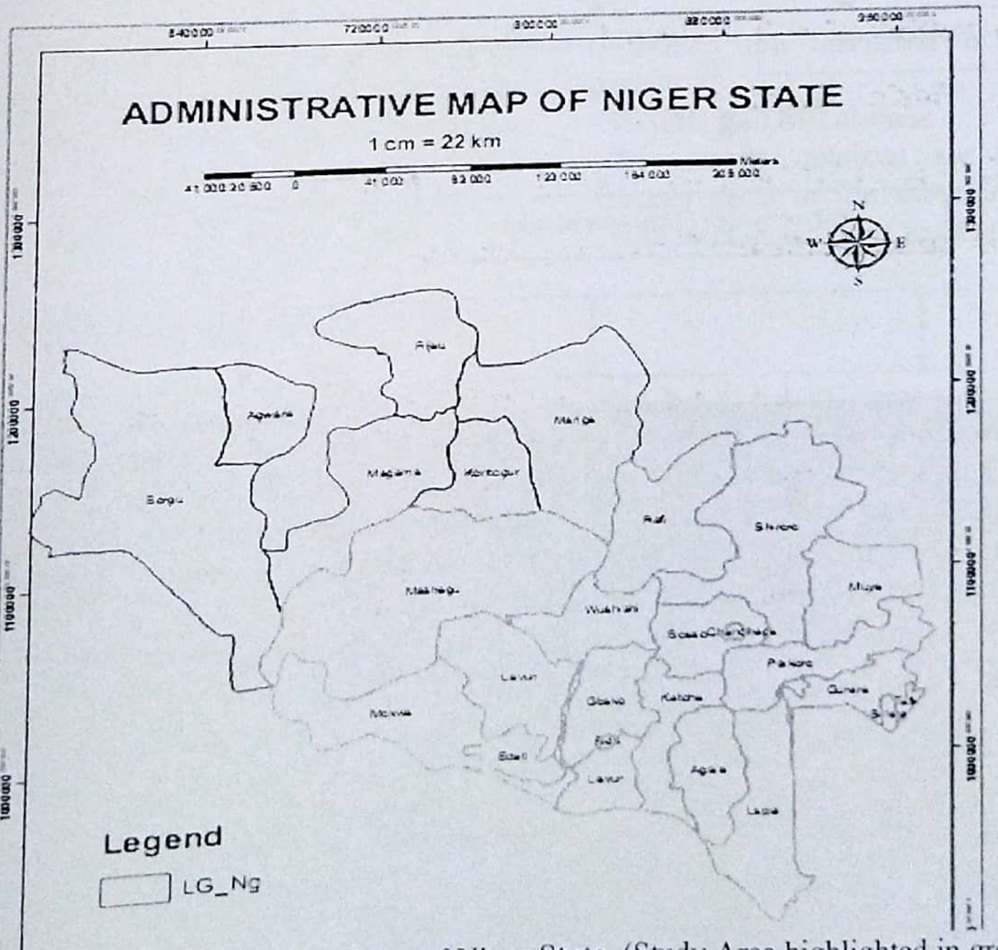
b is the local gradient at the point.

Although, several other variations in technique for determination of the "a" and "b" are being proposed, these shall not be investigated in this research as it is not the objective of this paper.

Study area

Niger State located in the North Central part of Nigeria is the largest state in the country (74,244 km^2) located between latitude 8° 22'N and 11° 30'N and longitude 3° 30E, and 7° 20'E. Niger state experiences both rainy season and dry season with an August break in between seasons and has an average elevation ranging between MSL elevation (at the Southern Areas close to the River Niger) and about 400m in the Northern and Eastern Parts.

Because the Southern Parts of the state (Mokwa, Edati and Borgu Local Government Areas) Share boundary with the River Niger, they appear to be flood vulnerable thus our choice of the study area. According to Salami (2010), after the construction of Shiroro dam there, were two serious floods in 1985 and 1988. Losses during these periods due to floods were in millions of naira and a large hectarage of arable land with crops submerged. The badly affected area was the Lavun local government area where properties worth millions of naira were destroyed. The flood damages to crops in Niger State during 1985 and 1988 cost hundreds of million naira. After 1985 and 1988 flooding, the reoccurrence is more frequent and the damages are higher. Lawal and Nagya (1999) also reported the occurrences of flood at Mokwa, Rabba and its environs in 1997, 1998 destroyed properties worth over five hundred million naira. The flooding has become an annual event.



Figures. 1: Administrative Map of Niger State. (Study Area highlighted in green)

Methodology

The Quantum GIS (QGIS) software was used in this study. QGIS is a "free downloadable" GIS software with capacity for both vector and raster analysis. Giving it further advantage over other GIS softwares is the availability of several downloadable and updatable "Plugins" which could be used for various user-required analysis.

Since we are considering flood channels as a function of topography, the major data used was the SRTM 30m resolution, 30-arc seconds data for the study area obtained from GMTED 2010 data. The metadata file for the SRTM data reveal that the data was obtained in November 2010.

After download, the pixel analysis of the data was done using QGIS and the pixel resolution (Ground Sampling Distance) was found to be 30.7022m.

The hydrology tools in the "SAGA plugin" were then used to determine the hydrological parameters.

Other raster tools as the clipper, raster calculator and vector union tools were then used to embellish the results so as to produce an aesthetically appealing map showing flood vulnerability within the study area.

Conceptual Design:

Figure 2. presents the flowchart highlighting the conceptual design of this research while the model formulation is presented as Figure 3.0.

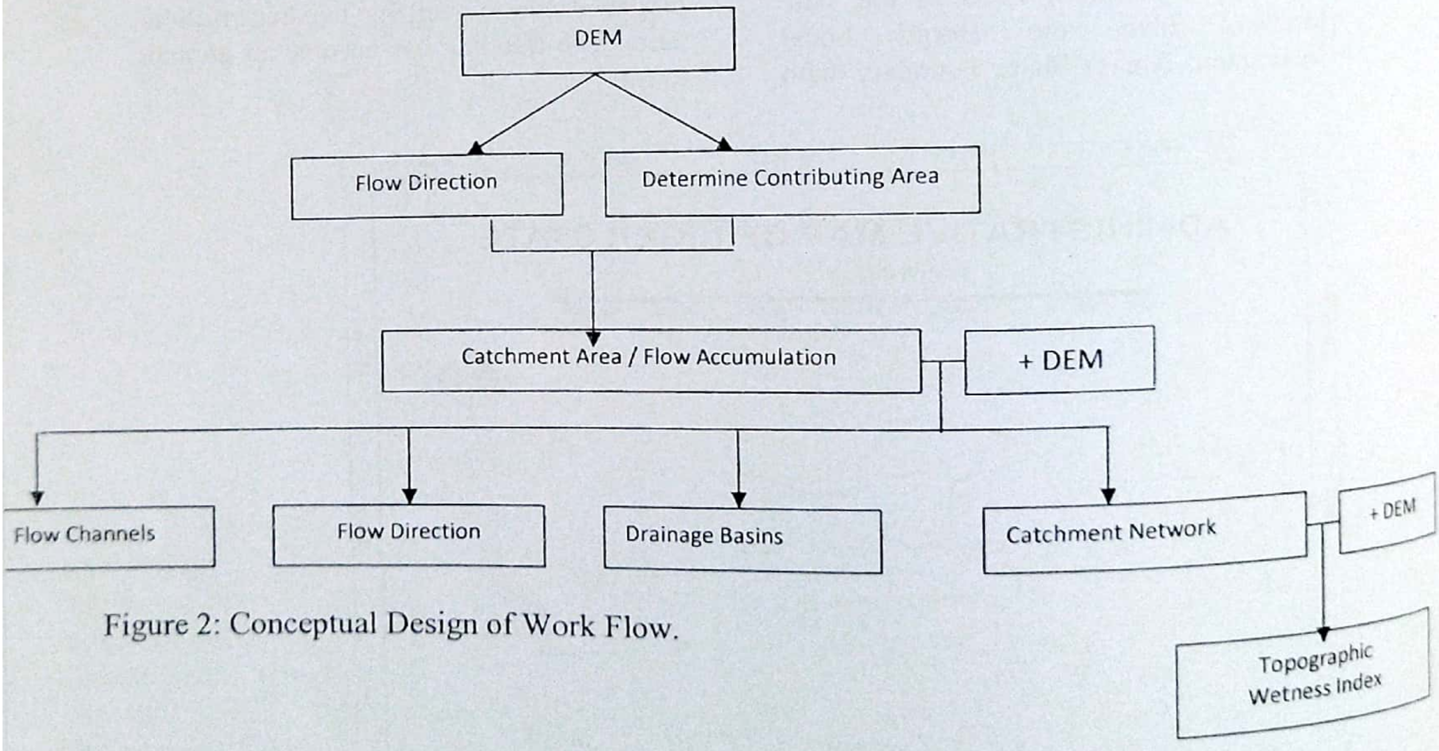


Figure 2: Conceptual Design of Work Flow.

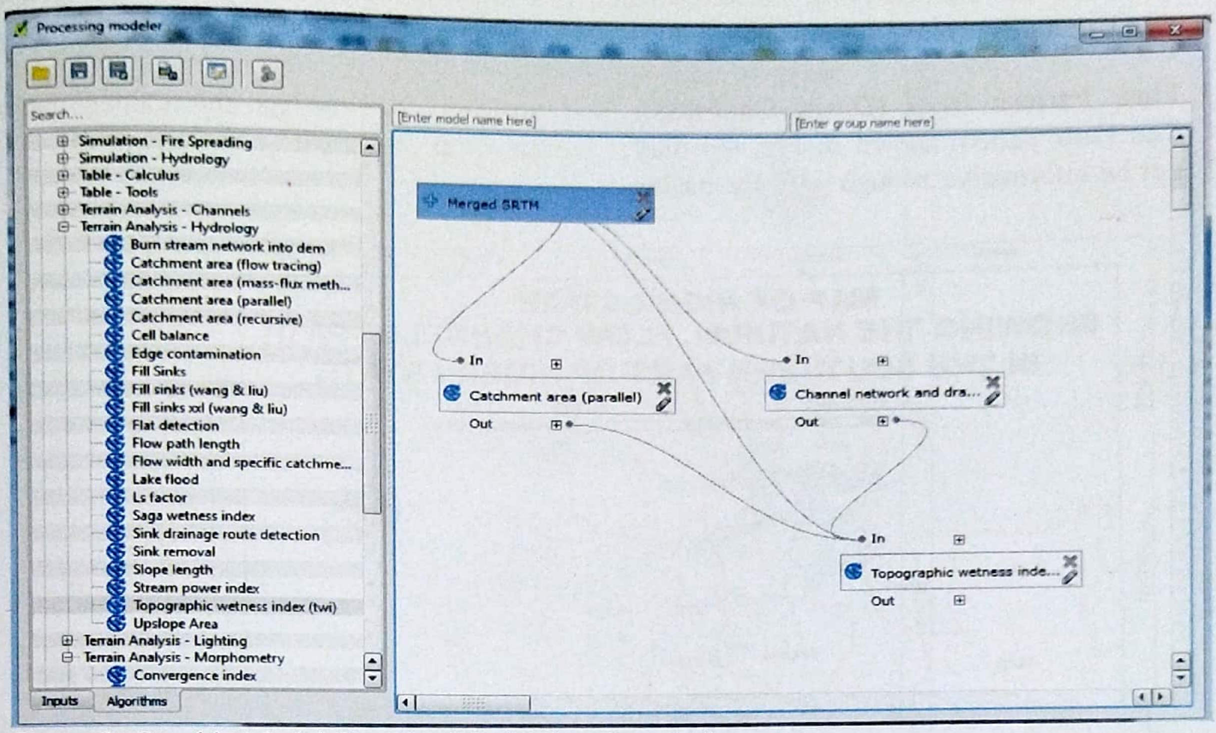


Figure 3: Graphic Model Showing Work Flow Description

The QGIS Graphic Modeller was used to run the process for determination of all three required hydrological parameters for determination of flow Pattern. The model is as shown in Figure 3 and the results obtained are discussed in the section below.

Results and discussions

The results obtained are presented in screen shots in the subsequent previews with brief discussions accompanying them.

Raw Digital Elevation Model (DEM):

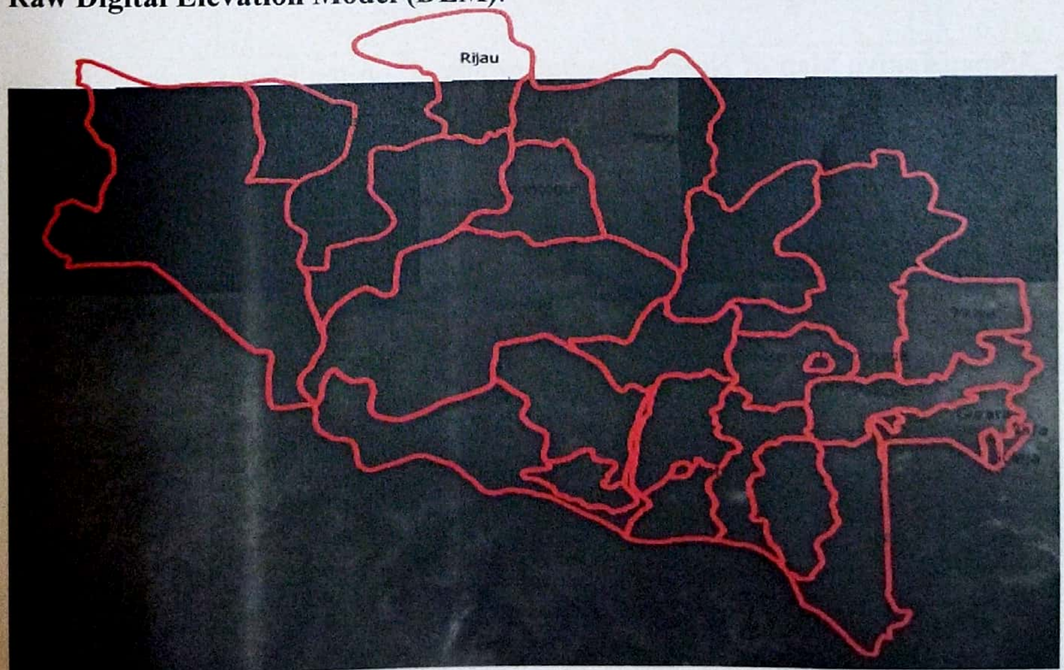


Figure 4.0: Administrative Map of Niger State Superimposed on the DEM for the Study Area.

From the above Figure, we see that the elevation is very low in the Southern parts of Niger State. Besides the low lying elevation region is a trace of the River Niger. This therefore raises so much concern for residents within Mokwa, Edati, Katcha, Agaie and Lapai.

Flow Pattern Map (Drain Channels): The Flow pattern shown in Fig. 4.0 may not be informative enough until the basins are overlaid. However, the drainage paths are as shown in Figure 5.0

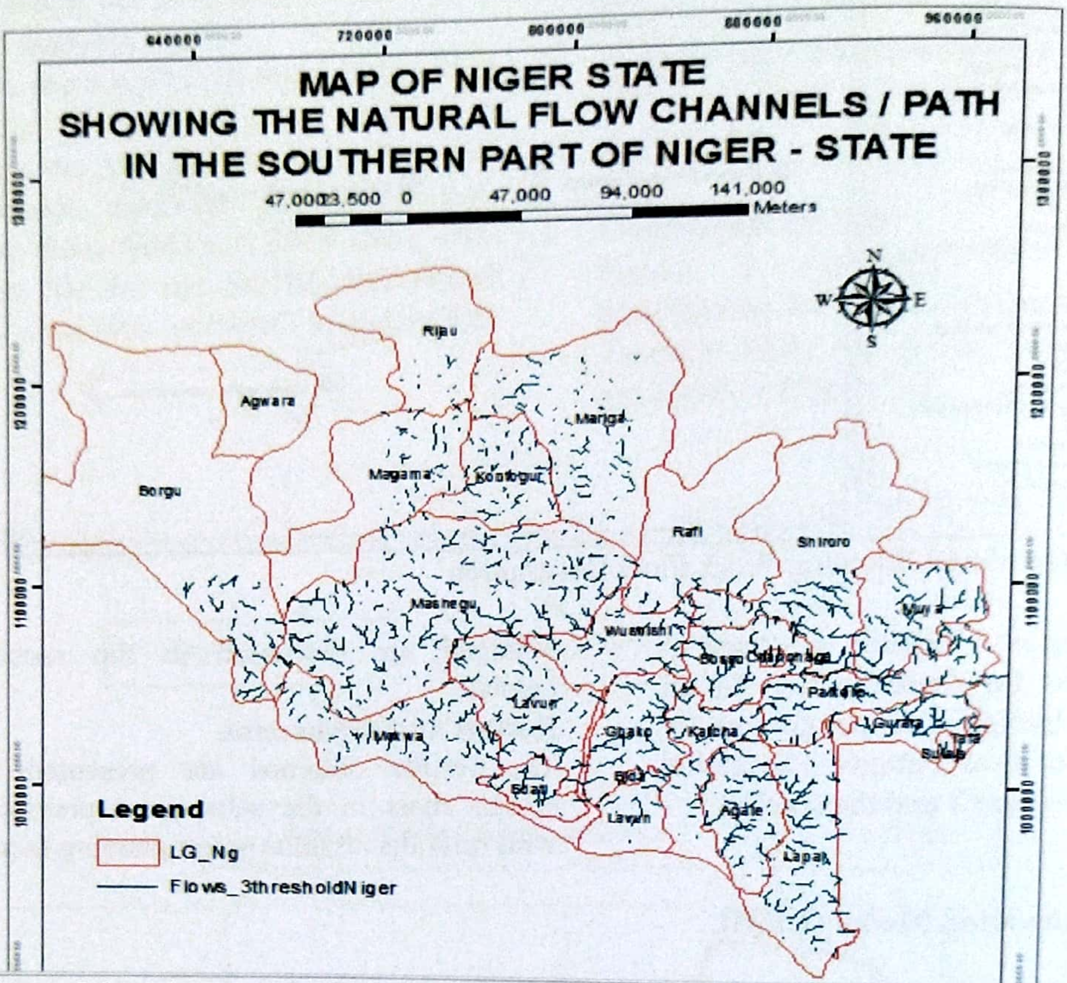


Figure 5.0: Administrative Map of Niger State Superimposed on the Flow Channels for the Study Area.

Drainage Basin

Three major basins are recognised within the study area. The Slightly wet (1), Wet (2) and Very Wet (3) basins. Contrary to lay expectations, the settlements along the river Niger do not have very wet basins. This shows us that the topography of the region naturally drains much of the water from the Northern parts into smaller lakes, streams and dams uphill before slightly seeping them in a regular gradient into the river Niger.

For instance, the study reveal a very Wet and Large Basin around Shiroro (The Shiroro Dam) and Wushishi. Also a Very Slight but large basin is also found around Gurara (Gurara Falls).

Figure 6.0(a) shows the major drainage basins within the study area while Figure 6.0(b) shows that the natural flow pattern within the study area pushes much of the flood direction towards the South-Eastern Parts of Niger State.

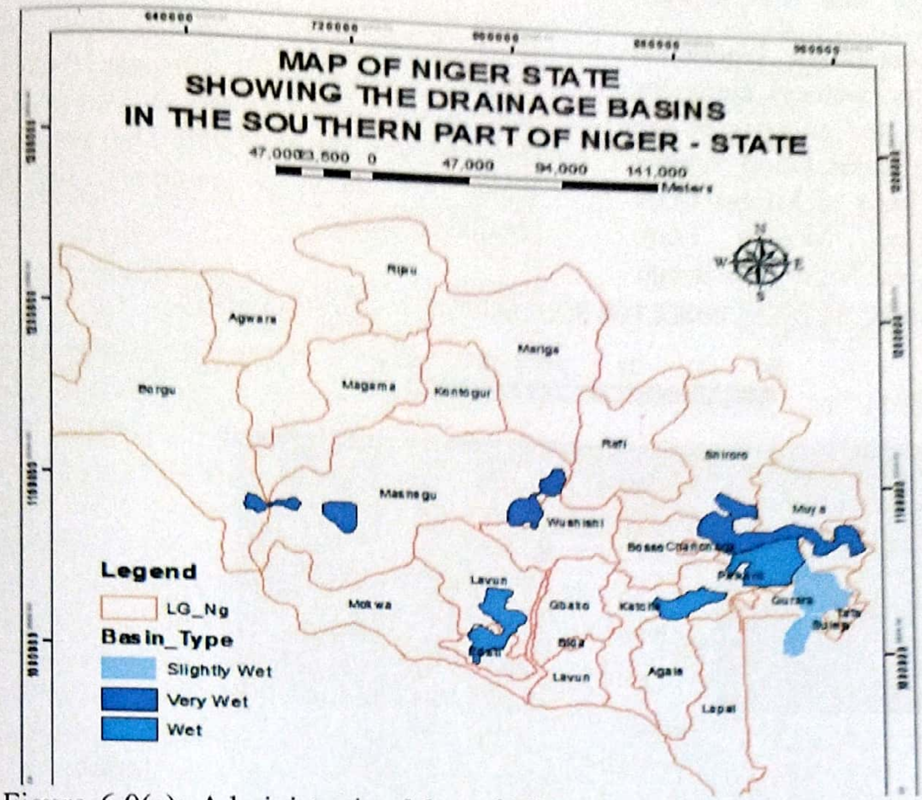


Figure 6.0(a): Administrative Map of Niger State Superimposed on the Drainage Basin for the Study Area.

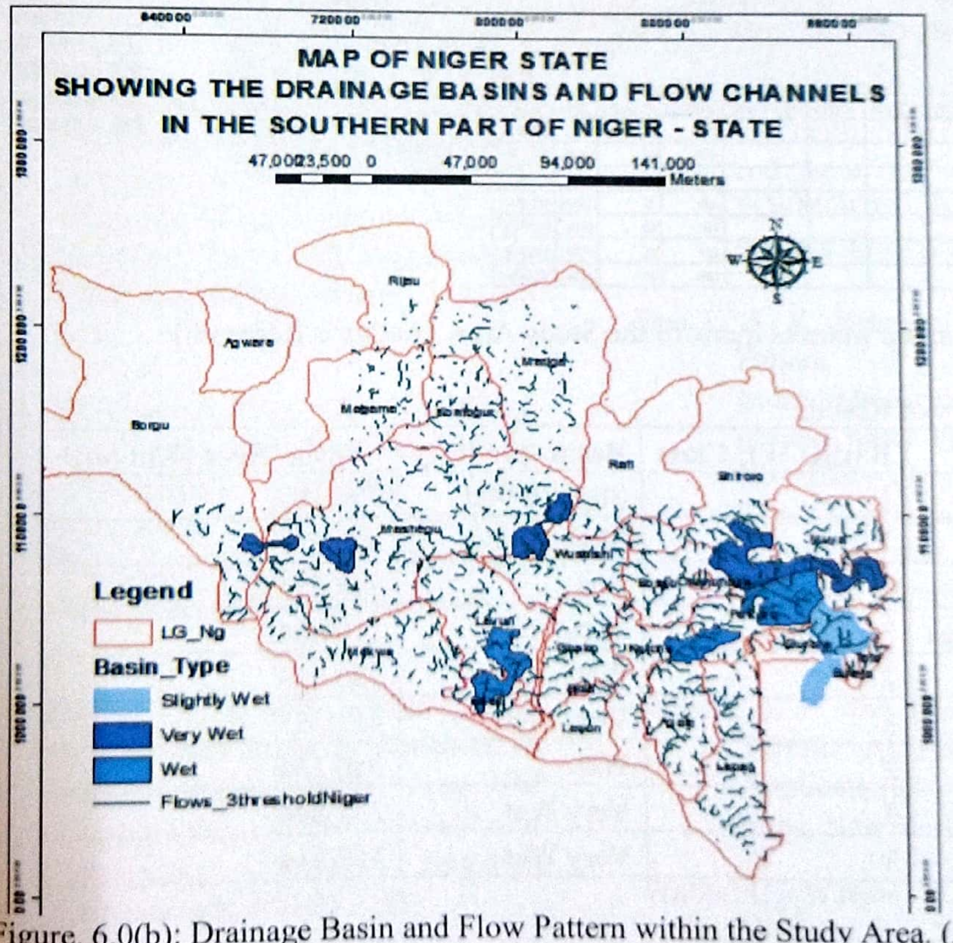
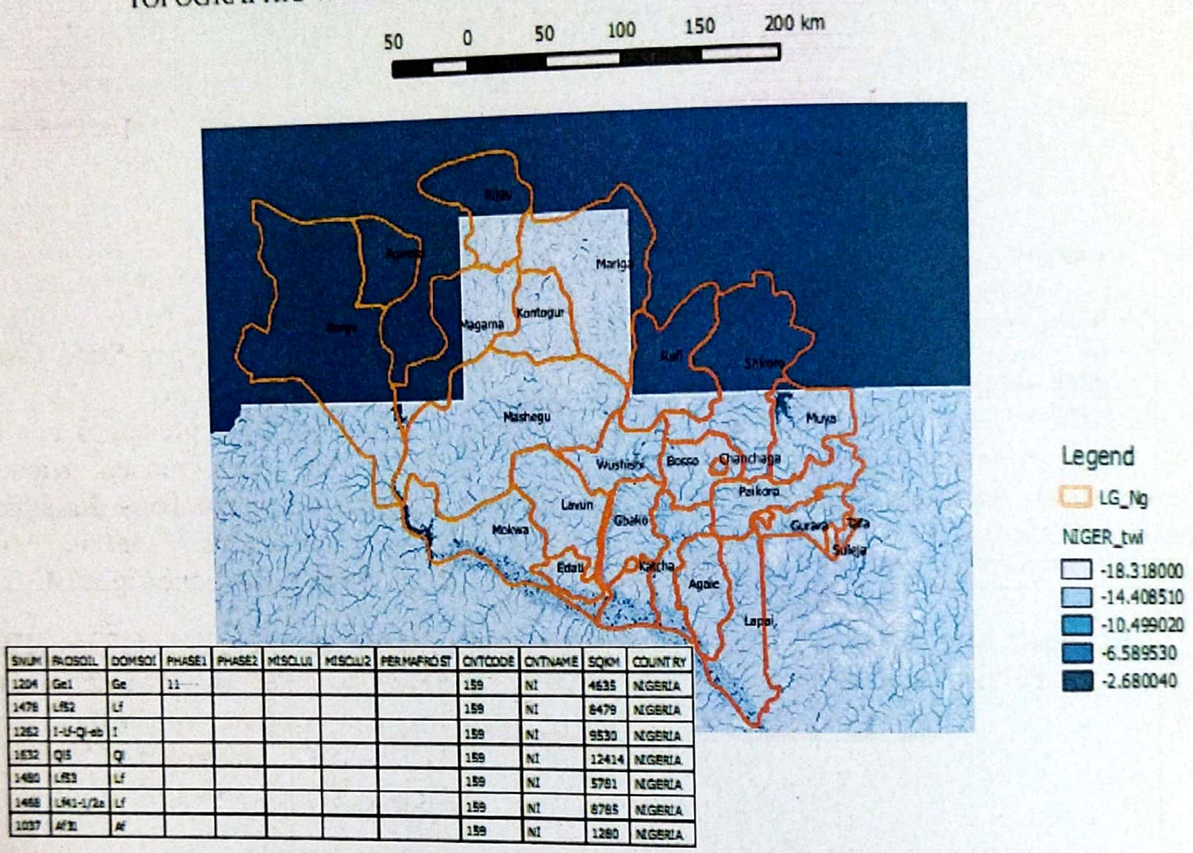


Figure. 6.0(b): Drainage Basin and Flow Pattern within the Study Area. (Author's Research)

Topographic Wetness Index: Figure 7.0 shows the topographic wetness index for the study area. From the analysis of the wetness index, three major Flood regions are identified being parts of Munya LGA (Shiroro Dam Area), Mokwa LGA (Settlements along River Niger) and Borgu LGA. Some areas along the flow path linking Wushishi, Chanchanga, Paikoro and Gurara Local Government Areas also show some traces of slightly high wetness. Table 1.0 shows a summary of the obtained results.

TOPOGRAPHIC WETNESS INDEX FOR SOUTHERN PART OF NIGER STATE.



SNUM	FAOSOIL	DOMSOI	PHASE1	PHASE2	MISCLU1	MISCLU2	PERMAFROST	CNTCODE	CNTNAME	SQKM	COUNTRY
1204	Ge1	Ge	11					159	NI	4635	NIGERIA
1478	Lf52	Lf						159	NI	8479	NIGERIA
1262	I-Lf-Ql-eb	I						159	NI	9530	NIGERIA
1632	Ql5	Ql						159	NI	12414	NIGERIA
1480	Lf53	Lf						159	NI	5781	NIGERIA
1468	Lf41-1/2a	Lf						159	NI	8785	NIGERIA
1037	Af31	Af						159	NI	1280	NIGERIA

Figure 7.0: Topographic wetness index of the Study Area. (Author's Research)

Table 1.0: Summary of Results.

Basin Name	BasinTWI_Class	Basin_property	Basin_Area (Km Sq)
Gurara 2	1	Slightly Wet	296.163
Gurara 1	1	Slightly Wet	596.616
Paikoro	2	Wet	748.651
Shiroro/Chanchanga	3	Very Wet	1104.045
Katcha	2	Wet	356.329
Mashegu	3	Very Wet	411.337
Edati / Lavun	2	Wet	580.136
Mashegu 2	3	Very Wet	232.844
Mashegu / Borgu	3	Very Wet	151.516

Conclusion

The use of SRTM data for regional study and analysis of drainage pattern, drainage basins and water flow paths has been validated for the study area. Areas with large and very wet basins have been highlighted and the causes identified. As earlier identified in sub-section 5.3, flood events around the settlements along river Niger are not consequent upon the topography of the region but as a result of other hydrological factors that affect a river regime. This shows us that the topography of the region naturally drains much of the water from the Northern parts into smaller lakes, streams and dams uphill before slightly seeping them in a regular gradient into the river Niger.

Government is therefore advised to look into the areas where large basins have been identified (Wushishi, Edati and Mashegu LGA) and construct artificial drainage path to avoid major Flood erosion in the nearest future.

References

Ajibade, L. T, Ifabiyi, I. P, Iroye, K. A and Oguntеru, S (2010); Morphometric Analysis of Ogunpa and Ogbere Drainage Basins, Ibadan Nigeria. Ethopian Journal of Environmental Studies and Management. 3 (1)13 - 19.

Chengzhi Qui, A-Xing Zhu, Lin Yang, Baolin Li and Tao Pei (2010); Topographic Wetness Index Computed Using Multiple Flow Direction Algorithm and Local Maximum Downslope Gradient

Chukwuocha, A. C and Igbokwe, J. I. (2014); GIS Based Demarcation of Natural Flow Routes using Old Topographic Data. Journal of Surveying and Mapping Engineering, 2(1) 25 – 36.

Lawal, A.F and Nagya, M.T (1999). Socio-Economic effects of flood disaster on farmers in Mokwa Local Government Area, Niger State, Nigeria. A paper presented at the 33rd Annual Conference of Agricultural Society of Nigeria held at National Cereal Research Institute, Badeggi, Niger State, Nigeria. pp 1 – 10.

Morisawa, M (1964) Streams: Their Dynamics and Morphology. McGraw-Hill Book Company.

Odumosu J. O, Ajayi O. G and Adesina E. A (2014); Modelling Surface Runoff and Mapping Flood Vulnerability of Lagos State from Digital Elevation Model. Conference Paper presented at the XXV FIG conference, Kaula-Lampur, Malaysia. 16 – 21 June, 2014. Available online at http://www.fig.net/pub/fig2014

Quinn P, Beven K. J, Lamb R (1995); The ln(a/tanß) index: how to calculate it and how to use it within the TOPMODEL framework. Hydrol. Process. (1995) 161-182

Rao L. A. K, Rehman Z, Sadique M and Zahoor I (2009); Hydro-geomorphological Studies for ground water Prospects using IRS 1D, LISS-III image, in Parts of Agra Distric along the Yamuna River. *Journal of Environmental Response Development* (4) 1204 – 1210.

Wilson, J. P. and Gallant, J. C. (2000), Terrain Analysis: Principles and Applications, John Wiley and Sons, New York, 479 p.

Wallis C, Watson D, Tarboton D. and Wallace R. (2009) Parallel Flow-Direction and Contributing Area

Calculation for Hydrology Analysis in Digital Elevation Models. Paper presented at the 2009 International Conference on Parallel and Distributed Processing Techniques and Application, Las Vegas, Nevada, USA. July 13th – 16th 2009.

Salami A.W. and Sule B.F (2010), An overview on Reservoir operational Impact of Kainji, Jebba and Shiroro Dams on the Environment. Paper presented at the One day seminar on Reservoir Operation, organized by Federal Ministry of Water Resources, Dams & Reservoir Operation department. Held at Vine Hotel, Durumi District, Abuja. 29th October, 2010. Available online at http://www.thetidenewsonline.com /2010/11/01/lecture-seeks-flood-routing-on-rivers-niger-kaduna/

Strahler A. N (1957). Quantitative analysis of watershed geomorphology. Trans. Am. Geophys. Union, 38:913-920.

Hajam, Rafiq Ahmad, Aadil Hamid, Naseer Ahmad Dar and Sami Ullah Bhat (2013) Morphometric analysis of Vishav drainage basin using geo-spatial technology (GST). International Research Journal of Geology and Mining (IRJGM) (2276-6618) Vol. 3(3) pp. 136-146, April 2013. Available online http://www.interesjournals.org/ IRJGM.

Hajam, Rafiq Ahmad, Aadil Hamid, and Sami Ullah Bhat (2013). Application of Morphometric Analysis for Geo-Hydrological Studies Using Geo-Spatial Technology – A Case Study of Vishav Drainage Basin. Hydrology Current Research, http://dx.doi.org/10.4172/2157-7587.1000157.www.wikipedia.com

Guide For Contributors and Authors

The Environment Technology and Science Journal (ETSJ) provides a forum for the dissemination of theoretical researches from various disciplines of the environment, engineering, pure and applied science, arts and social science, which have materials that emphasize on environmental issues. The editorial board hereby invites contributors to forward their paper/articles for publication in its biannual editions (April and November) in the following format

1. Manuscripts not more than 15 pages of A4 paper size (including abstracts, tables, figures and references and appendices), typed in spacing and font size of 12.
2. Each paper must be compiled in one column; all texts should be left and right justified. The page settings to be 25cm (1 inch) each for the top, bottom, left and right margins of an A4 paper. Decimal numbering of all sections of the articles is recommended (with exception of the reference and acknowledgment section).
3. To ensure anonymity in the pair reviewing process, articles must be structured in such away that the title of the paper, authors names, address and affiliation are written on the first page, followed by the abstract and body of the paper in that order.
4. Each article should contain an abstract of not more than 200 words
5. Each article should contain between 5 to 8 keywords (avoid the use of phrases)
6. The introduction should cover: the need for the study or problem statement, aims, objectives, scope and limitations and related works, while the main body should include:- brief explanations on methods, algorithms, data collected, instrumentation, fieldwork, laboratory works with computed or analyzed data, result and discussion, inferences and conclusions, recommendations and implementation strategies. Language shall be in English. Grammar/syntax and spelling should be properly checked. Use the SI (Systeme Internationale) units and symbols. Unusual characters and symbols should be explained in a list of nomenclature.
7. The editorial Board of the journal adopts the Harvard or APA format of referencing
8. Figures, table and graphs are to be placed at the appropriate place in the paper and not at the end of the paper.
9. Acknowledgment is optional, but researches being funded through established research grant letter.
10. Three (3) clean copies (hard copy) of the manuscript accompanied with processing fee sent to the editor-in-chief for pair assessment and review. Successful paper for publication may be sent back to the contributors for amendment and correction. However, all authors shall be communicated on the assessment status of their articles.
11. The corrected or revised electronic version of the article by authors should be sent back to the editor-in-chief using the e-mail address: etsjournal2006@yahoo.com or CD-ROM, while one hardcopy of the electronic version is sent by post mail as soon as possible, and to be accompanied with publication fee.
12. Payments are to be sent in bank drafts or cash to the Editor-in-chief, Environmental Technology and Science Journal (ETSJ), SET, Federal University of Technology, Minna, Niger State. Receipt will be issued to payees.
13. The editorial Board will not accept any responsibility for information provided or views expressed by the author(s).
14. Article not in the ETSJ specified format will be rejected.