Journal of Inventive Engineering and Technology (JIET)
ISSN: 2705-3865
Volume-4, Issue-1, pp-38-48
www.jiengtech.com
Research Paper Open Access

Analysis of Small Hydropower Potential of Osun River Using Geographic Information System and Remote Sensing in Southwestern Nigeria.

Dauda O. Olatunji[1], Daniel O. Johnson[2], Kabiru A. Hassan[3] and Godwin A. Ali[4]

[1](Olatunji Dauda O; *Department of Electrical and Electronic Engineering, Federal Polytechnic, Ede, Nigeria).*
[2](Johnson Daniel O; *Department of Electrical and Electronic Engineering, Federal Polytechnic, Ede, Nigeria).*
[3](Hassan Kabiru A.; *Department of Electrical and Electronic Engineering, Federal Polytechnic, Ede, Nigeria).*
[4](Ali Godwin A. *Department of Agricultural and Bio-Environmental Engineering, Federal Polytechnic, Ede, Nigeria).*

***Corresponding Author:* kabirzan.hk@gmail.com**

ABSTRACT : *This paper uses remote sensing and geographic information system (GIS) techniques to estimate hydrological parameters for measuring the small hydropower potential of river Osun. The technique is necessary because of the challenges posed by ungauged streams and the need for reliable data to manage water resources effectively. Hydrologic Engineering Center -River Analysis System (HECRAS) and Hydrologic Engineering Center - Hydrologic Modeling System (HECHMS) software tools were used for modelling the river and the X-Y geometry of the river shows the bank points at each cross-section from which the river width was derived. At the same time, data was generated showing the slope, river width, river depth and velocities across the channel at various river cross-sections at 200m. Model validation and ground truth data reveal little variations in the simulated and observed data. The result indicates the stream flow rate, water surface profiles and water availability along the river channel within three years. The simulated flow rate is 59.43 - 90.15m^3/s, with the mean being 75.76m^3/s while the river's flow behaviour shows that Kaplan turbine is best suitable for the hydropower potential on the river.. Conclusively, the paper demonstrates the capability of remote sensing and GIS techniques in improving the accuracy of hydrological models and enabling data availability for sustainable management of water resources for hydroelectric power system.*

KEYWORDS: *GIS techniques, HECRAS, HECHMS, river depth, water resources*

Date of Submission: 28-09-2023 Date of acceptance: 30-09-2023

I. INTRODUCTION

The potential for small hydropower generation from the River Osun in Nigeria is of immense interest, given its flow and topography. In order to estimate the hydrological parameters required to measure the small hydropower potential of the river, it is recommended that GIS and remote sensing techniques be utilized [1]. To this end, it is proposed that precipitation data be obtained using remote sensing techniques, whereby satellite-based rainfall products can provide information on the spatial and temporal distribution of precipitation within the region of interest [2]. This data can then be utilized to estimate the total rainfall in the River Osun catchment area.

In addition, it is proposed that surface runoff be estimated using GIS data on topography and land use. Specifically, the slope and aspect of the land can be calculated using topographic data, and land use data can be utilized to estimate infiltration rates. By integrating this information, the direction and amount of surface runoff, as well as the velocity of flow and volume of water that occurs in the catchment area and river channels, can be determined [3]. These hydrological parameters can be combined to develop a hydrological model that simulates water movement through the River Osun catchment area. The model can subsequently estimate the river's potential small hydropower generation capacity, thereby informing the development of strategies for sustainable river management.

Small hydropower technology is a micro-scale system that operates on a similar principle as large hydroelectric plants, requiring a flowing river, waterfall, or stream with a significant height (head) to rotate the turbine's blade. The turbine shaft is coupled to a generator, which produces electricity as the turbine rotates around magnetic fields in a stationary stator winding. The advantages of small hydroelectric systems are manifold, including their low acquisition cost, plant durability, ease of operations, and higher capacity factor (> 50%) than wind and solar, as well as their adaptability to site conditions, environmental friendliness, quality, and stable power production over long durations. [4]. However, it is essential to note that not all rivers are suitable for small hydropower development, and not all locations on harmonious river flow are suitable for small hydroelectric power schemes. Suitable rivers are perennial rivers with good flows all year round. As such, a thorough investigation and feasibility study are necessary for small hydroelectric projects to be sited at any suitable location. Critical requirements for small hydroelectric projects include meteorological and hydrological data, topographical mapping, flow duration curves, and geographical information systems (GIS), which provide valuable information for hydropower resource assessment [5].

HECRAS (Hydrologic Engineering Center's River Analysis System) and HEC-HMS (Hydrologic Engineering Center's Hydrologic Modeling System) are widely used software tools for modelling rivers and estimating hydrological parameters [6] compared HECRAS with other hydraulic models and found that HECRAS provided the most accurate results for flow rate and water level predictions. In [7] used HECRAS to evaluate the impact of climate change on streamflow and sediment yield in a river basin and found that HECRAS was a useful tool for predicting changes in hydrological parameters under different climate scenarios. A review article by [8] highlighted the strengths and limitations of HECRAS, including its ability to model unsteady flow conditions and its limitations in modelling complex hydraulic structures. The researchers in [9] used HEC-HMS to estimate the hydrological parameters of a river basin in Korea and found that the model could accurately estimate the streamflow and runoff characteristics. In [10], HEC-HMS was used to simulate the impact of land use change on the hydrological cycle of a river basin in Pakistan and found that the model accurately predicts the changes in hydrological parameters. HEC-HMS was compared in [11] with other hydrological models, and HECHMS was a reliable tool for simulating the hydrological cycle of river basins. HECRAS and HEC-HMS are widely used and reliable software tools for modelling rivers and estimating hydrological parameters. Various studies have used these tools to simulate the impact of climate change, land use change, and other factors on hydrological parameters. However, it is important to note that these tools have limitations, and their accuracy depends on the quality and accuracy of the input data used in the modelling process.

Estimating hydrological parameters, such as stream flow, sediment yield, and water quality, is crucial for sustainable water resource management. Studies have shown that remote sensing and GIS can accurately estimate these parameters. In China, a study by [12] used remote sensing and GIS to estimate stream flow, while [13] used them to estimate sediment yield in India. The researchers in [14] highlighted the applications of these techniques in estimating precipitation, vegetation cover, topography, soil properties, and land use/land cover. The work in [15] used these techniques to estimate water quality parameters in India, revealing good agreement with observed water quality parameters. While the accuracy of these estimates depends on the quality and accuracy of input data, they provide valuable information for sustainable water resource management.

II. MATERIALS AND METHODS

The HECHMS and HECRAS models were utilized to calculate the runoff from a watershed and the resulting water surface profiles, respectively. The necessary data for this research was obtained from remotely sensed data, existing maps, and secondary data sources. The origins of each data utilized in the study are explicitly stated in Table 1. Simultaneously, the significance of extracting Manning's roughness index, a crucial parameter for surface runoff modeling, is demonstrated in Fig. 1. Additionally, Fig. 2. highlights the importance of comparing topographic parameters like slope and computing the river's depth. Finally, Fig. 3 illustrates the significance of computing the river width and the appearance of the data.

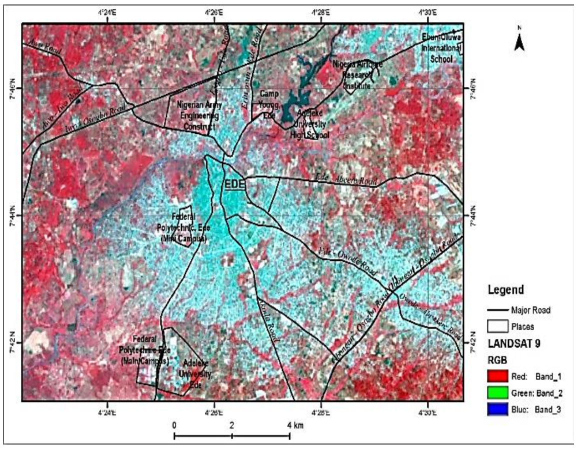


Fig. 1: Landsat 9 land cover of the river.

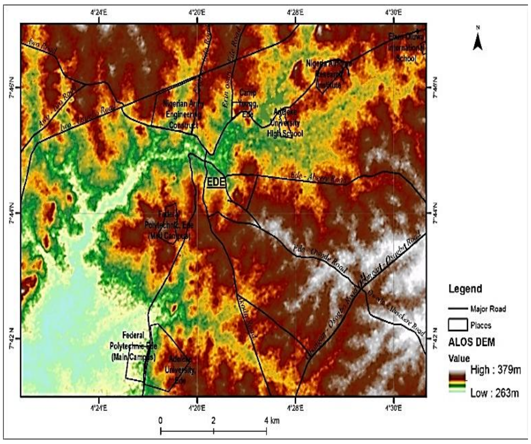


Fig. 2: ALOS DEM elevation of the river

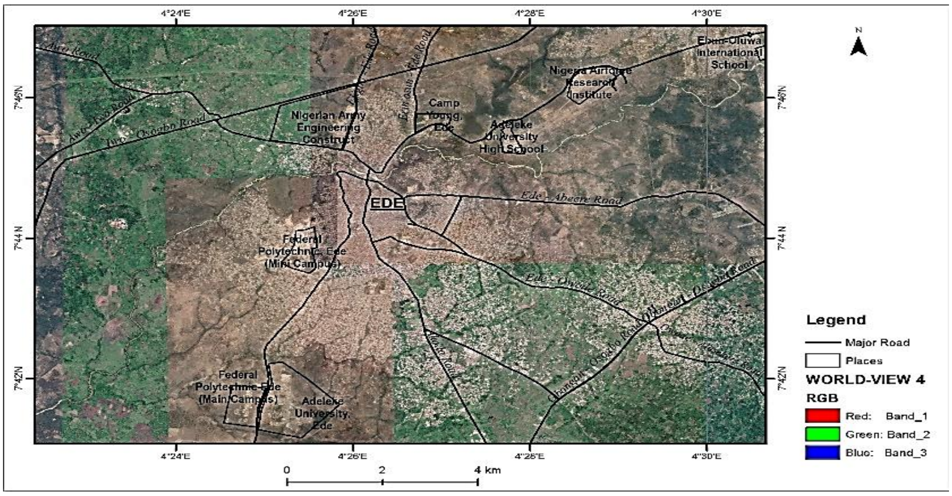


Fig. 3: Geometry view of the river.

Table 1: Sources of data

Data	Date	Purpose	Resolution	Source
Landsat 9	2022	Land Cover/River flow resistance	30m	USGS Earth Explorer Website
ALOS DEM	2011	Slope, Elevation	12.5m	ASF DAAC Website
World-view 4 Satellite image	2022	River Geometry	-	Google Earth
Osun State Administrative Map	-	Existing Road, Localities	-	Osun State Ministry of Lands
Rainfall data	1984-2021	Rainfall	-	TRMM

A. HYDROLOGICAL SIMULATION PROCESS OF ESTIMATE PEAK STREAM FLOW DATA IN HECHMS

The digital elevation model (DEM) data is loaded into HEC-HMS software, which processes it to extract watershed boundaries, stream networks, and flow direction. The DEM is defined using basin delineation, stream definition, and Flow Direction tools. Rainfall data is processed in MS Microsoft Excel and converted to HEC-HMS format, depending on available rainfall data. The HEC-HMS model is set up by creating a new project, defining basin properties, and setting up rainfall data. The model is then run to generate output data, including peak flow rate, which can be compared with observed stream gauge data to calibrate and validate the model. Finally, the HEC-HMS model is calibrated and validated using stream gauge data, adjusting model parameters to improve the agreement between modelled and observed flow rates.

B. STEADY STREAM FLOW ANALYSIS USING HECRAS

The River Channel Flow Geometry (HEC-RAS) is a computer-based system that utilizes GeoRAS drawing tools within the ArcGIS 10.3 interface to create polyline features that accurately represent the channel's flow geometry. This process generates the data required for HEC-RAS in terms of x, y, and z coordinates. The stream centerline is developed by drawing streamlines in a positive flow direction, with snapping enabled to ensure seamless connections between the end and beginning points of adjacent rivers. The RAS Geometry tool creates a 3D layer, which generates topology information, lengths/stations, and elevations for rivers and reaches. Cross-sections are created to capture elevation data and establish a ground profile across the channel flow at regular intervals along the stream length, perpendicular to the stream centerline. These cross-sections are constructed using the Create cross-sections tool, spaced 200 meters apart, with a consistent length of 500 meters, and enriched with essential information such as River/Reach Names, Stationing, Bank Stations, Downstream Reach Lengths, and Elevations for each cross-section using the RAS Geometry tool.

Each cross-section is assigned Maning's roughness values based on land-use characteristics and engineering judgment. The representative n-values are allocated to the relevant sections of each cross-section that intersect the respective land-use area, allowing for an accurate representation of roughness characteristics along the channel. Data export is performed using the Export RAS Data function, which generates a personal geodatabase containing crucial attributes such as x, y, and z coordinates of features and their relative distances, providing essential spatial information to accurately represent the channel's geometry and characteristics within the HEC-RAS data file. Standard flow analysis uses steady flow simulation, with boundary conditions established at all river nodes' ends using critical depth. The primary computational procedure HEC-RAS employs for water surface profiles is the direct step method, assuming a steady and gradually varied flow scenario. The direct step method calculates water surface elevation at the adjacent cross-section based on the flow and water surface elevation at one cross-section, with the direction of computations depending on the flow regime.

C. STREAM FLOW DATA ANALYSIS

Six occurrences were chosen to undergo stream flow modeling during both dry (November-April) and wet (May-October) months from 2018 to 2021 using HEC-HMS and a rainfall-runoff collection. Calibration of the model was executed for the period extending from 2008 to 2021. However, due to data unavailability, the model was exclusively calibrated for the wet season between May 2020 and October 2020. It was observed that the simulated mean flow rate and the stream flow rate selected at certain segments of the river exhibited minimal variation. After calibration, the model was utilized to simulate stream flow within the timeframe of 2018 to 2021. Plate 1 showcases the measurements utilized during model calibration and the ground truth of the river.

Plate 1: Model calibration, measurement and ground truth

D. MODELLING OF OUTPUT POWER

Osun River in Osogbo to Ede axis has been followed and monitored for more than a year, and the flow rate and speed have been carefully documented. It was discovered that a small hydroelectric plant is most appropriately cited at a location where the river course is most sloppy because the flow increase and the falling water's energy determines the quantity of generated electricity. The theoretical amount of power generated in the hydroelectric scheme is given in Eq. (1)

$$P_w \ = \eta \, \rho \, g \, Q_o \, X \qquad (1)$$

Where P_w is the generated output power, Q_o is the flow rate in m3/s, X is the head, in meter, η is the efficiency of operation, g and ρ are constant, and acceleration due to gravity and density of water, respectively. The river discharge rate is a significant factor to be considered when determining the output power to generate. The discharge rate majorly depends on the length, the width of the river (W) and the depth of water (D) available at a particular period and the time (t) taken of flow observed through a floating object placed on the flow path of the river. The expression of the discharge rate, Qd is shown in Eq. (2).

$$\text{Qd} = \frac{L_f \, W \, D}{t} \ \text{m}^3/\text{s} \qquad (2)$$

The optimal turbine design is found by computing the specific speed utilizing fluid flow parameters and shaft output speed [16]. Mathematically, speed can be determined from maximum power and net head (Ns) or flow rate discharge and net head. In the first situation, the specific speed is the turbine's rotational speed (r.p.m.) with a kW output. Ns as given in Eq. (3)

$$Ns = \frac{N \times {P_w}^{0.5}}{X^{\frac{5}{4}}} \qquad (3)$$

where, N is the turbine's speed in (rpm), X is the water head in (meter), and Pw is the turbine power output.

E. SELECTION OF A SUITABLE TURBINE

Hydropower plants are recognized by the hydraulic pressure that propels their turbines. The power turbine is regulated by three categories of water head heights [17]. The low turbine head, which measures less than 3 meters, is characterized by its brief and compact dam structure. Axial flow reaction turbines like Kaplan, with pitch-controlled blades, are preferred in low head and high flow conditions. The medium turbine head ranges from 10 to 300 meters. This type of hydropower plant employs Francis (reaction) or cross-flow impulse turbines. High-head turbines measure 350 meters or more, and Francis turbines are more prevalent in higher power settings. Nevertheless, Pelton or Turgo wheels may also be utilized. Table 2 displays the comparative analysis.

Table 2. Comparison of hydro turbines [18].

Type	Specific Speed rpm	Head ranges m	Efficiency %	Reservoir Type
Turgo	30 - 80	60 - 250	92	Low volume of water
Kaplan	10 - 180	2 - 40	95	Small compact reservoir
Francis	85 - 188	10 - 350	96	Large reservoir
Pelton	8 - 47	50 - 1800	95	Large reservoir
Cross Flow	20 - 200	3 - 250	94	Pumped storage type

The quantity of available head and water flow rate in a given place is typically the most important factors in determining which type of hydro turbine is best for a certain situation. One of the most essential indicators for designing hydro turbines is the specific speed of the turbine. Fig.4 Relationship between the water head in meter and flow rate of various turbines discharge. This section covers the critical issues to consider when choosing the particular speed and size of various hydro turbine designs.

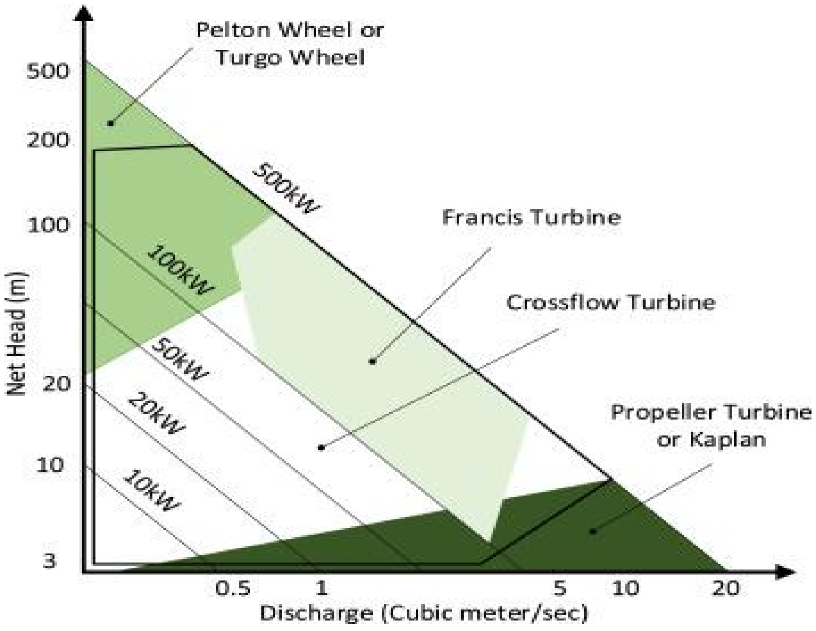


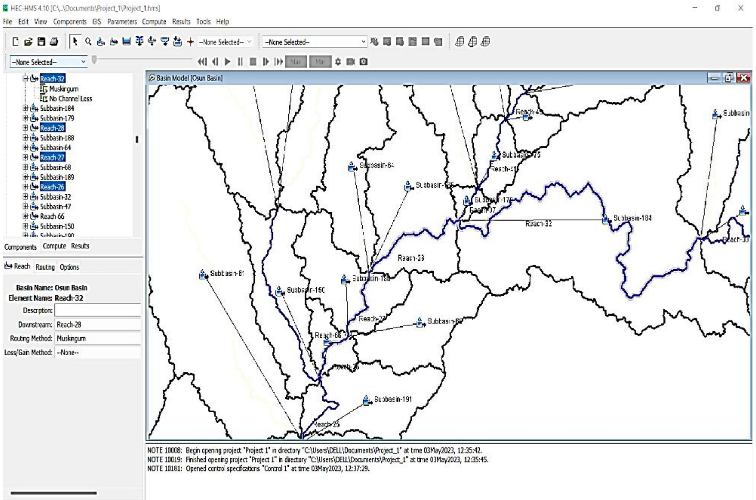
Fig. 4. Relationship between the head and flow rate of various turbines discharge [18].

III. RESULTS AND DISCUSSION

The watershed boundaries within the Ogun-Osun river basin were delineated using HECHMS. This process identified the contributing area that drains into specific locations within the basin. After the procedure, the study area was identified from the whole basin. This process enabled the streamlining of the model to the Ede Area for the stream flow simulation. Table 3 shows the simulated flow for the events and the peak flow rates resulting from the hydrology model with HEC-HMS while Fig. 5 shows the study area section in Ede from the HECHMS Model. The simulated flow rate is 59.43-90.15m^3/s, with the mean being 75.76m^3/s. The flow rate indicates the water availability along the river channel within 3 years. The essential information required for constructing a flow duration curve, enabling us to determine the frequency at which specific magnitudes' flows occurred within the recorded period (November 2018-October 2021). Fig.6 shows the resulting flow duration curve by plotting the discharge on the vertical axis and the percentage of time on the horizontal axis. The data used to calculate the flow duration curve between November 2018 and October 2021.

Table 3: Peak Flow Rate between November 2018 and October 2021

Event	Simulated Mean Flow Rate (m^3/s)
November 2018-April 2019	77.28
May 2019-October 2019	79.69
November 2019-April 2020	68.59
May2020-October2020	79.41
November 2020-April 2021	59.43
May2021-October2021	90.15
Mean	75.76



Basin Name: Osun Basin
Element Name: Reach-32
Description:
Downstream: Reach-28
Routing Method: Muskingum
Loss/Gain Method: --None--

```
NOTE 10008: Begin opening project "Project 1" in directory "C:\Users\DELL\Documents\Project_1" at time 03May2023, 12:35:42.
NOTE 10019: Finished opening project "Project 1" in directory "C:\Users\DELL\Documents\Project_1" at time 03May2023, 12:35:45.
NOTE 10161: Opened control specifications "Control 1" at time 03May2023, 12:37:29.
```

Fig.5: HEC-HMS model of the Osun River Basin

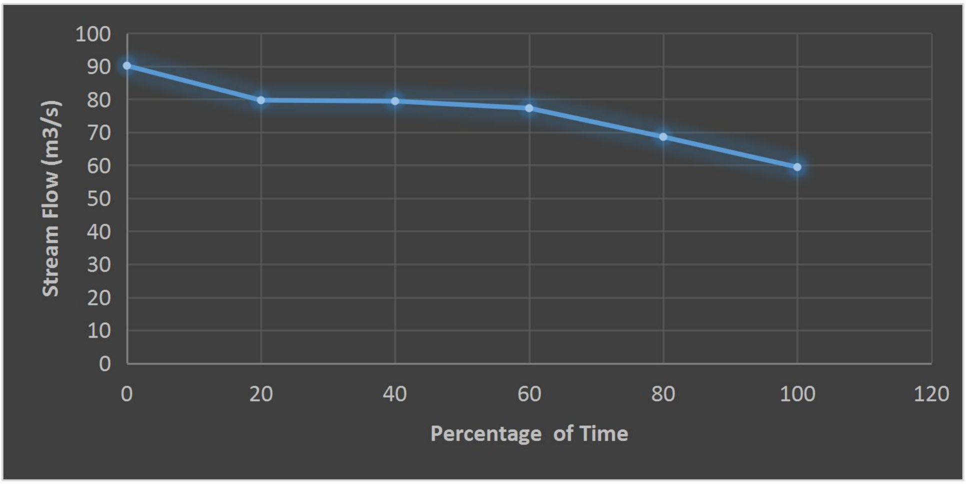


Fig. 6. Flow Duration Curve.

Table 4. Computation of Flow Duration Curve

Period	Flow rate	N	Cumulative	Percent Time
Nov.2018-April 2019	59.43	1	5	100
May 2019-Oct. 2019	68.59	1	4	80
Nov.2019-April 2020	77.28	1	3	60
May2020-Oct.2020	79.41	1	2	40
Nov. 2020-April 2021	79.69	1	1	20
May2021-Oct.2021	90.15	1	0	0

The simulation carried out to compute the water surface profiles under the given flow conditions of the mean flow rate within the period of study (75.76m^3/s) produced the water surface profiles from which water depths and channel sloppy points can be derived. The analysis from the river's flow behaviour shows that Kaplan turbine is best suitable for the hydropower potential on the river. Fig.7 shows the river's X-Y geometry, showing the bank points at each cross-section from which the river width was derived while Fig.8 shows the elevation of channel from upstream to downstream of the river.

The hydrology parameters generated in this study were subjected to mapping to enable the researcher visually understand and explore the distribution and characteristics of river width, river depth and channel slope. By utilizing this technique, the parameters were effectively communicated, analyzed, and interpreted into 3 quantitative categories. Fig.9. shows the classes of river slopes in the study area from which the locations with the sloppy points can be identified. Fig.10 shows the classes of river width in the study area from which locations with large river widths can be identified. Fig.11 shows the 3 classes of river depth in the study area from which locations with high depths can be identified.

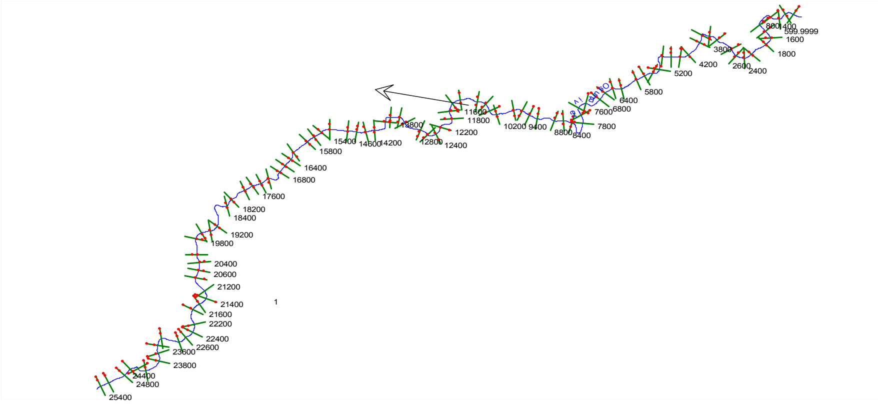


Fig. 7. Result of the XY river geometry modelled in HEC-RAS

Fig. 8. Graph of the elevation of channel upstream to downstream

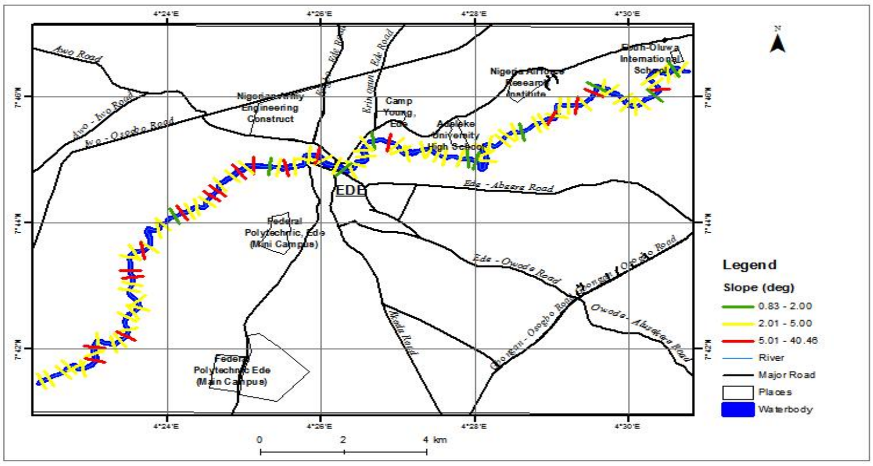


Fig. 9. Classification of the river segment into classes of slope

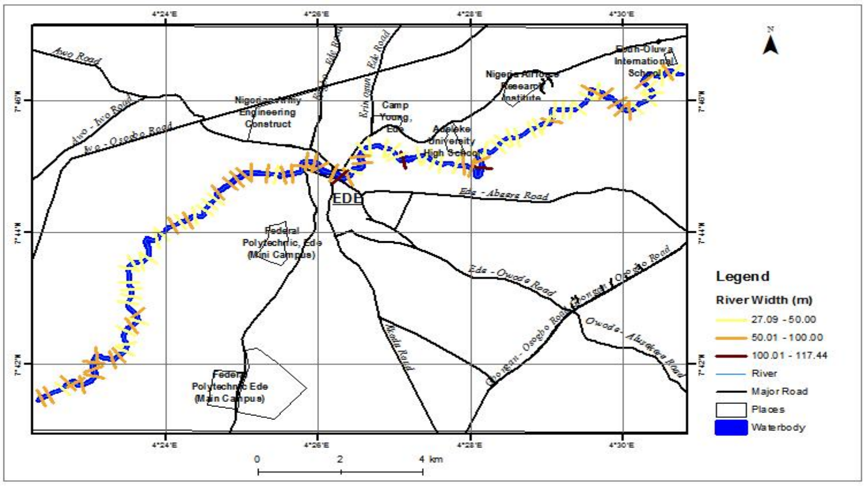


Fig. 10. Classification of the river segment into classes of river width

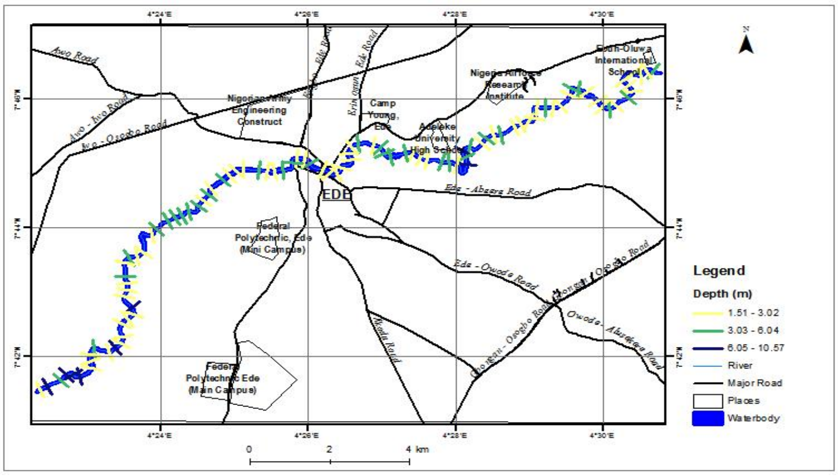


Fig. 11. Classification of the river segment into classes of river depth

IV. CONCLUSION

HECRAS and HECHMS software tools were used for modelling the river and estimating the stream flow rate and water surface profiles. The simulated flow rate is 59.43 - 90.15m^3/s, with the mean being 75.76m^3/s. This indicates the water availability along the river channel within three years. The X-Y geometry of the river shows the bank points at each cross-section from which the river width was derived. At the same time, data was generated showing the slope, river width, river depth and velocities across the channel at various river cross-sections at 200m. Model Validation and Ground truth data reveal little variations in the simulated and observed data. The analysis from the river's flow behaviour shows that Kaplan turbine is best suitable for the hydropower potential on the river. Conclusively, the research demonstrates the capability of remote sensing and GIS techniques in improving the accuracy of hydrological models and enabling data availability for sustainable management of water resources.

ACKNOWLEDGEMENT

This research work was fully funded and supported by TETFUND and Federal Polytechnic, Ede. Osun State Nigeria.

REFERENCES

[1] Thakur, P. K., Nikam, B. R., Garg, V., Aggarwal, S. P., Chouksey, A., Dhote, P. R., & Ghosh, S. (2017). Hydrological parameters estimation using remote sensing and gis for Indan region: A review. Proceedings of the National Academy of Sciences, India Section A: Physical Sciences, 87(4), 641–659. https://doi.org/10.1007/s40010-017-0440-z.

[2] Boluwade, A. (2020). Spatial-temporal assessment of satellite-based rainfall estimates in different precipitation regimes in water-scarce and data-sparse regions. Atmosphere, 11(9), 901. https://doi.org/10.3390/atmos11090901

[3] Arthur, E., Anyemedu, F. O. K., Gyamfi, C., Asantewaa - Tannor, P., Adjei, K. A., Anornu, G. K., & Odai, S. N. (2020). Potential for small hydropower development in the lower pra river basin, ghana. Journal of Hydrology: Regional Studies, 32, 100757. https://doi.org/10.1016/j.ejrh.2020.100757

[4] Ramke, H.-G. (2018). Collection of surface runoff and drainage of landfill top cover systems. In Solid Waste Landfilling (pp. 373–416). Elsevier. https://doi.org/10.1016/B978-0-12-407721-8.00019-X

[5] Dincer, I., & Ishaq, H. (2022). Hydro energy-based hydrogen production. In Renewable Hydrogen Production (pp. 191–218). Elsevier. https://doi.org/10.1016/B978-0-323-85176-3.00012-3

[6] Tao, Z., Qin, J., & Wu, L. (2018). Comparison of hydraulic models in river flood simulation. Water, 10(6), 760. https://doi.org/10.3390/w10060760

[7} Zhang, Y., Lu, H., Xu, Z., Zhang, W., & Fu, G. (2017). Impact of climate change on streamflow and sediment yield in a typical river basin of Loess Plateau, China. Journal of Hydrology, 551, 62-73. https://doi.org/10.1016/j.jhydrol.2017.05.027

[8] Biron, P. M., McLean, S. R., & Jowett, I. G. (2016). Review of the capabilities and limitations of HEC-RAS for modelling river hydraulic and ecological processes. Ecological Modelling, 332, 45-60. https://doi.org/10.1016/j.ecolmodel.2016.03.009.

[9] Choi, S. W., Kwon, H. H., & Son, M. (2017). Hydrologic modeling using HEC-HMS for a small mountainous watershed in Korea. Journal of Korean Society of Hazard Mitigation, 17(1), 195-201. https://doi.org/10.9798/KOSHAM.2017.17.1.195

[10] Habib, N., Ali, S., Aziz, N., & Ahmad, S. (2015). Impact of land use change on hydrological cycle using HEC-HMS model. Journal of Hydrology and Environment Research, 3(1), 24-30. http://dx.doi.org/10.1016/j.jher.2015.05.001

[11] Demirel, M. C., & Tayfur, G. (2019). An evaluation of HEC-HMS and SWAT models for simulating streamflow in a Mediterranean basin. Water, 11(11), 2351. https://doi.org/10.3390/w11112351

[12] Zhao, Y., Wang, L., Liu, C., Zhang, Y., & Lu, H. (2019). Estimation of streamflow using remote sensing and GIS techniques in the Yongding River basin, China. Remote Sensing, 11(7), 772. https://doi.org/10.3390/rs11070772.

[13] Samanta, S., Pal, D. K., Datta, D., & Singh, R. D. (2018). Estimation of sediment yield in a Himalayan river basin using remote sensing and GIS. Geocarto International, 33(9), 981-997. https://doi.org/10.1080/10106049.2017.1372929

[14] Wang, Y., Jiang, L., Sun, L., Zhang, X., & Liu, X. (2020). Applications of remote sensing and GIS in estimating hydrological parameters. Journal of Hydrology, 585, 124752. https://doi.org/10.1016/j.jhydrol.2020.124752

[15] Maity, R., & Kar, S. (2017). Estimation of water quality parameters in a river using remote sensing and GIS. Arabian Journal of Geosciences, 10(6), 130. https://doi.org/10.1007/s12517-017-2995-5

[16] Hatata, A. Y., El-Saadawi, M. M., & Saad, S. (2019). A feasibility study of small hydropower for selected locations in Egypt. Energy Strategy Reviews, 24, 300–313. https://doi.org/10.1016/j.esr.2019.04.013.

[17] Belyakov, N. (2019). Traditional hydropower plant technology. In Sustainable Power Generation (pp. 355–377). Elsevier. https://doi.org/10.1016/B978-0-12-817012-0.00027-X

[18] Uddin, W., Ayesha, Zeb, K., Haider, A., Khan, B., Islam, S. U., Ishfaq, M., Khan, I., Adil, M., & Kim, H. J. (2019). Current and future prospects of small hydro power in Pakistan: A survey. Energy Strategy Reviews, 24, 166–177. https://doi.org/10.1016/j.esr.2019.03.002