PAPER 162 – EFFECT OF RESAMPLED DIGITAL ELEVATION MODEL (DEM) ON FLOW AND SEDIMENT LOADING PREDICTION UPSTREAM OF OYUN RIVER CATCHMENT IN KWARA STATE

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ABSTRACT
This study investigates the effect of resampled Digital Elevation Model (DEM) on the prediction of flow and sediment loading upstream of Oyun River catchment in Kwara State. To delineate the watershed, a DEM of 90-meter resolution was sourced from the space Shuttle Radar Topography Mission (SRTM), and the ASTER global DEM data sources. The 90-meter resolution was resampled to four different resolutions which are 75-meter, 60-meter, 45-meter, and 30-meter resolutions. The watershed and streamline were delineated, and the hydrologic simulation was performed using Soil and Water Assessment Tool (SWAT). The results show an insignificant effect on flows for all the resampled DEMs as against the results obtained with the prediction of sediment concentration. The 90-meter resolution DEM has the lowest predicted value of sediment concentration 228,899.70mg/l while the 30-meter resampled DEM has the highest predicted value of 521,246.94 mg/l. Similarly, the sediment yield (SYLD t/ha) for 90-meter resolution DEM has the least value of about 528.90 t/ha while the 30-meter resampled DEM has the highest value of 2145.57 t/ha. Results obtained in this study can be a decision support tool for researchers when selecting an appropriate DEM resolution to simulate sediment loading in the watershed.

KEYWORDS: Resampled DEM; Sediment Concentration; Sediment Yield; SWAT; Model; Flow.

1. INTRODUCTION

Accurate estimation of water yield and water balance in a river catchment is essential for sustainable management of water resources at the watershed level. To achieve this, hydrological modelling is necessary, and the application of Geographical Information Systems (GIS) combined with Digital Elevation Model (DEM) has significantly improved this process. The integration of GIS with DEM has enhanced hydrological modelling in various areas, including data management, parameter extraction and interpolation, visualization, and interface development.

Digital Elevation Models (DEMs) are essential tools for studying land surface processes and modelling the flow of water and sediment in river catchments (Viglione et al., 2013). DEMs provide a digital representation of the elevation of the land surface, typically at a spatial resolution ranging from several meters to several kilometers (Tarboton et al., 2015). DEMs can be used for a wide range of applications, including terrain analysis, land use planning, environmental monitoring, and hydrological modelling (Su et al., 2017). The development of DEMs has revolutionized hydrological modelling by providing a detailed and accurate description of the topography of river catchments (Wu et al., 2013). The resolution of a Digital Elevation Model (DEM) can have a significant effect on flow and sediment loading predictions upstream of a river catchment. When a DEM is resampled to a lower resolution, it loses some of the fine-scale details that may have been present in the original data. This loss of detail can result in a coarser representation of the terrain, which can affect the accuracy of the flow and sediment predictions. Resampling a DEM can also introduce errors in the calculation of slope and drainage area, which are important parameters in predicting flow and sediment loading.

Based on the foregoing, it is common to resample DEMs to a coarser resolution to reduce computational requirements (Choi et al., 2015). Resampling involves averaging or aggregating elevation values over larger grid cells, which can result in a loss of fine-scale terrain details (Tarboton et al., 2015). However, high-resolution DEMs can also pose computational challenges due to their large file size and processing requirements.. Therefore, it is essential to carefully consider the effects of DEM resolution on the accuracy of predictions and to use appropriate methods to account for errors introduced by resampling.

2. THEORETICAL ANALYSIS

The simulation of hydrologic cycle by SWAT is based on the water balance Equation 1

$$SW_t = SW_o + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})_i \quad 1$$

where SW_t is the final soil water content (mm water), SW_o is the initial soil water content in day i (mm water), t is the time (days), R_{day} is the amount of precipitation in day i (mm water), Q_{surf} is the amount of surface runoff in day i (mm water), Ea is the amount of evapotranspiration in day i (mm water), $W_{seep}$is the amount of percolation and bypass
flow exiting the soil profile bottom on day i (mm water), and Q_{gw} is the amount of return flow in day i (mmwater).

The estimation of erosion/soil loss and sediment yield for each Hydrologic Response Unit (HRU) is carried out using the Universal Soil Loss Equation and Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975) respectively. The current version of SWAT model uses simplified stream power Equation 3.8 derived by Bagnold (1977) to route sediment in the channel.

$$S_{ed} = 1.292 EI_{USLE} K_{USLE} C_{USLE} P_{USLE} LS_{USLE} CFRG \quad 2$$

Where S_{ed} is the sediment yield on a given day (metric tons), EI_{USLE} is the rainfall erosion index (0.017 m-metric ton cm/(m^2hr)), other factors are as defined in Equation 3.7. The value of EI_{USLE} for a given rainstorm is the product of total storm energy (E_{storm}) times the maximum 30 minutes intensity (I30)

3. MATERIALS AND METHODS

3.1 Description of the study area

The study area is the Oyun River Basin, which has a terrain elevation of 259 meters above sea level and can be found between latitudes 9^0 $5^0$1 and 8^0 24^1North and Longitudes 4^0 38^1 and 4^0 03^1East. The river Oyun, which starts near Ila Oragun at an elevation of 465.003m above the sea level, flows for about 80 kilometres to the northeast and converges with River Asa in Ilorin, Kwara State. The watershed area of Oyun River in Kwara State is located southeast of Ilorin and is known for its open and undulating terrain, rocky outcrops, and varying slopes. The area is mostly used for farming with only a small section of forest reserve.

River Oyun is a major water source for Offa town and its neighbouring areas, and it also supplies raw water for the University of Ilorin water supply scheme. Figure 1 shows a map of the Oyun River basin, which includes a network of rivers and catchment areas, with the catchment area of interest being enclosed within the thick black boundary line.

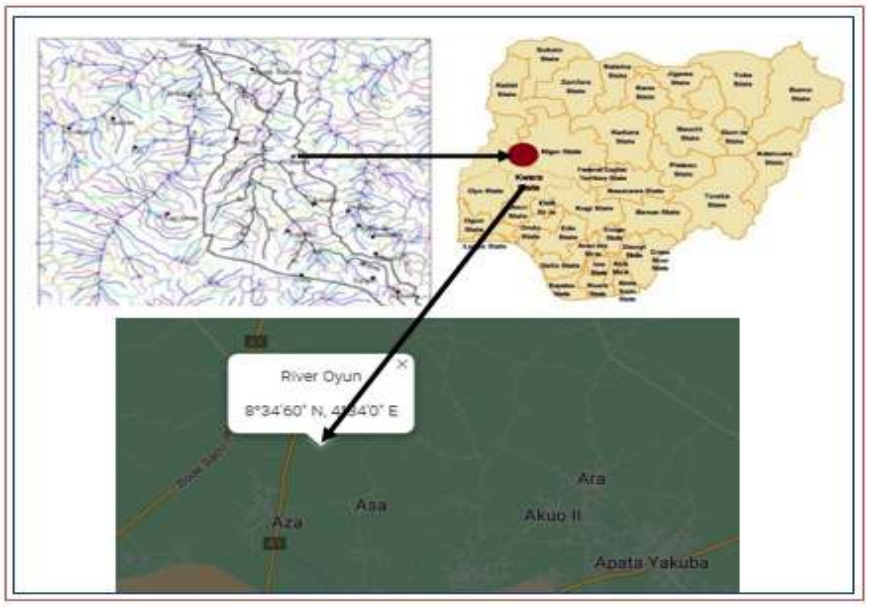


Figure 1: Location map of the study area.

3.2. Modelling Tool and GIS interface

The modelling tool selected for this study is the Soil and Water Assessment Tool (SWAT). SWAT was developed by the United States Department of Agriculture (USDA) to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large un-gauged basins (Arnold, et al.,1995). The creation of the sub catchment and other geo-processing of the spatial data were carried out using Map window GIS. Map window-GIS was developed by Leon (2011) and is a compact tool for the delineation of watershed from Digital Elevation Model. It is a window based, open-source GIS client which can be used to visualize, manage, edit, analyse data, and compose printable maps. It includes powerful analytical functions through integration with GEOS and GDAL (Geospatial Data Abstraction Library).

3.3. Digital Elevation Model (DEM)

Digital elevation model (Figure 2) used in this study is of resolution 90m and was obtained from online database developed by CGIAR (2012). The DEM provides the basis for watershed delineation into sub-basins. Also, topographic parameters such as terrain slope, channel slope and reach length are derived from the DEM. A resolution of 90m x90m was resampled into other resolutions (75m x 75m,60m x 60m, 45m x 45m, 30m x 30m) using the GIS component of the model.

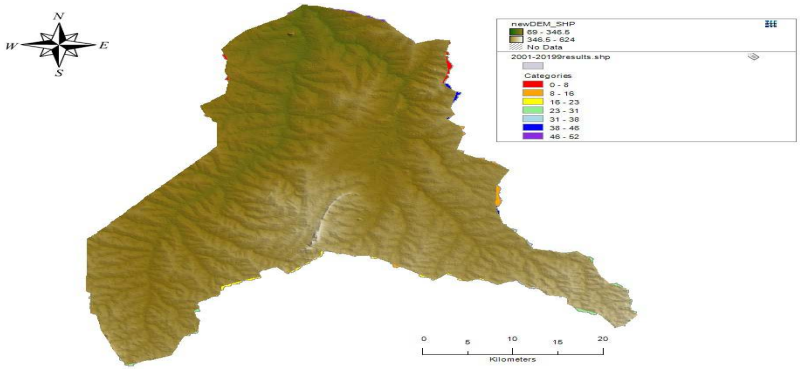


Figure 2: DEM map of the study area

3.4. Land Use and Soil data

The Land use map that is needed to run SWAT was extracted from the Global Land Cover Characterization (GLCC) database, and it is also used to estimate vegetation and other parameters representing the watershed area. The GLCC database was developed by United State Geological Survey and has a spatial resolution of 1Km and 24 classes of land use representation (GLCC, 2012). The digital soil data for the study was extracted from harmonized digital soil map of the world (Harmonized World Soil Database (HWSD)) produced by Food and Agriculture Organization of the United Nations, Rome (Nachtergaele et al., 2009).

3.5. Weather Data

Meteorological data necessary to run the SWAT model was obtained from Nigeria Meteorological Agency (NIMET) station based in Ilorin, Kwara State. The data collected includes daily precipitation, maximum and minimum temperature, solar radiation, relative humidity, and wind speed, in order to perform the hydrological analysis. The collected weather variables for driving the hydrological balance within the watershed were for a period of Nineteen (19) years i.e. (January 1, 2001, to December 31, 2019).

3.6. Watershed delineation into sub-basins and Hydrologic Response Units (HRUs)

The delineation of the watershed was achieved using reprojected DEM of the study area. In the Automatic Watershed Delineation (AWD) of the GIS interface, network delineation by threshold method was adopted. For uniformity, a threshold value of 20km^2 was adopted for all the resampled DEM resolutions. A total of 55 sub-basins were created in the watershed and was subdivided into 61 hydrologic response unit (HRUs). The HRU is the smallest spatial unit needed for running the hydrological model. Figure 3 shows the delineated subbasins in the study area.

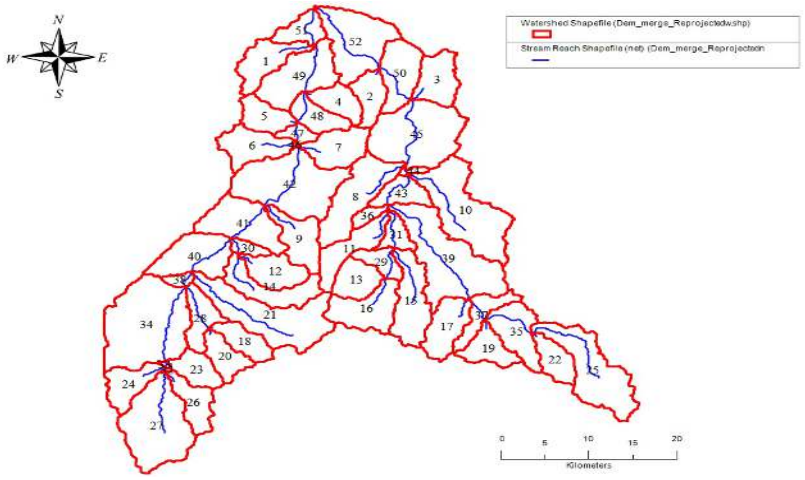


Figure 3: Watershed Delineation and Hydrological Response Unit (HRU)

3.7. Swat setup and run

SWAT was executed using the Soil Conservation Service (SCS) Runoff Curve Number method for estimating surface runoff from precipitation. The SCS curve number method is a rainfall-runoff model that was designed for computing excess rainfall (direct runoff). This method assumes an initial abstraction before ponding that is related to curve number. The daily weather (precipitation, wind, solar radiation, relative humidity and daily minimum and maximum temperature) data were prepared in the appropriate file format (as Microsoft excel file) required by the model and imported into the model. The resampled DEMs of the study area were used in turn for the prediction of flow and the sediment loadings. The simulation period is from 01 January 2001 to Dec 31, 2019. All necessary files needed to run SWAT were written, and the appropriate selection of weather sources done before running the model.

4. RESULTS AND DISCUSSION

4.1 Prediction of stream flow

The lowest predicted value of 2229.91m^3/s was observed at a lower resolution of 90m by 90m used for the hydrological modelling of the study area. However, this value increased to a maximum value of 2345.14m^3/s when the DEM was resampled to a resolution of 75m. It was also noticed that the value of stream flow predicted was a bit stable with values hovering between 2333.02m^3/s to 2344.19m^3/s. At a finer resolution of 45m and 30m respectively. It can also be inferred from the result that decreasing the resolution of the DEM above 60m does not have substantial effect on the predicted values of stream flow of the river. This result compared well with the findings of Ghaffari (2011) and Mou, et.al. (2015) with the conclusion that DEM resolutions impacted the predicted values of runoff, sediment yield and stream flow. These findings highlight the significance of considering the impact of flow on hydrological processes and the importance of optimizing DEMs resolution for accurate flow measurement and prediction. The results could have important implications for a range of applications, including water resource management, flood forecasting, and erosion control.

4.2 Prediction of sediment concentration and sediment yield

The study showed that the value of predicted sediment concertation increased as the DEM resolution becomes finer from 90m x90m towards 30m x 30m. DEM of 30m resolution has the highest predicted value of 521,246.94 mg/l while the least predicted value of 228,899.70mg/l was observed with a 90m DEM resolution. The result indicated that resolution of the DEM can significantly influence sediment concentration prediction. It was further discovered that the predicted sediment concentration is inversely proportional to the resolution of the DEM as shown in Figure 7. While the prediction of sediment yield in the study area showed a linear relationship between the DEM resolution and the predicted sediment yield and a similar pattern as it was obtained for stream flow. The result showed that as the predicted values of sediment yield and concentration increases as the resampled DEM decreases and tends to be stabilised at a higher resolution (45m, 30m). The sediment yield (SYLD t/ha) for 90m resolution DEM has the least value of about 528.90 t/ha while the 30m resampled DEM has the highest value of 2145.57 t/ha. This finding is significant because it suggests that the accuracy of sediment yield estimates can be influenced by the resolution of the DEM used. Details information about the predicted values

of sediment yield and concentration could be obtained from Table1 and graphically from Figure 4 to Figure 6. The spatial distribution of predicted sediment yield in the watershed and sediment concentration along the river reach is shown in Figure 7.

Table 1: Details information about predicted flow and sediment loading by each of resampled DEM.

S/N	DEM Resolution (m)	Flow (m^3/s)	Sediment Concentration (mg/l)	Sediment Yield (t/ha)
1	90 x 90	2229.91	228,899.70	528.90
2	75 x 75	2345.14	503,842.25	1,926.14
3	60 x 60	2338.02	486,447.25	1,965.07
4	45 x 45	2341.29	506,174.80	2,079.96
5	30 x 30	2341.19	521,246.94	2,145.57

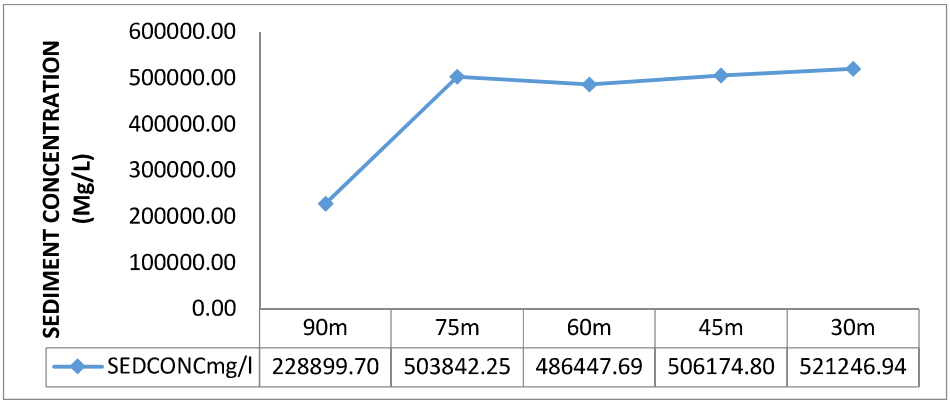


Figure 4: A plot of DEM resolution against the predicted sediment concentration

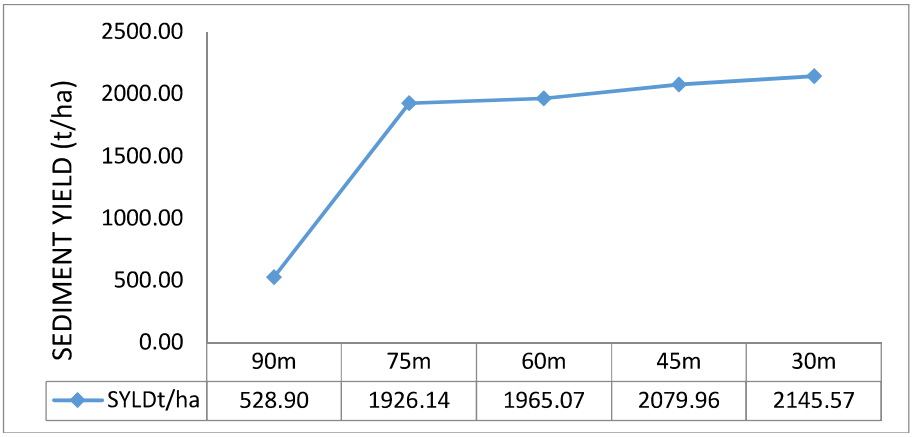


Figure 5: A plot of DEM resolution against the predicted sediment yield

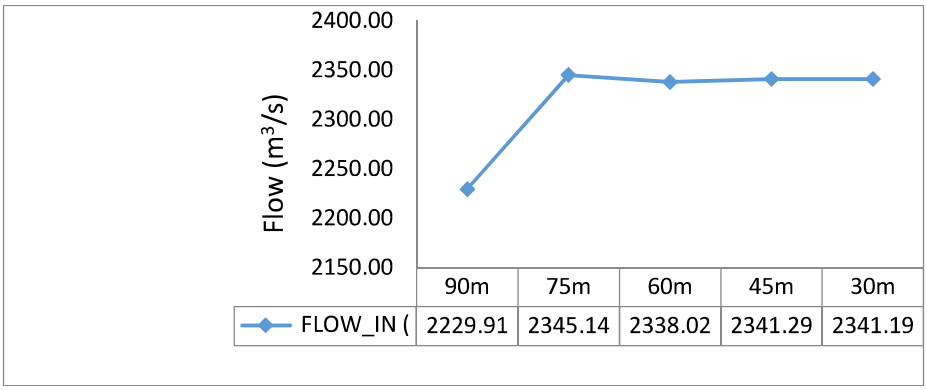


Figure 6: A plot of DEM resolution against the predicted stream flow

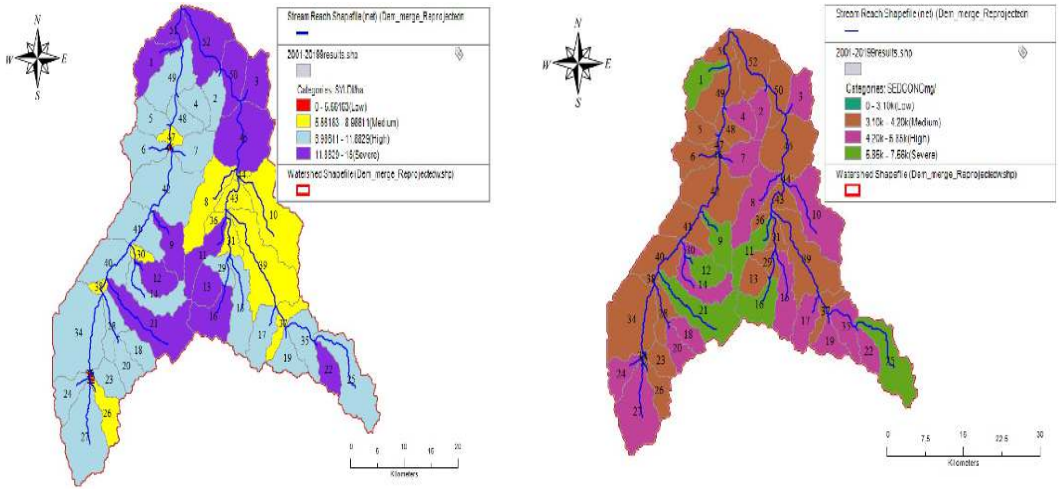


Figure 7: Spatial Variation of Sediment yield and Concentration in the Watershed

5. CONCLUSION

The study investigated the impact of Digital Elevation Models (DEMs) on the simulation of sediment loading, taking into consideration three parameters. The results revealed a similar pattern in the prediction of stream flow, sediment yield and sediment concentration and that the DEM with a resolution of 60m produced the best value when all three parameters were considered. These findings suggest that the choice of DEM resolution has a significant impact on the accuracy of sediment loading simulation. Therefore, this study could serve as a valuable decision support tool for researchers in the selection of an appropriate DEM resolution for stream flow sediment loading simulations. The importance of accounting for the effect of resampled DEMs on simulation accuracy cannot be overstated and the implications of these findings could extend to a range of applications in various fields.

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