PAPER 158 – INFLUENCE OF WATERSHED DELINEATION ON HYDROLOGICAL PROCESSES UPSTREAM WATERSHED OF ASA DAM RIVER, ILORIN, KWARA STATE, NIGERIA

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ABSTRACT
This study assessed the impact of watershed delineation on the estimation of water quality parameters in the Asa River in Ilorin, Nigeria. MAPWindow GIS interfaced with Soil and Water Assessment Tools (SWAT) and was used to pre-process the spatial data. The model was used to simulate water quality parameters such as organic phosphorus and nitrate at subbasin level of the study area. The watershed was delineated into 5, 9, 13, 15, 17, and 29 sub-basins, and each delineated sub-basin was modelled for 19 years (January 2001 to December 2019). The results showed that predicted values of organic phosphorus and nitrate concentrations ranged from 731607.04 mg/l to 6764932.7mg/l and from 1441992.79 mg/l to 3575204.59 mg/l respectively. The lowest annual predicted values of sediment yield, sediment concentration, and streamflow were obtained for a watershed delineation into 5 sub-basins. The highest predicted values, however, were obtained when the watershed was delineated into 29 sub-basins. The number of sub-basins however, had little or no influence on the average monthly predicted values of water quality parameters in the watershed. It could be inferred from the result that the number of sub-basins delineated in the watershed directly influence the predicted values of water quality parameters.

KEYWORDS: Asa Dam River, Hydrological process, Soil and Water Assessment Tools (SWAT), Sub-basins, Watershed delineation and Water quality parameters

1. INTRODUCTION

The process of delineating watersheds plays a significant role in the study of hydrological processes, as it affects the prediction and management of water resources in a given area. Hydrological cycle research, centred on the assessment of water resources through the quantifiable investigation and evaluation of the hydro-meteorological factors that control the circulation and transfer of water in all of its processes (Shiklomanov, 2011). It is concerned with the components of the water balance and its quantitative estimation, which comprises the following phases: the transfer of water from the atmosphere to the soil via precipitation, the settlement of water from the soil and open surface water into the atmosphere via evaporation and transpiration; the variation in the distribution and storage of water in multiple reservoirs, namely surface and groundwater reservoirs; and the distribution and redistribution of water on the land surface (Ngasoh, et. al., 2022).

Watershed delineation is a critical step in any spatial hydrological modelling. Watershed modelling has grown in importance as a method for evaluating the impacts of climate change and human impacts on water resources and the hydrologic cycle. However, the impact of watershed delineation is the capability of a model to adequately reflect the spatial variability of a river basin factor for the hydrological process. There is need to study the effects of several delineation of water production, as well as the watershed delineation in modelling, determine the precision required to obtain an accurate simulation modelling result.

The main objective of this study is to analyse the extent to which the watershed has affected the hydrological processes in Asa Dam, Kwara state of Nigeria. To achieve this objective, the following specific objectives have been identified: first, to delineate selected watershed into sub-basins for the purpose of hydrological modelling; secondly, modelling and to predict selected hydrological processes in the watershed through the application of Soil and Water Assessment Tool (SWAT) and using various watershed delineation of the watershed.

2. THEORETICAL ANALYSIS

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

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

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 (mm water).

Soil erosion rates on cultivated land was modeled in SWAT by using the Universal Soil Loss Equation developed by Wischmeier and Smith in 1978 (Neitsch et al.,2011). This method is based on statistical analyses of data from 47 locations in 24 states in the Central and Eastern United States. The Universal Soil Loss Equation can be written as in Equation 2

$$A = R * K * L * S * C * P0.11 \qquad 2$$

In Equation 2, A is the computed soil loss in tons/acre/year, R is rainfall factor, K is the soil-erodibility factor, L, slope-length factor, S, slope-steepness factor, C, cropping-management factor, and P, erosion-control practice factor.

3. MATERIALS AND METHODS/METHODOLOGY/EXPERIMENTAL PROCEDURE

3.1 Description of case study area

Asa Dam is located between latitudes 8° 36′ N and 8° 24′ N and longitudes 4° 36′ E and 4° 10′ E in Ilorin. Ilorin is the capital of Kwara State in Nigeria, West Africa. A geographical map of Nigeria showing the location of Study area in Nigeria is presented in Fig. 1. Asa Dam was built in 1984 on River Asa. It is a composite dam with an earth embankment. The dam is about 600 m long, 25 ft (7.5 m) high at its deepest section and has a crest width of 6 ft (1.8 m). The embankment is made of in situ soil overlay by clay seal and concrete material. The foundation is made of 4-ft-thick compacted soil and clay overlayed by 4-ft-thick concrete cement. The maximum water level at the upstream is 20 ft (7.5 m) while the downstream water level can be as low as 2 m in the peak of the dry season. Asa River is approximately 56 km long and has a maximum width of about 100 m. The river lies within Oyo and Kwara states in Nigeria, with a total catchment area of 1037 km^2 (Balogun and Ganiyu 2017). The tributaries of Asa River in Ilorin include Rivers Aluko, Agba, Odota, Okun, Osere, Atikeke, and Mitile. Asa River in turn empties its water into River Niger. The annual rainfall ranges between 75 and 112 cm, humidity and means annual temperature range from 60 to 89% and 27 to 30°, respectively (Ilorin Meteorological Stations).

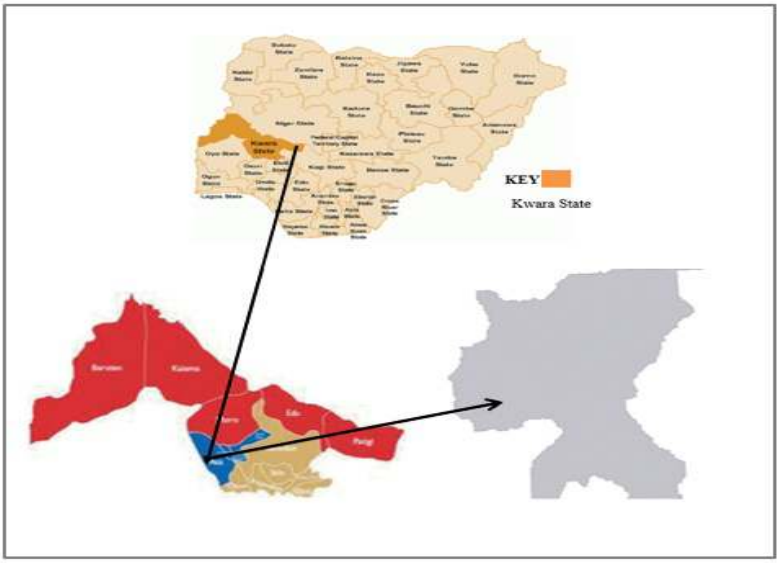


Figure 1: Map of Nigeria showing Kwara location of study area, Asa dam (Adeogun, et. al.2020)

3.2 Model Selection and Description

The Soil and Water Assessment Tool (SWAT) integrated with map window GIS was chosen as the model for this study, based on previous research on its efficacy as reported in many studies (Ayana et.al., 2012; Betrie et.al.,2011, Omani et al., 2007). Moreover, the model has a user-friendly interface, and its results are easy to visualize. SWAT

is a continuous daily step process-based model that was created to predict the impact of land management practices on water, sediment, and agricultural chemical yields over extended periods in vast, intricate watersheds with different soils, land use, and management conditions. The tool has been used and accepted by many researchers previously (Adeogun et al., 2022).

3.3. Model Data Requirements

SWAT modelling requires spatial data and temporal data for model parametrization. The spatial data encompass the Digital Elevation Model (DEM), soil and land use maps, while the temporal data, which is also known as weather data, comprises maximum and minimum temperature, humidity, wind, and solar radiation.

Digital Elevation Model (DEM): is one of the principal inputs of the SWAT model. Topography was delineated using a DEM, which describes the elevation of any point in a given area at a particular spatial resolution. A 90 m grid DEM was obtained from STRM (Shuttle Radar Topography Mission). The DEM was used to establish the boundary of the watershed and analyze the drainage patterns of the land surface terrain. Terrain parameters, such as slope gradient and slope length, as well as stream network characteristics, such as channel slope, length, and width, were derived from the DEM. Figure 2 displays the DEM of the study area.

Soil map: The soil textural and physicochemical properties necessary for the SWAT model include soil texture, available water content, hydraulic conductivity, bulk density, and organic carbon content for each soil type. Soil data was obtained from the harmonized digital soil map of the world (HWSD) produced by the Food and Agricultural Organization of the United Nations (Adeogun et al.., 2022). Table 1 displays the soil map and its information for the study area.

Land use map: The land use of an area is a critical factor that impacts groundwater flow, surface erosion, and evapo-transpiration in a watershed during simulation. The land-use map for this study was obtained from the Global Land Cover Characterization (GLCC) database and was used to estimate vegetation and other parameters representing the watershed area (GLCC, 2012). The GLCC database, which has a spatial resolution of 1 km and 24 classes of land use representation, was used to obtain the land-use map for the study area (GLCC, 2012). The database was developed by the United States Geological Survey. Figure 2 presents the DEM and the land-use map for the study area.

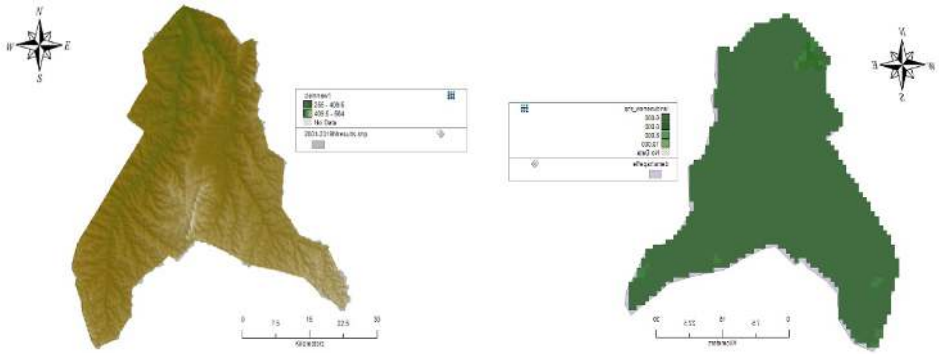


Figure 2: Digital Elevation Model (DEM) and Land map of the study area

Weather data: The required climatic data for the SWAT model simulation was obtained from the Nigeria Meteorological Agency (NIMET) station in Ilorin. The collected data consists of daily precipitation, maximum and minimum temperature, solar radiation, relative humidity, and wind speed for the period between January 2021 to December 2019. These weather variables were utilized to regulate the hydrological balance in the watershed. In the event of missing data, a weather generator integrated into the SWAT model was employed to estimate the missing values.

Creation of Hydrological Response Units (HRU): The HRU approach facilitates the modelling of hydrologic behaviour in a unit that is easy to represent. In this study, HRUs were delineated in a basin with high spatial heterogeneity by utilizing basin characteristics such as physiography, land use, soil, elevation, and slope in a geographical information system. The hydrologic behaviour of each HRU was analyzed based on basin characteristics, which can be incorporated in a physically based or conceptual hydrologic model for simulating groundwater and water yield.

3.4. Model Parametrization and Prediction of water quality parameters

The SWAT model can predict water quality parameters such as Nitrate, Organic phosphate, and sediment concentration. In this study, the prediction of water quality parameters in sub-basins of the watershed was conducted using spatial and temporal data for the study area. The obtained results were analyzed using Microsoft Excel software and the spatial and temporal variations of water quality parameters were visualized using the GIS component of the model.

4. RESULTS AND DISCUSSION

4.1. Delineation of watershed into sub-basins

The watershed was delineated into different sub-basins area, As explained earlier, the number of sub basins to be delineated can be varied by either increasing or decreasing the area of watershed within the boundary as specified in the automatic watershed delineation. Based on the division, the minimum number of delineations was 5 while the highest number of divisions was 29. Other subdivisions are 9, 13, 15, and 17. Figures 3 to 5 depict the various divisions of the watershed's delineation.

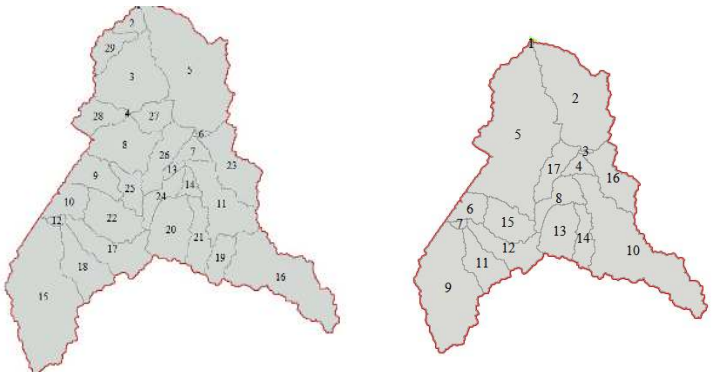


Figure 3: watershed delineated into (i) 29 sub basins and (ii) 17 sub basins.

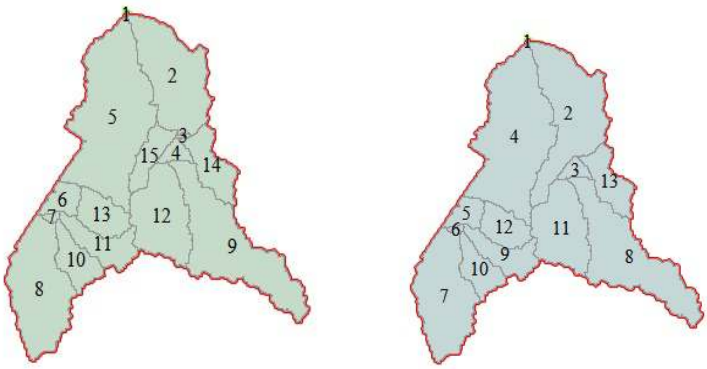


Figure 4: watershed delineated into (i) 15 sub basins and (ii) 13 sub basins.

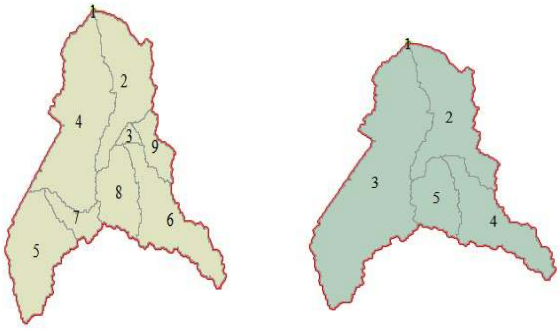


Figure 5: watershed delineated into (i) 9 sub basins and (ii) 5 sub basins.

4.2. Effects of watershed delineation on water quality parameters

The results of the model prediction on water quality parameters (sediment yield, flow, Nitrate, Organic phosphate and sediment concentration) using different numbers of delineated sub basins were compared. Generally, the results showed there is an increase in the value of water quality parameters as the number of sub-basins increases. For sediment concentration, SEDCON (see Figure 6). The result showed that the least annual predicted value of 54,119.96 mg/L, 635.04 m^3/s, 1441,992.97 t/ha, 98.20 ha and 731,607.04 mg/L for Sediment concentration, Stream Flow, Nitrate Concentration, Sediment yield and Organic Phosphorous respectively was obtained when the number of sub-basins was five (5). However, a higher predicted values was also obtained when the watershed was delineated into 29 sub basins with Sediment concentration of 304,713.25 Mg/L, Sediment yield of 977.46 t/ha , Organic Phosphorous of 6764932.7 mg/l, Stream flow of 1900.22 m3/s and Nitrate concentration of 3575204.59 mg/l. This result indicated that the predicted values of water quality parameters are directly proportional to the number of sub basins. However, it has little or no influence on the average monthly predicted values of water quality parameters in the watershed.

The result from this work is in tandem with a previous study conducted by Thushapan et al (2020) on the effects of watershed delineation on hydrological processes modeling. In his work, the study area was divided into eight sub catchments and concluded that the number of sub-catchments was increasing as the model performance was also increasing. The work of Adeogun et al. (2022) on the effects of watershed delineation on the prediction of water quality parameters in Gaa Akanbi Area Ilorin using SWAT with a physically based semi-distributed hydrological model interfaced with mapwindow GIS software also revealed that there was no noticeable change on the water quality parameters as the number of sub basins delineation increases in the watershed. He also recommended that the threshold value for deciding on the required number of watershed drainage density for the prediction of water quality parameters should be evaluated by trial-and-error procedure.

5. CONCLUSION

Watershed delineation is a critical process in hydrological modelling, and its accuracy has a significant impact on the estimation of hydrological processes such as runoff, evapotranspiration, and groundwater recharge. The accuracy of watershed delineation is influenced by various factors such as the quality and resolution of input data, the methodology used, and the spatial scale of delineation. Accurate watershed delineation is critical for effective water management and conservation, and therefore, careful consideration of the data sources and methodology is necessary for accurate watershed delineation. This study aimed to assess the impact of watershed delineation on the estimation of water The watershed was delineated into different numbers of sub-basins, and the results showed that the number of sub-basins directly influenced the predicted values of water quality parameters.

The study found that the lowest annual predicted values of sediment yield, sediment concentration, and streamflow were obtained for a watershed delineation into 5 sub-basins, while the highest predicted values were recorded when the watershed was delineated into 29 sub-basins. However, the number of sub-basins had little or no influence on the average monthly predicted values of water quality parameters in the watershed. This study highlights the importance of watershed delineation in accurately predicting water quality parameters, and the number of sub-basins used in the delineation process can have a significant impact on the predicted values. These findings could be useful for water resource management and policy development in the region, especially in addressing water quality concerns in the Asa Dam River watershed.

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