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Sustainable Management of Runoff and Sediment Yield in a Rapidly Urbanizing Residential Area: A Case Study of Malete, Kwara State, Nigeria

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Abstract
This study investigated the effects of the application of stone bunds and vegetative filter strip for sustainable management of runoff and sediment yield generated in Malete watershed, Kwara State, Nigeria. Soil Water Assessment Tool (SWAT) model interfaced with Geographical Information System (MapWindow GIS) was employed to simulate and predict the hydrological processes of the watershed into sub-basins which were further divided into Hydrological response units (HRUs). The model was used to evaluate the efficacy of the application of stone bund and vegetative filter strip in reducing storm water generated from the watershed. The outcome of the study showed that the total predicted surface runoff and sediment yield in the watershed were predicted as 131.53 million m^3 and 243.77 t/ha respectively. The maximum and minimum runoff predicted were 19.89 million m^3 and 17.76 million m^3 at sub-basins 13 and 7 respectively, and the average runoff predicted value was 16.44 million m^3. Also, the maximum and minimum sediment yield in the watershed occurred at sub-basins 41 and 8 having predicted values of 46.40 t/ha and 11.26 t/ha respectively, and the average sediment yield predicted was 30.472 t/ha. The results revealed that the implementation of stone bunds reduced sediment yield by 93% while vegetative filter strip reduced it by 37%. In addition, the model could serve as a decision support tool for stakeholders and relevant local authorities to formulate policies and strategies in the management of runoff and sediment yield generation in the study area.

Keywords: *Stormwater, Sediment yield, Stone bund, Surface runoff, Malete*

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1. Introduction

Storm water is a form of water generated as a result of all forms of precipitation such as rain, sleet, or melting snow. In an ideal situation, only a small percentage of storm water becomes surface runoff. This runoff usually flows into the nearest stream, creek, river, lake, or wetland. Runoff can cause problems like erosion of stream banks, flood increase and reduction in water quality (Agouridis et al., 2013). Due to the rapid global urbanization, the natural land covers are tending to be impervious and degrading the natural environment which increase runoff and peak flows that cause flash flooding, affect water quality and other water related problems (Dientz, 2007). Previously, the control schemes of urban flooding were focused on drainage which facilitates global construction of drainages to arrest flood problems but study by Agouridis et al. (2013) revealed that construction of drainages cannot solve the fundamental problem of flooding. Specifically, conventional storm water management approaches have focused on removing storm water as promptly as possible in order to mitigate the impacts of flooding in a particular watershed.

However, the use of pipeline drainage system has usually caused an increase in the discharge and velocity of runoff which poses danger to the downstream part of the water bodies in form of flooding. It is quite noted that the generated runoff carries along sediments which have great impacts on water quality, water reservoir capacity, and agricultural productivity of such area (Gyamfifi et al., 2016). The sediment in a large quantity known as sediment yield is transported from one location to another over a given period of time and it is usually expressed as tonnes per year (White, 2005). The recent studies by Trinkaus (2013) and Wei et al. (2012) have shown that green infrastructure and low impact development (LIDs) practices are innovative approaches to effectively manage the adverse effects of storm water globally. LID practices include green roofs, blue roofs, bioswales, bioretention, rain barrel, pervious pavement, and tree box planter (Jeaong et al., 2016). It was reported by Betrie et al. (2011) and Adeogun et al. (2016) that stone bunds and vegetative filter strips modeled and employed as sediment management techniques can effectively reduce sediment yield and sediment concentration in a watershed.

Malete is one of the fastest growing towns in Kwara State and this might not be unconnected with the location of Kwara State University in the town some years ago. This has brought a lot of infrastructural developments such as student hostels, good roads, construction of hotels and relaxation centres within the town. This rapid urban growth has significantly increased the runoff generated in the study area. Some of the associated effect of the urbanization includes water logging resulting in ground flooding and underground submerging. On this note, it is quite necessary to investigate the effects of the application of stone bunds and vegetative filter strip on sustainable management of storm water and sediment yield in the study area.

2. Materials and methods

2.1. Description of the study area

Malete is a town in Moro Local Government Area (LGA) of Kwara State with the headquarters at Bode Saadu which is about 85 km from Ilorin, the state capital. It is located between latitude $8^{0}36'$ and $8^{0}24'$ North and Longitudes $4^{0}36'$ and $4^{0}10'$ East. Moro LGA is a rural settlement, mostly comprised of local populations with low literacy and low-income level (Ajibade et al., 2005). It has an area of 3272 km square and a population of 108,792 at the 2006 census.

The topography of the study area is a fair representative of surrounding plains which can be described as undulating with very broad and gentle slopes. The town is characterized with combination of open storm water drainage systems and earth drain for the conveyance of generated storm water from the environment. The main occupation of Malete indigenous inhabitants is farming and hunting. The area has a good climatic condition, sizable expanse of arable and rich fertile soils. The vegetation which is mainly wooded guinea savannah, well suited for the production of a wide variety of staples like yam, melon, groundnut, cassava, maize, cowpea, fruits and vegetables (Yusuf et al., 2013). Figure 1 shows the map of the study area.

2.2. Model and GIS interface selection

The modeling tool employed for this study was Soil Water Assessment Tool (SWAT) which was developed by the United States Department of Agriculture Agricultural Research Service (Arnold *et al*., 1995). The modeling tool was coupled with Geographical Information System (Mapwindow GIS) as interface for the model. It has been used for estimating the effect of land management practices in large complex watersheds and it has been used widely in the United States of America and in developing countries (George and Leon 2007). The full description of SWAT model can be found in Adeogun et al. (2014), Adeogun et al. (2015), Fadil et al. (2011) and Setegn et al. (2008).

2.3 Model data requirements

Modeling in SWAT entails both the spatial and temporal (weather) data. Spatial data required includes: DEM (Digital Elevation Model), Land use map and soil use map while the temporal data includes daily: maximum and minimum temperatures, relative humidity, solar radiation, precipitation and wind speed for a period of 30 hydrological years (1986-2015). Summary of the model input data is presented in Table 1. The 90 x 90 m resolution topography data used for this study was extracted from the Shuttle Radar Topography Mission (SRTM) final version (CGIAR, 2012) and the Land use map was extracted from the Global Land Cover Characterization (GLCC) database (GLCC, 2012). The digital soil data was obtained from harmonized digital soil map of the world produced by Food and Agriculture Organization of the United Nations (Nachtergade et al., 2009). Figures 2 and 3 show the DEM and Landuse maps of the watershed respectively.

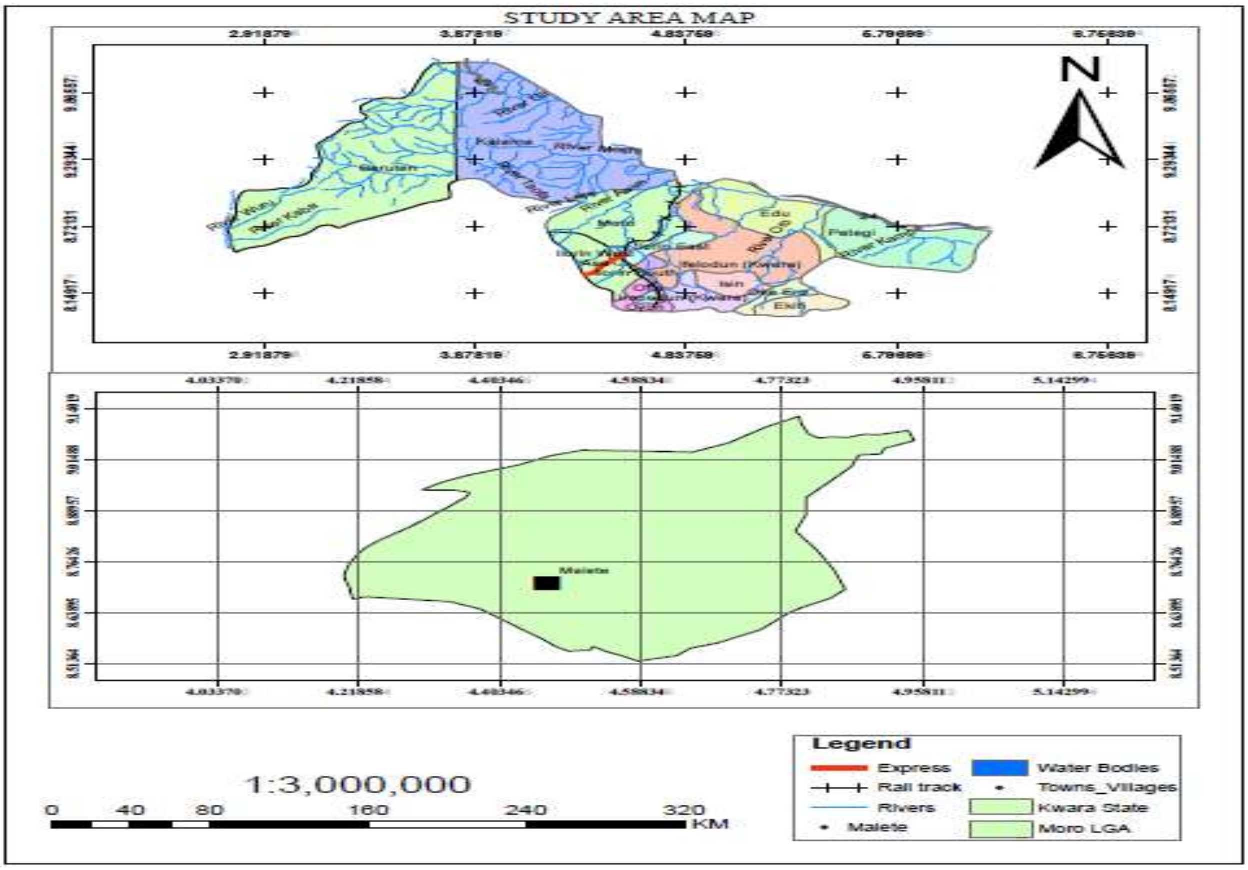

Fig. 1: Map of Kwara State showing the study area

Table 1: Model input data

Data type	Description	Resolution	Source
Topography	Digital Elevation Model	90m x 90m	Shuttle Radar Topography mission
Landuse map	Land Use Classification	1km	Global Land Cover Classification, Satellite Raster
Soil map	Soil Type and Texture	10km	Digital Soil Map of the world
Weather	Precipitation, Min and Max Temperatures, Relative Humidity, Solar Radiation and Wind	Daily	Nigerian Meteorological Agency (NIMET)

2.4 Pre-Processing of spatial data and watershed delineation

Adeogun et al. (2014) described the pre-processing and delineation of watershed using the GIS component of the modeling tool. For this study, a total number of 204 sub-basins and 214 Hydrological Response Units (HRUs) were delineated each with unique combination of land-use, slope and soil. Figure 4 shows the delineation of the watershed into sub-basin.

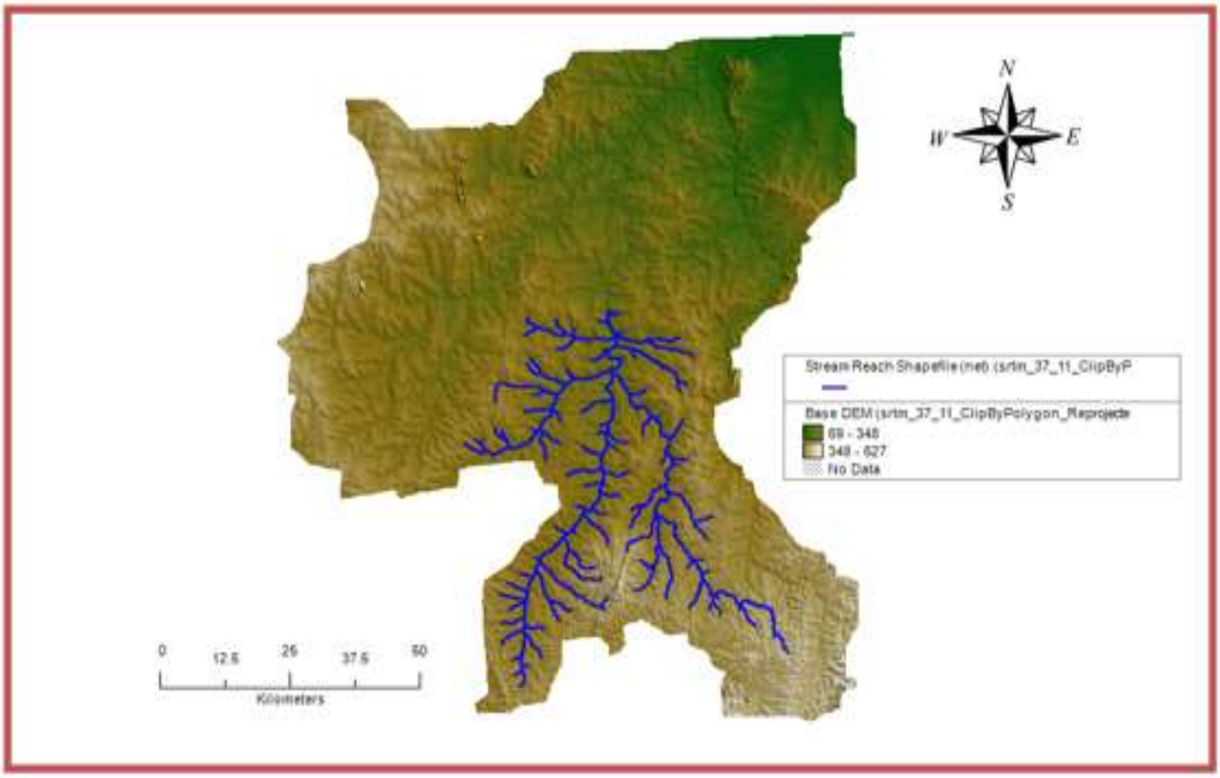

Fig. 2: DEM map of the watershed

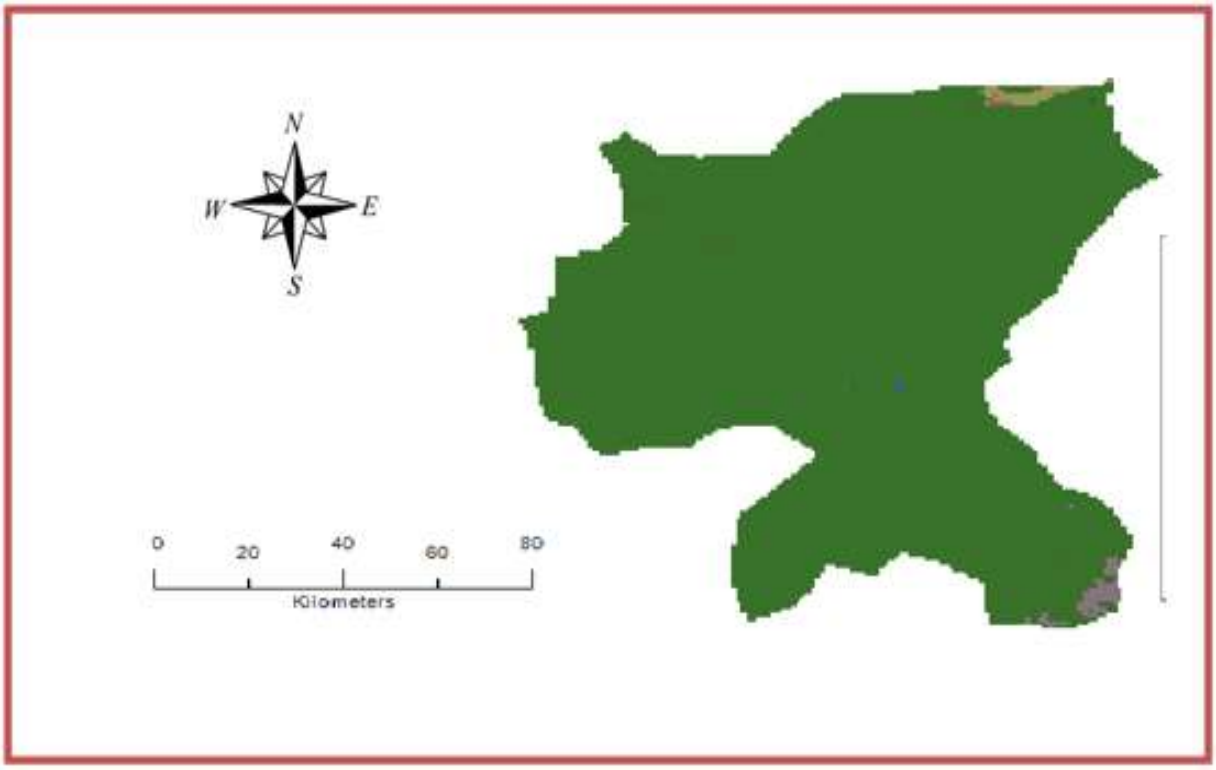

Fig. 3: land use map of the watershed

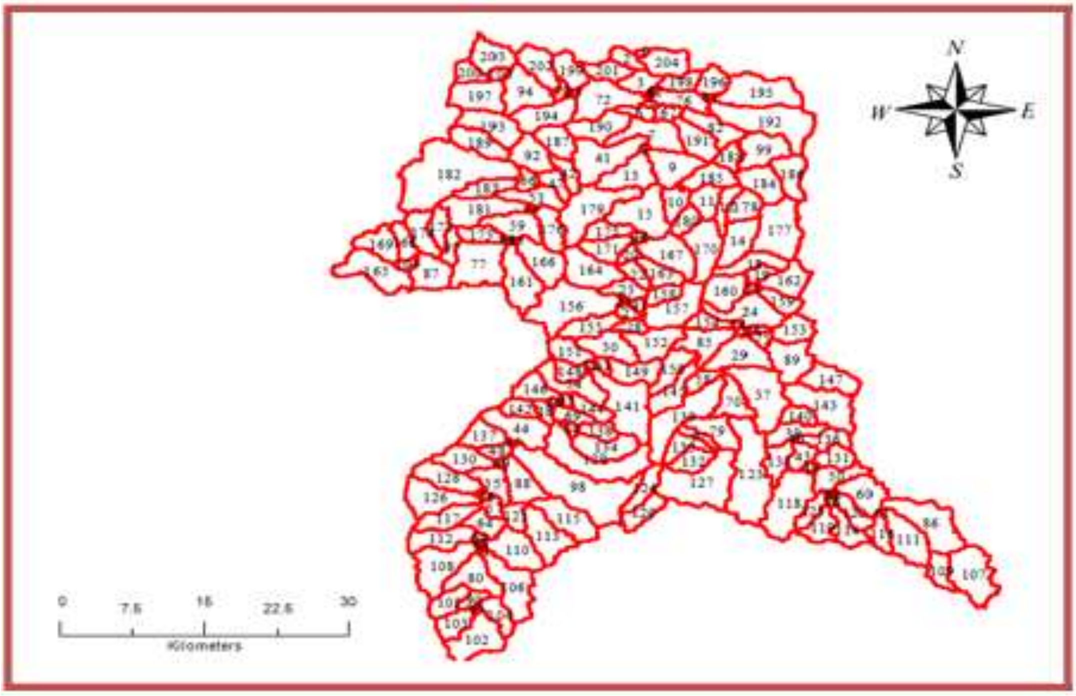

Fig. 4: watershed delineation into sub-basins

2.5 Model setup and run

SWAT was executed using the Runoff Curve Number method to estimate the surface runoff from precipitation, the Hargreaves method to estimate potential evapo-transpiration, and the variable-storage method to simulate channel water routing. The simulation period was from 01 January 1986 to Dec 31 2015 and each of the model run output was visualized using the GIS component of the model.

2.6 Modeling of stone bunds and vegetative filter strip

The construction of stone bunds as a management intervention involves construction of parallel terrace locally built from stone along the contour. Contour stone bunds are usually built with quarry rock or stones along the natural contour of the land to a height of 20-30 cm from the ground and spaced 20 to 50 m apart depending on the slope of the terrain. The stone bunds functions as an impediment that slows down water runoff and allow rainwater to infiltrate into the soil and spread more evenly over the land. A vegetative filter strip (VFS) is a strip of dense vegetation located to intercept runoff from upslope pollutant sources and filter it. VFS is thought to be one of the most effective methods to trap sediment effectively. SWAT tool editor was used to edit the model input to make provision for the implementation of stone bunds and vegetative filter strip in the watershed. Stone bund was simulated by altering average the slope length SLSUBBSN, the Curve Number (CN) and USLE support practice factor (USLEP) to values as recommended in similar studies. The selection of BMPs and their parameters were based on similar researches in the literature most especially, those involving catchments in Africa (Betrie et al., 2011; Huninkset al., 2013). The application of filter strip was simulated by modifying the width of filter strip (FILTERW) as embedded in SWAT model parameters as was previously carried out by Adeogun et al. (2018).

3. Results and discussion

3.1. Prediction of total runoff in the watershed

The result of simulated runoff in the watershed for the period of 30 years by the SWAT model was represented in Figure 5. The total predicted runoff for the watershed was estimated at 131.53 million m^3. The maximum and minimum predicted runoff in the watershed was estimated at 19.89 million m^3 and 17.76 million m^3 which occurred in sub-basins 13 and 7 respectively. It was also noted that the runoff quantity was highest in the Northwest part of the watershed. However, subbasins located at the central part of the basin were characterized with reduced runoff generation with a range between 16.52 million m^3 to 17.62 million m^3 in quantity towards the outlet of the sub-basin.

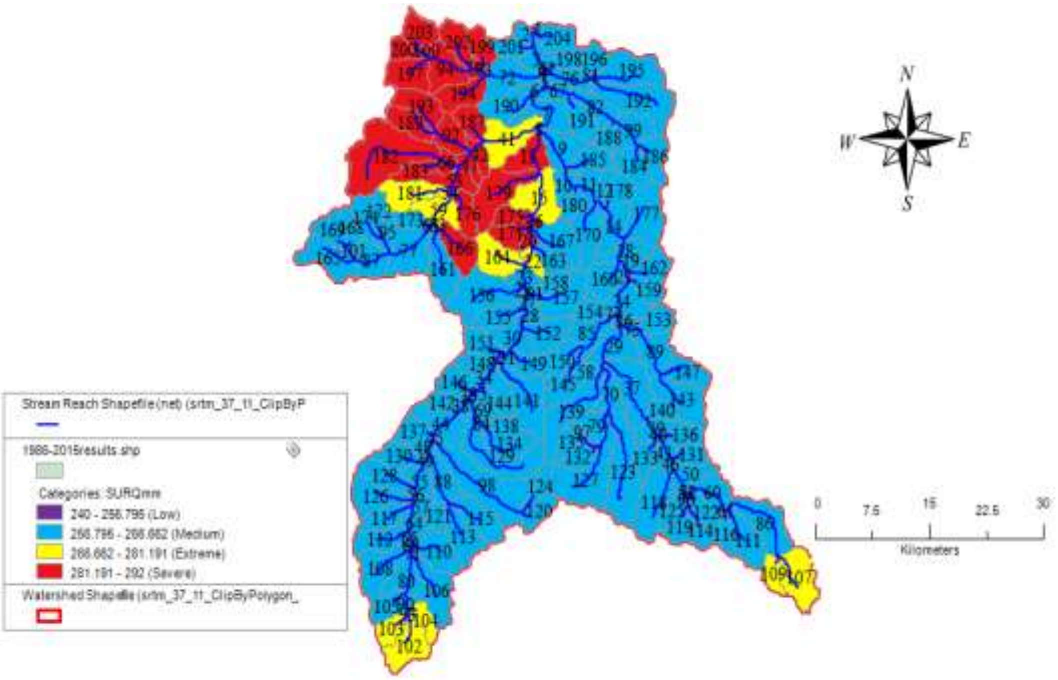

Fig. 5: Spatial map of the predicted **t**otal runoff in the watershed

3.2. Prediction of total sediment yield in the watershed

The total predicted sediment yield in the sub-basins that represent Malete watershed was 243.77 t/ha. This translates to about 1.68 million tons of sediments produced in the area. Also, the maximum and minimum sediment yield predicted were 46.40 t/ha and 11.27 t/ha at sub-basins 41 and 8 respectively. It was also discovered that low sediment yield characterized two of the river channels located upstream of the watershed. Subbasins with highest sediment yield could be found at both upper and lower areas of the entire watershed. Figure 6 shows the spatial variation of predicted sediment yield in each of the sub-basins of the study area.

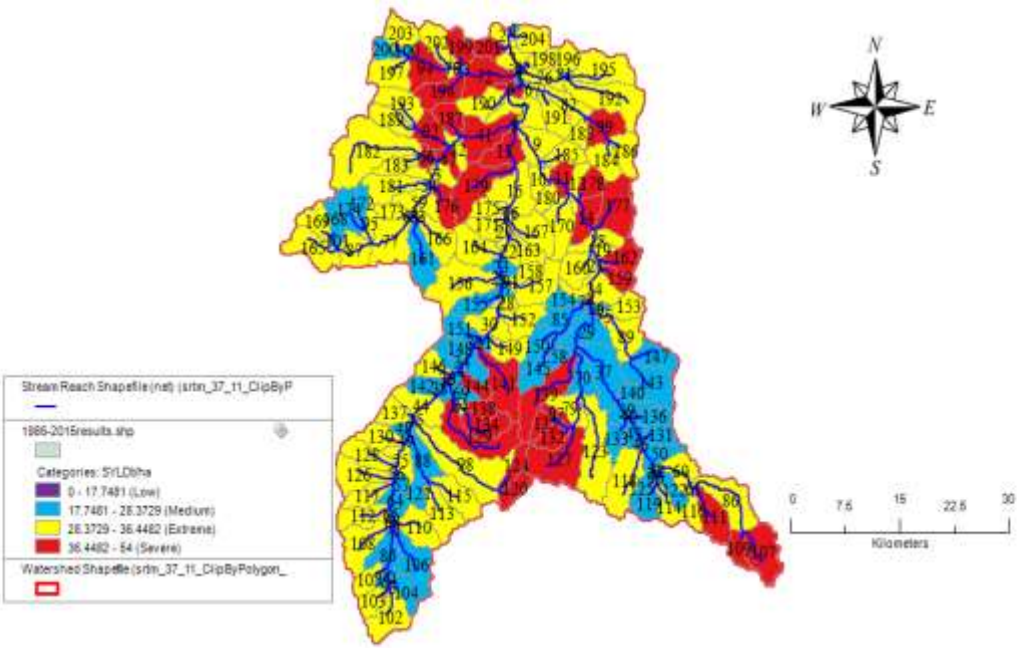

Fig. 6: Spatial map of the predicted **t**otal sediment yield in the watershed

3.3 Effects of application of stone bunds on sediment yield reduction

The application of stone bund in the watershed showed a total sediment yield reduction from 243.77 t/ha to 17.05 t/ha. The maximum and minimum sediment yield in the watershed in this scenario occurred at sub-basins 41 and 8 at estimated values of 3.11 t/ha and 0.95 t/ha respectively. The result revealed a reduction percentage of about 93 % of the total sediment yield when compared with the existing condition. This value obtained was in tandem with but a little bit higher than the result obtained by Adeogun et al. (2018) where the application of stone bund in a watershed in North central Nigeria represents approximately 89.2% reduction in the total sediment yield of the area. Also, Herweg and Ludi (1999) reported 72%–100% sediment yield reductions by stone bunds at a plot scale in the Ethiopian and the Eritrean highlands.

3.4 Effect of vegetative filter strip on total sediment yield reduction

The application of vegetative filter strip (VSF) in the watershed showed that the total sediment yield reduced from a predicted value of 243.77 t/ha to 153.83 t/ha. This result revealed a decrease of about 37 % of sediment yield produced in the watershed under the do-nothing scenario. Further analysis of the results indicated that the maximum sediment yield predicted with the application of VFS reduced from a previous value of 46.4 t/ha to 30.21 t/ha. This is equivalent to about 65 % reduction. The minimum sediment yield value also decreased from 11.27 t/ha to 6.24 t/ha (about 55 % reduction) of sediment yield in the study area. The result obtained also compared well with Adeogun et al. (2018) where a reduction of about 37 % was achieved in sediment yield and 34.3% reduction was obtained for sediment concentration in the reaches of the modelled watershed.

4. Conclusions

In this research, runoff and Sediment yield in the study area were modeled using SWAT model interfaced with Map Window GIS software. The model was simulated using both spatial data (DEM, Landuse and soil maps) and temporal data of 30 years (01 January 1986 to 31 December 2015). The study showed that the total predicted runoff for the watershed was estimated at 1911.06 mm which translates to volume of 131.53 million m^3 while the total sediment yield in the sub-basins that represent Malete watershed was estimated at 243.77 t/ha (1.68 million ton). However, simulation of the application of vegetative filter strip in the watershed showed about 37 % reduction in the sediment yield while the simulation of stone bund could reduce the sediment yield up to about 93 %. The model output could serve as a decision support tool for stakeholders and other relevant authorities in taking decisions and formulating policies for sustainable management of runoff and sediment yield generated from the watershed.

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References

Adeogun, A.G., Ibitoye, B.A., Salami, A.W. and Ihagh, G. (2018) Sustainable Management of Erosion Prone Areas of Upper Watershed of Kainji Hydropower Dam, Nigeria. Journal of King Saud University-Engineering Sciences 32 (1): 5-10.

Adeogun, A.G., Sule, B.F. and Salami, A.W. (2016) Cost Effectiveness of Sediment Management Strategies for Mitigation of Sedimentation at Jebba Hydropower Reservoir, Nigeria. Journal of King Saud University-Engineering Sciences 30(2): 141-149.

Adeogun, A.G., Sule, B.F. and Salami, A.W. (2015) Simulation of Sediment Yield at the Upstream Watershed of Jebba Lake in Nigeria using SWAT Model. Malaysian Journal of Civil Engineering 27(1): 25-40.

Adeogun, A.G., Sule, B.F., Salami, A.W. and Okeola, O.G. (2014) GIS-Based Hydrological Modelling Using SWAT: Case Study of Upstream Watershed of Jebba Reservoir in Nigeria. Nigerian Journal of Technology, 33(3): 351-359.

Agourigis, C.T. and McMaine, J.T. (2013) Managing Stormwater Using Low Impact Development (LID) Techniques. University of Kentucky College of Agriculture, Food and Environment, Lexington, KY, 40546.

Ajibade, L.T., Fatoba, P.O., Raheem, U.A. and Odunuga, B.A. (2005) Ethnomedicine and Primary Health Care in Ilorin, Nigeria. Indian Journal of Traditional Knowledge 4(2): 150-158.

Arnold, J.G., Williams, J.R. and Maidment, D.R.

(1995) Continuous-time Water and Sediment-routing Model for Large Basins. Journal of Hydraulic Engineering, 121(2): 171-183.

Betrie, G.D., Mohammed, Y.A., van Griensven, A. and Srinivasan, R. (2011) Sediment Management Modelling in the Blue Nile Basin using SWAT. Hydrology and Earth System Sciences, 15(3): 807–818.

CGIAR (2012) Shuttle Radar Topographical Misssion. SRTM 90m DEM Digital Elevation Database. http://srtm.csi.cgiar.org/. Accessed 11 February 2019.

Dietz, M.E. (2007) Low Impact Development Practices: A Review of Current Research and Recommendations for Future Directions. Water, Air, Soil & Pollution, 186(14): 351–363.

Fadil, A., Rhinane, H., Kaoukaya, A., Kharchaf, Y. and Bachir, O.A. (2011) Hydrologic Modeling of the Bouregreg Watershed (Morocco) Using GIS and SWAT Model. Journal of Geographic Information System, 3: 279-289.

George, C. and Leon, L.F. (2007) Waterbase: SWAT in an open-source GIS, The Open Hydrology Journal, 1(1): 19-24.

GLCC (2012) Global Land Cover Characterization. http://edc2.usgs.gov/glcc/glcc.php. Accessed 11 February 2019.

Gyamfifi, C., Ndambuki, M.J. and Salim, R.W. (2016) Simulation of Sediment Yield in a Semi-Arid River Basin under Changing Land Use: An Integrated Approach of Hydrologic Modelling and Principal Component Analysis. Sustainability, 8(11): 1133.

Herweg, K. and Ludi, E. (1999) The performance of selected soil and water conservation measures-case studies from Ethiopia and Eritrea, Catena, 36(1-2): 99–114.

Hunink, J.E., Niadas, I.A., Antonaropoulos, P., Droogers, P. and de Vente, J. (2013) Targeting of Intervention Areas to Reduce Reservoir Sedimentation in the Tana Catchment (Kenya) Using SWAT. Hydrological Sciences Journal 58(3): 600–614.

Jeong, H., Broesicke, O.A., Drew, B., Li, D. and Crittenden, J.C. (2016) Life Cycle Assessment of Low Impact Development Technologies Combined with Conventional Centralized Water Systems for the City of Atlanta, Georgia. Front. Environmental Scienc and Engineering, 10(6): 1.

Nachtergaele, F., Velthuizen, H.V. and Verelst, L. (2008) Harmonized World Soil Database (HWSD) version 1.1. Food and Agriculture Organization of the United Nations, FAO, Rome, Italy, and IIASA, Laxenburg, Austria.

Setegn, S.G., Srinivasan, R., Dargahi, B. (2008) Hydrological Modelling in the Lake Tana Basin, Ethiopia Using SWAT Model. Open Hydrology Journal, 2: 49-62.

Trinkaus, D.S. (2015) Low Impact Development for Sustainable Development and Stormwater Management. Advances in Flowing Waters 13(1): 1-14.

Wei, Y.L., Bao, L.J., Wu, C.C., He, Z.C. and Zeng, E.Y. (2015) Assessing the effects of urbanization on the environment with soil legacy and current-use insecticides: A case study in the Pearl River Delta, China. Sciience of the Total Environment, 514: 409-417.

White, S. (2005) Sediment Yield Prediction and Modelling. Hydrological Processes, 19(15): 3053-3057.

Yusuf, S.F.G., Lategan, F.S. and Ayinde, I.A. (2013) Profitability and Adoption of Watermelon Technologies by Farmers in Moro Local Government of Kwara State, Nigeria. Journal of Agricultural Science, 5(5): 91-99.