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EFFECTS OF LAND USE LAND COVER AND CLIMATE CHANGES TO WATER YIELD IN YOLABENUE RIVER BASIN ADAMAWA STATE

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Abstract: *Modelling the impacts of climate change (CC) and land use land cover changes (LULCC) to water yield (WY) is crucial to overcome the effects of climate change on hydrological processes. Hence, this study evaluates the effects of CC and LULCC on WY in Yola Benue River Basin Adamawa State Nigeria. LULCC of 1992, 2002, 2012 and 2022 were analysed through maximum likelihood supervised classification. The impacts of LULCC and CC on water yield, evapotranspiration and precipitation were analysed using the soil water assessmenttool (SWAT) model. The effects of the changes indicate an increase in WY and precipitation and a decrease in evapotranspiration, which is due to changes in the curve number (CN) values. The study demonstrates the variation in the hydrological components because of alteration in LULC that occurred in the river basin. The results demonstrate the speedy expansion in agriculture, built-up, and the decline in the forest is perhaps the main reason for the distinctionin the overall hydrological components. Simulation with the SWAT using land use land coverchanges and climate change indicates a reduction in evapotranspiration and an increase in WY and precipitation in the river basin. These outcomes are needed for the planning and management of water resources for enhancement of sustainability.*

Key words: Land Use Land Cover, SWAT, Climate Change, Water Yield

Introduction

Modelling the impacts of climate change (CC) and land use land cover changes (LULCC)to water yield (WY) is indispensable to overcoming the effects of climate change on water yield, precipitation and evapotranspiration (Bratley and Ghoneim, 2018). Water yield derivedfrom a sub-basin is usually been influenced by some climatic factors such as potentialevaporation, rainfall and characteristics of the sub-basin like land use and vegetation types (Zhang et al., 2018). Whereas, the effects of the factors of climate on water yield are well comprehended as hydrological models are usually employed to measure the impacts (Anand etal., 2018; Nguyen et al., 2019). However, regional estimation of the CC and LULCC effects on WY remains problematic. CC and LULCC could affect WY by modifying its hydrological processes via changing soil moisture and evapotranspiration dynamics (Cagle et al., 2020). Consequently, combined quantification of the climate and LULCC impacts on WY is a challenging task as climate change and land use land cover changes complexity influences the hydrological processes by exhibiting negative/positive feedback (Kumar, 2018). Even thoughthese studies invested efforts in examining the influence of land use land cover and climate change effects on WY and the availability of water resources based on hydrological models (Lyu et al., 2019; Luo et al., 2020; Pirnia et al., 2019). However, reporting the three hydrological processes (water yield, precipitation and evapotranspiration) together by previousstudies remains unaddressed. Thus, resulting in inadequate comprehensive reporting of the effects of LULCC and climate change on water resources. Therefore, this study includes the three hydrological processes in modelling and predicting the effects of land use land cover change and climate change on water yield using the soil water assessment tools (SWAT) model.This study could be highly important to the stakeholders in planning and managing water resources. Hence, this is needed to fast-track the accomplishment of sustainable development goals 6 (targets 6.1 and 6.4) set by the United Nations of 2030 agenda.

Materials and Methods

Study Area

Yola Benue River basin is located in the central Area of Adamawa State which lies on latitude10^o 16’ 00” and longitude 13^o 16’ 30”. It is located on Nigeria's topographical sheet number Yola 152 NE a metric sheet on a scale of 1:50,000 and 1:10,000. Also, it has township sheetscovering a substantial part of it on a scale of 1:2500.

Materials

There are eight main materials in this study, which include: (a) Multi-temporal Landsatsatellite image data sets of Enhanced Thematic Mapper Plus (ETM+), and Operational Land Imager (OLI). These data sets were used to generate LULC of the study area, (b) Ancillary data, and (c) ASTER GDEM (Advanced Space-borne Thermal Emission and ReflectionRadiometer digital elevation model) of 30 m spatial resolution. The weather data include (d) precipitation (Rainfall), (e) minimum and maximum temperature, (f) relative humidity, (g) wind speed and (h) solar radiation and (i) streamflow data for calibration and validation usingSWAT CUP software.

Data Collection

The data involved in this study includes: Images, Topographical map, Soil map, DigitalElevation Models (DEM), observed streamflow data and weather data (minimum and maximum temperature, rainfall, solar radiation, wind speed and relative humidity) The image data were obtained from the United States Geological Survey (USGS) (http://glovis.usgs.gov);

and google earth engine. Ancillary data which consists of the topographical map of the study area collected from map depot Federal surveys Kaduna state applied to collect ground control points (GCPs) for image registering georeferencing or image correction. Soil map obtained from Food and Agricultural Organization/United Nations Educational, Scientific and Cultural Organization (FAO/UNESCO) Soil map of the world. ASTER GDEM (Advanced Space-borne Thermal Emission and Reflection Radiometer digital elevation model) of 30 m spatial resolution obtained from the website of the United States Geological Survey (USGS) (http://glovis.usgs.gov) and Diva GIS, used to derive the vertical slope and delineation at the streamflow station. The observed streamflow station data and weather data (minimum and maximum temperature, relative humidity, wind speed, solar radiation and daily precipitation) were obtained from the hydrological station in the operation area of Upper Benue River Basin development authority Yola Adamawa State Nigeria for Jimeta bridge station (BN02) of Latitude. 09º 18’’ and Longitude 12º 28’’.

Figure 01: Study Area Showing Nigeria, Adamawa state and Yola Benue River Basin

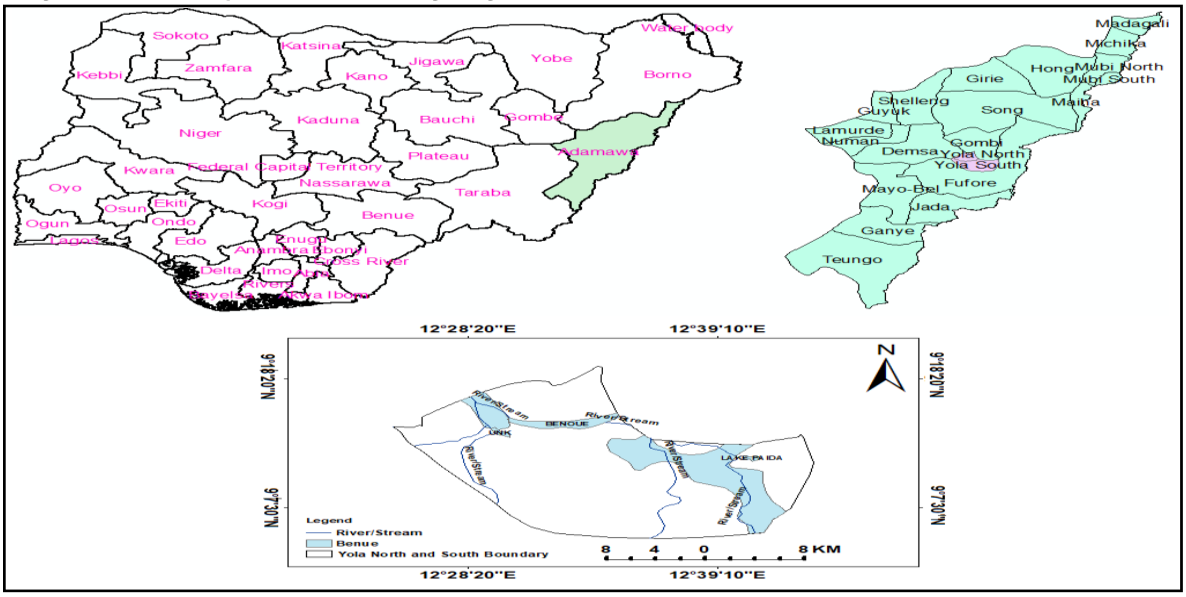
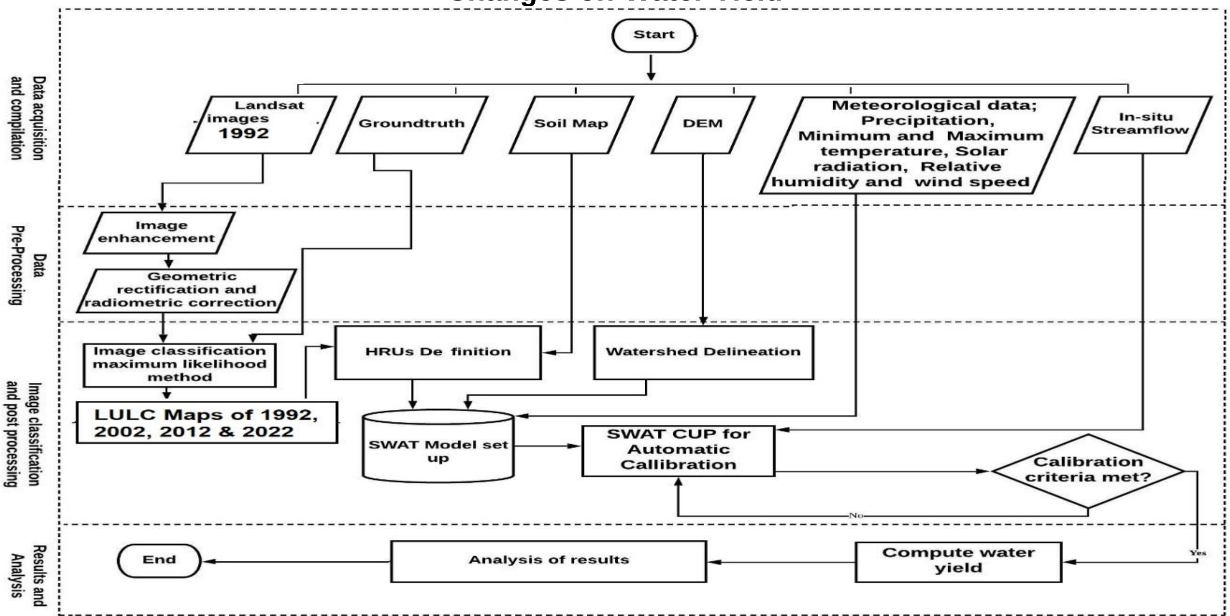


Figure 02: Flowchart For Evaluating the Impacts of Land Use Land Cover and Climate Changes on Water Yield



Method

Some of the explicit processes used include; simulation of precipitation (rainfall) changes.The classified image of 1992 was applied in the soil water assessment tool (SWAT) model. This section also employed SWAT to assess the impact of land use land cover and climate on water resources. The model is applied since it is flexible and has extensive range coverage in the assessment of water properties in the historical, present, and future. Also, it is common among hydrologists because of its ability to conduct calibration easily. The method uses spatialand meteorological data as contained in Figure 2 which describes all the procedures employedto accomplish the task.

Soil Water Assessment Tool Modification and Set-Up

The SWAT was run in the Arc SWAT 2012 interface, which works as an extension of ArcGIS 10.3 software. The SWAT model is obtained from https://swat.edu/software/arcswat/ (accessed on 31st January 2024). The first step needed during the model run set-up is the watershed delineation using a digital elevation model (ASTER GDEM), and the topographic characteristics of the watershed are estimated. Analysis of hydrological response units (HRU),in which, layers of land use land cover and soil maps were added, and slope ranges were defined. Subsequently, climate station data were added. The Input parameters were edited, checked, and validated through data quality checking. After running the model successfully, sensitivity, calibration, and validation were carried out. The sub-basin outlet is added based onthe location of the hydro-gauging station. The main purpose of adding an outlet point at the Jimeta Bridge monitoring station is for comparison between simulated and observed discharge.

Land use and soil maps are inputs to determine land/soil categories required for the establishment of hydrological response units (HRU). The SWAT categorizes the closest climate stations to the centroid of the sub-catchment and applies to all the HRUs inside the sub-basin. Modification of the SWAT model which involves the climate and soil parameters in the database. For the climate, SWAT requires daily variables to populate the weather matrix with averages for each month of the year over the total period covered by the station. The parameters are generated from a daily record of the observed data (ideally more than 30 years). For this study, the climate data is from 1990-2020 while discharge data is from 1990 - 2023. Some of the climate parameters that are essential to modify the weather generator (WGN) database in the SWAT model are; the latitude of the climate station (WLATITUDE), Longitude of the climate station WLONGITUDE, and Height of the climate station in meters above mean sea level (WELEV) etc. Soil information varies from place to place, so modification of the soil database in the SWAT is important for better modelling of water resources within the layers of soil. The soil parameters required to modify the SWAT models include; Soil hydrographic group (HYDGRP), Maximum rooting depth for soil profile (SOL_ZMX) (mm) etc. Thus, the SWAT model simulates according to the water balance equation (1).

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

where SW_t = Final soil water content (mm), SW_o = Initial soil water content on dayi (mm),t = time (days), R_{day} = amount of Precipitation on dayi (mm), Q_{surf} = amount of surface runoff on dayi (mm), E = amount of evapotranspiration on dayi (mmH_2O), W_{seep} = amount of water entering the vadose zone from the soil profile on dayi (mm), and Q_{gw} = amount of return flow on dayi (mm).

Soil and Water Assessment Tool Calibration

The land use land cover, DEM, Soil, and climate data (precipitation, minimum and maximum temperature, solar radiation, relative humidity, and wind speed) were applied as SWAT inputs. The observed monthly discharge (2000 – 2023) at Jimeta Bridge point was applied for calibration and validation. The model was calibrated from 2000 – 2013 (14 years).The SWAT-cup 2012 software developed by Abbaspour et al. (2007) was applied for sensitivity analysis of the calibration and validation of the SWAT model.

The global sensitivity analysis method was used to test 10 parameters with 500 runs (eachrun has various combinations) performing parallel with calibration. The fresh parameters obtained during the calibration of the model were used for validation of the model. The Sequential Uncertainty Fitting algorithm (SUFI-2), a semi-automatic inverse modelling procedure in the SWAT-CUP 2012 software, was selected because of its ability to handle and analyse many parameters in the smallest number of models runs (Abbaspour et al., 2017).

Soil and Water Assessment Tool Validation

The SWAT model performance was validated by applying monthly observed streamflow of Jimeta Bridge station (BN02) after calibration. Initial sensitivity analysis was carried out using the SUFI-2 method employed in the SWAT CUP 2012 software package (Abbaspour etal., 2004). The sensitive parameters are applied for calibration. The model was validated from2014 – 2023 (10 years). The monthly record for the gauge station was used for the calibrationand validation. Performance of the SWAT model was evaluated quantitatively by using the coefficient of determination (R^2), which, describes the rate of collinearity among the simulated and observed data, and ranges from 0 to 1. R^2 assesses the effectiveness of model simulation inreplicating the change of observed data generally R^2 data is more than 0.5 indicating satisfactory model performance in water resources simulation (Arnold et al., 2012).

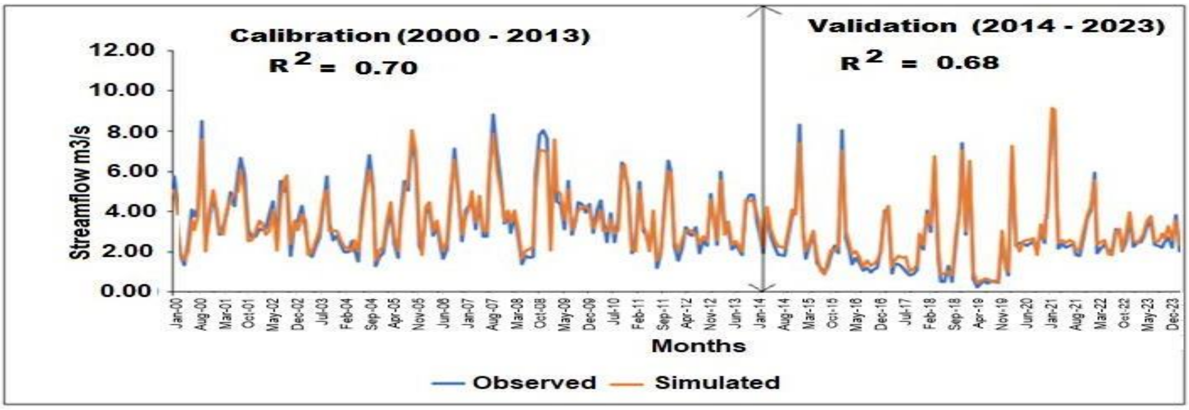
Results and Discussion

There are two main results presented in this study namely; (a) soil water assessment tool calibration and validation, and (b) impact of land-use change and climate variability on water yield, evapotranspiration (ET) and precipitation. The presented results shall contribute significantly to sustainable water resources and the monitoring of disasters caused by water.

Soil Water Assessment Tool Calibration and Validation

The observed and modelled monthly discharge at the Jimeta bridge outlet point or discharge point is demonstrated in Figure 4. The calibration period starts from January 2000 to December 2013 while the validation period from January 2014 to December 2023. The R^2 is 0.70 for the calibration period. Whereas 0.68 R^2 for the validation period. Based on Moriasi etal. (2007), for the calibration period, the values demonstrate that the SWAT model for the YolaBenue River Basin was deemed as a “good” performance for calibration and validation times.Consequently, a similar outcome was reported by Gao (2018) where the model demonstrates good discharge modelling performance in the catchment of Bukit Merah Reservoir, with the R^2 of 0.87 and 0.69 for calibration and validation periods respectively. For the NSE method, the SWAT output of 0.79 for calibration and 0.60 for validation periods. The performance of the SWAT model was regarded as “very good” in the calibration period while “satisfactory” inthe validation period.

Figure 03: Calibration and Validation at Rantau Panjang Streamflow Station



The performance of the SWAT model for the period of calibration is improved than that of validation this might be because of ineffectively taken in to account the temporal variations in the SWAT model parameters.

Effect of Land use Land cover Change and Climate Variability on Water Yield, Evapotranspiration (ET) and Precipitation

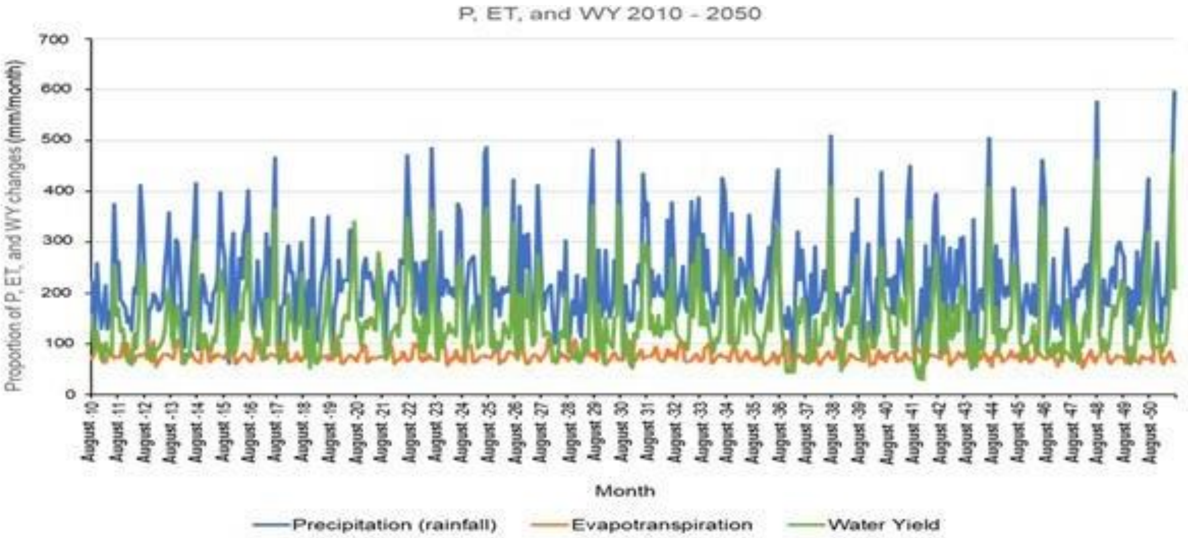
The impacts of LULC and climate changes on hydrological components like precipitation in the study area were analysed yearly. In addition, an outlet technique was used to assess the hydrological influence of climate change, in which simulations for the years 2010 - 2020 using the SWAT model were performed by applying LULC maps of 1992. Likewise, prediction for the year 2021 to 2050 using the same model was performed using the same land use land cover,with the same climatic record. This method of assessing the hydrological influence of climatechange demonstrates the hydrological effect of climate variability since the SWAT model is designed to simulate the long-term impacts of climate change on water resources (Ebrahimian*et al.*, 2016).

The yearly evapotranspiration (ET), Precipitation and water yield were estimated based on incessant simulations for 11 years (2010 – 2020) and unceasing predictions for 30 years (2021– 2050). The results of these simulations demonstrate that hydrological components of the basin have been altered. The changes in the yearly water yield, evapotranspiration, and precipitation due to land use land cover changes and climate variability of the study area were demonstrated in Figure 5. The forest area reduction may result in not only a decrease in the treewhich considerably reduces ET from both canopy intervention and plant transpiration, decreases ground vegetation leaf litter. The non-availability of vegetation results in a negative impact on topsoil (Anand et al., 2018). Numerous studies have examined the correlation between LULC changes and climate variability on hydrological components in tropical regions (Ebrahimian *et al.*, 2016; Romano *et al.*, 2018; Anand *et al.*, 2018) and the results are similar to this study.

The variation in yearly ET ranges from 846.64 mm decrease of 803.00 mm (-3.6%). The opposite influence was observed in the water yield and precipitation of the basin and these changes range from 1162.03 mm to 1658.74 mm (31.1%) and 1155.03 mm to 1644.81 mm (17.4%) increased respectively from the simulated and projected 2010 to 2050. Therefore, a large fraction of precipitation is transformed into water yield, which occurs because of surface runoff. An increase in built-up area (urbanization) will decrease vegetation coverage therefore causing a reduction in ET. Extension of impervious areas (such as buildings and roads) can change water yield because it reduces infiltration. As the built-up area rises, less water infiltrates into the soil consequently leading to less soil water storage. The analysis of the results of the SWAT simulated from 2010 – 2020 using the land use land cover of 1992, for the basin, demonstrates that the water yield has risen, while precipitationand evapotranspiration have declined (Figure 5). Similarly, the analysis of the results of the SWAT predicted from 2021 – 2050 using the same land use land cover for the basin shows thatthe water yield and precipitation have increased, while evapotranspiration has declined (Figure5).

Based on the hydrological simulation, the outcomes of the study provide a robust sign that land use land cover changes, and climate variability have changed the hydrological components of the basin. The study shows that distinction in land use land cover as a result of deforestation expansion of agricultural land, and built-up area as well as climate change has increased simulated and predicted water yield and precipitation and compatibly reduced the annual evapotranspiration. Several studies have examined the correlation between land use land cover changes and climate variability on hydrological components in tropical regions (Ebrahimian et al., 2016; Romano et al., 2018; Anand et al., 2018) and the results are similar to this study.

Figure 04: Result of Simulated and Predicted Rainfall, Evapotranspiration and Water Yield from 2010 – 2050



Discussion

Land use land cover (LULC) and climate variability effects on water yield have become one of the global essential issues in sustainable development. Hence, satellite systems have the potential to provide useful data that can be used in the SWAT model for precise estimation of water yield (Anand et al., 2018; Kundu et al., 2017). The land use land cover changes, such as excessive agricultural activities, urbanization, and deforestation, lead to severe infiltration rate on the earth surface. Thus, this study bridges the gap by examining the LULC influence on water yield for a long-term period. The role played by climate variability on water yield changes, especially in precipitation, evapotranspiration and water yield changes in the watershed for an agricultural-based economy in Yola Benue River Basin Adamawa State werealso assessed using the SWAT model method. These achievements are crucial for an effectiveecological planning, restoration and guidance for regional socio-economic development and management.

Consequently, the results attained shall provide a significant scientific basis and input to three main sectors of the society, these include the environment, economy, and related industries. The result can serve as a means for water monitoring, which will support in managing the rising of water demand (such as agriculture, domestic, and industries) and tragedy triggered by water. Sufficient comprehensive and understanding of land use land cover and climate changes influences, on water yield, evapotranspiration and precipitation as well as causes and consequences of these phenomena, for better management and sustainability of the ecosystem shall be accomplished. Economically the results will contribute to the understanding of the degree of urbanization in the planning and distribution of resources within the give area. Equally, it offers information to improve the land use land cover changes and climate at various scale. Also, it serves as dependable spatial details and contents for land use land cover and climate variability to make a fundamental decision by policymakers (landscape planners). Similarly, it is useful for assessing the influence of natural and anthropogenic activities on the environment, mainly on the extension of agricultural and the reduction of theforest. These developments could result in a decrease or increase in water yield, which influences soil erosion. Also, the results will be highly significant for efficient land use planning, ecological restoration and management, addressing water challenges as well as guidance for regional socio-economic development. The results are supportive in fast-trackingthe accomplishment of the United Nations Sustainable Development Goal 6 of 2030 agenda.

Conclusion

This study demonstrates the capability of remotes sensing satellite-based as a means for evaluating the effects of land use land cover and climate change on water yield in Yola Benue River Basin Adamawa State. The influence of land use land cover and climate changeson water yield, evapotranspiration and precipitation were achieved, via soil water assessment tool. The climate and spatial data were used as input data to the model. The simulated results were highly satisfactory. According to the simulation results, it was concluded that the land use land cover and climate variability both contributed to the increase in water yield and precipitation and a decrease in evapotranspiration. The influence of land use land cover and climate change is because of the variation in curve number (CN) values. CN values record higher with the rises in the settlement, agricultural land, and forest areas. The ET decrease to -3.6%. The opposite influence was observed in the water yield and precipitation of the basin by 31.1% and 17.4% increased respectively from the simulated and projected of 2010 to 2050. Change in curve number values is increasing with the time that may have an effect on the water resources of the region in the future with a decrease in evapotranspiration, increased in precipitation and water yield. These impacts can be considered in development, management, and planning approaches of water resources for the near future.

Recommendation

(a) The SWAT model modified should be used in other parts of the world since each area requires a new database modification table, because each area has its own dissimilar climate and spatial data. Hence, forthcoming studies should focus on modifying the SWAT model for a new study area.

(b) The modified QUEST-GSI methodology should be used in other regions of the country to check its feasibility.

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