Modeling climate and landuse change impacts on streamflow and sediment yield of an agricultural watershed using *SWAT*

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Abstract: Quantifying the hydrological response due to changes in climate and land-use is imperative for the proper management of water resources within a watershed. The impact of climate and land-use changes on the hydrology of the Upper Ebonyi river (UER) watershed, South East Nigeria, was studied using the Soil and Water Assessment Tool (SWAT) hydrological model. A climatological time series analysis from 1985-2014 using non-parametric test showed significant negative trends in precipitation and relative humidity trend while minimum and maximum temperature, solar radiation and wind speed showed significant positive trends. Future hypothetical land-use change scenarios representing urbanization and conversion of forest to agricultural land were combined with future downscaled climate model (CSIRO-Mk3-6-0) and simulated in SWAT model. Scenario 1 represents urbanization and climate data of 2020-2030; Scenario 2 represents urbanization and climate data of 2040-2050; Scenario 3 represents conversion of forest to agricultural land and climate data of 2020-2030 and Scenario 4 represents conversion of forest to agricultural land and climate data of 2040-2050 while the Baseline Scenario is the present land-use and climate data of 2005-2014. Relative to the Baseline (2005-2014), the results showed a decrease in streamflow by 10.3%, 26.2%, 11.8% and 26.72% for Scenarios 1, 2, 3, and 4 respectively, while sediment yield decreased by 7.54%, 19.4%, 11.1% and 9.01% for Scenarios 1, 2, 3, and 4 respectively. The results suggest development of adaptation strategies to cope with the predicted hydrological conditions under future climate and land-use change in the watershed.

Keywords: climate change, land-use change, swat model, hydrology, upper ebonyi watershed

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1 Introduction

The hydrologic response of watersheds to climatic (rainfall and temperature) and vegetation (land use) change is an important component of water resource planning and management (Vorosmarty et al., 2000; Khoi and Suetsugi, 2014). Anthropogenic activities such as burning of fossil fuels and changes in the vegetative cover are the leading cause of global warming and have increased Green House Gas concentrations (GHG) in the atmosphere. The United Nations Intergovernmental Panel on Climate Change (IPCC) reported that between 1906-2005, temperature has increased at a rate of 0.074± 0.018°C per decade and is projected to rise by 4°C in 2100 (IPCC, 2007). Climate change have significant impact on the hydrologic cycle and have resulted in reduction of available freshwater and decrease in annual average runoff, increased evaporation rates and rainfall variability (Adams and Peck, 2008). Within the African continent, the sub-Saharan, particularly, Nigeria is particularly vulnerable because agricultural production depends mostly on rainfall (Abiodun et al., 2011). Evidence of climate change in Nigeria has been reported by Enete and Amusa (2010) to include shifts in rainfall regime and increased temperature etc. Changes in landuse through conversion of forest to agricultural land (deforestation) and urbanization alters the hydrologic cycle and components like streamflow volume and rate,

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evapotranspiration, infiltration etc.

Climate and landuse change impacts are related to the hydrology of a watershed. An effective watershed management integrates these complex relationships among climate, landuse cover, soil, water and the environment. Under changing conditions, hydrologic models can be employed as management tool to create scenario and simulate hydrological components in a watershed (Mango et al., 2011). Different hydrologic models have been developed and applied to help understand such interactions. They provide a framework for investigating the complex effects of landuse change (Wang et al., 2014; Khadka, 2012; Gyamfi et al., 2016), climate change (Aich et al., 2014; Yira et al., 2017; Fang et al., 2015) and combined impacts of climate and landuse changes on watershed hydrology (Legesse et al., 2003; Qi et al., 2009; Sead et al., 2010; Mango et al., 2011; Khoi and Suetsugi, 2014). Sead et al. (2010) studied the impacts of land use and climate change on streamflow in the Blue Nile River using the Soil and Water Assessment Tool (SWAT) model. The simulated results showed that, in the future, changes in climate and land use will have a significant impact on streamflow. Mango et al. (2011) applied the SWAT model to assess the hydrological impacts to changes in landuse and climate change in the Mara river basin, Kenya. They reported that further deforestation would increase peak flows and reduce dry season flows while rising temperature caused by climate change will increase evapotranspiration and reduced runoff. Qi et al. (2009) applied the Precipitation Runoff Modeling System (PRMS) model to evaluate the hydrologic response to changes in climate and landuse in North Carolina. They reported that the catchment is more sensitive to changes in climate than landuse change, though both can cause significant water quantity and quality problems. Gyamfi et al. (2016) reports the impacts of various land use and cover change in the olifants Basin, South Africa. They reported a 46.97% increase in runoff as a result of decrease in rangeland while agricultural land, urban and forest lands were increased. Khoi and Suetsugi (2014) studied the impacts of climate and land-use changes in *Be* catchment Vietnam. They reported an increase in temperature and rainfall over the years has led to an increase in annual streamflow and sediment yield by 28.0% and 46.4%.

Climate change impacts on Nigeria have been reported by (Bello, 1998; Abiodun et al., 2011; and Oguntunde et al., 2011). There are limited studies on hydrological modeling of climate and landuse change on Nigeria's watershed. Hydrological modeling studies in major basins in Africa especially Nigeria, have been limited by availability of observed data, since most basins are ungauged (Ndulue et al., 2018; Sead et al., 2010).

In this study, SWAT model was used to assess the impact of climate and landuse change on stream flow and sediment yield in an experimental watershed, Upper Ebonyi river (UER) watershed. Specific objectives include, to (i) verify and quantify the extent of climate change in observed meteorological data using Non-parametric test (Mann-Kendall and Sen's slope estimator) and (ii) simulate future climate and landuse change scenarios on streamflow and sediment yield using SWAT model.

2 Materials and method

2.1 Study area

The study was carried out in the Upper Ebonyi River watershed, Nsukka, South Eastern Nigeria (Figure 1). It is located between latitude 6.87°N to 6.93°N and longitude 7.55°E to 7.62° E and it is the experimental catchment for Soil & Water Resources, Department of Agricultural and Bioresources Engineering, University of Nigeria, Nsukka. The study area is a sub-watershed of River Ebonyi head water catchment (Campling et al., 2002). Based on its location, it shares the characteristics of Guinea Savannah vegetation type of Northern Nigeria and the rain forest belt of the South, with elevation ranges between 195 and 498 m above sea level. Mean annual rainfall is between 1600-2000 mm, with bimodal peaks in July and September (Igwe et al., 2013); while dry season runs through December to February. The geology of the area comprises of sandstone escarpment of the Udi-Nsukka Cuesta and the shale peneplains of the Cross River Plains (Campling et al., 2002).

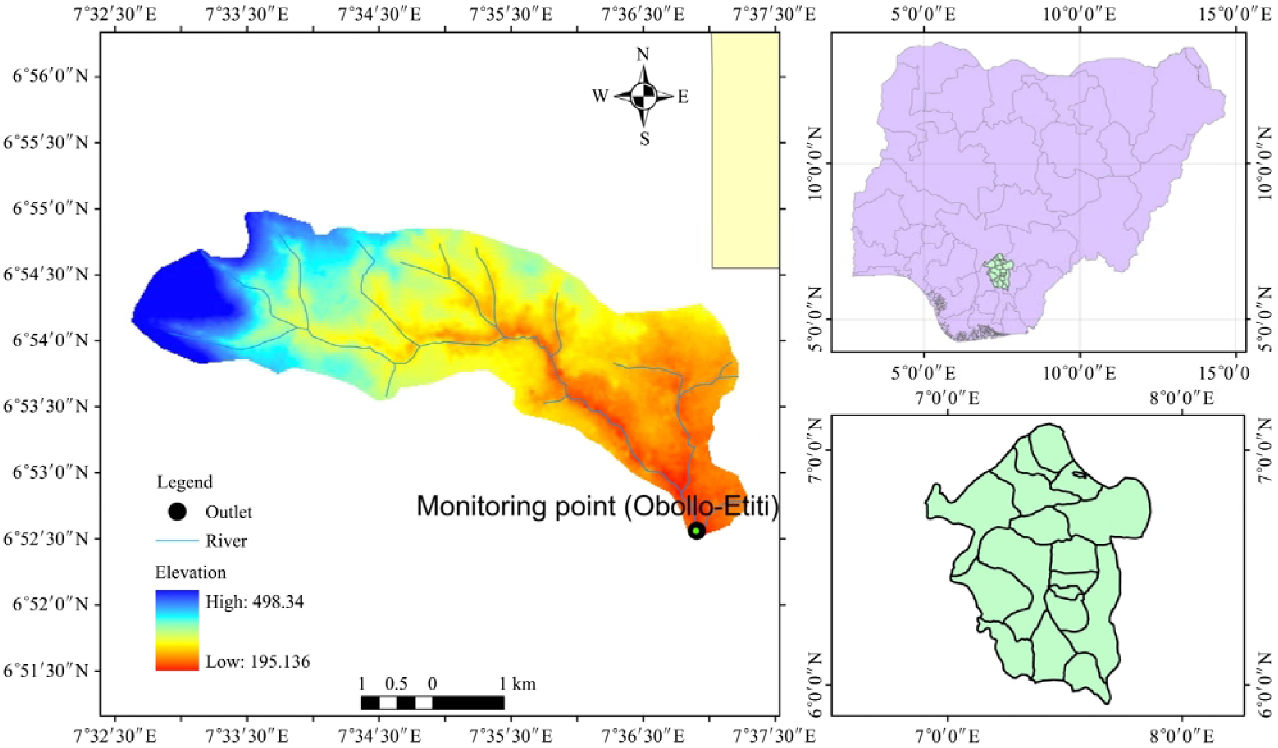


Figure 1 Location of Upper Ebonyi Watershed showing drainage network and Outlet on the map of Nigeria and Enugu state in Udenu LGA

2.2 Hydrological modeling using SWAT model

SWAT - Soil and Water Assessment Tool, is a semi-distributed, continuous time, processed-based river basin or watershed scale model, developed to predict the impact of management on water, sediment, and agricultural chemical yields in ungauged watersheds (Arnold et al., 1995). SWAT when interfaced in ArcGIS is called ArcSWAT was used in this study. Details of model configuration, structure and processes is found in Arnold et al. (1998) and Neitsch et al. (2011).

A previous study confirmed the application of SWAT model and found suitable to model the hydrology of the UER watershed. A summary of SWAT model inputs - Topography, soil map, landuse map and climate as described in Ndulue et al. (2018) is given. A 30 m resolution SPOT-5 digital elevation model (DEM) was used processed in ArcGIS 9.3 to generate elevation, terrain attributes, contour lines and stream network. The soil map was derived from the dominant soil map of Nigeria and the Harmonized World Soil Database (HWSD v1.2) and is classified as Plinthosols. The landuse map was developed from Landsat spectral satellite image of December 17 2001 (Ndulue, 2015). Using supervised classification-maximum likelihood algorithm in ENVI 4.7 with an overall accuracy of 85%, 5 different landuse were identified as settlement (11.64%), water body (1.13%), riparian vegetation (9.68%), cultivated area (29.73%) and upland vegetation (47.82%). Historical weather data was downloaded from http://globalweather.tamu.edu/. Details of the model setup, run, sensitivity analysis, calibration and validation are reported in (Ndulue et al., 2018). Daily observed streamflow and sediment yield were used for calibration and validation. The statistical results between observed and simulated were within the recommended benchmark given by Moriasi et al. (2007), that is (R^2, NSE > 0.5, PBIAS ±15 < PBIAS < ±55, for streamflow and sediment yield).

2.3 Climate data

Observed daily rainfall, minimum and maximum air temperature, relative humidity, wind speed, solar radiation was downloaded from http://globalweather.tamu.edu/ and used for trend analysis test. The data covers the reference period of 1985 to 2014. MarkSimGCM (http://gismap.ciat.cgiar.org/MarkSimGCM), was also used to obtain future climate data. MarkSimGCM is a weather generator that works on the principle of a third order Markov chain process (Jones and Thornton, 1993; 1997; 1999; 2000). It employs both stochastic and climate typing to downscale future climate projections for the IPCC GCMs (Jones and Thornton, 2013). MarkSIMGCM, is a globally accepted model (Hijmans et al., 2005; Trotochaud et al., 2016) and has been calibrated with WorldClim dataset which include historical weather database such as NOAA, NCDC and GHCN.

MarkSimGCM was downscaled to the Upper Ebonyi watershed (Figure 2), with boundary conditions set by CSIRO-Mk3-6-0 global circulation model and Representative Concentration Pathway (RCP 2.6). RCP 2.6 assumes an equivalent CO_2 ~490 ppm, radiative forcing of 2.6 W m^{-2}(Van Vuuren et al., 2011), global population above 9 billion and high global economic growth. The predicted meteorological variables for the period 2020-2030 and 2040-2050 were used as input to the SWAT model as described by Trotochaud et al. (2016).

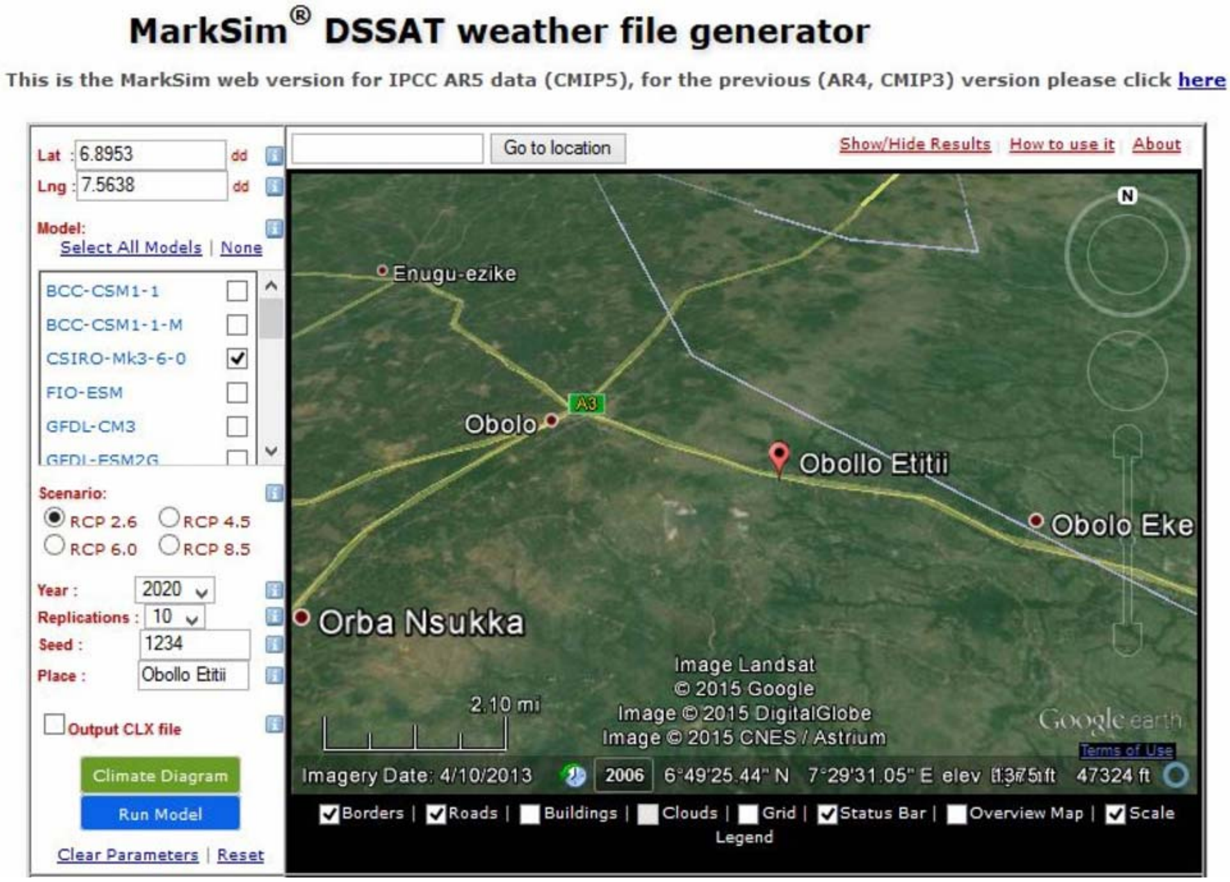


Figure 2 Upper Ebonyi watershed in MarkSimGCM

2.4 Trend analysis

Statistical tests are employed for trend and seasonal variation in environmental time series. They have been applied in hydro-climatological studies, water quality, environmental monitoring and climate change studies (Partal and Kahya, 2006; Oguntunde et al., 2011; Onyutha et al., 2015; Gao et al., 2011; Diop et al., 2017; Karmeshu, 2012; Gilbert, 1987; Mustapha, 2013). The non-parametric test is usually preferred over the parametric test because it does not consider the skewness of the data, normal distribution and independence (Gilbert, 1987).

The Mann-Kendall test (Mann, 1945; Kendall, 1975) is mainly used for detecting monotonic trend. The test statistics (S) is given as:

$$Z=\begin{cases}\dfrac{s-1}{[\sqrt{VAR(S)}]} & if \quad S>0\\ 0 & if \quad S=0\\ \dfrac{s-1}{[\sqrt{VAR(S)}]} & if \quad S<0\end{cases} \tag{1}$$

where:

$$S=\sum_{k=1}^{n-1}\sum_{j=k+1}^{n} sign(x_j-x_k) \tag{2}$$

$$sign(x_j-x_k)=\begin{cases}x_j-x_k=1 & if \quad x_j-x_k>0\\ x_j-x_k=1 & if \quad x_j-x_k=0\\ x_j-x_k=-1 & if \quad x_j-x_k<0\end{cases} \tag{3}$$

$$VAR(S)=\frac{1}{18}[n(n-1)(2n-5)-\sum_{p=1}^{g} t_p(t_p-1)(2t_p+5)] \tag{4}$$

where, S is the Mann-Kendall test value; X_j and X_i are the sequential data values, g is the number of tied groups (a tied group is a set of sample data with the same value); t is the number of data points in the gth group. The null hypothesis, H_o, is rejected if $-Z_{1-\alpha/2} \geq Z \geq Z_{1-\alpha/2}$, where α is the significant level.

A positive value of Z indicates an increasing trend, and a negative value indicates a decreasing trend. An estimate of true slope of trend was computed using Sen's non-parametric method (Gocic and Trajkovic, 2013), which is preferred over regression slope because it is more robust (Tabari et al., 2015).

The slope (Q_i) of all data points is computed as:

$$Q_i = \frac{x_j}{j} - \frac{x_k}{k} \quad \text{for } i = 1, 2, \ldots, N \tag{5}$$

where, Q_i is slope estimator; x_j and x_i are data values at time j and k (j>k). Gocic and Trajkovic (2013) gave a detailed description and formulae of the Sens's slope estimator

3 Results and discussions

The MAKESEN 1.0 (2002) (Mann-Kendall test for trend and Sen's slope estimates) developed by the Finnish Meteorological Institute was used for the analysis. Table 1 and 2 show the summaries of the annual and monthly analyses.

Table 1 Mann-Kendall test statistics for Annual minimum and maximum temperature, temperature, precipitation, relative humidity, wind speed, and solar radiation in the UER catchment

Time series	First year	Last Year	N	Test Z	Signific.	Q
Precipitation (mm)	1985	2014	30	–1.28	*	–13.002
Max. Temperature (°C)	1985	2014	30	3.53	***	0.062
Min. Temperature (°C)	1985	2014	30	2.28	*	0.024
Relative Humidity (%)	1985	2014	30	–2.85	**	–0.132
Solar Radiation (MJ/m²/day)	1985	2014	30	2.75	**	0.038
Wind speed (m/s)	1985	2014	30	2.78	**	0.005

Table 2(a) Summary of Mann-Kendall trend test for monthly maximum temperature, minimum temperature, precipitation

Month	Max. Temperature			Min. Temperature			Precipitation		
	Z	Signific.	Q	Z	Q	Significance	Z	Q	Significance
January	2.94	**	0.057	–0.89	–0.026		–0.19	–0.015	
February	3.16	**	0.060	1.57	0.059		–0.84	–0.122	
March	3.45	***	0.144	2.14	0.040	*	–2.09	–1.320	*
April	1.38		0.048	1.86	0.022	+	–1.64	–2.088	
May	1.54		0.058	2.03	0.020	*	–1.35	–2.556	
June	2.71	**	0.081	3.39	0.030	***	0.24	0.398	
July	3.75	***	0.070	4.64	0.049	***	0.99	1.236	
August	2.95	**	0.048	3.80	0.038	***	–0.58	–1.261	
September	2.37	*	0.033	3.23	0.022	**	–0.58	–1.278	
October	2.14	*	0.030	3.02	0.021	**	0.58	0.989	
November	2.79	**	0.047	1.80	0.020	+	–1.01	–0.299	
December	2.79	**	0.063	–0.16	–0.005		–1.91	–0.290	+

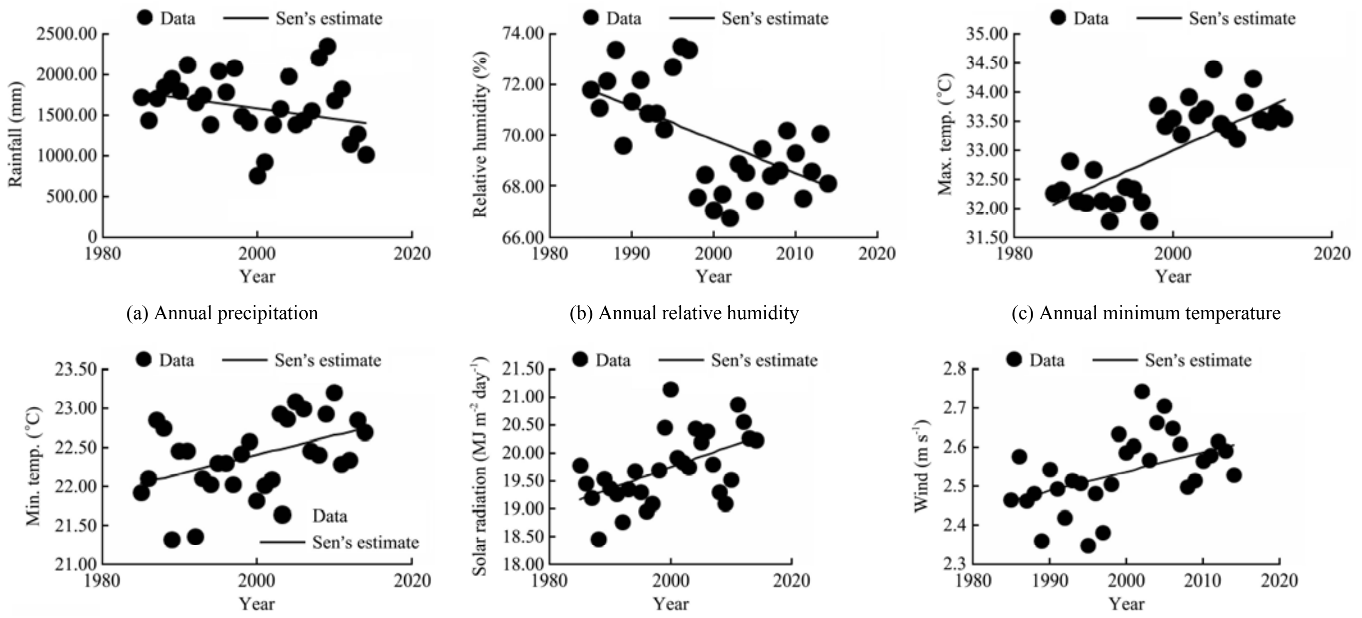
Table 2(b) Summary of Mann–Kendall trend test for monthly, relative humidity, solar radiation and wind speed

Month	Relative Humidity			Solar Radiation			Wind speed		
	Z	Signific.	Q	Z	Q	Significance	Z	Q	Significance
January	2.94	**	0.057	0.31	0.006		1.01	0.004	
February	3.16	**	0.060	–0.41	–0.011		1.56	0.011	
March	3.45	***	0.144	2.16	0.099	*	0.78	0.005	
April	1.38		0.048	–0.28	–0.009		2.43	0.013	*
May	1.54		0.058	1.05	0.027		1.33	0.011	
June	2.71	**	0.081	1.12	0.033		1.10	0.007	
July	3.75	***	0.070	2.71	0.079	**	2.79	0.005	**
August	2.95	**	0.048	2.17	0.086	*	3.03	0.008	**
September	2.37	*	0.033	1.22	0.048		0.06	0.000	
October	2.14	*	0.030	0.71	0.025		0.13	0.000	
November	2.79	**	0.047	2.75	0.043	**	0.36	0.001	
December	2.79	**	0.063	0.44	0.004		–0.10	0.000	

Note: *** if trend at α = 0.001 level of significance, ** if trend at α = 0.01 level of significance, * if trend at α = 0.05 level of significance, + if trend at α = 0.1 level of significance.

3.1 Analysis of trend variations in the UER watershed

Table 1 summarizes trends in minimum and maximum temperature, precipitation, relative humidity, wind speed, and solar radiation in the Upper Ebonyi river watershed from 1985-2014 and is shown graphically in Figure 3. Minimum and maximum temperature, solar and wind speed shows positive trend while rainfall and relative humidity shows negative trend. Also, the table shows significant positive trend for annual maximum temperature of 0.062°C and 0.024°C for minimum temperature. This implies that over the period, maximum and minimum temperature has increased by approximately 1.8°C and 0.72°C respectively. This is similar to the findings of Oguntunde et al. (2011) and Abiodun et al. (2011), though our results differ in magnitude but agree in trend. Abiodun et al. (2011) showed that between 1971-2000, maximum and minimum temperature showed significant positive trends of 0.014°C per year and 0.025°C per year respectively, indicating that maximum temperature increased by 0.5°C while minimum temperature increased by 0.8°C. Solar radiation and wind speed were also observed to show significant trend of 0.038 MJ m^{-2} day^{-1} and 0.005 m s^{-1} respectively.



(a) Annual precipitation (b) Annual relative humidity (c) Annual minimum temperature

(d) Annual minimum temperature (e) Annual solar radiation (f) Annual wind speed in the UER catchment (1975-2014)

Figure 3 Linear trends in mean

Furthermore, the analysis shows statistically significant negative trend for rainfall (–13.2 mm yr^{-1}). This agrees with the report of Oguntunde et al. (2011), Ogungbenro and Morakinyo (2014), and Abiodin et al. (2011), Oguntunde et al. (2011) reported that rainfall showed negative trend of 7.0 mm yr^{-1} over the 1961-1990 periods. According to Abiodun et al. (2011), with the ensemble dataset, they reported that rainfall showed a negative trend of 2.67 mm yr^{-1}. Relative humidity was also observed to show a negative trend of 0.1% over the period. This agrees with the analysis of Uguru et al. (2011). The null hypothesis, Ho, was therefore rejected for annual minimum and maximum temperature, precipitation, relative humidity, solar radiation and wind speed time series. That is there was trend in annual minimum and maximum temperature, precipitation, relative humidity and wind speed.

The Mann-Kendall test was further applied to the data series for monthly precipitation, maximum and minimum temperature, solar radiation and wind speed as summarized in Table 2(a) and 2(b). There were significant trends in most of the monthly maximum temperature and relative humidity except for April and May. In the case of the monthly precipitation, there were no significant trends except for March and December.

3.2 Climate change scenario

An analysis of historical observations from 1960-1990 and downscaled MarkGCM data in order to validate the downscaled simulation for the UER watershed was carried out. Using precipitation for example and as shown in

Figure 4, the historical observations showed the bimodal peak of rainfall which is a characteristic of the area. A comparative study of observation between the historical and downscaled climate from the MarkSIM GCM showed that total mean monthly precipitation decreased by 66 mm (4.29%) and 72 mm (4.61%) when compared with climate data of 2020-2030 and 2040-2050 respectively as shown in Figure 4. Also Figure 4 shows a projected decrease in rainfall between February to September and an increase in rainfall amount between October to January. Oguntunde and Abiodun, (2012) reported a decrease in rainfall amount in the Niger River basin during the rainy season using the regional climate model, RegCM3 driven by ECHAM5. Yira et al. (2017) reported wetter conditions mixed with droughts in some months using the CCLM-CNRM and HIRAM-NorSEM model for the Dano catchment, Burkina Faso, West Africa.

Total mean monthly minimum and maximum temperatures increased by 4.94% and 3.45%, respectively, when compared with climate data of 2020-2030 and increased by 7.68% and 5.43%, when compared with climate data of 2040-2050 respectively, as shown in Figure 5 and 6. The predicted temperature was constantly higher than historical data for all months. Thus, temperature is expected to be higher in the future. This is in agreement with Yira et al. (2017) and Abiodun et al. (2011). Abiodun et al. (2011) applied nine GCMs and predicted that temperature is expected to increase by approximately 0.02°C to 0.04°C per year from 2000 to 2100.Yira et al. (2017) compared 6 RCMs-GCM for 2021-2050 with climate data between 1971-2000, they reported that all six climate models indicated a temperature rise in the future.

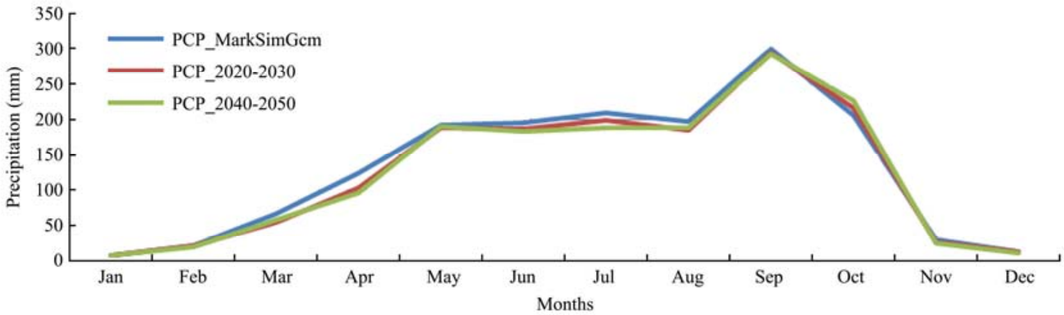


Figure 4 Comparison of historical and simulated mean monthly variation of precipitation by MarkSimGCM

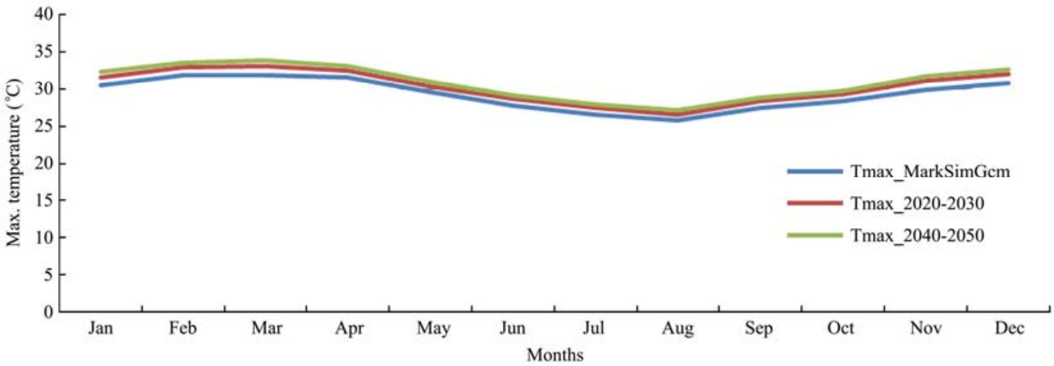


Figure 5 Comparison of historical and simulated mean monthly variation of maximum temperature by MarkSimGCM

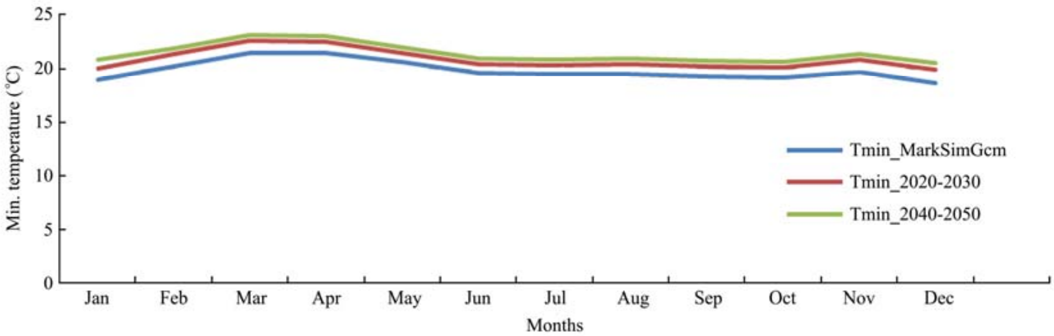


Figure 6 Comparison of historical and simulated mean monthly variation of minimum temperature by MarkSimGCM

3.3 Landuse change scenario

Based on the fact that the study area is a developing area, hypothetical landuse change scenario depicting economic growth and increased population was developed. Studies on changes in landuse in Nigeria and in the Southeast have reported decrease in vegetation cover (Forest) while Agricultural lands, urbanization or settlement have increased (World Bank, 1998; Ezeomedu and Igbokwu, 2013; Tappan et al., 2017). Cotillon (2016) reported that between 2000 and 2013, Forest land decreased by 20.41% and 45% respectively. In this study, we assumed that settlement (URBN) would increase by 6.27% and 16.25% between 2020 to 2030 and 2040 to 2050 respectively while a 3.72% and 12.55% increase in (AGRL) agricultural land for landuse of 2020 to 2030 and landuse of 2040 to 2050 was also implemented. Using the landuse update file in SWAT (lup.dat) (Guse et al., 2015; Pai and Saraswat, 2011), future changes in landuse was implemented in the UER catchment.

3.4 Responses to climate and land-use change scenarios analysis

Having simulated the hydrology of UER watershed reasonably well, the model was implemented in experimental mode to investigate the impacts of future climate and landuse change on streamflow and sediment yield using these four scenarios:

Scenario 1: Urbanization under the future climate of 2020-2030

Scenario 2: Urbanization under the future climate of 2040-2050

Scenario 3: Conversion of Forest to Agricultural land under the future climate of 2020-2030

Scenario 4: Conversion of Forest to Agricultural land under the future climate of 2040-2050.

For all scenarios, the baseline or control scenario is the present land-use and climate of 2005-2014.

Relating the baseline or control scenario to scenario 1, 2, 3 and 4, it is seen that streamflow decreased by 60.86 $m^3 s^{-1}$ (10.3%), 154.89 $m^3 s^{-1}$ (26.2%), 69.75 $m^3 s^{-1}$ (11.8%) and 158.04 $m^3 s^{-1}$ (26.72%) while sediment yield decreased by 83872.7 tons (7.54%), 21619.48 tons (19.4%), 12,343.92 tons (11.1%) and 10,016 tons (9.01%) respectively as shown in Table 3. This is also in line with similar research carried out by Aditya et al. (2013), Yeboah et al. (2013) and Yira et al. (2017). Aditya et al. (2013) reported a decrease of up to 40% in river flow as a consequence of decreasing rainfall and increasing temperature in River Volta basin while Yeboah et al. (2013) reported a decrease of 22% and 50% in the mean annual streamflow for the 2020s and 2050s in the White Volta basin and a 22% and 46% decrease in the mean annual streamflow for the 2020s and 2050s in the Pra basin.

Table 3 Comparison of scenario results to show% change in streamflow and sediment yield

Scenario	Streamflow ($m^3 sec^{-1}$)	Sediment yield (tons)	% change in streamflow	% change in sediment yield
Baseline	591.43	111,206.49	-	-
1	530.57	102,818.79	10.3	7.54
2	436.54	89,587.01	26.2	19.4
3	521.43	98,862.57	11.8	11.1
4	433.39	101190.49	26.72	9.01

Since the results showed that streamflow and sediment yield are on a decreasing trend in the future, development of adaptive and mitigation strategies to cope with the predicted hydrological conditions under future climate and land-use changes should be encouraged. These include development of small soil and water conservation structures like reservoir, development of water saving techniques like rainwater harvesting, proper management of water resources and reduction activities that increase CO_2 in the atmosphere like burning of fossil fuels and wood.

4 Conclusion

A climatological time series analysis from 1985-2014 using non-parametric test (Mann-Kendall test and Sen's slope) showed a decreasing trend in precipitation and relative humidity while minimum and maximum temperature, solar radiation and wind speed observations showed a positive increasing trend. CSIRO-Mk3-6-0 global circulation model, RCP 2.6, produced within the MarkSimGCM was downscaled to the UER watershed to obtain future climate data (2020-2030 and 2040-2050) and used as inputs to run SWAT model between the time periods. Scenarios representing future changes in landuse were combined with future data to assess hydrological impacts on streamflow and sediment yield. Four scenarios were created representing Urbanization and conversion of Forest to Agricultural land were run with the projected climate data of 2020s (2020-2030) and 2050s (2040-2050). Scenario 1 represents urbanization and climate data of 2020-2030, scenario 2 represents urbanization and climate data of 2040-2050, Scenario 3 represents conversion of Forest to Agricultural land and climate data of 2020-2030 and Scenario 4 represents conversion of Forest to Agricultural land and climate data of 2040-2050 while the Baseline study is present landuse and climate data for 2005-2014 period. The results showed that there was decrease in streamflow by 10.3%, 26.2%, 11.8% and 26.72% for Scenario 1, 2, 3, and 4 respectively while sediment yield decreased by 7.54%, 19.44%, 11.1% and 9.01% for Scenario 1, 2, 3, and 4 respectively. The result suggests development of adaptive and mitigation strategies to cope with the predicted hydrological conditions under future climate and land-use change.

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