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Impact of Landuse and Landcover Changes on Hydrological Components of the Oti Sub-Basin of Ghana

Steve Ampofo, Mercy Ama Boadi Manu, Boateng Ampadu, Melvin-Guy Adonadaga*

C. K. Tedam University of Technology and Applied Sciences (CKT-UTAS), School of Environment and Life Sciences, P. O. Box 24, Navrongo, Ghana.

**Corresponding Author: E-mail: madonadaga@cktutas.edu.gh. Tel: +233825025*

ABSTRACT

Landuse and landcover have over the decades been undergoing changes as a result of natural and human activities. These changes for a given area can be attributed to fluctuations in the infiltration ability of the land, leading to changes in the hydrological cycle of a given catchment area. This research assessed some of the impacts that landuse and landcover changes coupled with climate variations have on the hydrological components of the Oti sub-basin of Ghana using the Soil Water Assessment Tool (SWAT) with ArcGIS® interface for the development of models from which conclusions were drawn. The research incorporated into the SWAT system two landuse and landcover data: 1984 and 2013 which were modeled and evaluated alongside soil, slope and climate dataset. The results from running the model indicated a very significant change in landuse and landcover and a loss of forest cover which has negative effect on the hydrological components of the basin. Also, the rainfall trend analysis gave negative significant values of -2.28 and -2.78 for the two stations located at Zabzugu and Bimbila within the basin. Together, these changes have led to an increase in evapotranspiration (ET) and decrease in surface water, lateral flow and groundwater recharge. This is an indication that climate change impact on the basin is a function of the landuse and landcover changes. There is an urgent need for all stakeholders to help protect the basin from anthropogenic activities such as farming too close to the basin in order to prevent future water availability issues in the basin.

***Keywords:** SWAT, Landuse and Landcover, Runoff, Groundwater, Evapotranspiration, Lateral Flow.*

INTRODUCTION

Landcover is the vegetative cover of the earth surface which includes grassland, water, shrubs, forest, bareland, whereas landuse is the management and modification of the natural environment into built environment such as settlements and agricultural lands. Globally, the landuse and landcover over the decades have undergone certain changes which according to Bates *et al.* (2008) are predicted to have much effect on various phases of the human society, from agriculture to water supply. It is also said to have an influence on the topographic distribution of soil thereby bringing about changes in the hydrological components which include runoff, groundwater recharge, evapotranspiration (Hu *et al*., 2005; Awotwi, 2009; Awotwi *et al*., 2014). The study of landuse and landcover changes is thus imperative for the understanding of the global environmental change processes (Srivastava *et al.,* 2012).

Many studies have supported the notion that, changes in the landuse and landcover have had impact on the health of river basins (Nagendra, *et al.,* 2004; Welde, 2016; Welde and Gebremariam, 2017). These impacts that the changes have on the river basins have been of great interest in recent years since that can help in taking remediation measures (Ayana *et al*., 2014; Mousumi, 2016). For instance, the study of Tekeze dam watershed in northern Ethiopia on the effect of landuse and landcover dynamics on hydrological response of the watershed indicates that the Tekeze dam watershed had experienced some degree of changes in the landuse and landcover over a 22 year period where cultivated land increased, with grassland decreasing (Gizachew, 2017; Welde, 2016). These changes were consistent with the annual stream flow and sediment yield which both experienced increments. Thus a reflection of the impact of landuse and landcover dynamics on the hydrological components of the Tekeze dam watershed (Welde & Gebremariam, 2017).

The Soil Water Assessment Tool (SWAT) is a popular tool among watershed hydrologist for studying the impacts of agricultural activities and landuse management on the overall watershed health including streamflow and water quality (Ghosh, 2016; Ullrich and Volk, 2009; Pisinaras *et al.,* 2010 Rajib *et. al,* 2014). The model is capable of predicting long-period influences that climatic and environmental conditions changes coupled with hydrological factors have on large basins. This helps in the management and also observation of agricultural practices within a stipulated time in a basin.

Also, economic progress of most countries is inextricably tied to the development of the agricultural sector especially in the study area, where vast lands are at their disposal with about half the population into agriculture. Crop yield and its eventual economic implications is greatly dependent on irrigated agriculture in this era of climate change, especially in an area where the dry season period predominates the wet season, and where the river basin serves as a source of water supply for agricultural activities regardless of the climatic conditions.

Moreover, irrigated agriculture is dependent on stream flow, which is subjected to challenges including: changes in precipitation, temperature, and landuse and landcover (Kyei-Baffour and Ofori, 2006). These alterations in the water cycle and landuse and landcover therefore have implications on soil-water balance of a basin. The complexity of the combined effects of all these changes might sometimes be difficult to identify. It is therefore interesting, at a basin level to study carefully each element’s susceptibility to change, in order to identify their degree of change in a certain time period and their possible implications on the river basin. This study investigated the spatial and temporal changes in the landuse and landcover in the catchment area of the Oti sub-basin and its relationship with the hydrological components.

MATERIALS AND METHODS

Study area

The Oti sub-basin of Ghana is located along the eastern boarders of the Northern region and around the middle part to the northern side of the Volta region. It extends from about 10°50’ N to around 7°30’ N latitude geographical (Figure 1). It has its mean annual inflow into Ghana being about 276 m^3/s (Opoku-Ankomah, 1998) with a permanent flow, though most of its tributaries dry up during the period of the dry season. The tributaries in Ghana include So, Mo, and Kpasa rivers.

The Oti river begins in the Atakora Mountains at Boom, a forest reserve in Northern Benin, as River Pendjari. It passes through, and flows along, the border of Burkina Faso with Benin, Northern Togo highlands to Ghana, and finally drains into the Volta Lake to the east of Kete Krachi. According to Abdul-Razak *et al*. (2009), the total area of the basin is 17,942 km² and a total length of 936.7 km.

Thus it exhibits the following bio-physical characteristics: a single rainy season that starts from May and ends in October with harmattan winds that begin during the months of December to early February, and climatic conditions that make the lands suitable for crop growth. However, this sometimes does not become feasible as a result of effects from longer harmattan seasons, predominantly characterized by the following vegetative covers: grassland, intermingled with guinea savanna woodland which are symbolized by trees that are resistant to drought with examples being; acacia, baobab, shea etc. (GSS, 2005). The soil types present in the study area includes: lixisol, fluvisol, and ferric luvisol. The commonly produced crops are yam, maize, millet, guinea corn, rice, groundnuts, soya beans and cowpea as a result of the biophysical conditions present within the area.

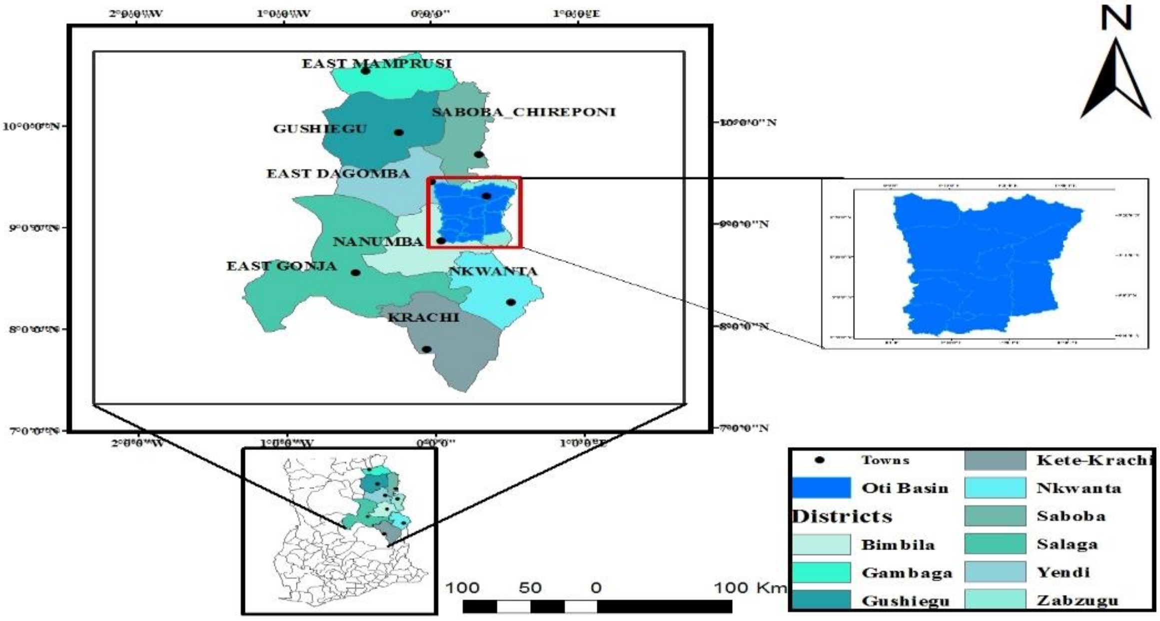

Figure 1: Map of Ghana showing the location of the study area

Description of SWAT model

The SWAT model is an appropriate software for basin characteristics analysis due to its ability to encompass data parameters such as: DEMs, climate, LULC, soil and all other hydrological parameters including discharge gauges that may be of need in order to ascertain water equilibrium.

SWAT is purposely for hydrological modelling and also used in forecasting the influence of land use and agricultural management parameters such as sediment loads, duration of chemical discharges in gauges-free watersheds, (Bouslihim *et al*., 2016). This can be realized by studying the relationship between LULC and soil moisture changes in a given period of time which in this study is from 1975-2013. It also takes into account studying complex watershed's drainage density by mapping the varying soils.

There have been many research works carried out using the SWAT model for calibrating and validating the impacts of LULC on water budget (Easton *et al*., 2008; Ullrich and Volk, 2009; Pisinaras *et al*.., 2010; Baker and Miller, 2013). For example, Baker and Miller (2013) showed land use impact on water resources in an East African watershed.

The SWAT model is a water balance equation which can be used to justify the hydrologic cycle that goes on in a basin. The model is given as:

$$SW_f = SW + \sum_{i=1}^{t}[R_{day} - (Q_{surface} + ET + W + Q_{ground})] \quad (1)$$

SW_f is final soil water content in day (mm); SW is initial soil water content in day (mm); t is time (days); R_{day} is daily precipitation (mm); $Q_{surface}$ is daily surface run-off (mm); ET is daily evapotranspiration (mm); W is daily percolation (mm) and $Q_{ground}$is daily groundwater flow (mm).

Model input data and their preparation

Two types of data were used for running the SWAT model namely: GIS data and climate data. Table 1 and Table 2 below provide details on the sources of the various datasets used for the SWAT model. The softwares used were ArcSWAT® extension of, ArcGIS ®.

Data Preparation

Landuse and Landcover data

Landuse and landcover datasets for the years 1984 and 2013 were obtained for the study area with about six (6) distributions namely: Decidous Forest (FRSD), Wetlands Non-Forested (WETN), Agricultural Land-Row Crops (AGRR), Urban (URBN), Forest (FRST), Water Body (WATR). A summary of the various LULC within the basin is presented in Table 1. The number of classes was six (6) namely: Savanna, Wetland, Urban, Forest gallery, Agricultural land and Water with Savannah having the largest land take in both 1984 and 2013 as 85.62 and 53.12% respectively. Table 1 shows the various land take for the individual LULC within the study for both 1984 and 2013.

Table 1: Landuse and Landcover Type Distribution in the Sub-basin

SWAT Codes	1984 Area %	2013 Area %
FRSD	85.62	53.12
WETN	0.62	3.49
AGRR	4.62	36.39
URBN	0.14	0.18
FIRST	7.97	5.77
WATR	1.03	1.05

FRSD; Decidous Forest, WETN; Wetlands Non-Forested, AGRR; Agricultural Land-Row Crops, URBN; Urban, FRST; Forest, WATR; Water Body

Soil Data

The soil data was downloaded from the Greenhouse Illinois website of FAO in the form of a zip file. Three different soil classes were identified in the study area with lixisol class of soil being the dominant soil type in the basin. Table 2 provides details on the various soil classes and their area of coverage. The importance of the soil data in the model was to help determine the soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layer according to each soil type.

Table 2: Soil Type Distribution in the Oti Sub-Basin

Soil Classes	Area(km²)	Land take (%)
Fluvisol	0.670	16.50
Lixisols	1.558	37.00
Ferric luvisol	3.805	46.50

DEM

Digital Elevation Model (DEM) with resolution 1 arcscene for the Oti sub-basin was used. The DEM was used for watershed delineation including stream definition, outlets and inlets definitions as well as calculation of the sub-basins parameters. The DEM map of the study area can be seen in the Figure 2. The DEM was also used to determine the slope of the study area, hence determining the seasonal offsets of the area with respect to water recharge and nature of land.

Climate data

The climate data consisted of data on rainfall, solar radiation, relative humidity, temperature and wind with the year range from 1979-2014, a period of 35 years. This was the last data prepared before commencing the SWAT model. This data had an objective of making use of available rain gauge data in the Oti sub-basin to check the possible change in the rainfall pattern and also justify the possible implications of these changes on stream flow for the benefit of irrigational activities within the environs of the basin.

SWAT Model Setup

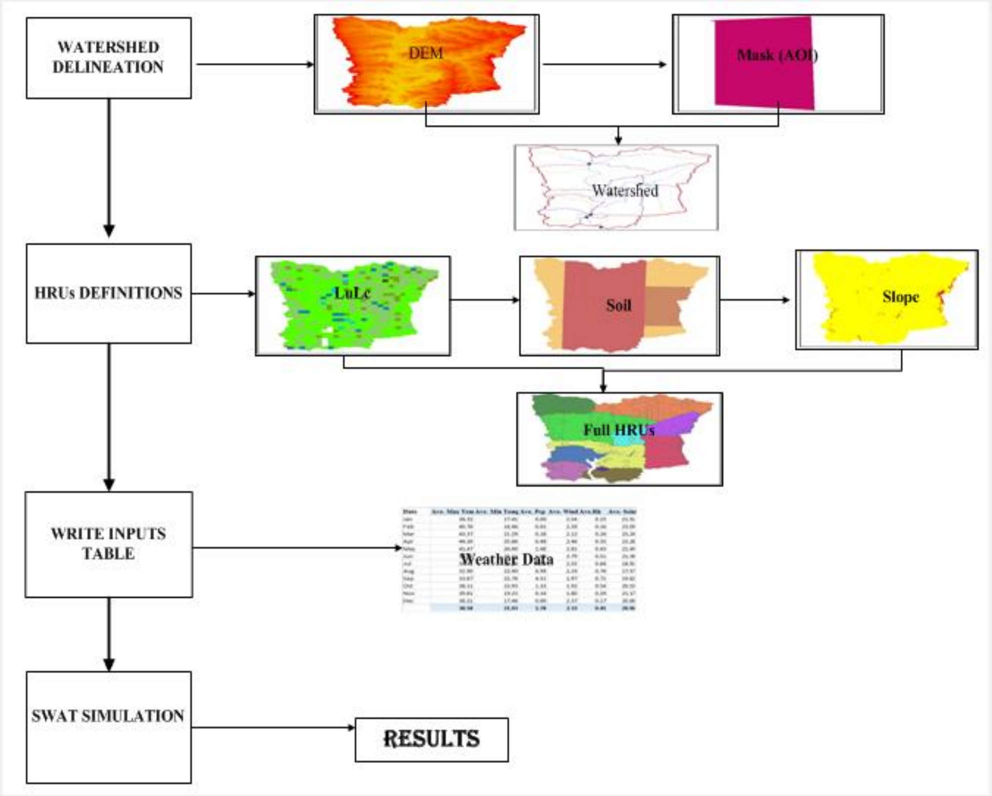

Figure 2: Conceptual Framework of the SWAT Model Setup

Figure 2 above is a summary on the concept behind the SWAT model, the various stages and input data needed in running a successful model. The stages involve watershed delineation which makes use of the DEM for the generation of streams, their inlets and outlets, flow direction, accumulation and creation of basins and sub-basins. The Hydrologic Response Units (HRUs) make use of LULC, soil raster data, and slope as its input data. It then generates sub-units for the watershed based on their similarities with respect to the soil, LULC and slope.

The next stage after the HRUs definitions is the write-input tables. This section of the model makes use of climate data and creation of tables needed for the final results from the watershed delineation all through to the HRUs and the climate data as a whole. Then the final stage being the simulation stage, which involves setting of date range for simulating the result parameters of interest to be modeled.

In order to understand the rainfall variability for possible climate change detection in the basin, the Mann-Kendall trend test and the Sens estimator were applied to two rainfall stations within the basin. The Kendall tau, the standardized statistic Zs, the p-value, and the Sens slope were the statistical indicators from the trend test. The Kendall tau determines the correlation between time and rainfall based on the rank of the data. The statistic Zs and the p-value measure the significance of the trend while the Sens slope estimates the magnitude of the trend similar to the tau value, (Krishnakumar *et al*., 2009; Awotwi *et al*., 2017).

RESULTS AND DISCUSSIONS

Hydro-Climatic Changes Analysis

The Mann-Kendall trend test was performed based on the annual averages for rainfall for different periods that correspond to reliable data availability. Along with these trend tests, the moving average method (for thirty five years) was also applied to show graphical representation of the general trend in the time series data. The information is presented in Figures 3a, 3b, and 4a, 4b for the stations at Zabzugu and Bimbila respectively. The results showed that the two stations had two separate trends; that of Bimbila had an increased trend in precipitation while Zabzugu had a slightly decreased trend in precipitation (Fig. 3 and 4). Also the test of significance value showed that the impact of rainfall at the Zabzugu station to be more significant than the Bimbila station. The Mann Kendall trend test revealed the tau value of -2.72 while the Sens slope is -0.361 for Zabzugu station, suggesting a decreasing rainfall since 1984.

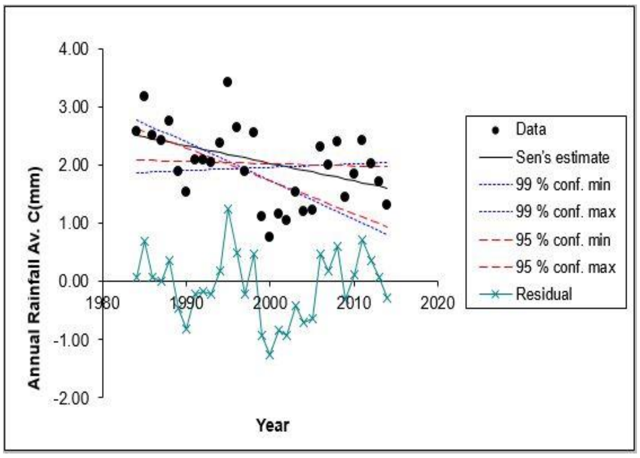

Figure 3: Rainfall trend (Zabzugu)

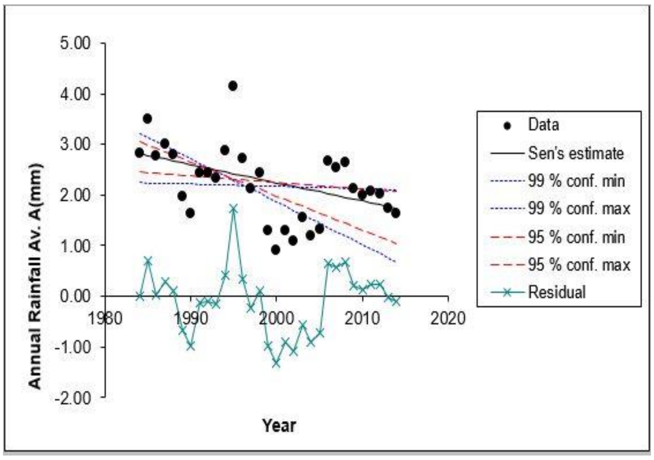

Figure 4: Rainfall Trend (Bimbila)

Analysis of LULC Maps for 1984 and 2013 and it's Impacts on Hydrological Components of the Basin

Table 3 Presents details on the land take for the cover types while Figures 5a and 5b represent the two landcover types used for running the model.

Table 3: LULC Type Distribution in the Sub-Basin

SWAT Codes	1984 Area %	2013 Area %
FRSD	85.62	53.12
WETN	0.62	3.49
AGRR	4.62	36.39
URBN	0.14	0.18
FIRST	7.97	5.77
WATR	1.03	1.05

FRSD; Decidous Forest, WETN; Wetlands Non-Forested, AGRR; Agricultural Land-Row

Crops, URBN; Urban, FRST; Forest, WATR; Water Body

The period of 1984 to 2013, representing a 30-year change in the landscape of the study area, shows very marked changes in the various landuse and landcover components. The deciduous forest (FRSD) component decreased from 85.62% to about 53.12% representing a decrease of about 32.50%. This is a very significant change and is indicative of the loss of forest cover which has negative effect on the hydrology of the study area. Also during this period, Agriculture increased from 4.62% to 36.39%, a positive change of about 31.77%. There was appreciable increases for Water cover (WATR), Urban (URBN), Wetlands Non-forested (WETN). The other cover type that witnessed a decrease though marginally when compared to FRSD is the Forest (FRST).

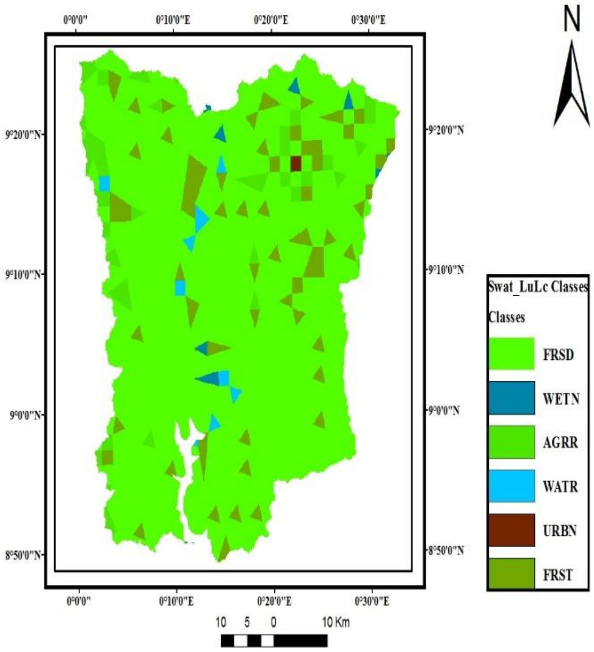

Figure 5a: LULC for 1984

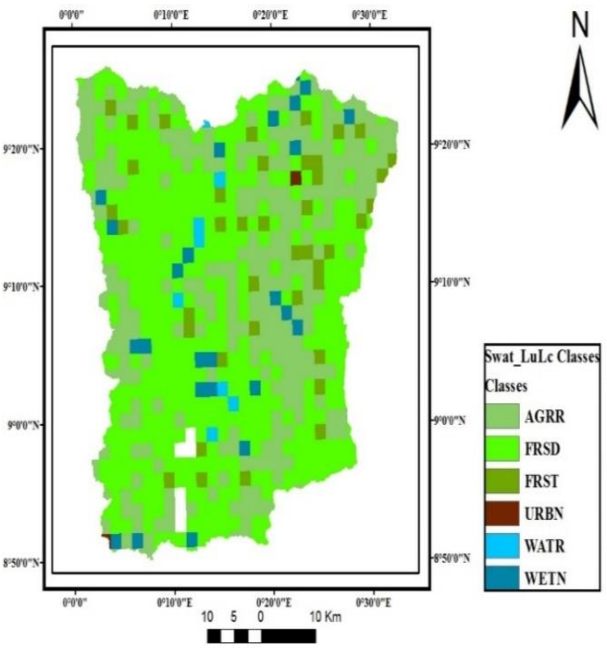

Figure 5b: LULC for 2013

Comparing the results from the Table 3 and Figures 5a and 5b, the general trend of change for the LULC from 1984 to 2013 is evidently a conversion from various forest types to other cover types especially Agriculture. This decrease can be attributed to increase in population growth with the accompanying high demand for food and urbanization.

From a change detection analysis to observe the spatial trend of change, (Figure 6a), it is clearly seen that Agricultural Land-Row Crops (AGGR) in the North-Northeast (NNE) regions of the study area was where the increase occurred much, followed by the area in and around Southeast (SE) with slight portions of it being within the Northeast (NE). It was then followed by a third class which was distributed in two different locations of the study area being the Northwest (NW) and Central. The fourth classes also occurred at three locations which were NW to some parts of NE, NE and then southern-most part of the study area. The last class had its distribution within the SE sector with slight distribution falling within the West (W).

Figure 6a: Changes in AGRR cover change

The change detection analysis was carried out for both FRSD and FRST landcover types and Figure 6b and 6c below show their varying distributions within the study area.

Figure 6b: Changes in FRSD Geospatially

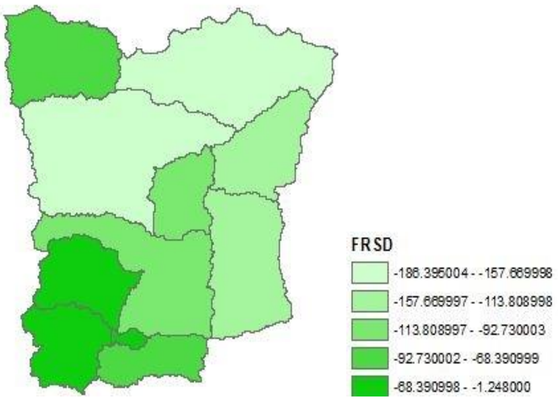

Figure 6c: Changes in FRST Geospatially

LULC Effects on Inflow Parameters

Inflow parameter considered here is groundwater recharge value. The experienced changes was as a result of alterations in the LULCs. The change was determined by running the SWAT model twice with the 1984 and 2013 LULC maps on separate accounts with the weather and soil data being kept as constant variables. Hydrographs were then generated for the two scenarios and necessary comparisons made. Thus, as LULC varied from 1984-2013, in the same vain, the values for groundwater recharge decreased during the period from 31.83mm to 27.81mm. The decrease in the groundwater value is attributed to the effects from human activities such as agriculture.

Landuse and landcover Effects on the Outflow Parameters (Evapotranspiration **(ET))**

Changes in the LULC have great impact on the outflow parameter as it has on inflow parameters. The outflow parameter here is the Evapotranspiration (ET) which experienced an increase in value from 581.4mm to 609.4mm within the 29 years period. The surface runoff (Surf-Q), the groundwater flow (GW-Q), and the lateral flow (LAT-Q) of the annual water balance components all witnessed decreases of 14.9%, 6.76%, and 12.54% respectively for the period 1984-2013. Evapotranspiration (ET-Q) on the other hand appreciated by 2.36%, an indication of the positive contribution to stream flow while the other indicators resulted in a reduction in stream flow. The decreasing Surf-Q, GW-Q and LAT-Q is as a result of increasing agricultural activity. The result of increase in ET has been similarly reported by . Awotwi *et al.* (2014) and Akpoti *et al* (2015) who looked into the impact of rainfall variability, landuse and landcover change on stream flow for hydropower generation in the Black Volta Basin, and the effect landuse and landcover changes have on water balance component of White Volta basin of West Africa. The findings of those studies thereby validate the results for this research. Table 4 shows the statistics on hydrological components for 1984 and 2013 landuse and landcover

Table 4: Hydrological Components of Oti Sub-Basin for 1984 and 2013 LULC

	Surf-Q m³/s	GW-Q m³/s	ET-Q m³/s	Lat.-Q m³/s
Year				
1984	132.68	31.38	581.40	2.11
2013	99.70	27.41	609.40	1.64

Table 5: Changes Occurring in the Hydrological Components of Oti Sub-Basin for 1984 and 2013 Landuse and landcover

Hydrological component (LULC 1984-2013)	%Change
Surf-Q	-14.19
GW-Q	-6.76
ET-Q	+2.36
Lateral-Q	-12.54

Surface runoff (Surf-Q), Groundwater flow (GW-Q), Lateral flow (LAT-Q),

Evapotranspiration (ET-Q)

CONCLUSION

Decrease in the inflow parameter, groundwater recharge value, of the water-balance components and increase in that of the outflow parameter, evapotranspiration, in reference to landuse and landcover changes affirms that, changes in climate and landuse and landcover affect the health of a watershed.

Finally, the rainfall trend analysis revealed that, the impacts of the hydro-climatic changes was not directly on the watershed but collectively functions alongside the landuse and landcover changes. This is confirmed because its significance value was -2.28 and -2.78 for the two locations of the stations which is less than the 1.96 cut-off value of significance.

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