A Tropical River Discharge Response To Land Use Land Cover Change

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Abstract- River discharge is a function of land use land cover (LULC) among others within a given watershed. The watersheds in Kenya are rapidly changing due to the expansion and intensification of agriculture thus influencing river discharge. The study was conducted in Chepkaitit and Moiben Rivers watershed located along Trans Nzoia, Uasin Gishu and Elgeyo Marakwet counties in Kenya. The specific objective was to determine how change in LULC influences the river discharge under three scenarios of the current, 100% agriculture and 100% forest LULC. The LULC change analysis data used Landsat satellite imagery downloaded from USGS website while the SWAT model was used in river discharge analysis. The weather data was downloaded from "Global Weather data for SWAT" website and DEM (slope data) downloaded from USGS website while model output calibration used SWAT-CUP. The study also found out that changes in the LULC significantly influenced the river discharge with R^2 of 0.96 at $p = 0.00001$ at a significant level of 0.05. The change in river discharge was more pronounced in April where scenario 2 river discharge varied by -28.51% and 19.57% for scenario 3. The study concluded that the significant changes in LULC influenced river discharge significantly with synchronized flow under forest cover.

I. INTRODUCTION

The livelihood of East Africa depends majorly on agriculture. Therefore, in order to meet the demand for land, natural forests have been substituted with human settlement, urban centres, farmlands and grazing land (Maitima, *et al.*, 2009). Loss of indigenous forests on streams that were originally in forested catchments and their subsequent conversion to agricultural use (e.g. in East Africa) is one of the major threats to surface water quality (FAO, 2010). Major water catchment areas in Kenya have lost their forest cover over time (World Bank, 2007). Deforestation according to Bonan, *et al*., (2004), changes the hydrological, geomorphological and biochemical states of streams. Anthropogenic changes in vegetation generally results in increased discharge because root density and depth have been reduced by agricultural activities (Canadell, *et al.,* 1996). Additionally, a reduction in dry season flow is often cited as a consequence of deforestation (Liu, *et al.* 2015). There is a common argument that forests act both as 'pumps' through enhanced evapotranspiration (ET) rates and as 'sponges' through increased infiltration rates and soil moisture retention (Bruijnzeel, 2004; Arancibia, 2013). Forested watersheds therefore exhibit smaller streamflow rates than watersheds dominated by other managed land uses during and after a rainfall event. Forest cover loss results in changes in albedo, reduction in aerodynamic roughness, reduction of leaf area, and reduction in rooting depth, consequently causing a reduction in evapotranspiration (ET) which subsequently affects stream-flow (Costa, *et al.,* 2003; Farley, *et al.*, 2005).

Odira, *et al.,* (2010) and Gitau (2021) in their studies on Nzoia River concluded that deforestation in the catchment region affects stream flow in that during the rainy season, stream flow rate increase compared to when there is forest cover. In a study by (Mwetu 2019), in Njoro River in Kenya, it was also observed that with increased reduction in land cover in the river upper catchment, there was a reduced average annual discharge.

However, this is not conclusive since there is still a debate in looking at the complex relationship between forest and water resources (Ellison, *et al*., 2012, Lacombe, *et al.*, 2016, Filoso, *et al*., 2017). Therefore, there was a need to assess how loss of forests, for other land uses, has impacted on Moiben and Chepkaitit rivers. The aim of the study is to model the influence of LULC on rivers Chepkaitit and Moiben water discharge using Soil and Water Assessment Tool (SWAT).

II. METHODS AND MATERIALS

2.1. Area of Study

The area under which this study was carried out is Chepkaitit and Moiben Rivers watersheds found within the Nzoia River basin in Kenya (Figure 1). The watersheds are located along Uasin Gishu, Trans Nzoia and Elgeyo Marakwet counties. Chepkaitit and Moiben

Rivers are located between the coordinates $35^0 20'01.5''$- $35^0 07'57.6''$E and $1^0 02'18.1''$- $0^0 55'06.9''$ N. (WGS 84). It forms part of the upper catchment of the 12 903 km^2 Nzoia River watershed. The western escarpment of Cherangani hills forms an important source to Moiben and Chepkaitit rivers, Chebiywo, *et al*., (2004).

The Moiben and Chepkaitit Rivers originate on the western side of the Cherangani hills escarpment at 2400 m asl. Chepkaitit River originates from Mt. Elgon and the Western part of Cherangany hills forest ecosystems. Moiben River on the other hand is approximately 81 km long from its source in the Kipkunnur forest to its confluence with the Kapolet River, where they join to form the larger Nzoia River. The rivers join Nzoia, which drains to Lake Victoria (GoK, 1973). The land-use systems and practices in the basin broadly range from forestry, small-scale farming to large-scale mechanized agriculture. The basin is an area of high agricultural potential and is densely populated, which influences land use. The river drains a forested area at its upper reaches before entering a valley where mixed farming is practiced.

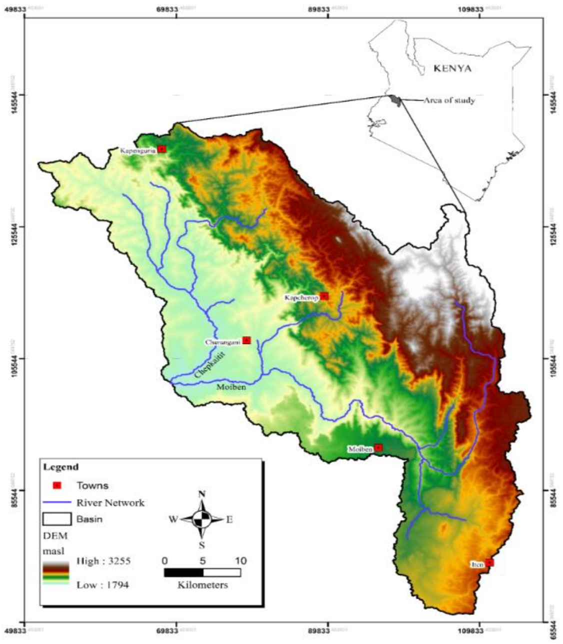


Figure 1: Chepkaitit and Moiben Watershed Map

2.2. Soil and Water Assessment Tool (SWAT) Model

The Soil and Water Assessment Tool (SWAT) is a model of small watershed basin that simulates the quantity and quality of surface and ground water and foretells the environmental impacts of land use, land management practices and climate change. The flow of water in and out of the hydrological system, informs all the processes in the SWAT model. Daniel, *et al*., (2011) postulated that SWAT is deterministic, continuous watershed model that operates on daily and hourly basis. SWAT model was developed by the Agricultural Research Service of the United States Department of Agriculture. It can model changes in the hydrologic response of the catchment, water quality, and erosion and estimating the effects of Land Use changes. In order to model a hydrological unit, entire catchment is divided into sub catchments which are further divided in to hydrologic response units (HRU) based on land use, vegetation and soil characteristics (Arnold, *et al.,* (2013); Neitsch, *et al*., (2011)). SWAT then estimates run off of each HRU separate and then the total runoff for the entire basin. Master water balance approach is used in SWAT model to compute run off volumes and peak flows (Arnold, *et al*., 1998) and is expressed as equation below;

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$$

….Equation 1

Where SW_0 is initial soil water content and SW_t is the final soil water contents on day *i*. All other measurements are taken in millimeters and time (t) is in days. The equation subtracts all forms of water loss on day *i* from precipitation on day *i* (R_{day}) including surface runoff (Q_{surf}), evapotranspiration (Ea), loss to vadose zone (w_{seep}) and return flow (Q_{gw}) (Neitsch, Arnold *et al*. 2009). By manipulating this equation, the model can predict changes in variables of interest like runoff and return flow. The input data that is used in the model include land cover map, Digital Elevation models (DEM), channel geometry and soil Map (Srinivasan, Arnold 2012). Hydrological modeling is then done and output generated.

2.3. SWAT Modeling Process

The preliminary step was the definition of the slope, soil, LULC parameters, and climatological data in databases (dbf tables). Each table had to be defined clearly using the nomenclature provided in the SWAT user's manual. The watershed delineation process was conducted and extracted the watershed, sub-divided the watershed into hydrological response units and built the streams and the stream outlets using the DEM. The SWAT model generated 19 hydrological response units (HRU) from the sub-watershed (figure 2). In the creation of these HRUs, all the required data for hydrological simulations of the watershed were determined for each unit. Then for each land use, different soil types and slope associated with each were selected. For the LULC and soil definition, shape files were added in ArcGIS and linked to the SWAT database. To use the maps provided, the SWAT interface required a table linking the values represented to types already defined in the hydrological model.

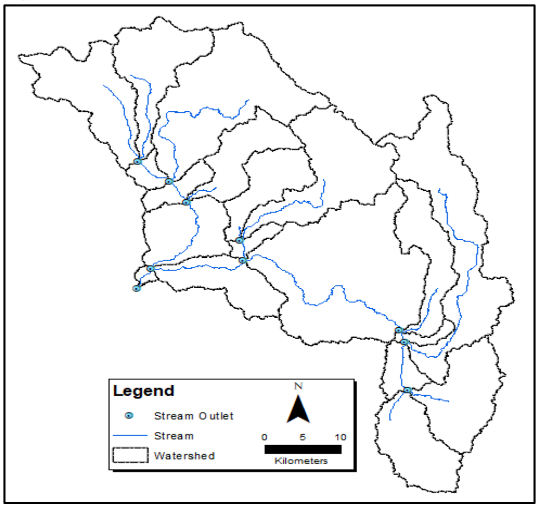


Figure 2: The stream, HRUs and the stream

2.3.1. LULC Data

The LULC spatial data was sourced from Landsat satellite imagery downloaded from USGS website (https://earthexplorer.usgs.gov). The downloaded data was in WGS 1984 and was projected to UTM Zone 37N. The data for LULC the year 1980 used Landsat 2 with a resolution of 60 meters and 180/059 path/row scene covered ; for the year 2000 Landsat 7 with a resolution of 30 meters was used and for year 2020 Landsat 8 satellite image with a resolution of 30 meters were processed. For both Landsat 7 and Landsat 8, three imagery scenes were downloaded covering paths/row 170/059 (zone 36N), 169/059 (zone 37N) and 169/060 (zone 36N). Figure 3 shows the satellite images used in the three time periods of 1980, 2000 and 2020. The year 1980 LULC data used Landsat 2 satellite imagery of 16th May 1979 as this is the closest to 1980 without clouds. The Landsat 2 imageries have 4 bands and the useful bands for vegetation analysis are band 4 (green band), band 5 (red band) and band 6 (blue band) all with a 60 meters ground resolution. The year 2000 LULC data used Landsat 7 satellite imageries of 27th January 2000 for path/row 169/059 and 169/060 and 6th February 2000 for path/row 170/059. The Landsat 7 imageries have 7 bands and the useful bands for vegetation analysis are band 4 (green band), band 5 (red band) and band 6 (blue band) all with a 30 meters ground resolution. The year 2020 LULC data used Landsat 8 satellite imageries of 11th March 2020 for path/row 169/059 and 169/060 and 7th January 2020 for path/row 170/059. The Landsat 8 imageries have 9 bands and the useful bands for vegetation analysis are band 3 (green band), band 4 (red band) and band 5 (blue band) all with a 30 meters ground resolution.

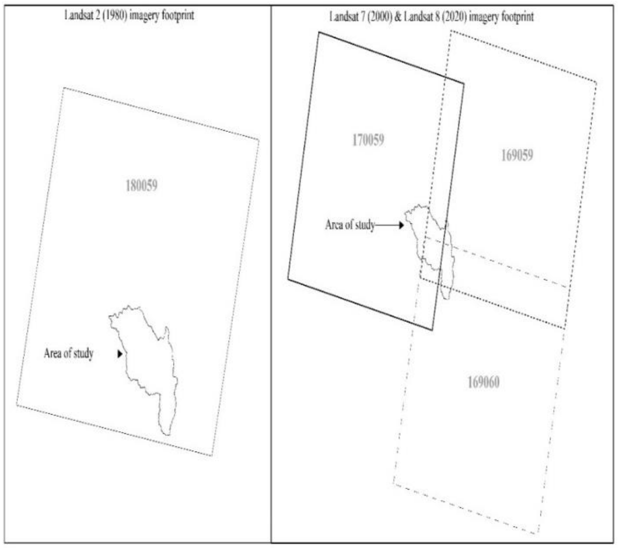


Figure 3: The downloaded imagery data footprint

The satellite imageries processing and analysis was done using ArcGIS version 10.5. Using the three bands for vegetation analysis, composite images were generated and extraction of the area of study done (figure 4). The satellite images classification was performed through onscreen digitization. Further, processing and analysis of these spatial data was carried out in the same environment. Other LULC data required for SWAT model were generated in ArcGIS. This applies to the LULC data for scenarios 2 (100% forest cover) and scenario 3 (100% agriculture). New shapefiles were generated by coding the entire basin shapefile accordingly.

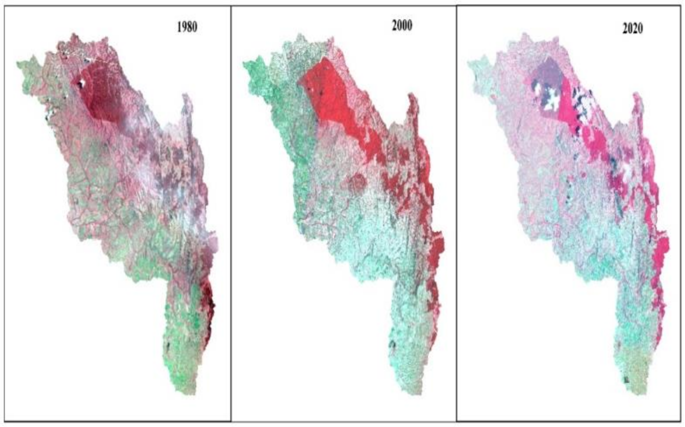


Figure 4: Extracted area of study

2.3.2. Climate Data

The SWAT model makes use of weather data namely temperature, precipitation, wind, relative humidity and solar radiation parameters among others. The weather data was downloaded from the "Global Weather data for SWAT" website (https://globalweather.tamu.edu/). This weather data was downloaded by selecting the location of interest in the map providing email where the download link is sent. For this research the climate data was requested in Arc-SWAT format. The used weather data was from Jan 1979 – Dec 2013.

2.3.3. Soil Data

Soil data is a critical input for any hydrological simulation model (Nam, *et al*, 2010; Melesse, 2006).

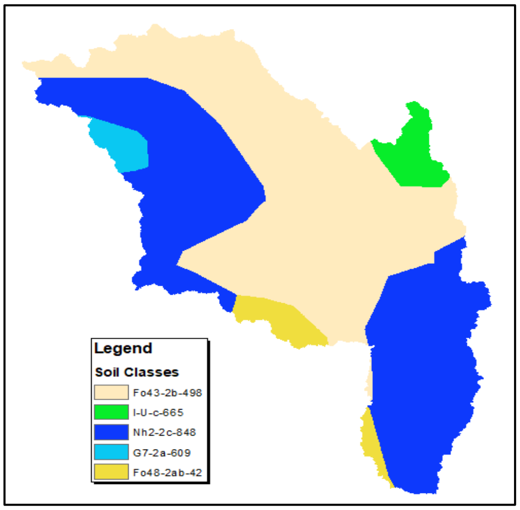


Figure 5: Map showing the different classes of soil

Soil properties (commonly texture and hydraulic conductivity) affect hydrologic processes such as infiltration and lateral transport of water in the soil. The soil data used by SWAT is divided into two major groups according to their characteristics; physical and chemical. In this study, physical characteristics of the soil data was considered since they control the motion of water through the soil profile and thus have a major impact on the cycling of water within each hydrologic response unit (Arnold, *et al*, 2011). Soils were generally classified into different hydrologic response units (which comprise soils with similar runoff potential under similar storm and surface cover conditions) based mainly on their infiltration characteristics. Processed and classified spatial soil data for use in the SWAT model was downloaded from FAO website (https://swat.tamu.edu/media/116406/af_soil.zip) (figure 5).

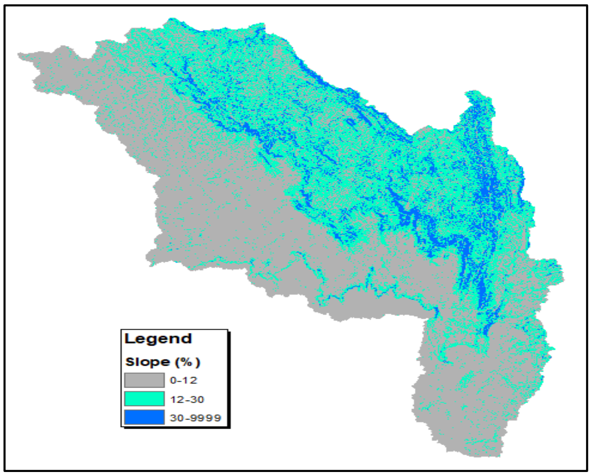


Figure 6: map showing the elevation of the area

2.3.4. Slope Data

The slope data of the watershed was derived from DEM data to be downloaded from USGS website (https://earthexplorer.usgs.gov). A Digital Elevation Model (DEM) of the study area (figure 6) at a 30 by 30 meters resolution was obtained. The DEM was used to delineate the topographic characterization of the watershed and to show the hydrological parameters of the watershed such as the slope, flow accumulation, flow direction, and stream network.

2.4. SWAT Setup

Table 1: The LULC scenarios used in SWAT model

The SWAT model was run from 1st January 1979 – 31st December 2013 on monthly basis. The SWAT model warm-up period was 3 years i.e. 1979 to 1981. The SWAT data used comprised of slope, soil, weather and LULC. Three SWAT model scenarios were generated each using different LULC data. The base scenario used the 1980 LULC; while scenario 2 assumed 100% Montane forest LULC and scenario 3 assumed 100% agriculture LULC (table 1).

2.4.1. Model performance

SWAT output calibration was conducted in SWAT CUP. The SWAT CUP is an acronym that stands for SWAT Calibration and Uncertainty Program that was developed for automatically computing sensitive model parameters. Sequential uncertain fitting ver-2 (SUFI-2) algorithm in the SWAT-CUP was used for this function. The SUFI-2 captures as many optimal simulations as possible that are within 95% prediction uncertainty (95PPU). Evaluation of the model performance, the coefficient of determination (R^2) statistic was applied.

III. RESULTS

3.1. LULC change

Scenario	**Montane forest**	**Plantation forest**	**Bush-land**	**Agriculture**	**Wetland**	**Water**
Base	17.60	1.69	28.61	46.50	5.57	0.04
2	100.00	0.00	0.00	0.00	0.00	0.00

3	0.00	0.00	0.00	100.00	0.00	0.00

The LULC of the years 1980, 2000 and 2020 were processed from the Landsat satellite imagery and analysed in ArcGIS. The spatial data showed the kinds and extent of LULC in the watershed in the times under study (figure 7). The identified LULC were montane forest, bushland, tea plantation, cropland, plantation forest, wetland, woodlot and urban area

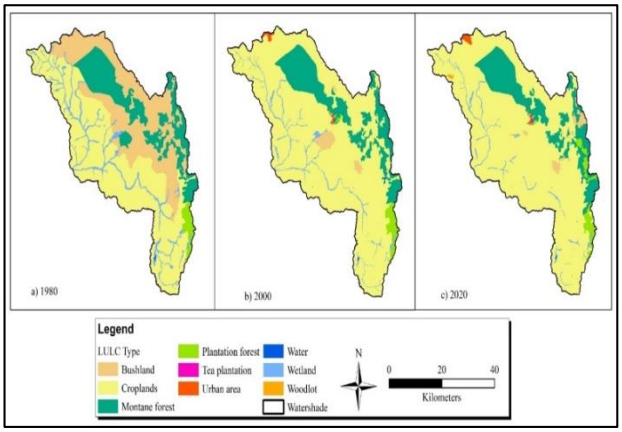


Figure 2: LULC of the years 1980, 2000 and 2020 in

The spatial LULC results indicate that the “Bushland” category has drastically reduced in 2000 and 2020 after domination in the northern section of the watershed in 1980 with a corresponding expansion of “Cropland”. The “Wetlands” appear to have reduced with time from continuous to broken sections in 2020. Notably, new LULC that appeared in 2000 are the “Urban areas” and “Tea plantation”. The “Montane forest” spatial distribution is more or less the same unlike the “Plantation forest” which is expanding to the northeast from southeast of the watershed. The LULC trend was tabulated and the changes (km^2) with time (table 2) were quantified. The results from the table 2 indicate that there has been a significant change in the LULC in the watershed between 1980 and 2020. It is evident from the study that there was a reduction in the size of land under montane forest, bush land and wetland. Montane forest area reduced by 10% from year 1980 to 2000, and eventually decreased by 13% by the year 2020.

Table 2: The LULC changes between year 1980, 2000 and 2020

	Years			**Change**		**% Change**	
LULC Type	1980	2000	2020	2000	2020	2000	2020
Crops	1006.23	1680.35	1701.55	674.11	695.31	67	69
Montane forest	380.81	340.99	330.79	-39.82	-50.03	-10	-13
Plantation forest	36.50	39.70	48.37	3.19	11.86	9	32
Tea plantation	0	1.61	1.99	1.61	1.99	100	100
Urban area	0	5.44	7.73	5.44	7.74	100	100
Woodlot	0	0	2.42	0	2.42	0	100
Water	0.84	1.65	1.54	0.80	0.69	95	82

Bush land	619.18	37.16	30.17	-582.02	-589.01	-94	-95
Wetland	120.47	57.14	39.48	-63.33	-80.99	-53	-67
Total	2164.06	2164.06	2164.06				

The wetland declined by 53% and 67% in the years 2000 and 2020 respectively, compared to that of the year 1980. There is a very great change in the area of bush-land. It reduced by 94% from year 1980 to 2000 and by 2020 it had reduced by 95%. The area under water on the other hand, increased from 1980 to 2000 by 95% and then reduced to 82% in 2020.

In contrast, there was an increment in the size of land under crops (cropland), where in the year 2000, there was an increase of 67% and as at 2020, the increase was 69% compared to 1980. Additionally, it is also noted that the area under plantation forest has increased such that by 2000, it had increased by 9% and by 2020 it had increased by 32%, comparing it with the 1980 value. It is also noted that the tea plantation and urban areas which did not exist in the year 1980 emerged in the year 2000 and its size had increased to 0.1% and 0.4% respectively in the year 2020. The study area is thus seen to have witnessed a reduction in the montane forest, bush land and wetland. This reduction could be attributed to deforestation to create land for crop farming, tea plantation and creation of urban space. It is thus seen that deforestation is taking place in favour of other land uses such as tea plantation, urban centres and crop land. The area has seen the introduction of urbanization and tea plantation in the area, whereas at the same time the montane forest has reduced. This then implies that there is increased deforestation in the region from the year 1980 to 2020. The plantation forest could be linked to the initiative by the government urging people to plant trees and at times giving them incentives to do so. The study also indicated a progressive reduction of wetland from 120.5km^2 in 1980 and to 39.5 km^2 in 2020. This is indicative that most of the wetlands have been reclaimed for agricultural purposes.

Studies in Moiben and Chepkaitit rivers' watershed have also revealed from the analysis that the region has been subjected to a gradual process of conversion to other LULC due to high population pressure. The period 1980 – 2020 indicated a significant change in LULC. While the crop land is increasing, the bush land, forest and wetlands are reducing. This is an indication that deforestation is being carried out in the region to create room for cultivation. Further, the wetlands also have been reclaimed to create room for agriculture. It means then that the population has increased therefore, there is need to produce more food, and this creates pressure which drives LULC changes as observed by (Cheruto, *et al*, 2016).

Table 3: River discharge (cm/s) for the three LULC scenario

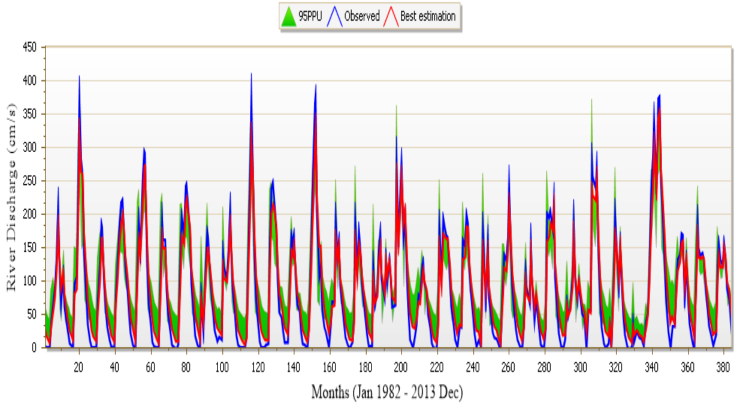
	Base Scenario	**Scenario 2**	**Scenario 3**	**Scenario 2 % Change**	**Scenario 3 % Change**
Jan	24.53	30.50	21.11	24.36	-13.92
Feb	15.41	17.91	14.30	16.17	-7.21
March	15.95	15.67	16.81	-1.75	5.42
April	58.62	44.83	70.09	-23.51	19.57
May	116.36	100.77	128.50	-13.40	10.43
June	144.57	133.95	153.05	-7.35	5.86
July	187.62	180.47	194.18	-3.81	3.50
Aug	224.31	223.69	224.75	-0.28	0.20
Sept	165.96	184.79	152.11	11.35	-8.35
Oct	113.20	128.74	102.02	13.73	-9.88
Nov	80.71	90.38	74.35	11.97	-7.88
Dec	44.72	54.41	38.36	21.66	-14.23

3.2. Impacts of LULC change on river discharge

The results of the modelled river discharge (table 3) are presented on monthly basis for the entire period under study. The river discharge is not uniform throughout the year having minimum of 15.41cm/s in the month of February and maximum of 224.31cm/s in the month of August. The lower values indicated the dry months while the higher values indicated the wet months.

The SWAT-CUP calibration yielded the coefficient of determination (R^2) of 0.96 (figure 8) indicating a very good SWAT model performance. According to Moriasi, *et al*, (2007), R^2 is a standard regression technique that is used to determine the strength of linear relationship between simulated and measured (observed) data. R^2 values ranges from 0 to 1 which represents the trend between the observed and simulated data. R^2 Values greater than 0.5, are considered acceptable. This is an affirmation that the hydrological processes were realistically modelled in this study.

Figure 3: Monthly time series of simulated and observed stream-flow (in cubic meters per second) for Chepkaitit and Moiben Rivers watershed.



3.2.1. Scenario 2: 100% forest LULC

The stream hydrograph is more or less the same as the base scenario with differences in the rate of water flow. The stream-flow varies from the base scenario in both positive in January, February and September – December while it was negative in March to August (figure 9). In the month of January, the stream-flow rates increased by 24.36% while the maximum decrease is in the month of April by 23.51%. This means that the presence of trees reduces the surface water run-off by increasing retention time thereby encouraging water infiltration.

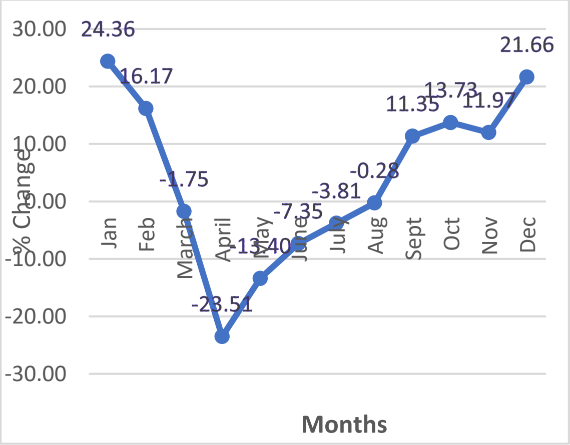
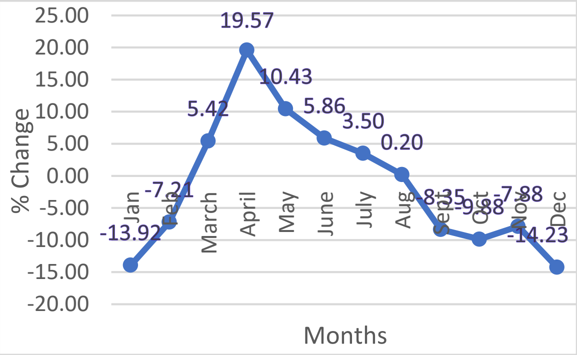


Figure 4: River discharge change for scenario 2 LULC

3.2.2. Scenario 3: 100% agriculture LULC

In this scenario, the stream-flow varies from the base scenario in flow rate though the hydrograph pattern is identical. The percentage change is positive between March and July while the negative changes occur both in January, February and September – December (figure 10). In the month of December, the stream-flow rates decreased by 14.23% while the maximum increase is in the month of April by 19.57%. This means that the agricultural land generally encourages excessive surface water run-off by reducing retention time thereby discouraging water infiltration.

Figure 5: The rate of change of river discharge at 100% Agriculture LULC



IV. DISCUSSION

The results of the SWAT model indicated that the river discharge is different for different months due to the difference in the seasonal weather pattern and the different LULC scenarios. The simulations when the forest was assumed to be 100% showed that the river discharge during the wet months was very low compared to the dry months. This means that when the watershed is highly forested, the river discharge is not affected by run-off that occurs during rainy season. It thus holds that forest prevents the excessive run-off. The forest vegetation increases water retention time thereby allowing infiltration. This study then agrees with what other researchers have observed in other regions. Andreassian (2004) indicates that the increase of the forested area causes a decrease of the maximum peak flow and an increment in the base flow discharge values in a study in Russia. These changes could be attributed mainly to deviations in evapotranspiration, surface roughness and water infiltration rate in the soil. At 100% agriculture on the other hand, it showed very high river discharge during the rainy season. The reason for this is due to lack of forest to prevent excessive run-off. The simulated scenarios then agrees with the theory that forests are sponge-like, in that it holds water during the rainy season and releases it during the dry period. Deforestation according to Bonan, *et al*., (2004), changes the hydrological, geomorphological and biochemical states of streams. Changes in vegetation generally results in increased discharge because root density and depth have been reduced by agricultural activities (Canadell, *et al.*, 1996). Forest floors have leaf litter and porous soil which easily accommodate intense rainfall as infiltration takes place slowly until the soil is saturated. The trees funnel water into the underground aquifers where it will be stored to supply rivers during drought. Tree leaves also hold some rain water that evaporates directly to the atmosphere. Run-off is thus controlled by this nature of trees and therefore soil is protected from being eroded into the rivers. It holds therefore that deforestation will highly lead to increased river discharge during the rainy season and reduced river discharge during the dry weather seasons (Liu, *et al*., 2015).

Land use was observed to influence the soil hydrological properties which are measured by the movement of water in the soil. Compaction of soil interferes with the movement of water, increases soil bulk density and reduces hydraulic conductivity and infiltration (Nzitonda, *et al*, 2019). The least river discharge for agricultural land during the dry period was due to the low levels of infiltration and excessive runoff during the wet season. The low infiltration rate is due to compaction of lower soil horizons resulting from continuous tillage of agricultural land (Ankeny, *et al*, 1990). This compaction also increases the bulk density of the soils (Logsdon, *et al*, 1990) and thus will determine the run-off volume. Because of the low levels of infiltration, the replenishment of the groundwater was very low and thus reduced river discharge during the dry seasons. The scenario for the agricultural land indicates that water interception in the sub-catchment is low and thus meaning less time for infiltration. This is mainly caused by decrease in forest cover and increase in croplands therefore reducing rain water interceptions leading to increase in surface run-offs in the sub-catchment (Olang', 2009). Forests are less compacted and that is why they have high infiltration rates and high hydraulic conductivity compared to other land uses (Nzitonda, *et al*, 2019).

5. 1. Conclusion

The modeling of data sets using the SWAT-CUP under two scenarios, scenario 2 (100% forest LULC) and scenario 3 (100% agriculture LULC), showed an impact in the river discharge. The LULC changes along the watershed led to changes in the river flow discharge rates. The changes in Land Use from forest land to agricultural land led to increase in runoff and thus increase in river discharge during the wet months. During the dry months, the flow was very low in agricultural lands because the underground aquifers were not replenished during the wet months due to excessive runoff. The forested areas on the other hand were opposite to that of the agricultural land. Under this situation, the infiltration occurred during the rainy season and thus the river discharge was normal.

5.2. recommendations

The study recommends that: the impact of LULC changes to the river discharge is not impressive and thus, the study recommends that deforestation should be controlled by all means. The locals, the environmentalists and the forest department should all take their parts. The laws that govern forest resource should be re-visited and thorough routine checks be done. Forest management authorities should normalize disciplinary measures through penalties for the policy breakers and the authorities should ensure that reforestation be done in the government forest lands that have been degraded. The owners of the lands also living at the catchment of the rivers should be encouraged to plant more trees in their farms, as the trees are good protectors of the soil. Agroforestry should be encouraged always.

The relevant authorities responsible for watershed and catchment management also, should encourage people to plant trees that can provide fruits, medicine, fodder, live fence and for aesthetics on their farms. When these trees will be planted in plenty, it will assist in conserving soil and water, apart from its primary purpose of providing the primary needs.

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