# Influence of Sub Basins with Dominant Land Covers on Spatial and Temporal Variations of Water Balance Components in the Sondu Miriu River Basin, Kenya

**Nancy C Koech[1], Johnson U. Kitheka[2], Hesbon Otieno[3]**

[1]Ministry of Water, Sanitation and Irrigation, P.O Box 49720 – 00100, Nairobi, Kenya
[2]Department of Hydrology and Aquatic Sciences South Eastern Kenya University, P.O Box 170-90200, Kitui, Kenya
[3]Department of Agricultural & Biosystems Engineering South Eastern Kenya University, P.O Box 170-90200, Kitui, Kenya

**Abstract:** ***Understanding the dynamics of the land cover changes and behaviour of hydrological processes in the river basin is important in the sustainable management of water resources. However, there is limitation of data and information on the extent to which dominant land use types particularly tea plantations, forests and mixed farming affects water balance components in tropical river basins and Kenya in particular. The main objective of this study was to determine the influence of sub basins with dominant land covers on spatial and temporal variations of water balance components. The study was undertaken in a 3,450 km2 Sondu Miriu river basin located in the western region of Kenya in the period between 1960 and 2020. Hydrological SWAT model was used to estimate the key hydrological components in the sub basins dominated by tea plantation, forest and mixed farming. These sub basins were Kipsonoi for mixed farming, Timbilil for tea plantations and Kiptiget for forest cover. Meteorological data was obtained from the Kenya Meteorological Services (KMS) and Water Resources Authority (WRA). Further, historical river discharges data was obtained from WRA and Ministry of Water, Sanitation and Irrigation. It was observed that land uses and land covers have insignificant influence on the rainfall variability in the three sub basins. Negative relation between area under forest cover and rainfall with correlation r of -0.37 was shown in the sub basin dominated by forest cover. But increase in rainfall in the sub basins led to expansion of tea plantations and mixed farming hence positive relations and reduction of forest cover. The positive relationship between evapotranspiration and mixed farming, evapotranspiration and forests cover was low ranging between correlation r of 0.05 and 0.14 while in tea plantations very low negative relation was shown. The sub basins dominated by tea plantations, forest and mixed farming shown an insignificant impact on soil moisture.***

**Keywords:** Evapotranspiration, water balance, SWAT model, Soil Moisture and rainfall

## 1. Introduction

Knowledge on effect of spatial variations in the patterns of land cover and land use on the hydrologic cycle of a river basin over time is critical. The hydrological phenomena at basin and sub basin scales are affected positively or negatively by dynamics of the land cover and land use patterns. A positive balance of hydrologic components in the river basin enables achievement of sustainable water resources management and development (Setti et al., 2017). However, continuous interference of the natural land uses and land covers over time affects the water balance (Said et al., 2021). Therefore, there is need for frequent assessment and monitoring of the behaviour of hydrological components in the short- and long-term. The vertical components are rainfall, evaporation, infiltration, through fall, percolation and transpiration. The horizontal components are surface runoffs, lateral flow and baseflow. The storage components are interception, surface sinks, soil moisture in unsaturated zone, groundwater aquifer and streams. These components respond differently in sub basins with dominating land uses and covers. The response of key hydrological components and water balance in sub basin dominated by tea plantation in East Africa region and Kenya is unknown. The tea plantation is characterized by low height plants of about 1 m high from the soil surface, thick canopy and bush density. In the water cycle context, tea plantation has thick and dense canopy cover and its impact on the hydrological processes such as interception, transpiration and evaporation of the intercepted water on the leaf surfaces has not been estimated. However, a study to unveil this theory is required especially in sub basin with expanding tea plantation land cover over time. This assists in understanding effects of tea plantations in the hydrologic cycle of the river basin. Physical canopy appearance in the forest and tea plantation has led to assumption that the land covers have similar hydrological effects (Gebrejewergs *et al.*, 2020). However, this has not been determined in the previous research studies. The similarities of the forest and tea in comparison with mixed farming are yet to be determined in the river basin. Hence becomes difficult to recommend suitable land cover that ensures sustainable water resources availability.

## 2. Literature Survey

Previous study conducted in Tanzania highlands revealed that human activities which transformed the river basin land cover severely affects hydrological components (Näschen et al., 2018). Rainfall is the main input component of the water balance and can be influenced by changes in the local weather of the river basin (Badjana et al., 2017). A study conducted in White Volta River Basin indicated that deforestation increases surface runoffs; decreases base flows and increases surface evaporation while reducing transpiration and infiltration (Awotwi et al., 2014). In temperate regions attempts have been made to understand some hydrological components in different river basin undergoing land use land cover transformation. In a sub basin with forest land cover in India, water balance studies have shown that evapotranspiration is the leading hydrologic component consisting approximately 45% of the rainfall input while surface runoffs, lateral flows and baseflow were about 20% (Setti et al., 2017). Study conducted in Buzi sub basin further showed that interception in the forest cover was high compared to other hydrologic components (Chemura et al., 2020). Afforested Pakistan sub basin was assessed and revealed that forest cover influences hydrologic components and the water balance. Different land covers respond uniquely to the vertical and horizontal components of the hydrological processes (Saddique et al., 2020). Evaporation and transpiration are components of hydrology which depend on land cover changes and affect water resources availability at the catchment area. It was realized that increase in vegetative land cover increases evaporation and transpiration. But conversion of forested land into bare land decreases evaporation and transpiration (Tamm et al., 2018). On the other hand, dry periods exposed that stream flows reduced by almost 1.2% while evaporation and transpiration was reduced by about 0.1%. Groundwater and percolation were reported to decline by about 8%. Also, lateral flows reduced during dry periods by almost 4% (Chauhan et al., 2020). From the analysis it was concluded that vegetation with high water consumption and loss through transpiration are not suitable for the upstream catchment area in that it reduces flows affecting downstream water users and ecosystem (Chen et al., 2019). Also, it was agreed that changes in land use affect negatively availability of water resources (Ponpang-Nga and Techamahasaranont., 2016). In tropical river basins in data and information on the spatial and temporal variations on hydrological components under different land use types in a sub basin is limited. Few studies have been conducted in the river basins in Kenya and have tried to reveal the impacts of mainly surface runoffs is one of the hydrologic components on the changes of the land uses and land cover. In a study done in the upstream of Athi River showed that forest cover generates fewer surface runoffs of about 10% (Mathenge et al., 2020). Reduction of forest cover into crop fields and grassland increases surface runoffs by about 10% and 60% respectively (Notter et al., 2007). In Nyando assessing the effect of land cover changes on water resources found that catchment degradation has led to conversion of forest cover into agricultural and urban centres. This land use changes has led to increase in surface runoffs and reduces evaporation and transpiration (Opere and Okello, 2011). A study conducted in the upstream sub basins of Lake Nakuru revealed that forest cover generates surface runoffs consisting about 18% (Kimaru et al., 2019). In a study conducted in Naivasha Kenya, the results obtained led to similar conclusions drawn from study done in Heihe River Basin.

## 3. Problem Survey

The water per capita in Kenya is about 600 $m^3$/capita/year portraying water scarce situation and there is need for proper planning of available water resources to meet the needs of increasing population. But continuous transformation of the natural land covers in a freewill manner is a threat to future water resources. Tea plantations in Kenyan Sondu Miriu sub basins have been expanding in coverage due to the need to boost economic development by the communities and companies. The tea plantation and mixed farming land covers in Sondu Miriu River Basin replaced the natural forests and there is need to study the behaviour of hydrological components in relation to the change of land cover in sub basins dominated by tea plantations, forests and mixed farming. The main objective of this study was to determine the influence of sub basins with dominant land covers on spatial and temporal variations of water balance components rainfall, evapotranspiration and soil moisture in the Sondu Miriu River Basin.

## 4. Materials and Methods

***Description of the study Area***

The Sondu Miriu River Basin is located in western region of Kenya (Figure 1). Its headwaters are situated in Nakuru and Kericho Counties. The basin is situated within the latitude 0°17’ and 0°53’ South and longitude 34°45’ and 35°45’ East. It covers a surface area of about 3,470 $km^2$ with an altitude ranging from 3000 m above sea level at the Mau Complex to about 1100 m above sea level at the downstream near Lake Victoria (Masese et al., 2012). The basin supports livelihoods in Nakuru, Kericho, Nyamira and Kisumu counties.

***Land use and climate***

The Sondu Miriu River Basin is characterized by presence of various land covers and land uses. The main land covers in the basin are natural forest, tea plantation and mixed farming. Prior to interference within the Mau complex natural canopy cover, the total area under forest was approximately 420, 000 hectares (Kroese et al., 2020). However following degradation since 1970s and in the year 2000, the forest canopy has reduced by approximately 32% and the small patches of forest cover are now left in the central upper part of the basin. The reduction in forest cover has been attributed to encroachment by settlers and farmers (Masese *et al.*, 2012). The forest cover is the leading land cover in the basin coving a surface area of about 934 $km^2$. The forests cover approximately 26.7% of the total basin area. The second largest land cover is tea plantations covering an area of 898 $km^2$ which is approximately 25% of the total basin area. Settlement and sugarcane plantations cover an estimated area of 785 $km^2$ and 402 $km^2$, respectively. However in this study land uses and land covers were further clustered into three major groups. These land covers and land uses are tea plantation in Timbilil Sub basin, forest in Kiptiget Sub basin and mixed farming in Kipsonoi Sub basin (see Figure 1).

The climate of the Sondu Miriu River Basin is influenced by movement of the intertropical convergence zone (ITCZ) leading to bimodal rainfall within a given year. The river basin is characterized by humid and semi humid climatic zones with significant variations in temperature and rainfall. The long rains occurs in the periods between April and July and short rains occurs in the period between October and December (Weeser et al., 2018). In the upper region of the river basin, the mean annual rainfall is high as compared to the lower parts of the basin. The upland zone receives mean annual rainfall of approximately 1,800 mm per annum while lowland zones receive about 1,500mm per annum. The temperatures at the upland zones are low with an average of about 16˚C in the periods between June and July. Temperatures are highest about 24˚C in the lowland zones of the basin near Lake Victoria in the period between January and March (Weeser et al., 2018: Ochieng et al., 2019).

***Hydrology and Drainage***

The drainage of the Sondu Miriu River Basin is characterized by dendritic pattern in which tributaries and stream join the river system at an angle of less than $90_o$ (Weeser et al., 2018). There are two main tributaries in the upper zone of the basin namely Kipsonoi and Yurith. The Kipsonoi tributary has its headwaters in Keringet areas of Kuresoi in Nakuru County. The tributary traverses Bomet County, Nyamira County and Homabay County. The Yurith tributary comprises Timbilil, Kiptiget and Itare-Chemosit sub tributaries. The three tributaries converge at Kabianga tea estate to form Yurith tributary. The Kipsonoi and Yurith tributaries converge at Ikonge tea plantation. The total length of the Sondu Miriu River is approximately 190 km from its head to the shores of the Lake Victoria.

***Topography and soils***

Sondu River Basin comprises of uplands at the upper catchments and low lands towards the shores of Lake Victoria. Mau Escarpment that occurred due to formation of the rift valley characterizes the upstream part of the basin. The maximum altitude of the river basin is about 3000 m above sea level. The lowest elevation in the downstream zone of the basin is about 1100 m above sea level (Ochieng et al., 2019). The steep slope terrains contribute to the increased velocity of the surface run off especially in areas with limited vegetation cover. At the middle zone of the basin, the slope ranges from gentle to flat as it approaches shores of the Lake Victoria. The main soil type found in sub basins of the Sondu Miriu River Basin are nitisols, andosols, lithosols, greyzems, cambisols, arenosols, phaeozems, planosols, rankers, regosols,vertisols, xerosols and luvisols (Mungai et al., 2011). At the upland zone of the basin, phaeozems dominates the sub basins dominated by tea plantation; forest and mixed farming land covers and land uses. The Phaeozems are deep, dark-redish to brown colour soils having clay and thus are able to retain moisture for longer period after the rains (O'Geen and Schwank, 2005) The middle zone of sub basin dominated by mixed farming are Acrisol and Xerosol that are humic and supports forests. In the downstream zone after confluence of Yurith and Kipsonoi tributaries, Regosol soils dominate the area of Sondu and Miriu in Kisumu and Homabay Counties (Nyaganga, 2008).

**Data requirement:** The data used in this study was mainly secondary data acquired from various sources. Land cover and land use spatial data with a spatial resolution of 30 m Digital Elevation Model (DEM) was acquired from the USGS remote sensing database. The soils data from FAO database was acquired and used to provide information on soil properties required for hydrological modelling. Historical observed daily climatic data and river discharge data for six decades from 1960 to 2020 was acquired from WRA, Ministry of Water, Sanitation and Irrigation and Kenya Meteorological Department. The output datasets considered in this study were evapotranspiration data, rainfall data, stream flows and soil moisture.

**Setting up the SWAT model:** The ArcSWAT was used to delineate study area, define stream networks and sub basin outlets and simulate hydrological components in the sub basins dominated by tea plantation; forest and mixed farming land covers and land uses. The threshold percentage of 5% in the model was applied to enable generation of significant HRUs in simulating results hence increasing the model computation efficiency. The daily rainfall, temperature, soils and land use data were inputted into the model for simulation of hydrological components (Arnold and Fohrer, 2005).

**SWAT Model Calibration and validation:** The calibration of watershed, sub basin parameters and land management operations were conducted using the observed stream discharge data for the period 1960 to 1980 at RGS 1JG03. Parameters (see Table 1) used in the calibration of the SWAT model were selected based on their performance in simulating stream flows and sediment yields. The validation of the model was done in the period 1981-1996 using daily stream discharges. The coefficient of determination, $R_2$ (Equation 1) and Nash-Sutcliffe Efficiency NSE (Equation 2) were used to determine a good balance between simulated and observed data (Briak *et al*., 2019).

$$R^2 = \left\{ \frac{\sum_i^N (Q_o - \bar{Q}_o)(Q_m - \bar{Q}_m)}{\sqrt{\sum_i^N (Q_o - \bar{Q}_o)^2 \sum_i^N (Q_m - \bar{Q}_m)^2}} \right\}^2 \quad \text{Equation 1}$$

$$\mathrm{NSE} = 1 - \frac{\sum_i^N (Q_o - Q_m)^2}{\sum_i^N (Q_o - \bar{Q}_o)^2} \quad \text{Equation 2}$$

$Q_o$ is observed stream discharges ($m_3$/s), $Q_m$ is simulated stream discharges ($m_3$/s), N is the nth data, $\bar{Q}_m$ and $\bar{Q}_o$ are mean simulated and observed stream discharges respectively.



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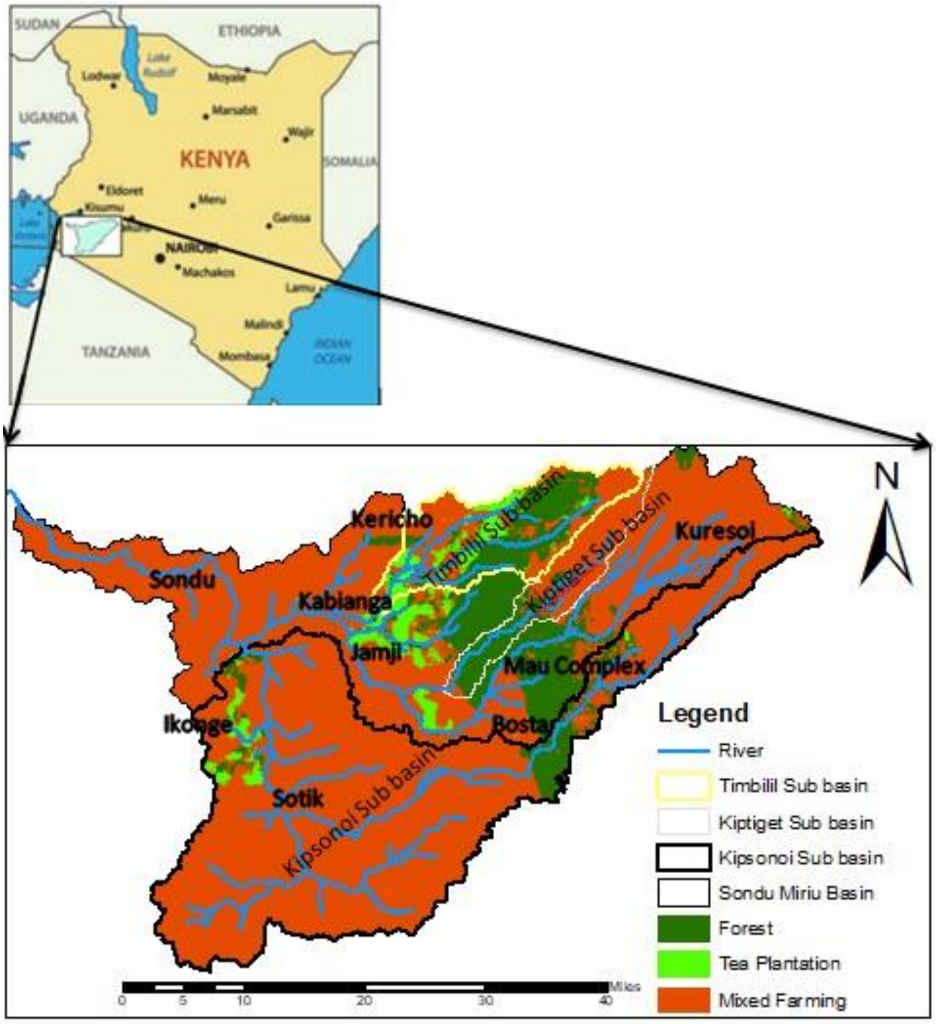


**Figure 1:** The location of sub basins in the Sondu Miriu River Basin in Kenya

**Table 1:** Model Parameters used in SWAT model calibrations

| No. | Parameter | Minimum Value | Maximum Value | Fitted Value |
|---|---|---|---|---|
| 1 | v ALPHA_BF.gw | 0 | 1 | 0.65 |
| 2 | v GW_DELAY.gw | 30 | 450 | 350 |
| 3 | v GWQMN.gw | 0 | 5000 | 3500 |
| 4 | v ESCO.bsn | 0 | 1 | 0.8 |
| 5 | v EPCO.bsn | 0 | 1 | 0.8 |
| 6 | v SURLAG.bsn | 0.05 | 24 | 6 |
| 7 | r SOL_BD.sol | 0.9 | 2.5 | 1.2 |
| 8 | r SOL_AWC.sol | 0 | 1 | 0.4 |
| 9 | v CH_K2.rte | 0.01 | 500 | 320 |
| 10 | v REVAPMN.gw | 0 | 500 | 200 |
| 11 | v RCHRG_DP.gw | 0 | 1 | 0.7 |
| 12 | v DEEPST.gw | 0 | 50000 | 20000 |
| 13 | r ALPHA_BNK.rte | 0 | 1 | 0.8 |
| 14 | v SLSUBBSN.hru | 10 | 50 | 14 |
| 15 | r_ USLE_K.sol | 0 | 0.65 | 0.2 |

## 5. Results and Discussions

### 5.1 Analysis of the SWAT Model performance

The developed SWAT model for Sondu Miriu River Basin was calibrated using the observed daily stream discharges for the periods 1960 to 1980 while data for the period January 1981 to February 1997 was used in validation of the model. The calibration output showed a good balance between the model generated data and observed stream discharges data (Figure 2). The model yielded a coefficient of determination $R_2$ of 0.8 and Nash–Sutcliffe model efficiency value (NSE) of 0.78 which indicated that the model output performance was good. The simulated mean stream discharge at RGS 1JG03 was 60.98 $m^3$/s while the observed mean discharge was 59.10 $m_3$/s. The validation of the model in the period 1981-1997 revealed that the peak and low discharges were well simulated (Figure 3). The relationship between simulated and observed river discharges showed good positive relation with coefficient of determination was $R^2$ of 0.75 and NSE value of 0.6. The 95% confidence level for the simulated discharges was 7.74 $m^3/s$ that is very close to the observed discharges with value of 7.48 $m^3/s$.

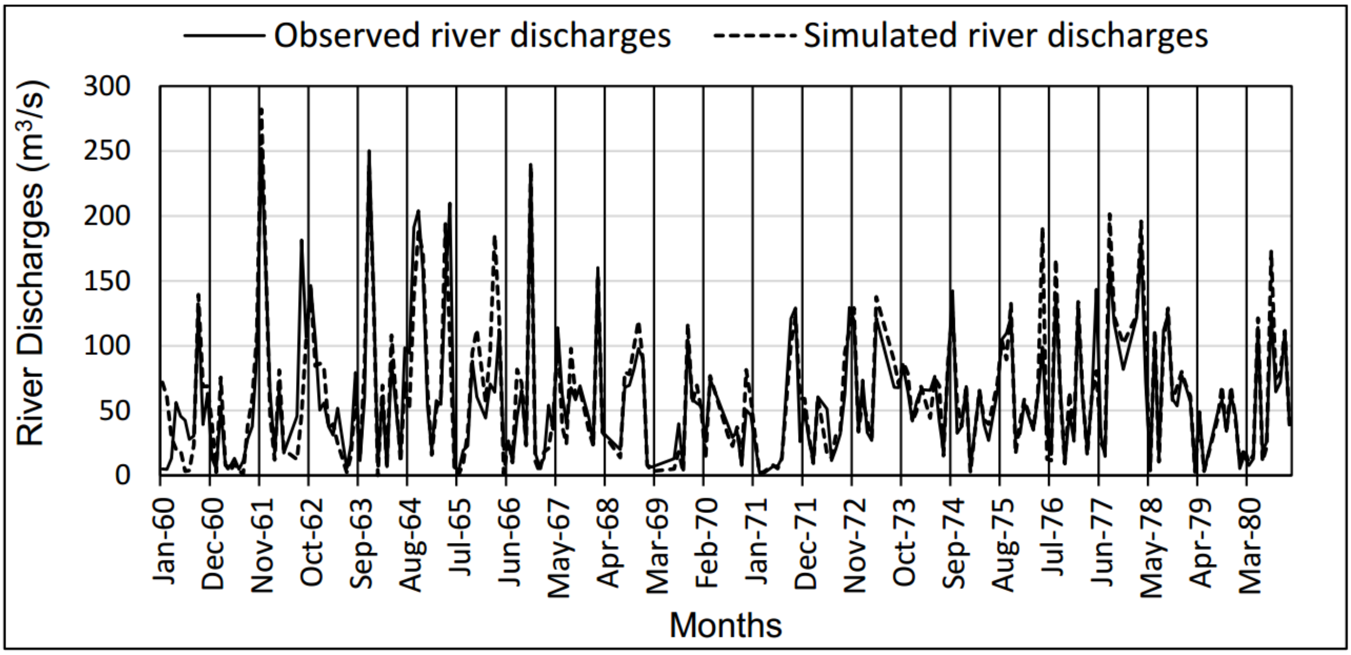


**Figure 2:** The comparison between simulated and observed river discharges for the calibration period 1960 - 1980

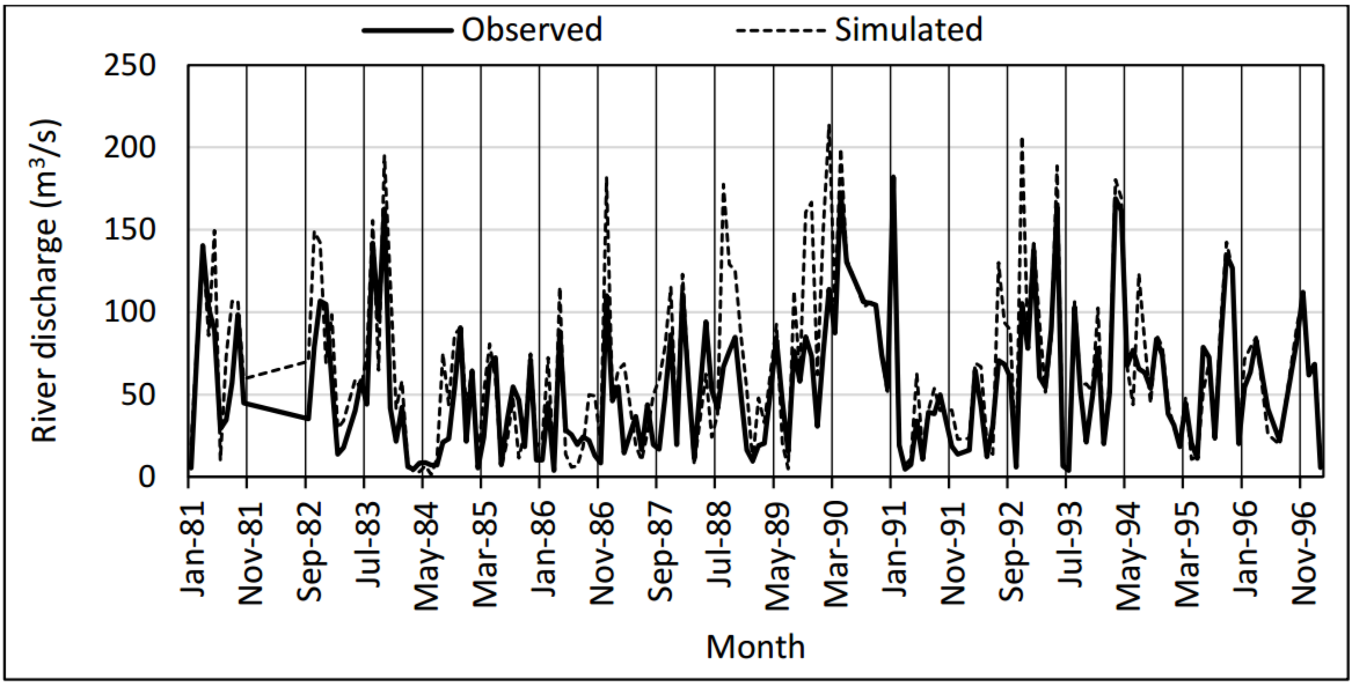


**Figure 3:** Simulated and observed stream discharges for the validation period 1981 - 1997

**5.2 Rainfall in the sub basins dominated by tea plantations, forest and mixed farming land cover**

*5.2.1 Rainfall in the Timbilil sub basin dominated by tea plantations land cover*

The rainfall received in the sub basin dominated by tea plantations was measured at Kericho and Timbilil Meteorological stations. The rainfall has shown an increasing trend in the period between 1960 and 2020 (Figure 4). The mean monthly peak rainfall occurred in March, April and May ranging from 170 mm/month to 270 mm/month. The mean annual rainfall in the sub basin was 1832.8 mm. The minimum rainfall was 1270 mm and maximum of 2500 mm (see Table 2). The inter annual rainfall variations in the period 1981-1995 showed an increase of 100 mm and in similar period the area under tea plantations increased by approximately 6 $km^2$. Also, in the period between 2006 and 2011, rainfall increased by about 127 mm and area under tea plantations expanded by 6 $km^2$. (Figure 5). The relationship between rainfall and area under tea plantation in the sub basin was a positive with coefficient of determination of $R^2$ = 0.15. This showed that the changes in the area under tea plantations in the sub basin were insignificant to the variations of rainfall. The significant of rainfall variations was attributed to climate change.

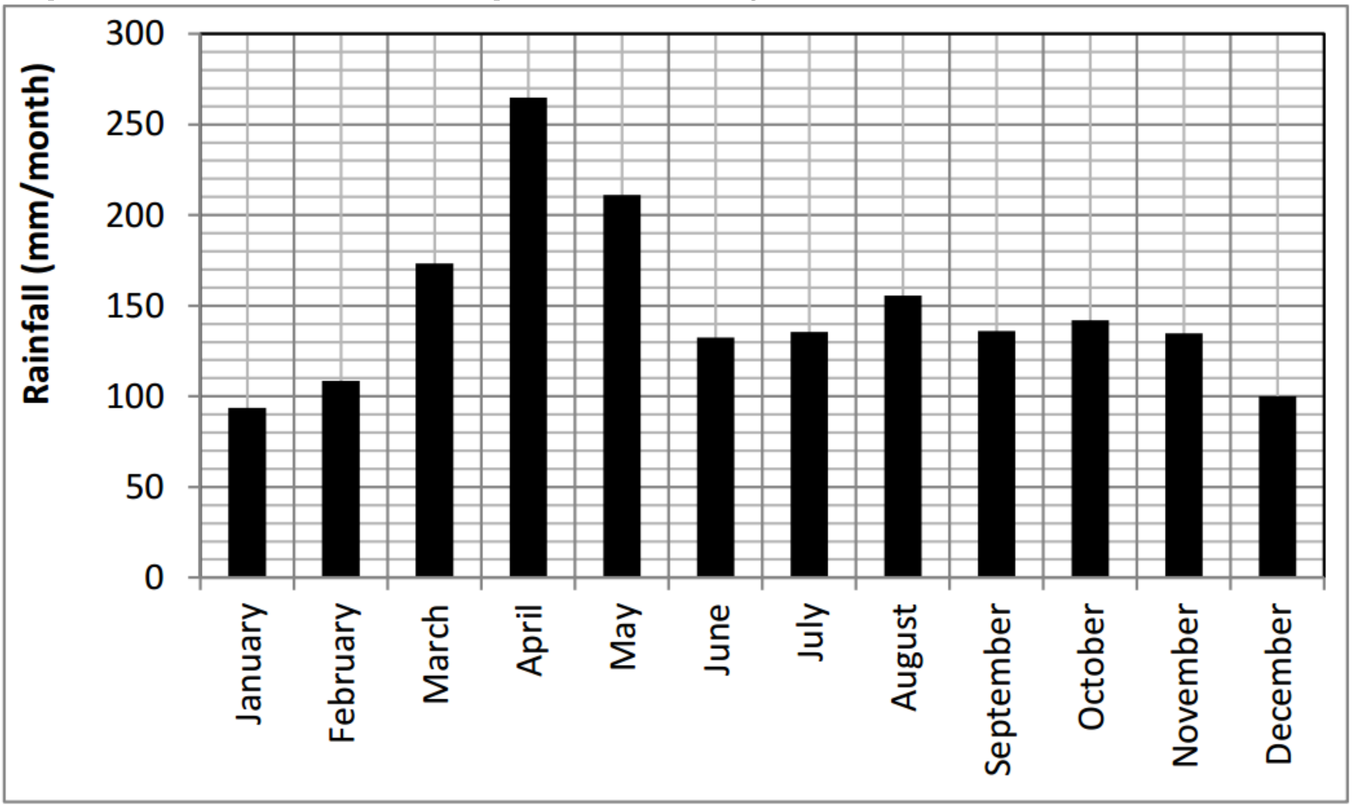


**Figure 4:** Mean monthly rainfall in the Timbilil sub basin dominated by tea plantation in the period January-December

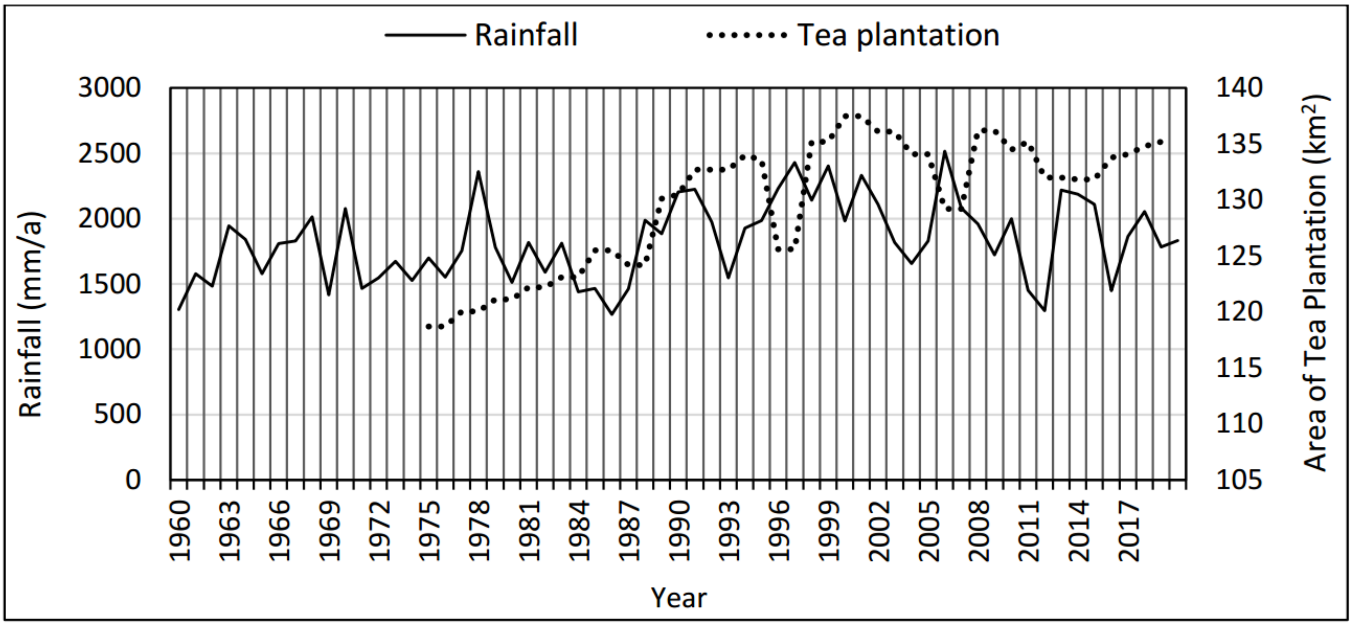


**Figure 5:** Annual rainfall and tea plantations in the Timbilil sub basin dominated by tea plantation in the period 1975 - 2020

*5.2.2 Rainfall in the Kiptiget sub basin dominated by forest land cover*

The rainfall in the sub basin dominated by forest land cover showed different trends in three periods. In the period from 1960 to 1970, rainfall increased by770 mm/a. In the period between 1975 and 1986 the rainfall reduced by 434 mm/a while area under forest cover increased by 10 $km^2$. On the other hand rainfall increased in the period between 1987 and 2004 by 391 mm/a while area of forest cover reduced by 20 $km^2$ (Figure 6). The negative relationship was observed between rainfall and area of forest cover with $R^2$ of 0.14 and correlation r of -0.37. This clearly indicated that forest cover in the sub basin had no influence on the rainfall variations. This significant change could be attributed to change in regional climate because the increase in the area under forest cover in this period was insignificant (Figure 6). These findings were contrary to the findings of previous studies conducted in West Africa where positive relationship between rainfall and forest cover (Badjana et al., 2017; Diasso and Abiodun, 2018). The mean rainfall in the sub basin was approximately 1830 mm per annum. The minimum and maximum rainfall in the sub basin was 1265 mm and 2516 mm respectively (see Table 2).

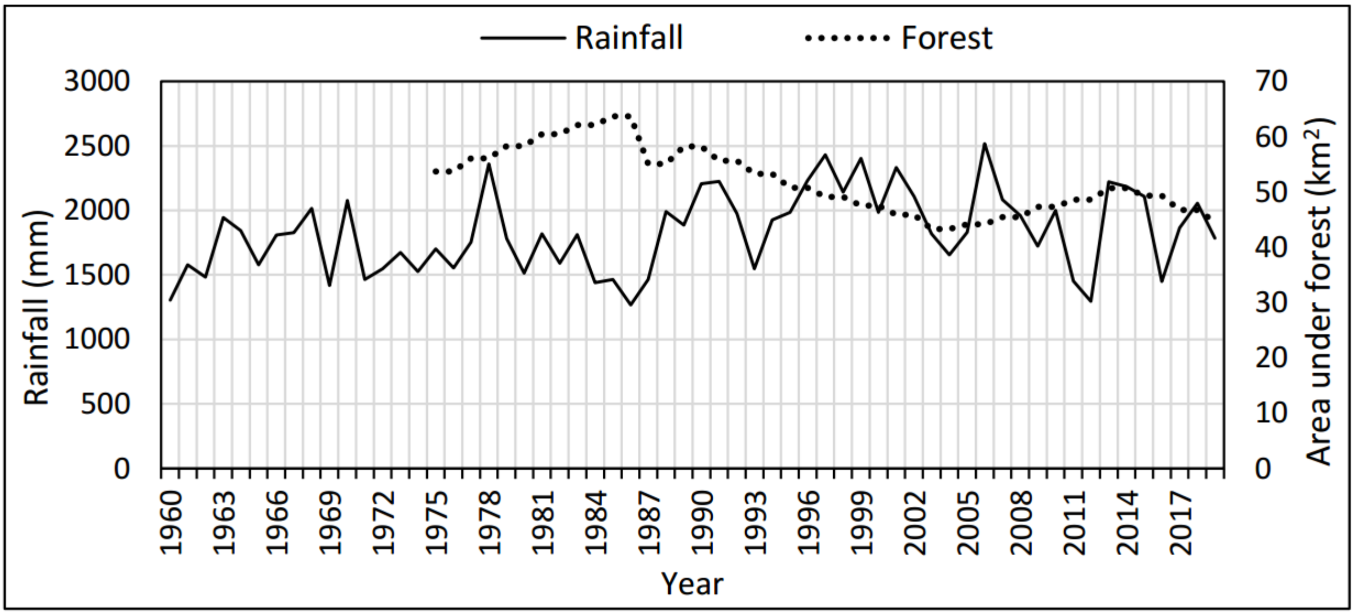


**Figure 6:** Rainfall and forest land cover in the Kiptiget sub basin dominated by forest land cover

*5.2.3 Rainfall in the Kipsonoi sub basin dominated by mixed farming land use*

The rainfall time series showed seasonal and inter annual variations in the sub basin. The rainfall data from Sotik, Kaboson and Bomet meteorological stations showed that the monthly peak rainfall occurred in April, August and November. In April the mean monthly rainfall received was approximately 200 mm/month while in August and November mean monthly rainfall estimated were 132 mm/month and 129 mm/month respectively (Figure 7). The mean annual rainfall received in the sub basin was about 1409 mm/a. The minimum and maximum rainfall in the sub basin was 750 mm and 2030 mm respectively (see Table 2). In the period between 1960 and 1977, the rainfall showed an increasing trend from 1344 mm to 1752 mm. The period between 1978 and 1987 showed a decreasing trend from 1732 mm to 1174 mm. In the period between 1988 and 1998 the rainfall increased from 1216 mm to 1624 mm. The area of land under mixed farming decreased by 86 $km_2$ in the period 1978 and 1987. In the period between 1988 and 1998, the area of land under mixed farming increased by 53 $km_2$. Similar trends were observed in time series for rainfall and area under mixed farming in the sub basin. This indicates that the rainfall availability attracts expansion of area under mixed farming while less farming was conducted in low rainfall periods. The changes in the area under mixed farming were insignificant to cause variations in the rainfall of the sub basin. This was confirmed by the low positive relationship between area under mixed farming and rainfall with coefficient $R_2$ of 0.03 and r of 0.17. Hence rainfall variability observed was attributed to the changes in the climatic conditions (Figure 8).

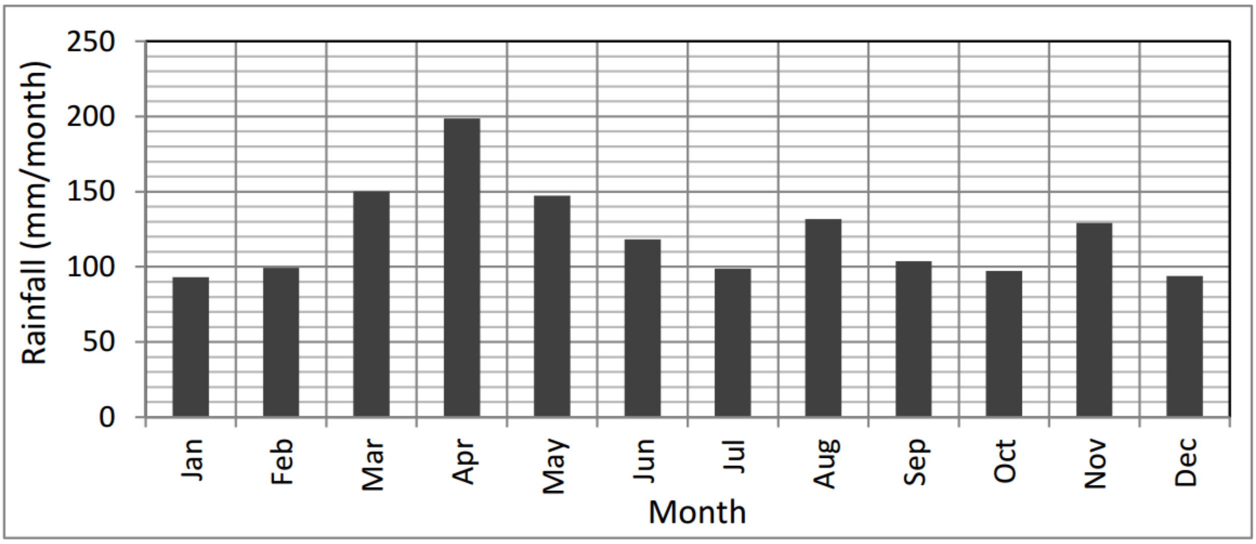


**Figure 7:** Mean monthly rainfall observed in the Kipsonoi sub basin dominated by mixed farming land uses

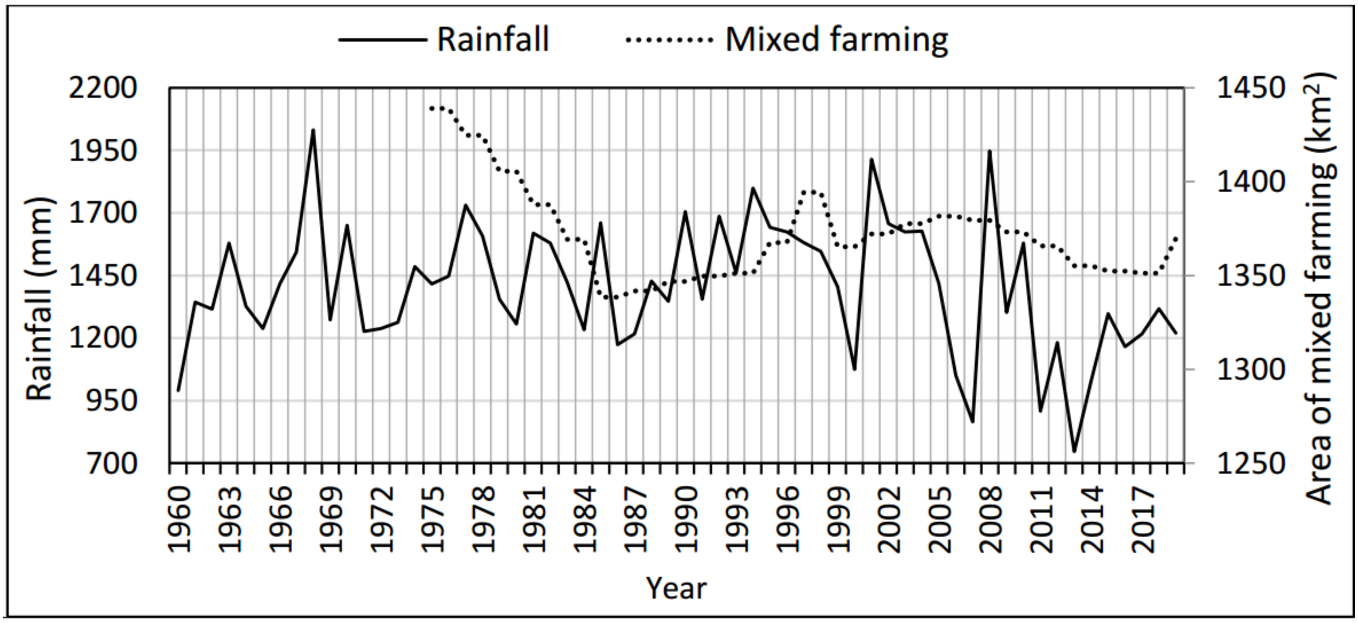


**Figure 8:** Rainfall and mixed farming land cover in the Kipsonoi sub basin dominated by mixed farming land cover and land uses

***5.3 Stream discharges in the sub basin dominated by tea plantations, forests and mixed farming***

*5.3.1 Stream discharges in the Timbilil sub basin dominated by tea plantations land cover*

The sub basin dominated by tea plantations land cover showed changes in the area under tea plantations and variations in stream discharges (Figure 9). In the period from 1975 to 1990 the stream discharges increased by 7 $m_3/s$ while in the area under tea plantations shown an increase of 14 $km_2$. In the period between 1997 and 2018 the stream discharges decreased by 9 $m_3/s$ while area under tea plantations expanded by approximately 10 $km^2$. The changes in stream discharges in the period between 1960 and 2020 was partly attributed to changes in the area under tea plantations land cover and also mainly to the rainfall (see Figure 5). The influence of rainfall on the changes was confirmed by the strong positive relationship between rainfall and stream flows were observed with $R_2$ of 0.96 and r value of 0.98. The minimum stream discharge was 5.66 $m_3/s$ and it occurred in 1960. The mean stream discharge was 10.8 $m_3/s$ (see Table 2).

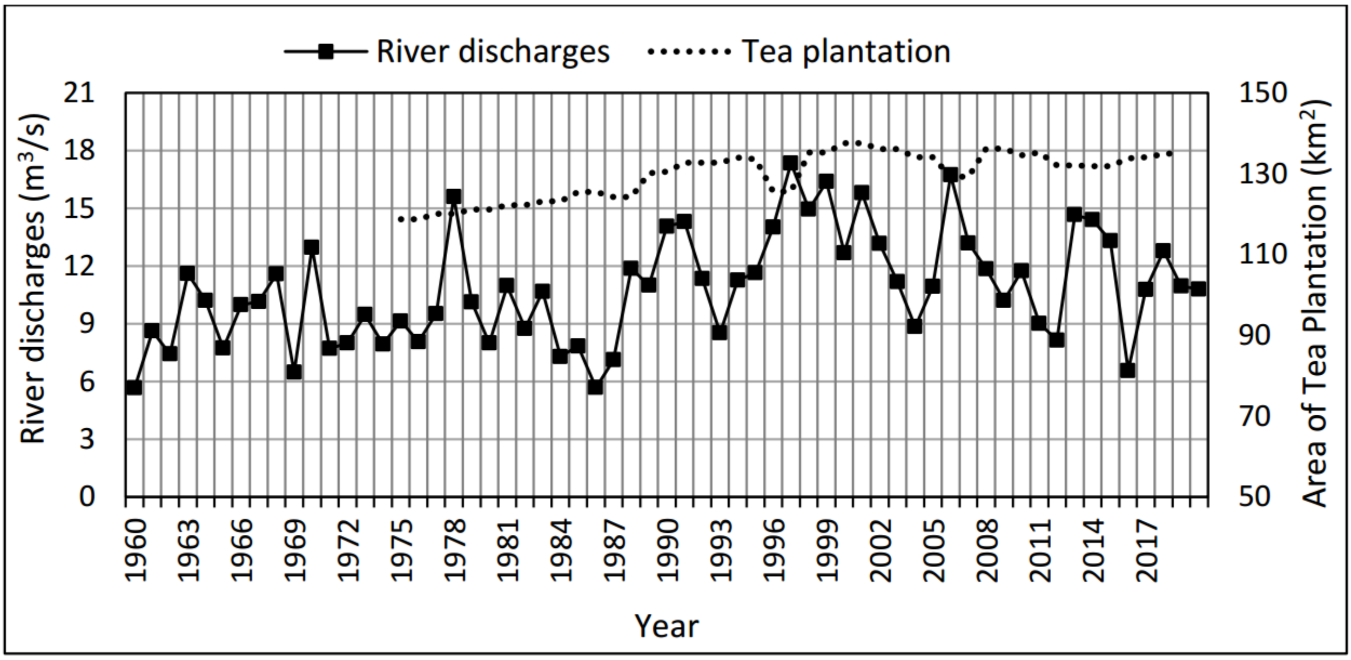


**Figure 9:** Discharges and area of tea plantations in the Timbilil sub basin in the period 1961 - 2020

*5.3.2 Stream discharges in the Kiptiget sub basin dominated by forests cover*

The long-term stream discharges in the sub basin dominated by forest land cover indicated a decline in the forest land cover from 1985 and an increase of peak discharges as depicted in Figure 10. In 1970 peak river discharges of 5.6 $m_3/s$ occurred and the peak return period recurred in 1997 with river discharges 7.5 $m_3/s$. The decrease in the land under forest covers drastically in the period 1986 - 2001 losing an area of approximately 16 $km_2$. In the same period an increase in the stream discharge by 5 $m_3/s$ was observed. However, in the period from 2006 to 2014, the area of land under forest cover was expanded by approximately 7 $km_2$ and a reduction in the peak discharges was observed. Negative relationship $R_2$ of 0.186 and r of -0.4 between area of forest cover and stream discharges was observed. Despite the fact that findings showed an influence of forest cover on the changes in the stream flows, rainfall is the main contributor to variations in the stream flows. This was due to increased surface runoffs generation on deforested areas. But it could also be due to rainfall variability during the same period. The maximum stream discharge was 7.5 $m_3/s$ while the minimum discharge was 2.02 $m_3/s$. The mean stream discharge in the sub basin was 4.5 $m_3/s$ (see Table 2).

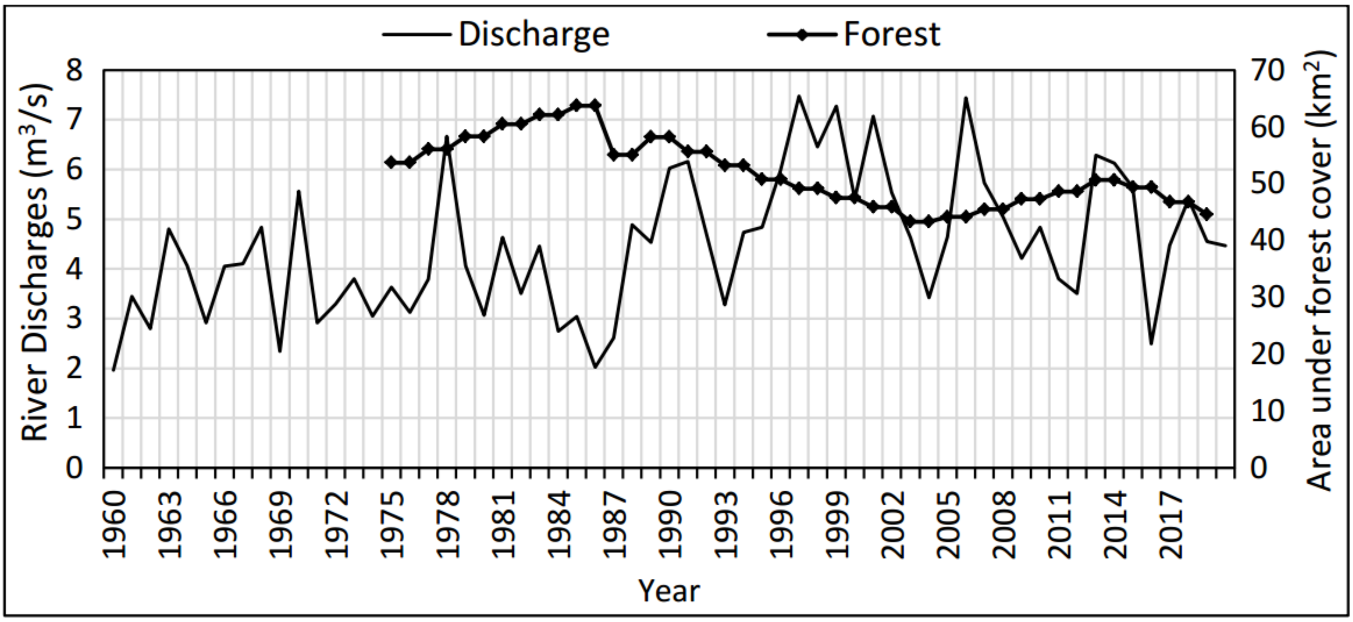


**Figure 10:** Stream discharges and area under forest cover in Kiptiget sub basin in the period 1961-2020

*5.3.3 Stream discharges in the Kipsonoi sub basin dominated by mixed farming land cover*

Stream flows in the sub basin dominated by mixed farming shows significant inter annual variability. In the period 1975-1983 there was a reduction of the area under mixed farming by 101 $km_2$ (see Figure 11). In this period stream flows increased by approximately 5 $m_3/s$. This significant increase in stream flows was be attributed to increase in surface runoffs due deforestation and also rainfall received in the sub basin. The relationship between river discharges and area under mixed farming was positive but weak with coefficient of determination $R_2$ of 0.025 and correlation coefficient r value of 0.15. The relationship between rainfall and stream flow was $R_2$ of 0.84 and r of 0.96. The mean stream discharge was 32.4 m3/s (see Table 2).

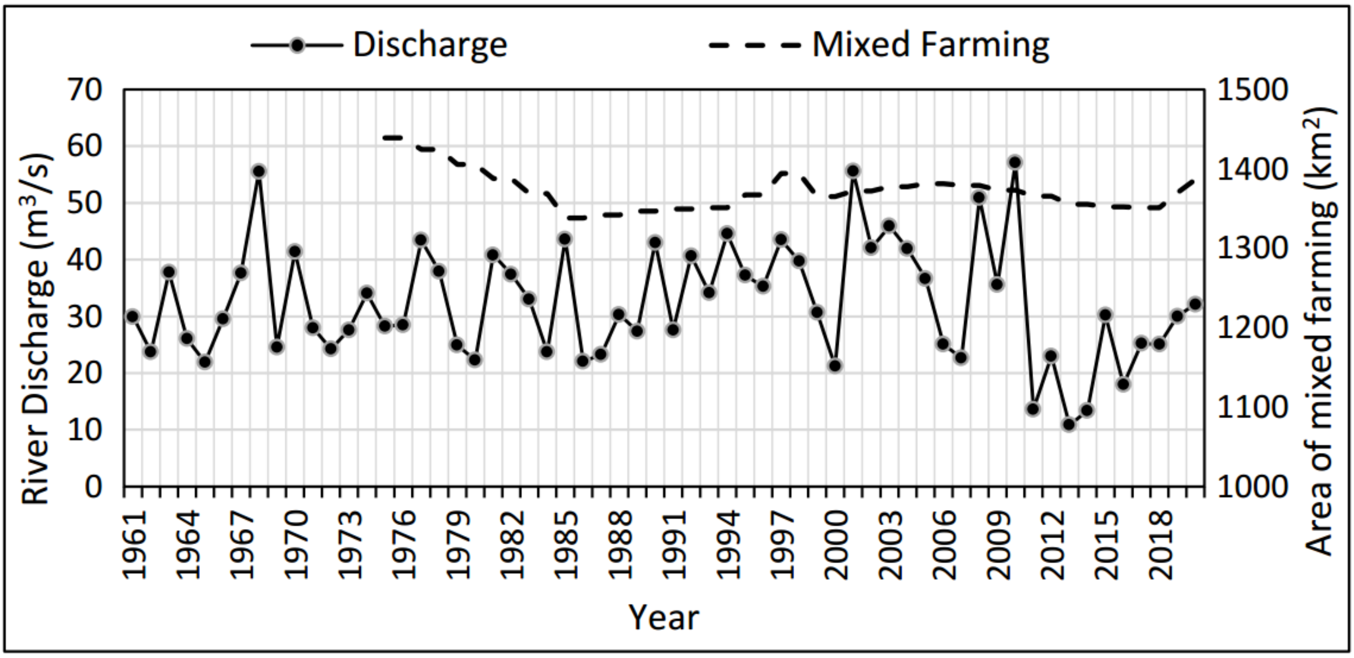


**Figure 11:** River discharges and mixed farming land cover in the Kipsonoi sub basin dominated by mixed farming in the period 1961-2020

*5.4 Evapotranspiration in the sub basin dominated by tea plantations, forests and mixed farming*

*5.4.1 Evapotranspiration in the Timbilil sub basin dominated by tea plantation land cover*

In the sub basin dominated by tea plantation, data showed that evapotranspiration and the area under tea plantation had insignificant relation (Figure 12). The seasonal variations showed that high evapotranspiration occurs in the period between March and August with peak in April. During this period, evapotranspiration ranges from 40 mm/a to 110 mm/a. The lowest evapotranspiration occurred in the periods between October and February with evapotranspiration of the order 20 mm/a (Figure 13). The mean evapotranspiration was 750 mm; minimum evapotranspiration was 500 mm and maximum of 830 mm (see Table 2). In the period between 1985 and 1995, the expansion of tea plantations by 10 $km_2$ and the evapotranspiration increased from 674 mm to 820 mm was observed. The decrease in the area under tea plantations between 1996 and 1997 by 8 $km_2$ and evapotranspiration reduced by 143 mm. In the period between 1998 and 2010, an increase in evapotranspiration by160 mm and the expansion of the area under tea plantations was 6 $km_2$. However, in the period 2010-2013 the decrease in the area under tea plantations by 2.5 $km_2$ and evapotranspiration decreased by 346 mm. The overall evapotranspiration ranged between 500 mm and 850 mm. The relation between area under tea plantations and evapotranspiration was low and negative with coefficient of determination $R_2$ of 0.0063 and correlation r of -0.08. This showed that changes in the area under tea plantations were insignificant to the temporal variations of evapotranspiration. Hence the significant changes were attributed to the rainfall given that high evapotranspiration occurred during rainy months and the relationship between rainfall and evapotranspiration was positive with correlation r of 0.4 and $R_2$ of 0.16.

*5.4.2 Evapotranspiration in the Kiptiget sub basin dominated by forest land cover*

There are significant seasonal variations of evapotranspiration in the Kiptiget sub basin with the highest evapotranspiration occurring in the period between March and October ranging from 38 mm/month to 118 mm/month. The lowest evapotranspiration occurred in the period between October and February ranging from 20 mm/month to 63 mm/month (Figure 14). The mean evapotranspiration in the sub basin was 905 mm, minimum evapotranspiration was 560 mm and maximum evapotranspiration was 1006 mm (see Table 2). There is insignificant trend in the evapotranspiration in annual pattern with positive relationship between evapotranspiration and area under forest cover $R_2$ of 0.0021 and correlation r of 0.045. For instance, in the period between 1991 and 1999, there was a decrease in the area under forest cover from 55 $km_2$ to 47 $km_2$ while the evapotranspiration decreased from 988.6 mm to 807.5 mm (Figure 15). Similar relationship was observed in the period between 2004 and 2010 where increase in the area under forest cover by 4 $km_2$ and evapotranspiration increased from 869 mm to 989 mm. This is similar observations made in the Timbilil sub basin dominated by tea plantations. The insignificant influence of forest cover on the evapotranspiration could be due to small scale sub basin used and significant change was due to rainfall that showed similar trends as presented in Figure 6. Further the relationship between area of forest cover and rainfall was $R_2$ of 0.13 and r of 0.36.

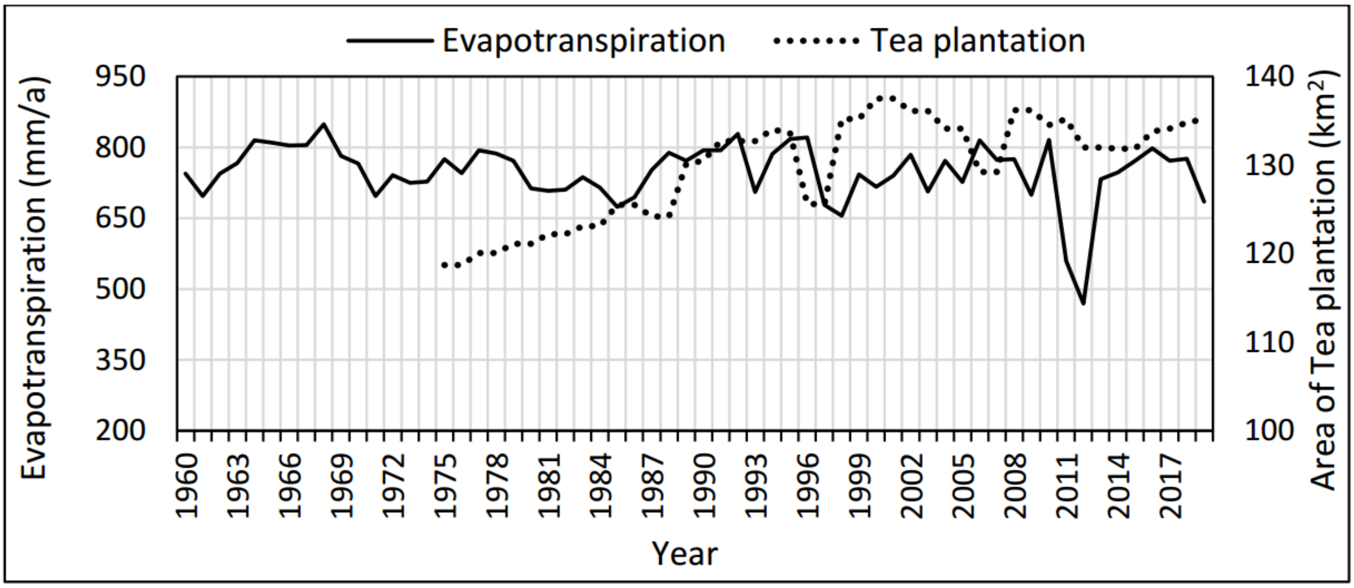


**Figure 12:** Evapotranspiration in Timbilil the sub basin dominated by tea plantation

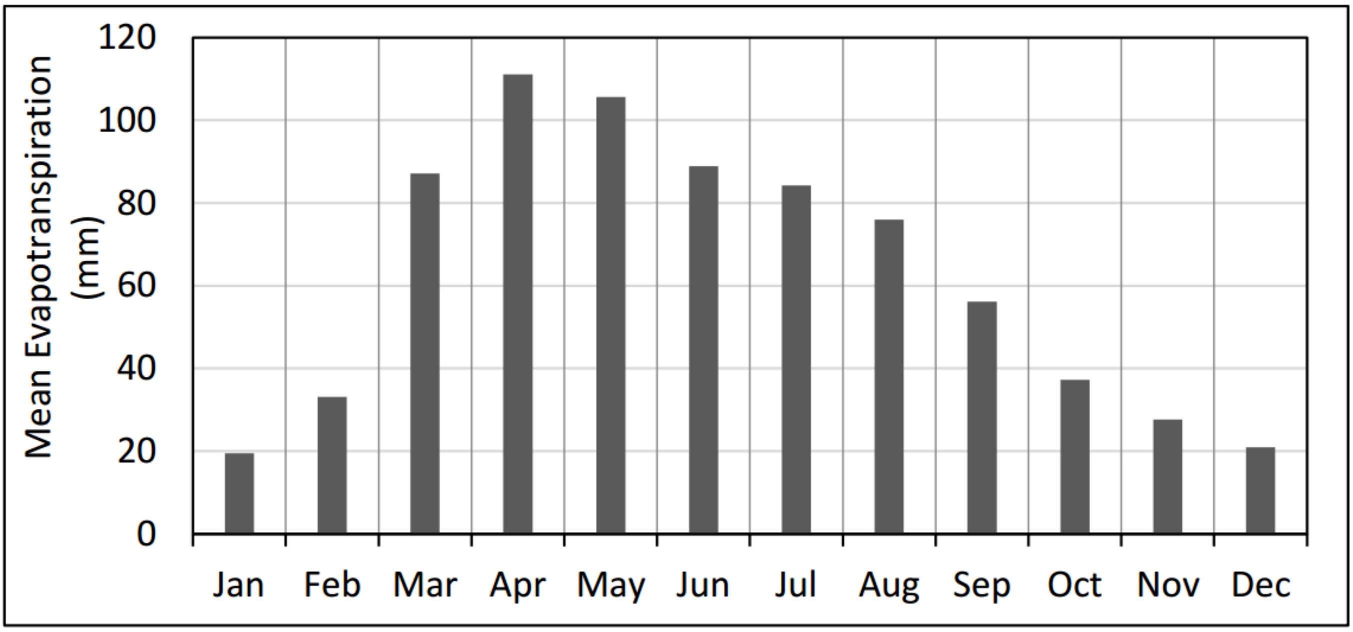


**Figure 13:** Mean monthly evapotranspiration in the Timbilil sub basin dominated by tea plantation

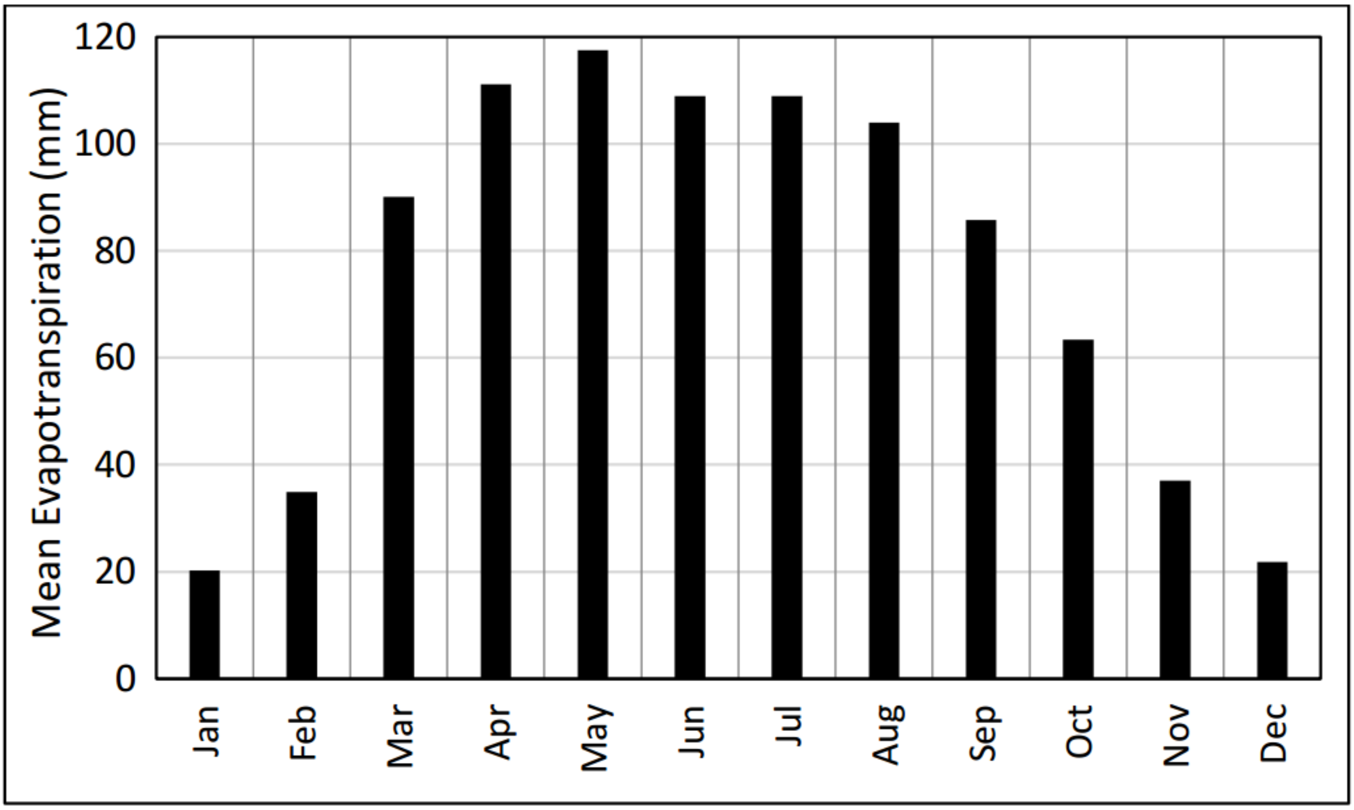


**Figure 14:** Monthly evapotranspiration in the Kiptiget sub basin dominated by forest land cover

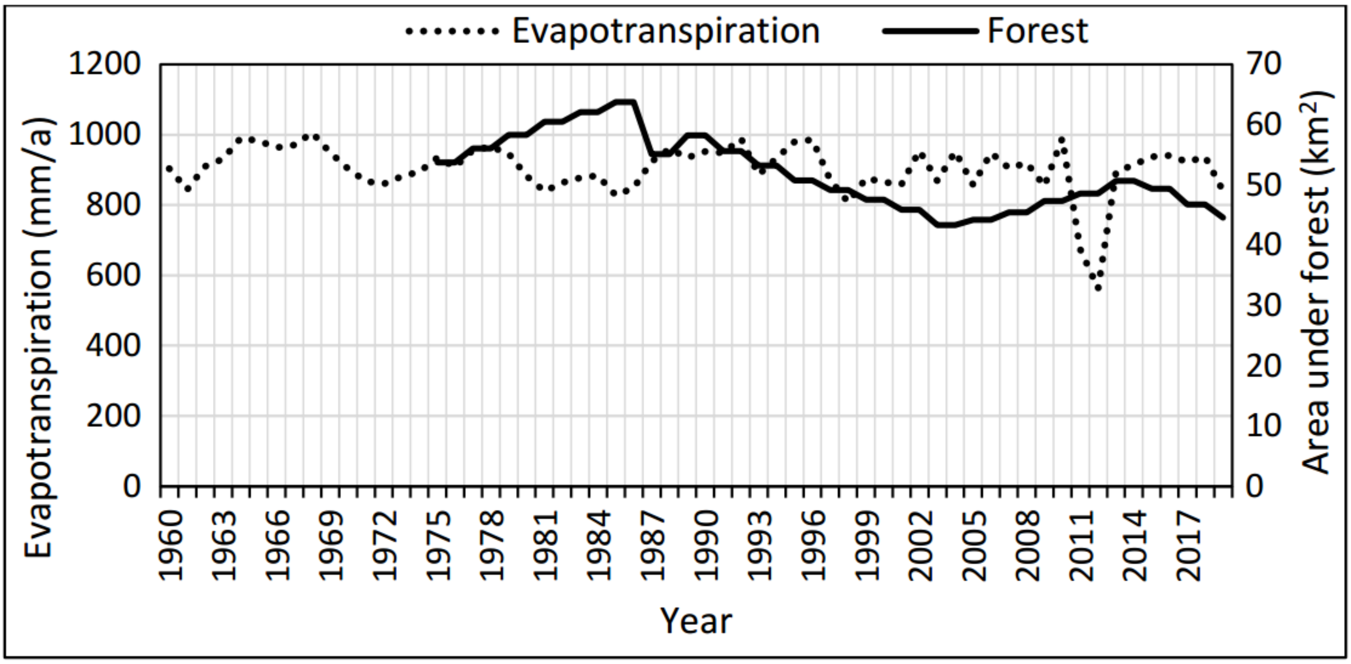


**Figure 15:** Evapotranspiration and forest land cover in Kiptiget the sub basin dominated by forest land cover

*5.4.3 Evapotranspiration in the Kipsonoi sub basin dominated by mixed farming land cover and land uses*

The evapotranspiration in the sub basin dominated by mixed farming land cover and land uses shown a poor relationship between area under mixed farming and evapotranspiration. This was due to low values of correlation coefficient r of 0.14 and coefficient of determination $R_2$ of 0.0189. This relationship is however not significant statistically. The mean evapotranspiration in the sub basin was 760 mm. The minimum evapotranspiration was 400 mm and maximum evapotranspiration was 920 mm (see Table 2). In the period between 1977 and 1986, the evapotranspiration showed a declining trend from 878 mm in 1977 to 734 mm in 1986. During this period the area under mixed farming land showed declining trend from 1425$km_2$ in 1977 to 1338 $km_2$ in 1986. In the period 1987 to 1996, the evapotranspiration showed an increasing trend from 734 mm in 1987 to 919 mm in 1996. While the area under mixed farming during this period increased by 52 $km_2$ (Figure 16). This low relationship showed that mixed farming has insignificant impact on the evapotranspiration. Like sub basins dominated by tea plantations and forest cover, rainfall influences the rate of evapotranspiration in every sub basin. The relationship between rainfall and evapotranspiration was good with $R_2$ of 0.39 and correlation r of 0.62.

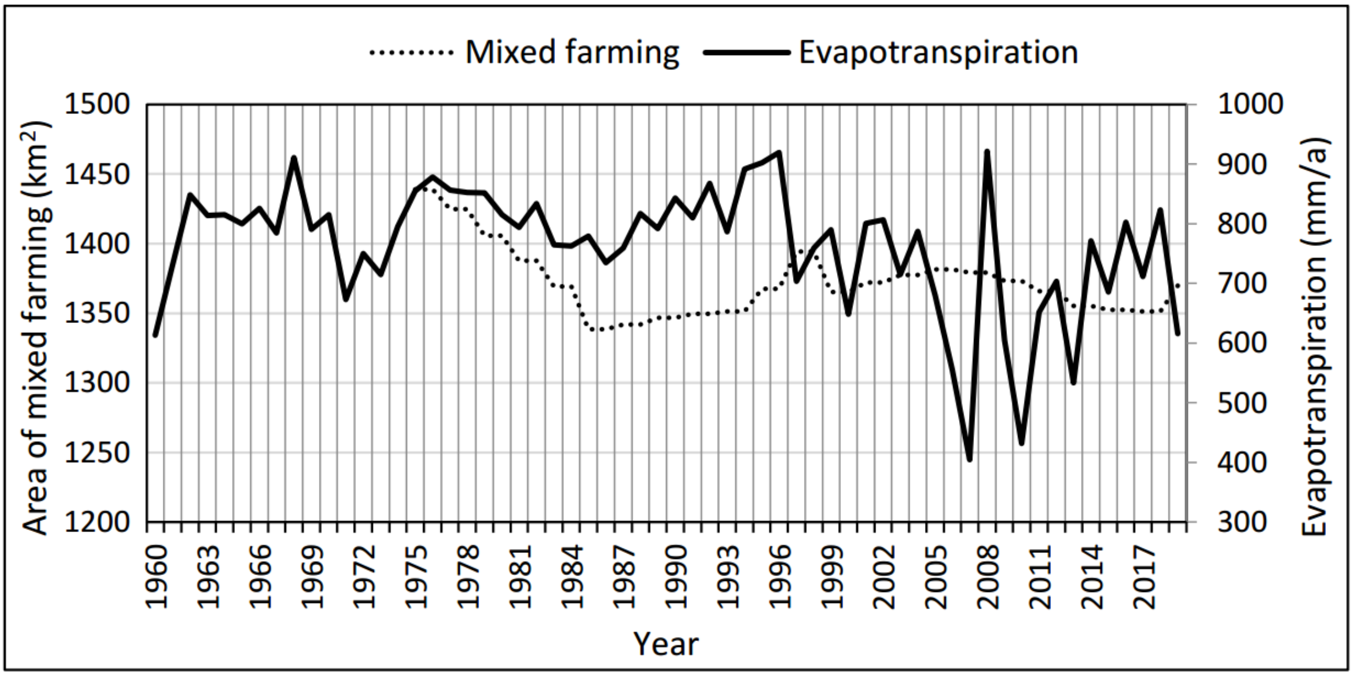


**Figure 16:** Evapotranspiration and mixed farming land cover in the Kipsonoi sub basin dominated by mixed farming in the period 1960-2020

*5.5 Soil Moisture in the sub basins dominated by tea plantations, forests and mixed farming*

*5.5.1 Soil moisture in the Timbilil sub basin dominated by tea plantations land cover*

The mean annual soil moisture in the sub basin was 22.9 mm. The minimum soil moisture in the sub basin was 13.8 mm and maximum of 37.6 mm (see Table 2). There is a significant inter annual variations in soil moisture in the sub basin dominated by tea plantations (Figure 17). In the period between 1989 and 1993 an increase in the area under tea plantations by 3 $km_2$ led to decrease in the soil moisture from 24.3 mm to 16 mm. However, in the period between 1997 and 2004, the area under plantations increased by 8.5 $km_2$ led to decrease of the soil moisture decreased from 32.1 mm to 17.2 mm. This indicates that the negative insignificant relationship between area under tea plantations and soil moisture $R_2$ of 0.00001 and correlation r of -0.003. Rainfall was attributed to the significant temporal variations of soil moisture in the sub basin. This was due to strong positive relationship between soil moisture and rainfall with $R_2$ of 0.42 and correlation r of 0.65.

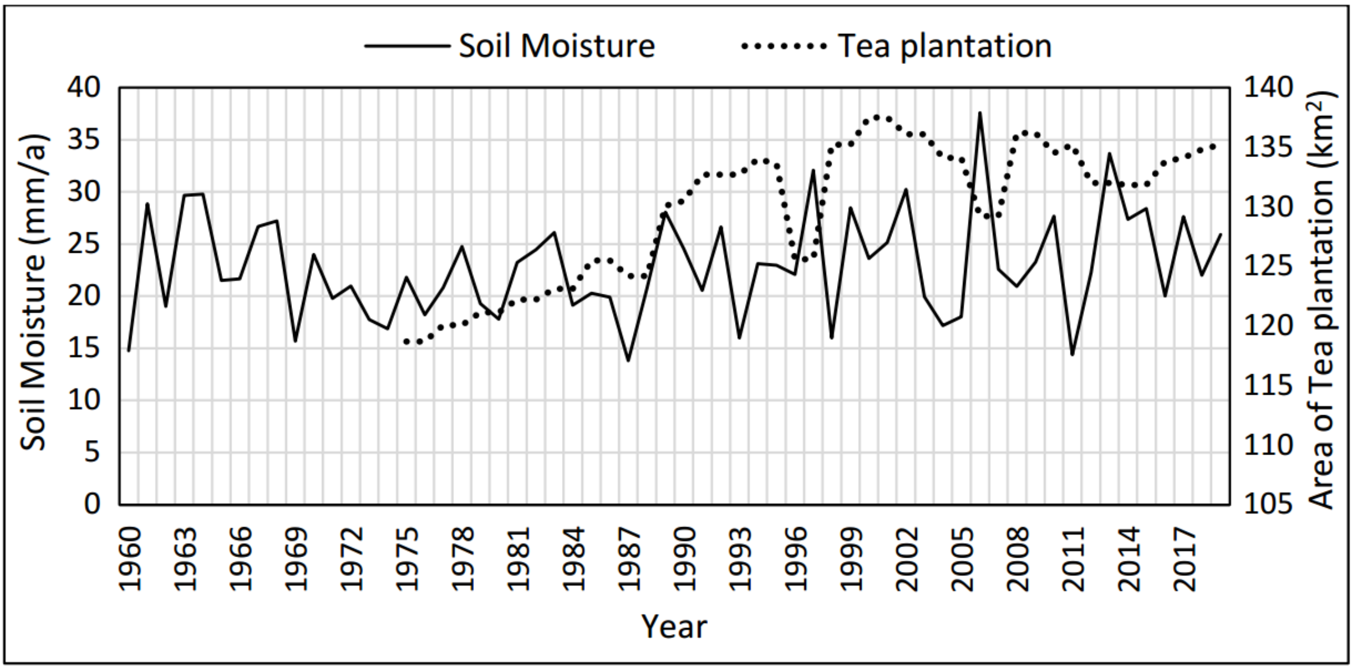

**Figure 17**: Soil moisture in the sub basin dominated by the tea plantation

*5.5.2 Soil moisture in the Kiptiget sub basin dominated by forest land cover*

The trend in soil moisture and area under forests in the sub basin dominated by forest land cover is insignificant. Decrease in the area under forest cover increases soil moisture in the sub basin. In the period between 1986 and 2002, the area under the forest cover declined from 17.8 $km_2$ and an increase in the soil moisture by 19.7 mm was observed. The mean annual soil moisture in the sub basin was 26.3 mm. The minimum soil moisture was 14.1 mm and maximum soil moisture was 40.2 mm (see Table 2). Also, in the period between 2004 and 2011, the area under forest cover increased from 5.3 $km_2$ and the decreased in the soil moisture by 19.7 mm was observed (Figure 18). This shows that there is negative relationship between soil moisture and area under forest cover with coefficient of determination, $R_2$ of 0.07 and correlation r of -0.26. The significant variations observed in the temporal soil moisture were due to rainfall. This was confirmed by the strong positive relationship between rainfall and soil moisture $R_2$ of 0.49 and correlation r of 0.7.

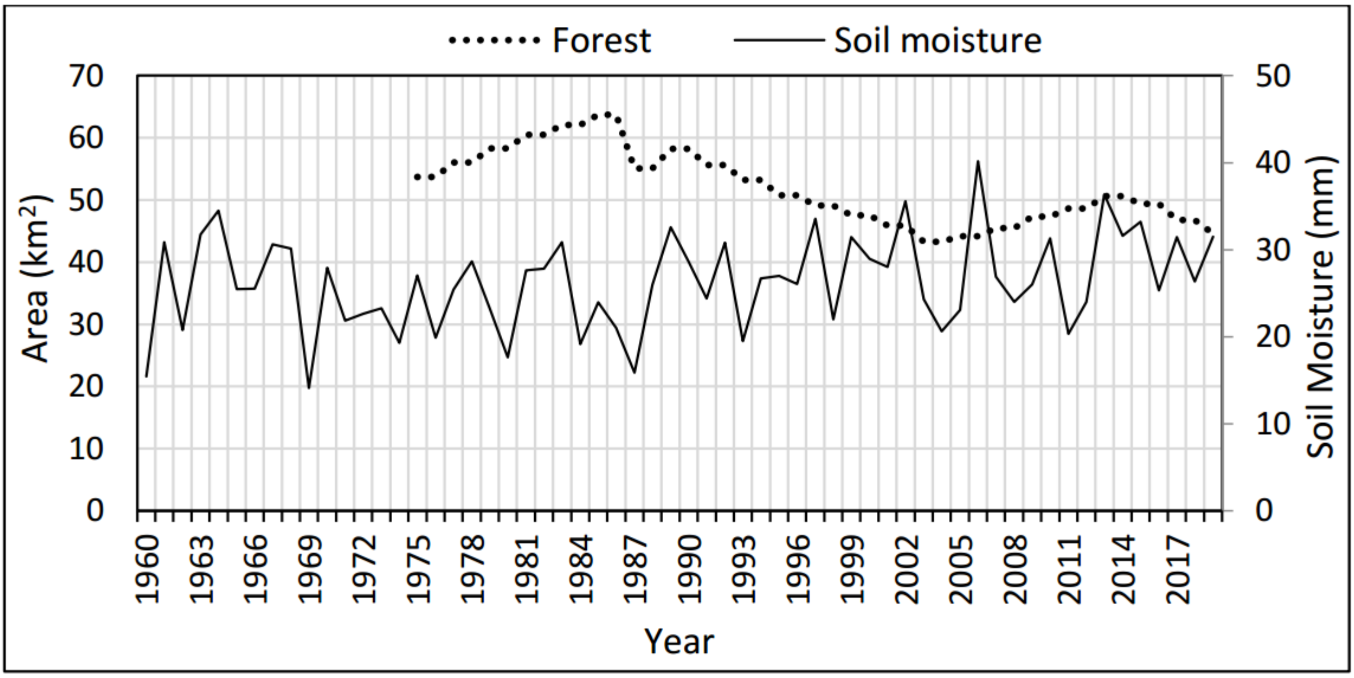


**Figure 18:** Soil moisture and forest land cover in the Kiptiget sub basin dominated by forest land cover

*5.5.3 Soil moisture in the Kipsonoi sub basin dominated by mixed farming land uses*

The mean annual soil moisture in the sub basin dominated by mixed farming was 19.8 mm. The minimum soil moisture was 6.4 mm while maximum soil moisture was 30 mm (see Table 2). The relationship between soil moisture and area under mixed farming was not significant. The coefficient of determination $R_2$ was 0.0063 and correlation, r of 0.06 was obtained. In the period between 1987 and 2002, the soil moisture showed an increasing trend from 12.8 mm to 29.5 mm. The area under mixed farming during this period showed an increasing trend from 1338 $km_2$ to 1378 $km_2$. In the period 2003-2018, the soil moisture decreased by 17.2 mm while the area under mixed farming decline by 26 $km_2$ (Figure 19). This showed that mixed farming has an influence on the soil moisture in the sub basin though insignificant statistically. Similar to the sub basins dominated by tea plantations and forest cover, the relationship between rainfall and soil moisture in this sub basin was positive with $R_2$ of 0.3 and correlation coefficient r of 0.55. Hence rainfall was the main contributor to variations of soil moisture compared to mixed farming land use.

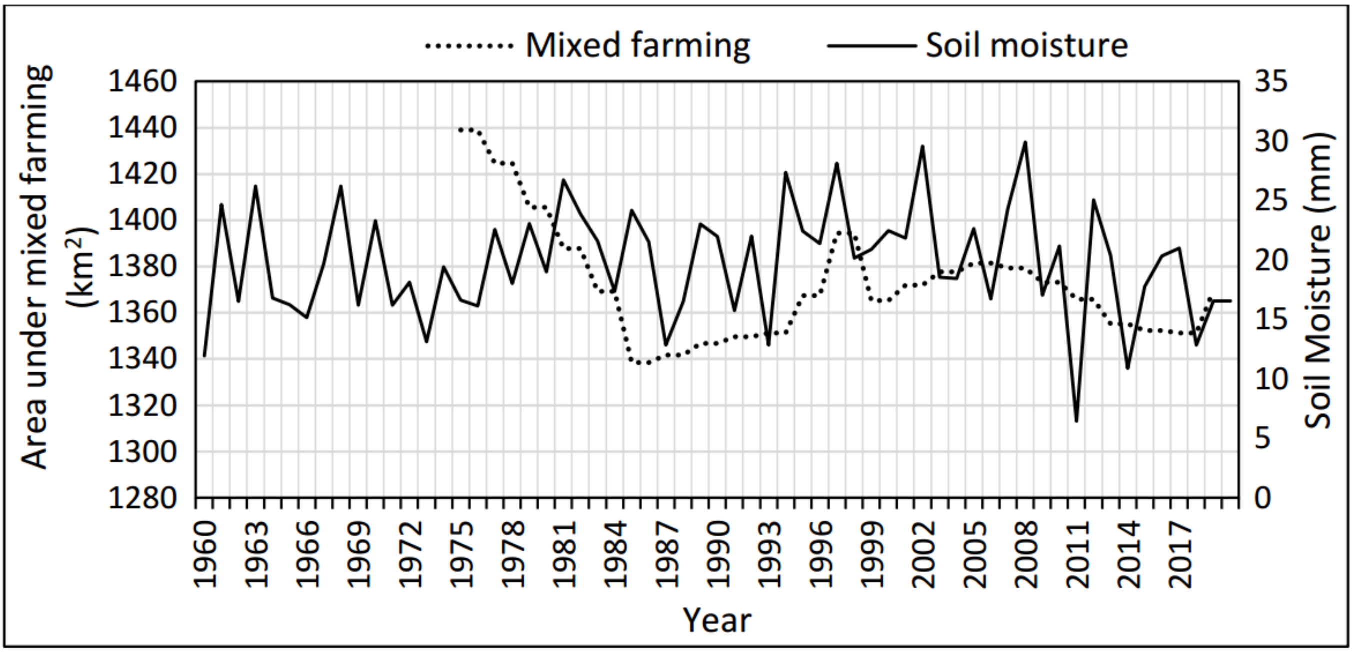


**Figure 19:** Soil Moisture and mixed farming land cover in the Kipsonoi sub basin dominated by mixed farming in the period 1960- 2020

**Table 2:** Mean, maximum and minimum values of water balance components in the period 1960-2020 in dominant land covers and uses

| Components | Land use/cover | Tea Plantation | Forest | Mixed farming | Combined |
|---|---|---|---|---|---|
| Rainfall (mm) | Mean | 1832 | 1830 | 1409 | 1350 |
| | Max | 2504 | 2516 | 2030 | 2087 |
| | Min | 1303 | 1265 | 750 | 500 |
| Evapotranspiration (mm) | Mean | 750 | 905 | 760 | 630 |
| | Max | 830 | 1006 | 920 | 800 |
| | Min | 500 | 560 | 400 | 250 |
| Soil Moisture (mm) | Mean | 22.9 | 26.3 | 19.8 | 19.2 |
| | Max | 37.6 | 40.2 | 30 | 32.5 |
| | Min | 13.8 | 14.1 | 6.4 | 26.5 |
| Mean Stream flow (m3/s) | Discharge | 10.8 | 4.5 | 32.4 | 4.5 |
| | Surface runoff | 3.2 | 1.8 | 28.2 | 1.8 |
| | Base flow | 7.6 | 2.7 | 4 | 2.7 |

## 6. Discussions

This study has shown that there was positive relationship between area under tea plantation and rainfall, a positive relationship between rainfall and area under mixed farming and a negative relationship was found between rainfall and the area under forest land cover. The positive relationship between area under tea plantation, area under mixed farming and rainfall was attributed to the expansion of tea plantations and mixed farming by the communities living in the Sondu Miriu River Basin due to increase in the rainfall availability. The negative relationship between area under forest cover and rainfall was attributed to reduction of forest cover to pave way for tea plantation and mixed farming due to high rainfall received. The spatial distribution of rainfall in the sub basins showed that sub basin dominated by tea plantations and forest cover received high rainfall almost of equal magnitude. While sub basin dominated by mixed farming receives low quantity of rainfall (see Table 2). This agreed with the previous study conducted in Southwest Burkina Faso where the relationship between mixed farming and rainfall was reported to be strong and positive correlation (Zoungrana et al., 2015). Despite the fact that insignificant relation existed between rainfall and tea plantation and forest cover, it was believed in this study that cooling effect generated by tea plants and forests trees influence local weather conditions as it was reported in a study conducted in the Kara River Basin in West Africa where increasing forest cover was reported to increase the local rainfall (Badjana et al., 2017). Contrary to the findings of this study, reforestation in dry areas in West Africa showed positive relationship between forest cover and rainfall (Diasso and Abiodun, 2018). The difference between the observations made in this study and previous studies could be due to the small-scale size of the sub basin with dominant forest cover of 152 km2 compared to large scale river basin. In addition, ITCZ has significant influences rainfall within the tropics especially in equatorial region (Waliser and Jiang, 2015). Also, the Kiptiget sub basin is surrounded by sub basins with forest cover hence changes taking place in the sub basin had no influence on the rainfall.

In the sub basin dominated by the forest cover it was noted that decline in the forests increases stream discharge. In natural forested area, tree canopy and trunks reduce amount of water reaching the land surface through interception and velocity reduction through flow obstructions. The clearing of forests exposes the land in the sub basin to high flow velocity that will raise the quantity of surface runoffs by 40% of the stream discharges (Kiplagat et al., 2018). In a study conducted in East Africa it was noted that a decrease in the forest land cover increases stream flows by 16% while increase in the forest cover decreases stream flows (Guzha et al., 2018). This study further showed that high surface runoffs are generated from the sub basin dominated by mixed farming compared to surface runoffs generated from sub basins dominated by tea plantations and forest cover (Table 2). The results of this study established that average surface runoffs contribute to about 88% of the stream flows while 12% was the base flows in Kipsonoi River. This indicated that in the mixed farming land cover infiltration is low compared to tea plantations and forest resulting in insignificant increase in the base flow. These findings were in consistent with observations made in the previous study in the Kimwarer River Basin that the mixed farming land cover and land use increases surface runoffs and reduces base flows (Kiplagat et al., 2018).

It was observed that insignificant relationship exists between area under tea plantations and evapotranspiration in the sub basin dominated by tea plantation while the relationship between area under forest cover and evapotranspiration was positive. The insignificant relation between tea plantation and evapotranspiration could be due to tea plantation has low interception capacity. But insignificant relation between area under forest cover and evapotranspiration is because the changes in the area covered by forest cover were small. Rainfall also plays critical role in the evapotranspiration rates. The relationship between rainfall and evapotranspiration in the sub basins dominated by forest, tea plantations and mixed farming cover. The negative relationship between evapotranspiration and area under tea plantation was attributed to close canopy cover that reduces evaporation from the soil surface. Compared to forest cover evapotranspiration in the forest cover is higher than tea plantations because tea plants have low albedo because of the shorter height of tea plantations (see Table 2). Hence expansion of tea plantations reduces forest cover and evapotranspiration. Albedo increases evaporation of intercepted water. The tall heights and deep roots of forests trees increases groundwater uptake and their high stomatal conductance increases transpiration. This was consistent with the previous study done in Ghaggar river basin, India and Brazil had similar findings to this study that increase in the forest land cover increases evapotranspiration (Setti et al., 2017; Jerszurki et al., 2018; Chauhan et al., 2020). Also, dense forest cover high stomatal conductance that allows water loss through transpiration. This was consistent with the previous study conducted in the Buzi sub basin that indicated that evapotranspiration in tea plantation respond differently than other land covers and land uses (Chemura et al., 2020). The positive relationship between the area under mixed farming and evapotranspiration was attributed to poor farming practices which expose the soil surface and subsurface to direct solar radiation causing increase in evaporation. Also, during crop growing season high transpiration rates occurs than in post harvesting season. Hence expanding mixed farming resulted in increasing evapotranspiration. This was consistent with the findings obtained in the study conducted in Rift Valley Ethiopia. It was reported that the extension of mixed farming land covers and land uses increased evaporation and transpiration (Meaza et al., 2019).

The results of this study also showed that there is insignificant negative relationship between soil moisture and the area under tea plantation. Increase in the area under tea plantation led to the decrease in the soil moisture. Similar negative relationship exists between soil moisture and forest land cover while positive relationship between soil moisture and in the sub basin dominated by mixed farming the different relationships were exhibited in different land covers and land uses. Tea plantations and forest cover withdraws water from the soil column through capillary rise and release through transpiration. Hence expansion of tea plantations and forest cover reduces soil moisture resulting in the negative relation. Alternatively, the negative insignificant relationship between soil moisture and forest cover showed that reduction of forest cover increases soil moisture. This was related to expansion of mixed farming that decreases area under forest cover. The tillage in the agricultural fields breaks the soils allowing water to infiltrate in the mixed farming hence increasing the soil moisture and this resulted in the positive relationship. Therefore, decrease of the forest cover results in the increase of mixed farming and soil moisture. In Table 2, the soil moisture was high in tea plantations and forest cover with ranging between 20-25 mm compared to mixed farming. But results of the previous study conducted in Western Himalayan showed that the relationship between soil moisture and forest cover was positive (Tyagi et al., 2013). The different observations between this study and previous was the land cover used in replacing forest cover. In the previous study it was stated that deforestation reduced soil moisture because of exposing soil moisture to evaporation and reduction of infiltration. While in this study forest cover was reduced and replaced by mixed farming that increases soil moisture. This resulted in increase in soil moisture while reducing forest cover.

## 7. Conclusion

Water balance components in the sub basins dominated by tea plantations, forests and mixed farming showed spatial variability in different temporal scales. It was established that stream flows increase with decrease in forest cover and increases with expansion of the mixed farming. Hence continuous translations of the forested lands to agricultural fields will result in seasonality of the streams in the Sondu Miriu River Basin. The spatial and temporal variations of the water balance components in the Timbilil, Kiptiget and Kipsonoi sub basins were caused mainly by climatic conditions and little influence was observed from the land cover and land use change. It was also noted that high rainfall received in the upper part of the river basin encourages expansion of land under tea plantations and mixed farming and this may decrease the area under forest cover. Also, it was realized that soil moisture was high in the sub basins dominated by forest cover and tea plantation may be due to canopy cover, increase of water infiltrating into the soil sub surface and high amounts of rainfall received compared to the sub basin dominated by mixed farming.

## References


[1] Arnold, J.G and Fohrer, N (2005). SWAT2000: current capabilities and research opportunities in applied watershed modelling. Hydrological Processes 19,563–572.

[2] Awotwi, A., Yeboah, F., Kumi, M (2014). Assessing the impact of land cover changes on water balance components of White Volta Basin in West Africa. Water and Environment Journal. 29. 10.1111/wej.12100.

[3] Badjana, H., Fink, M., Helmschrot, J., Diekkrüger, B., Kralisch, S., Afouda, A., Wala, K (2017). Hydrological system analysis and modelling of the Kara River basin (West Africa) using a lumped metric conceptual model. Hydrological Sciences Journal. 62. 10.1080/02626667.2017.1307571.

[4] Briak, H., Moussadek, R., Aboumaria, K and Mrabet, R (2016). Assessing sediment yield Kalaya gauged watershed (Northern Morocco) using GIS and SWAT model. International Soil and Water Conservation Research4 (2016)177–185.

[5] Chauhan, N., Kumar, V and Paliwal, R (2020): Quantifying the impacts of decadal land use change on the water balance components using soil and water assessment tool in Ghaggar river basin. Published: 06 October, 2020, article number 1777(2020). DOI: 10,1007/542452-020-03606-0.

[6] Chemura, A., Rwasoka, D., Mutanga, O., Dube, T and Mushore, T (2020). The impact of land-use /land cover changes on water balance of the heterogeneous Buzi sub catchment, Zimbabwe. Remote Sensing Applications: Society and Environment. Volume 18, April 2020, 100292.

[7] Chen, X., Zhao, P., Hu, Y., Ouyang, L., Zhu, L., Ni, G., 2019. Canopy transpiration and its cooling effect of three urban tree species in a subtropical city-Guangzhou, China. Urban For. Urban Green. 43, 126368

[8] Diasso, U and Abiodun, B (2018). Future impacts of global warming and reforestation on drought patterns over West Africa. Theoretical and Applied Climatology 133(1). DOI:10.1007/s00704-017-2209-3

[9] Gebrejewergs, A., Atinkut, M and Atkilt, G (2020). The effects of the land use land cover change on hydrological flow in the Giba catchment, Tigray, Ethiopia. Environmental Science 6: http://doi.org/

10.1080123311843.2020. 1785780
[10] Guzha, A.C., Rufino, M.C., Okoth, S., Jacobs, S and Nóbrega, R.L.B (2018). Impacts of land use and land cover change on surface runoff, discharge and low flows: Evidence from East Africa. Journal of Hydrology: Regional Studies Volume 15, February 2018, Pages 49-67.
[11] Jerszurki, D., Souza, J.L.M and Coivreur, V (2018). Water balance output components are distinctly regulated by precipitation and evaporation in Southern Brazil. DOI: 10.18671/scifor, for. v46n119.11
[12] Kimaru, A. N., Gathenya, J.M and Cheruiyot, C.K (2019). The temporal variability of rainfall and streamflow into Lake Nakuru Kenya, assessed using SWAT and hydrometeorological indices. http://doi.org/10.3390/hydrology6040088.
[13] Kiplagat, D.K., Kollongei, K., Kiptum, K (2018). Modelling the impacts of land use changes on stream flow in the Kimwarer Catchment using SWAT model. American Journal of water science and engineering, 2018, 4(4) 107-116: http://doi.org/10.11648.14.
[14] Kroese, J.S., Batista, P.V.G., Jacobs, S.R., Breuer, L., Quinton, J.N and Rufino, M.C (2020). Agricultural land is the main source of stream sediments after conversion of an African Montane Forest. Sci Rep 10, 14827 (2020). https://doi.org/10.1038/s41598-020-71924-9
[15] Masese, F. O., Raburu, P. O., Mwasi, B. N., and Etiegni, L. (2012). Effects of Deforestation on Water Resources: Integrating Science and Community Perspectives in the Sondu-Miriu River Basin, Kenya. In (Ed.), New Advances and Contributions to Forestry Research. Intech Open. https://doi.org/10.5772/34373
[16] Meaza, H., Franki, A, Demm, B and Poesen, J (2019). Water balance components of the potential agricultural grabens along the rift valley in northern Ethiopia. http://doi.org/ 10.1016/j.ejrh.2019.100616
[17] Mungai N.W., Njue A. M., Samuel A.G, Said V, A and John D.I (2011). Periodic flooding and land use effects on soil properties in Lake Victoria basin. African Journal of Agricultural Research. Vol. 6(19), pp. 4613-4623, DOI: 10.5897/AJAR11.741
[18] Näschen, K., Diekkrüger, B., Leemhuis, C., Steinbach, S., Seregina, L. S., Thonfeld, F and Linden, R (2018). Hydrological Modeling in Data-Scarce Catchments: The Kilombero Floodplain in Tanzania. Water 2018, 10, 599; doi: 10.3390/w10050599
[19] Neitsch, S. L., Arnold, J. G., Kiniry J. R, and Williams, J. R (2002). Soil and Water Assessment Tool, Manual: Version 2000, Agricultural Research Service and Texas A&M Blackland Research Center, Temple, TX, USDA.
[20] Neitsch, S. L., Arnold, J. G., Kiniry J. R, and Williams, J. R (2005). Soil and Water Assessment Tool, Theoretical Documentation: Version, Agricultural Research Service and Texas A&M Blackland Research Center, Temple, TX, USDA.
[21] Notter, B., MacMillan, L., Viviroi R., Weingartner, R and Liniger, H. P (2007). Impacts of environmental change on water resources in the Mt. Kenya region. Journal of Hydrology (2007) 343, 266– 278. doi:10.1016/j.jhydrol.2007.06.022
[22] Nyangaga, J. M (2008). The effects of enviromental degradation on stream flow. Volume and turbidity in the itare sub catchment within the lake victoria drainage basin, in Kenya. Ph.D (Hydrology) Thesis 2008, Department of Geography and Environmental studies, University of Nairobi. 113 pages. http://erepository.uonbi.ac.ke:8080/xmlui/handle/123456789/21121.
[23] O'Geen, A.T and Schwank, L. J (2005). Understanding soil erosion in irrigated agriculture, Oakland, University of California Division of Agriculture and Natural Resources, publication 8196.
[24] Ochieng, W., Olu dhe, C and Dulo, S (2019). Sustainable and appropriate climate change adaptation strategies for hydropower developments in the Sondu Miriu River Basin. International Journal of Scientific and Research Publications (IJSRP). 9. p8735. 10.29322/IJSRP.9.03. 2019.p8735.
[25] Opere, A.O and Okello, B.N (2011). Hydrological analysis for river Nyando using SWAT. Journal of Hydrology 8: 1765-1797. Ponpang-Nga, P and Techamahasaranont, J (2016). Effects of climate and land use changes on water balance in upstream in the Chao Phraya River Basin, Thailand. Agriculture and Natural Resources. 50. 10.1016/j.anres.2016.10.005.
[26] Saddique, N., Mahmood, T and Bernhofer, C (2020): Quantifying the impacts of land use and land cover change on water balance in afforested river basin, Pakistan, Envi.sci.79 448 (2020)
[27] Said, M., Hyandye, C., Mjemah, I.C., Komakech, H.C and Munishi, L.K (2021): Evaluation and prediction of the impacts of land cover changes on hydrological processes in data constrained Southern slopes of Kilimanjaro, Tanzania. https://doi.org/10.3380/earth2020014
[28] Savabi, M.R. and Stott, D.E (1994). Plant residue impact on rainfall interception. Trans. of the ASCE, Vol. 37, pp. 1093-1098. Setti, S., Rathinasamy, M and Chandramouli, S (2017): Assessment of water balance for a forest dominated coastal river basin in India using a semi distributed hydrological model. Publishing AG. Part of springs Nature 2017.
[29] Tamm, O., Maasikamäe, S., Padari, A and Tamm, T (2018). Modelling the effects of land use and climate change on the water resources in the eastern Baltic Sea region using the SWAT model. CATENAVolume 167, August 2018, Pages 78-89. https://doi.org/10.1016/j.catena.2018.04.029
[30] Tyagi, J.V., Qazi, N and Rai, S.P (2013). Analysis of soil moisture variation by forest covers structure in lower western Himalayas, India. Journal of Forestry Research 24, 317–324. https://doi.org/10.1007/s11676-013-0355-8
[31] Waliser, D.E., and Jiang, X (2015). Tropical meteorology and climate/Intertropical Convergence zone (ITCZ).http://doi.org/10.101016/B978
[32] Weeser, B., Stenfert, K. J., Jacobs S. R., Njue, N., Kemboi, Z., Ran, A., Rufino, M.C and Breuer L. (2018). Citizen science pioneers in Kenya - A crowdsourced approach for hydrological monitoring. Sci Total Environ. 2018 Aug 1; 631-632:1590-1599. doi: 10.1016/j.scitotenv.2018.03.130. Epub 2018 Mar 28. PMID: 29727983.