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(Running head: Impact of agroforestry on hydrology of Mara River Basin in East Africa)

KEY WORDS land–use; agroforestry; SWAT model; hydrology; catchment water balance

Abstract:

Land–use change is one of the main drivers of change of watershed hydrology. The effect of forestry related land–use changes (e.g. afforestation, deforestation, agroforestry) on water fluxes depends on climate, watershed characteristics and spatial scale. The Soil and Water Assessment Tool (SWAT) model was calibrated, validated and used to simulate the impact of agroforestry on the water balance in Mara River Basin (MRB) in East Africa. Model performance was assessed by Nash-Sutcliffe Efficiency (NSE) and Kling-Gupta Efficiency (KGE). The NSE (and KGE) values for calibration and validation were: 0.77 (0.88) and 0.74 (0.85) for the Nyangores sub-watershed, and 0.78 (0.89) and 0.79 (0.63) for the entire MRB. It was found that agroforestry in the watershed would generally reduce surface runoff, mainly due to enhanced infiltration. However, it would also increase evapotranspiration and consequently reduce the baseflow and the overall water yield, which was attributed to increased water use by trees. Spatial scale was found to have a significant effect on water balance; the impact of agroforestry was higher at the smaller headwater catchment (Nyangores) than for the larger watershed (entire MRB). However, the rate of change in water yield with increase in area under agroforestry was different for the two and could be attributed to the spatial variability of climate within MRB. Our results suggest that direct extrapolation of the findings from a small sub-catchment to a larger watershed may not always be accurate. These findings could guide watershed managers on the level of trade-offs to make between reduced water yields and other benefits (e.g. soil erosion control, improved soil productivity) offered by agroforestry.

1 INTRODUCTION

Forests provide a number of ecosystem services, such as, improving soil water infiltration conditions, soil erosion control and provision of wood–related products like timber and fuelwood (Calder, 2005; Ong *et al*., 2006). The fertility potential of soils under forests and the need to increase crop production makes forests a target for conversion to agricultural land through deforestation (Pope *et al*., 2015; Laurance *et al*., 2014). There is therefore high competition for land between forests and agricultural production in some regions of the world, particularly in the tropics (Laurance *et al*., 2014). In such situations, agroforestry is seen as a compromise between agricultural production and provision of forest/tree–related benefits (Garrity, 2012). In agroforestry systems, trees in different forms of arrangements are integrated into agricultural land (Nyaga *et al*., 2015; Nair, 1993). This kind of arrangement therefore ensures that the environmental services provided by the trees/forests are met, to some extent, while at the same time agricultural land continues with its main role of crop production (Ong *et al*., 2006). Countries, particularly those whose economy mainly rely on agriculture, find agroforestry as a feasible means of increasing their forest cover and a way of controlling degradation of natural forests (Garrity, 2012). Indeed, this may be one of the best practical solutions of increasing tree cover in areas that have been deforested and settled by communities whose main source of livelihood is agricultural cultivation (Mbow *et al.*, 2013). In such situations, complete afforestation may not be practical because people's livelihood is a priority.

With agroforestry, the question that arises is how much land can practically and sustainably be put under tree cover. At the farm level, this trade-off is highly dependent on the extent of available land. However, at the watershed level, the trade-off and synergies between provisions of various ecosystem services is an important consideration (cf. Brauman *et al*., 2007).

For water resources managers, information on how and by how much agroforestry practices will affect water availability is pertinent. Determination of the thresholds of area of agroforestry (percent of tree cover) that would not compromise provision of watershed services is of paramount importance (Brown *et al*., 2005; Mwangi *et al*., 2015a). The question of how change in vegetation affects watershed hydrology is mainly centred around the impact on different components of catchment water balance. This is partly because different types of vegetation result in different levels of rainwater infiltration capacities. For example, forests are generally known to offer enhanced infiltration of rainwater compared to most other land-uses (Bruijnzeel, 2004). This is mainly brought about by a normally higher organic matter content and little anthropogenic disturbance in the forest soils as compared to, for example, cultivated lands. Therefore, the partitioning of rainwater into surface runoff and the water that infiltrates into the ground differs for landscapes with different types of vegetation - even in cases where soil type is similar. Plant water use (transpiration) also differs with vegetation type (Jian *et al*., 2015; Julich *et al*., 2015). Some vegetation, especially trees, generally consumes more water than others (Albaugh *et al*., 2013; Julich *et al*., 2015). The rooting depth of vegetation also determines the depth to which plants of a particular type can draw water especially in the dry seasons when the top soil is dry (Thomas *et al*., 2012; David *et al*., 2013). Deep-rooted vegetation is able to extract groundwater from deeper aquifers particularly when the water table is low compared with shallow rooted vegetation (Pinto *et al*., 2014; Nosetto *et al*., 2012). Consequently, the extent of groundwater removal by vegetation of different types influences the amount of groundwater released to the streams as baseflow (Salemi *et al*., 2012). Water extraction by deep-rooted vegetation reduces the groundwater storage and decreases the amount released to streams (Fan *et al*., 2014). It is therefore obvious that introduction of trees into crop lands (agroforestry) would cause changes in a watershed's water balance (Palleiro *et al*., 2013; Ong *et al*., 2006). The

direction and magnitude of the change in different water balance components may differ with the watershed characteristics (e.g. soil, topography), climate, agroforestry tree species and more importantly the proportion of the watershed under tree cover (Brown *et al.*, 2013; Julich *et al*., 2015).

Field studies on the hydrological impacts of agroforestry (e.g. Zhao *et al.*, 2011; Ghazavi *et al*., 2008; Muthuri *et al.*, 2004; Radersma and Ong, 2004) have demonstrated the need to include (or improve) tree water uptake (transpiration) and canopy interception in watershed modelling. Ghazavi *et al*. (2008), for example, observed decreasing water table levels near hedgerows during the growing season (spring and summer) in Brittany, France which they attributed to high transpiration by hedgerow trees. A modelling study (using Hydrus-2D model) for the same site by Thomas *et al.* (2012) showed that transpiration is a substantial component of water balance representing 40% of total water output. Similar conclusions were drawn by Muthuri *et al.* (2004) who modelled water use by agroforestry systems in Nyeri County, Kenya, using the WaNuLCAS (Water, Nutrient and Light Capture in Agroforestry Systems) model.

In this study, we use SWAT (Soil and Water Assessment Tool) model (version 2012) to assess the impact of agroforestry on hydrology of the Mara River Basin. Although SWAT has been extensively used for land–use change studies, its use for agroforestry simulation studies is not well documented. The Mara River basin is located in East Africa and has undergone significant land–use changes in the last 50 years, particularly deforestation and conversion to agriculture in the headwaters (Mati *et al*., 2008). Intensive cultivation is currently predominant in the formerly forested areas and the Government of Kenya (GoK) is keen on restoring back to forest cover as much area as possible (GoK, 2009; NEMA, 2013). Considering that the basin is now densely settled by communities whose livelihood depend on agricultural cultivation (Kanogo, 1987), one of the feasible solutions to increase the tree

cover in the upper Mara basin is through agroforestry (Atela *et al*., 2012; KFS, 2009). Because Mara is a trans-boundary river basin between Kenya and Tanzania, the upstream watershed activities, including land–use changes, are of interest not only to Kenya but also to Tanzania (Gereta *et al*., 2009). A thriving tourism industry in the shared Maasai Mara (Kenya) and Serengeti (Tanzania) game reserves ecosystem is also heavily dependent on the water resources provided by the Mara River (Gereta *et al*., 2002). For this reason, prediction of the effect of agroforestry on the water balance of the Mara River basin is paramount for sustainable water resources management.

2 METHODS

2.1 Study area

The Mara River Basin (henceforth referred to as MRB) covers a total area of about 13,750 km^2, which is shared between Kenya (65%) and Tanzania (35%) (Figure 1). The two main headwater tributaries of the Mara River (Nyangores and Amala) originate from the Mau Forest, join on the Kenyan side of the border with Tanzania to form the main Mara River which drains into Lake Victoria on the Tanzanian side of the border. There are three main gauging stations with in MRB: 1LA03 at Bomet (for Nyangores sub-watershed), 1LA02 at Mulot (for Amala sub-watershed), and Mara mines in Tanzania (for the larger MRB) (Figure 1). The drainage areas at the three outlets are: 692 km^2, 695 km^2 and 10,550 km^2 for Nyangores, Amala and Mara watersheds, respectively. The elevation of MRB ranges from about 3,000 m asl at the source in the Mau Forest complex to about 1100 m asl as the river drains into Lake Victoria. The basin experiences a bimodal rainfall pattern that varies with altitude. The long rains occur from March to June while the short rains occur from September to November. The mean annual rainfall ranges from about 1800 mm in the forested headwaters to about 600 mm in the downstream sections of the basin.

Forests and agriculture are the main land-uses in the upstream region of MRB (Figure 1). Pastoralism and wildlife conservation (in Maasai Mara and Serengeti National Reserves) dominate the middle sections of the basin (Figure 1). The areas adjacent to the game reserves are mainly used for livestock grazing and also as wildlife dispersal areas through some arrangements (e.g. conservancies) with the local pastoral communities (Osano *et al.*, 2013; Homewood *et al.*, 2012; Ogutu *et al*., 2009; Thompson and Homewood, 2002). The downstream region of the MRB in Tanzania is mainly dominated by subsistence agriculture and gold mining. The main soil types (World Reference Base classification) are: Planosols (30%), Phaeozems (26%), Andosols (12%) Vertisols (10%), and Cambisols (9%). Other soils (13%) are: Leptosols, Luvisols, Nitisols, Greyzems, and Regosols.

2.2 SWAT Model

SWAT is a physically based, semi-distributed, meso-scale-watershed model (Arnold *et al*., 1998) widely used for prediction of the impact of land management on water, sediment and agricultural chemical yields (Neitsch *et al*., 2011; Gassman *et al*., 2007). The main inputs of the model are: Digital Elevation Model (DEM), land-use, soil, and climate data. SWAT first sub-divides a watershed into sub-watersheds which are further partitioned into smaller Hydrologic Response Units (HRU). Each HRU in a sub-basin has unique land-use, soil type, and slope class combination. Simulation of agroforestry scenarios in this study was based on HRUs land units.

2.3 Model parameterization: SWAT input data

Climatic data was obtained from Kenya Metrological Department and the Tanzania Meteorological Agency. Daily rainfall data from 20 stations within and in close vicinity of the watershed (Figure 1) was used. For the selected period of model calibration and validation, the rainfall data was nearly 100% complete for more than half of the stations. Daily data sets of the other climatic variables i.e. maximum and minimum temperature, humidity, radiation and wind speed were obtained for Narok, Kisii, Kericho, and Musoma meteorological stations (Figure 1). For short gaps, missing data for a particular day was filled by arithmetic mean observed for the day in the neighbouring stations, whereas longer gaps (more than 10 days) were filled using the weather generator model, WXGEN, incorporated in SWAT (Neitsch *et al*., 2011) that relies on monthly mean values.

Shuttle Radar Topography Mission, 90-m, DEM was used for watershed delineation in SWAT. Soil data (scale of 1:1 million) was obtained from Kenya Soil Survey and Soil and Terrain Database (SOTER) of the International Soil Reference and Information Centre (ISRIC) (Batjes, 2002). Some soil parameters that were not available from the databases, e.g. saturated hydraulic conductivity, were estimated using pedotransfer functions (Nemes *et al.*, 2005). A Land–use map of 1983 (GoK, 1983) was used for model setup (Figure 1). The map was compared with Landsat satellite images and land–use maps by Mati *et al*. (2008) for the same period. The land–use map was deemed appropriate for periods used for calibration and validation of the SWAT model. The proportions of the land-uses are: 10%, 21% and 69% for agriculture, forests, and rangeland, respectively (Figure 1).

Discharge data (for Nyangores, Amala and Mara (at Mara mines) Rivers) was obtained from Water Resources Management Authority (WRMA) in Kenya and the Ministry of Water in

Tanzania. Nyangores data was 100% complete for both periods of calibration and validation. Mara and Amala data had gaps which were left unfilled.

2.4 Model parameterization: Plant growth

Although SWAT has been widely used for land–use study in the tropical watersheds, its plant growth module is better suited for temperate regions. As such, it has some shortcomings in modelling the growth of trees and perennial crops in the tropics (Wagner *et al.*, 2011). This is because, unlike in the temperate regions, plants in the tropics do not have a dormant period and there is no seasonal shedding and sprouting of leaves for perennials. For this reason, the robustness of the model and the accuracy of output based on default plant growth module parameters in the tropics or absence of information on its parameterization altogether has been criticized (van Griensven *et al.*, 2012; Strauch and Volk, 2013).The plant growth in SWAT is based on the heat unit theory which postulates that plants require specific amount of heat to bring them to maturity (Neitsch *et al*., 2011). Thus, SWAT accumulates heat units from planting and maturity is reached when the plant-specific total heat units (PHU) are attained. A heat unit is equivalent to each degree of daily mean temperature above a base temperature (plant-specific temperature below which there is no growth).Thus, PHU is the summation of all heat units from planting to maturity. However, for perennials and trees, PHU are the accumulated heat units between budding and leaf senescence (Strauch and Volk, 2013; Neitsch *et al*., 2011). Once the maturity is attained, the plant stops to transpire and take up water and nutrients (Neitsch *et al*., 2011). The repeat of the growth cycle for perennials and trees in SWAT is triggered either by dormancy (in-turn triggered by latitude-dependent shortening of day length) or use of 'kill' operation (Strauch and Volk, 2013; Neitsch *et al*., 2011). When growth cycle is restarted, the accumulated heat units drop to zero and the Leaf

Area Index (LAI) is set to minimum. LAI partly controls water uptake by plants (transpiration) in SWAT. Transpiration is simulated by Equation 1 for Priestley and Taylor, and Hargreaves methods. Thus, when LAI drops to minimum, transpiration reduces accordingly.

To adapt plant growth for our study site, the 'kill' operation was used to restart the growth cycle for trees and perennials. The minimum LAI for trees was increased from the default 0.75 (which is based on tree physiology in temperate regions) to 3.0 which is typical for the tropics (Broadhead *et al*., 2003; Muthuri *et al*., 2005; Maass *et al.*, 1995; Kalácska *et al*., 2004). This ensured that the tree water use does not go unrealistically low for this tropical watershed. Growth is initiated after a certain fraction PHU is attained. For this study, this fraction was reduced from the default of 0.15 to a small value of 0.001 to ensure that growth starts immediately after the growth cycle begins and hence there is continuous transpiration. Simulated forest LAI using SWAT default values and the adjusted values (Figure 2) clearly shows that the default values do not represent the growth that is typical in the tropics and therefore underestimates the transpiration (Equation 1). The Priestley and Taylor (1972) method was used for calculation of transpiration in this study. Considering the data availability and quality in the study site, this method was preferred because it uses less climatic data unlike the widely used Penman-Monteith method that is data intensive. The Priestley and Taylor (1972) method has been found to give better results than many other methods (e.g. Lu *et al*., 2005; Ding *et al*., 2013; Juston *et al*., 2014) particularly in area with data availability or quality challenges.

$$E_t = \frac{E_0'.LAI}{3} \qquad 0 \leq LAI \leq 3$$

$$E_t = E_0' \qquad LAI > 3 \qquad (1)$$

Where E_t is the maximum transpiration on a given day (mm), E'_0 is the potential evapotranspiration adjusted for evaporation of free water in the canopy (mm), and *LAI* is the leaf area index.

The adjusted values (case 2 in Figure 2) were considered to provide a better representation of the leafing phenology and tree water use as has been reported in literature studies of the region (Broadhead *et al*., 2003; Muthuri *et al*., 2004; Radersma *et al*., 2006; Ong *et al*., 2007). The seasonal variation in LAI also matched with the bimodal pattern of rainfall in the watershed with minimum LAI coinciding with the dry seasons of January-February and July-August when growth is limited by moisture availability. The July-August is also the coldest months of the year further limiting plant growth. The maximum LAI, and by extension high evapotranspiration, coincided with the long and short rains which well simulated the two cycles of leaf flush of trees observed in this region (Muthuri *et al*., 2004; Broadhead *et al*., 2003).

2.5 Calibration

Streamflow data for Nyangores tributary and the main Mara River at Mara mines were used for calibration and validation while that of Amala tributary was used for validation only. Nine years of daily streamflow data was used: four years (1979-1982) for calibration and five years (1974-1978) for validation. Two-year 'warm up' period was allowed for both calibration and validation. Both calibration and validation periods included dry and wet years and therefore low and high flows were well represented. The selection of this period (1974-1982) was guided by consideration of the completeness and degree of confidence of both meteorological and streamflow data at the three gauging stations. The main gauging station at Mara Mines has no recent streamflow data sufficient for model calibration; the data after 1990 is largely missing (McClain *et al*., 2014; Melesse *et al*., 2008). Of the two upper tributaries, the

available streamflow data for Amala is of lower quality compared with that of Nyangores (Dessu and Melesse, 2012). It has many and long gaps; and we further established that the data had higher uncertainty for period after 1980, arising from wrong use of rating equations. The land-use map used (for 1983) was considered appropriate to represent the land conditions during the calibration and validation periods. During the model setup, the MRB (up to Mara mines gauging station) (Figure 1) was subdivided into 92 sub-basins. The spatial variability of the watershed conditions in the MRB was taken into account during the model calibration. The calibration was done in two stages: first for the sub-basins in the upper Mara and then for the larger basin without changing the calibrated parameter values obtained for the upper Mara sub-basins.

For the upper Mara, calibration was done with the main outlet at Nyangores River at Bomet and the corresponding measured streamflow data for the station was used. After calibration and validation of the Nyangores sub-watershed, the optimized parameter set were then transferred to the neighbouring Amala sub-watershed. The two sub-watersheds are similar in topography, size, land–use, soils and climate. Due to its low quality, the streamflow data for Amala was only used for validation, and the validation period was prior to 1980 when the data quality is better. Considering the low quality of observed streamflow data for Amala and taking advantage of its topographical similarity with Nyangores, we sought to investigate how well the model parameters calibrated for Nyangores would perform when transferred to Amala.

Calibration parameters (Table I) were identified by sensitivity analysis and Latin hypercube sampling was used to select sets of parameter values for automatic calibration using Particle Swarm Optimization (PSO) algorithm (Kennedy and Eberhart, 1995; Eberhart and Shi, 2001). The principle of PSO is based on the social behaviour of a population of particles (i.e. swarms such as flocking birds) moving towards the most promising area of the search space

(e.g. location of food) (Reddy and Kumar, 2007). PSO is initialized using a group of random particles (e.g. through Latin hypercube sampling) with each particle representing a possible solution. Each potential solution is also assigned a randomized velocity which directs the 'flying' of the particles (Eberhart and Shi, 2001; Reddy and Kumar, 2007). The potential solutions are then "flown" through the problem space (Eberhart and Shi, 2001; Shi and Eberhart, 1998). At the end of each iteration, the position and velocity of a particle (i.e. parameter set) are updated. The position represents the current value within the search space and velocity represents the direction and the speed the search is moving in (i.e. rate of change in the dimensional space). The positions of the particles are changed (updated) within the search space based on the social tendency of the individuals (particles) to emulate the success of other individuals (Reddy and Kumar, 2007). All the particles have fitness values which are evaluated by the objective function to be optimized. Each particle keeps track of its coordinates in the solution space which are associated with the best solution (fitness) it has achieved so far i.e. the 'pbest'. PSO also tracks the best solution achieved at any point by any particle in the population (swarm) which is referred to as global best solution ('gbest') (Poli *et al.*, 2007; Eberhart and Shi, 2001). Each PSO iteration aims to move each particle, by changing its velocity, closer to its personal best ('pbest') position and the global best position. After several iterations, one good solution (optimized) is produced when the particles converge towards the global optima.

2.6 Evaluation of model performance

Goodness-of-fit (fit-to-observation) was used as the main criterion for evaluation of the model performance (Moriasi *et al.*, 2007; van Griensven *et al.*, 2011). In addition, we also evaluated the catchment water balance in order to ensure the various components (e.g. runoff, evapotranspiration and groundwater contribution to streamflow) were within reasonable

ranges typical of the study area. The aim was to ensure a realistic representation of hydrological processes and watershed conditions of the MRB (fit-to-reality). We also aimed at ensuring that the calibrated model was fit for the intended purpose of land-use change simulation (fit-to-purpose) (van Griensven *et al.*, 2011). We focused on selection of realistic ranges of the model input parameter values in order to reduce uncertainty in the model outputs (Arnold *et al*., 2012). Selection of realistic ranges of SWAT input parameters prior to calibration has been shown to reduce model prediction uncertainties (Zhenyao *et al*., 2013; Benaman and Shoemaker, 2004). We particularly paid special attention to model parameters that govern the water 'loss' from the system e.g. *CH_K, GWQMN, GW_Revap* and *Rchrg_dp* (Table I) (Neitsch *et al*., 2011). Wrong selection of these parameter values may lead to unrealistic water balance even when there is a good fit between observed and simulated streamflows. For example, high values of *Rchrg_dp* may lead to high deep percolation losses which may be compensated by unrealistically low levels of evapotranspiration, even in cases where streamflow is within the ranges of observed values. van Griensven *et al*. (2011) gives qualitative and quantitative guidelines on the appropriate ranges of these parameters for the study region.

Modeller's knowledge of the watershed is important in hydrologic modelling as there is no automatic procedure of parameterization and calibration which can substitute for actual physical knowledge of the watershed (Arnold *et al*., 2012). Zhenyao *et al*. (2013) studied the impact of parameter distribution uncertainty on hydrological modelling using SWAT and recommends use of any available knowledge of the watershed in selection of realistic parameter ranges to reduce prediction uncertainties. Besides the guidelines by van Griensven *et al*. (2011), we used our knowledge of the watershed as well as knowledge from our past experience of SWAT application in the region (e.g. Gathenya *et al*., 2011, Mwangi *et al*., 2012, Mwangi *et al*., 2015b) and literature of SWAT application in the area (e.g. Dessu and

Melesse, 2012; Mango *et al*., 2011; Githui *et al*., 2009; Baker and Miller, 2013) to select reasonable SWAT input parameter ranges (Table I). In addition, preliminary model runs were used to guide the selection of the parameter ranges that represent reasonable water balance conditions of the watershed. Typical ranges of water balance components e.g. surface runoff, baseflow and evapotranspiration were also assessed based on the knowledge of the watershed as well as published literature in the region (e.g. Dagg and Blackie, 1965, 1970; Krhoda, 1988; Water Resources and Energy Management, 2008; Mati *et al*., 2008; Mutiga *et al*., 2010; Recha *et al*., 2012; Dessu and Melesse, 2012; Baker and Miller, 2013; Mwangi *et al*., 2016). Dagg and Blackie (1965, 1970) reported that 'deep percolation loss' is minimal for their experimental study site in Mau forest. This information, for example, guided us in setting up the upper limit for the parameter *Rchrg_dp* and results of 'deep percolation loss' from preliminary model runs helped in adjusting the parameter value range. In another example, our previous study in the watershed (Mwangi *et al*., 2016) had showed that baseflow constitutes a large percentage (ca. 80%) of the streamflow of Nyangores sub-watershed. We used this information to evaluate the water balance components in our preliminary model runs and adjust relevant ranges of the relevant input parameters e.g. *GWQMN* (Table I). Further model parameterization, particularly regarding the adaptation of the plant growth module for the watershed, ensured that the calibrated model was fit for the purpose (i.e. land–use simulation).

Statistical fitting of the simulated and observed streamflow was then used for model performance evaluation during automatic calibration. Nash-Sutcliffe Efficiency (NSE) (Nash and Sutcliffe, 1970) was used as the objective function in the PSO algorithm. NSE is a normalized statistic ranging from - ∞ to 1 and is calculated as follows:

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}\{q_{obs}(t) - q_{sim}(t)\}^2}{\sum_{i=1}^{n}\{q_{obs}(t) - q_{meanObs}\}^2}\right] \quad (2)$$

where $q_{obs}(t)$ is the observed discharge at time step t, $q_{sim}(t)$ is the simulated discharge at time step t, $q_{meanObs}$ is the mean of the observed discharge over the simulated period, and n is the total number of observations.

One limitation of NSE is that it underestimates peak flows and overestimates low flows (Gupta *et al*., 2009). In light of this, a second objective function, Kling–Gupta Efficiency (KGE) (Gupta *et al*., 2009), was used for evaluation of model performance to overcome the weakness of NSE. KGE statistic is based on the decomposition of model error into three distinct components which measure the linear correlation, the bias and the variability of flow respectively (Gupta *et al*., 2009; Kling *et al.*, 2012). The latter two components relate to the ability of the model to reproduce the distribution of flow as summarized by first and second moments (i.e. mean and standard deviation) while the former relate to the ability to reproduce the timing and shape of the hydrograph. KGE is calculated as follows:

$$KGE = 1 - \sqrt{(r-1)^2 + (\alpha-1)^2 + (\beta-1)^2} \quad (3)$$

$$\alpha = \frac{\sigma_{sim}}{\sigma_{obs}} \quad (4)$$

$$\beta = \frac{\mu_{sim}}{\mu_{obs}} \quad (5)$$

where r is the correlation coefficient between simulated and observed streamflow, α is the variability ratio, β is the bias ratio, σ and μ are the standard deviation and the mean of the streamflow respectively, and indices *sim* and *obs* represent simulated and observed values of streamflow respectively.

2.7 Simulation of agroforestry

After calibration and validation of the SWAT model, agroforestry land–use scenarios were simulated. The structure of the SWAT model allows only one plant or crop type per HRU.

The most typical systems of agroforestry in the watershed are: 1) intercropping sparsely distributed trees with different crops, 2) trees along the hedges and borders, and 3) woodlots (Nyaga *et al*., 2015; Lagerlöf *et al*., 2014). The first two agroforestry systems posed a challenge to be explicitly implemented in SWAT due to the model structure. Thus, agroforestry was implemented as woodlots at the HRU level. Woodlots have recently become popular in Kenya due to high demand for wood products (Nyaga *et al.*, 2015).The woodlots were considered to offer, at the watershed level, a general spatial representation of the practical agroforestry system. Additionally, the hydrological impact (i.e. water use and infiltration characteristics) of the agroforestry at the farm level was, to a larger extent, captured at the sub-basin level.

The agroforestry scenarios were simulated on land currently under cultivated agriculture implemented on a SWAT project based on 2014 land-use (Lariu, 2015). The selection of agroforestry scenarios was based on tree cover increment in the MRB upstream of Mara gauging station (Figure 1). To increase the area under agroforestry (tree cover), the number of HRUs with trees (forest) were increased by conversion of some HRUs previously under agriculture to woodlots (i.e. pure tree stand with properties of a forest). To implement this in SWAT, we considered slope as a practical criteria which additionally provided another advantage of maintaining the same HRU configurations across all the scenarios. We therefore selected four slope classes i.e. 0-10%, 10%-15%, 15%-20% and over 20% when creating the HRUs and which were later used as the basis for implementing the agroforestry scenarios.

All the scenarios were assessed relative to the base scenario that represents the current land-use/cover (for year 2014) in the basin (Figure 3a). For clarity, Figure 3 only shows maps of land–use and agroforestry scenarios for the Nyangores sub-watershed. The first scenario was implemented by changing all the HRUs under cultivated agriculture, that fall within the slopes above 20%, to woodlots (Table II). Similarly, the second scenario was simulated by

converting the HRUs in the slope category of 15 - 20% which were under cultivated agriculture to woodlots. So, in total for this scenario, all the agricultural HRUs in slopes >15% were simulated as woodlots. The same was done for the slope class of 10 - 15% for the third scenario. Other than change in vegetation, infiltration properties of the target HRUs were also adjusted from that of agriculture to that of forest. This was accomplished in SWAT by change in curve number (Table I). The curve number is a parameter of the United States Soil Conservation Service (SCS) empirical equation (SCS, 1972) used for estimation of surface runoff. It is a function of soil permeability, land–use, and antecedent soil water conditions. Agricultural HRUs in the slope class of 0-10% were not converted to woodlots as that would have simulated complete afforestation of the upper Mara watershed which was not the objective of this study and is neither practical in this area where smallholder agriculture is the main source of livelihood (Atela *et al*., 2012).

3 RESULTS AND DISCUSSION

3.1 Calibration and validation

The monthly NSE (and KGE in parenthesis) values obtained for calibration are: 0.77 (0.88) and 0.78 (0.89) for Rivers Nyangores and Mara respectively (Table III). The validation NSE (and KGE) are: 0.74 (0.85), 0.75 (0.68) and 0.79 (0.63) for Rivers Nyangores, Amala and Mara respectively. These values indicate that the SWAT model performance for this study was better compared to other previous studies in the watershed (Mango *et al*., 2011; Dessu and Melesse, 2012). This is probably because of the better representation of tree growth (particularly with regard to water use) for tropical conditions. Unrealistic representation of forest transpiration in the tropics has been cited as one of the possible causes of marginal effect of forest-related land–use change on water balance in some of the previous simulation studies (e.g. Mango *et al*., 2011; Githui *et al*., 2009) conducted in the region (van Griensven

et al., 2012). Separate calibration of the headwater sub-watersheds before including the rest of the basin may have also improved the model performance in this spatially-variable watershed. The daily hydrographs (Figure 4) show that the model, to a higher level of degree, reproduced the observed streamflow at all the gauging stations and thus well represented the rainfall runoff processes of the basin. This is confirmed by percent bias (PBIAS) which measures the average tendency of the simulated streamflow being larger or smaller than observed streamflow (Gupta *et al*., 1999). The PBIAS values for calibration (and validation in parenthesis) are: 1.3% (-8.9%), -0.12% (-34%) and (3.9%) for Rivers Nyangores, Mara and Amala respectively. All the values except for validation at Mara mines are within the ± 25% range proposed by Moriasi *et al.* (2007) for satisfactory calibration. The slight overestimation of average flow for Mara mines could be caused by slightly higher simulated peak flow which is also visible in the other hydrographs. This may be caused by the uncertainty in the observed streamflow data arising from inability to accurately measure high flows in the manual river gauging stations or from rating equations when converting gauge heights of high flows to discharge (cf. Juston *et al*., 2014). The model performance at Amala sub-watershed (Table III; Figure 4c) implies watershed characteristics that are similar to Nyangores and that the streamflow of Nyangores River can be used to infer the hydrology of Amala sub-watershed (Klemeš, 1986). The validated model could also be useful in correcting streamflow records for Amala River for the period after 1980.

3.2 Impact of agroforestry on catchment water balance

Simulation results (Table IV) show that surface runoff, lateral flow, groundwater contribution to streamflow and the overall water yield decreased with increase in area under agroforestry. This was compensated by an increased rate of evapotranspiration. Surface runoff decreased

by about 14%, 31% and 54% (Figure 5a) when the area of the watershed under tree cover is increased by 6.4%, 14.4% and 27.9% (Table II) respectively. Similarly, groundwater contribution to streamflow decreased by about 5%, 11%, and 20% respectively for the three scenarios. The overall effect of the three scenarios on total water yield was a decrease by about 5%, 12%, and 22% respectively in that order of increasing tree cover. On the other hand, the evapotranspiration increased by 2%, 4% and 7% respectively. These results are consistent with the findings reported from paired catchment experimental studies (Brown *et al*., 2013; Zhao *et al*., 2012; Zhang *et al*., 2012; Scott and Lesch, 1997) and model simulation studies (Suarez *et al*., 2014; Githui *et al*., 2009) that have reported decrease in water yield and increase in evapotranspiration following establishment or increase of watershed tree cover.

The decline in surface runoff can be attributed to increased infiltration (Brown *et al*., 2005; Benegas *et al*., 2014) and canopy interception (Ghazavi *et al*., 2008). Establishment of trees on land formerly under cultivated agriculture improves the infiltration conditions of the soil, thereby absorbing more rainfall and reducing the surface runoff. Field experimental study by Anderson *et al*. (2009), for example, reported significantly higher infiltration in the agroforestry buffer treatments compared with row crop treatments. Ketema and Yimer (2014) also reported higher infiltration for agroforestry treatments than for maize treatments for their study in Southern Ethiopia. Practising of intensive agricultural cultivation, as is the case currently in the upper Mara, continually degrades the soil and reduces its capacity to absorb rainwater mainly due to compaction of lower soil horizons, decrease in organic carbon and porosity (Recha *et al*., 2012; Bruijnzeel, 2004). Trees on the other hand, aid in the recovery of degraded lands (Udawatta *et al*., 2008; Lagerlöf *et al*., 2014). High organic matter, presence of live and dead roots, increased soil micro-fauna and enhanced macro-pore flow are some of the factors that improve soil infiltration after establishment of agroforestry (Ketema and Yimer, 2014; Udawatta and Anderson, 2008). However, it should be noted that

soil infiltration capacity recovery may take some time (Bruijnzeel, 2004) and potential gains in water infiltration reported here may not be achieved immediately after the establishment of agroforestry (Brown *et al*., 2013).

Although there was increased infiltration for the agroforestry scenarios, which ideally increases recharge of aquifers, there was also a decrease in baseflow. This can be attributed to increase in water extraction from the soil and aquifer by the trees. Trees have deeper and more extensive rooting systems than most plants which enable them to extract water from shallow aquifers to meet the evapotranspiration demand, especially during the dry seasons when the top soil is dry (Thomas *et al*., 2012; FAO, 2006; Calder, 2005). A study by Pinto *et al*. (2014), for example, estimated that annual soil and groundwater contributions to tree transpiration were about 70% and 30%, respectively. However, during the dry summer months the groundwater contribution became dominant and rose to 73% of transpiration. Additionally, trees have higher aerodynamic roughness than crops that favour higher evapotranspiration rates (Calder, 2005). The differences in leaf, size, shape, thickness, anatomy and chlorophyll content between trees and other plants and even between trees species also affects the rate of transpiration (Muthuri *et al*., 2009). Therefore, increase in tree cover through agroforestry also increases water use in the watershed in form of evapotranspiration. A study by Muthuri *et al*. (2004) in central Kenya found that the water use in the agroforestry systems was higher than for treatments under only maize cultivation. The decrease in groundwater in shallow aquifers, due to increased uptake by trees, decreases the water available and the amount released to the streams as baseflow (Fan *et al*., 2014). Generally, the change in baseflow may be either positive or negative depending on the water budget in the aquifer storage (Bruijnzeel, 2004). If the incoming water, as a result of improved infiltration, surpasses the extra water removal by trees, then the extra storage may lead to increase in baseflow. The reverse is also true in case of negative change in aquifer

storage as was the case in our study (Brown *et al*., 2005; Bruijnzeel, 2004). The overall water yield, which is essentially a summation of surface runoff, lateral flow and groundwater contribution to streamflow, also decreased with increase in area under agroforestry.

The water balance results (Table IV) are based on past climatic conditions (1980-1990). The period was chosen to intersect with the period used for the calibration of the model. Because the base scenario was based on current land-use conditions (based on 2014 land-use map), the changes in climate between the 1980's and the 2014 may slightly affect the absolute values of the water balance. The changes are however expected to be minimal. For the upper Mara, Mwangi *et al*., (2016), estimated that climate variability only contributed about 2.5% increase in streamflow for Nyangores sub-watershed in the last half a century, the rest being contributed by land-use changes. No major changes are, however, expected on the relative results obtained for simulation of agroforestry (Figure 5), because all the scenarios were assessed based on the base scenario (i.e. same climatic conditions between base scenario and all the other scenarios).

Similarly, climate change may as well affect the absolute values of water balance but not the relative changes (percentage change in water balance) due to implementation of agroforestry. Mwangi *et al.* (2016) estimated that climate change would cause a 15% increase in streamflow (for the next 50 years) in upper Mara watershed, which is indicative of how the absolute values of water balance might change. The change in individual water balance components might, however, not be linear due change in climate seasonality (Dessu and Melesse, 2013).

3.3 Impact of spatial scale

For the larger MRB, the surface runoff decreased by about 4%, 7% and 12.5% respectively for the three scenarios in the order of increasing of area under agroforestry (Table V; Figure

5b). The groundwater contribution to streamflow and the water yield similarly decreased by 2%, 4.5% and 8.5%, and 2.5%, 5% and 9% respectively for each of the three scenarios. The evapotranspiration however increased by about 0.5%, 1%, and 2% (Figure 5b). The results show a similar trend as that of the Nyangores sub-watershed (Figure 5a) and can be attributed to similar causes. The only difference is in the magnitude of the relative changes. For all the water balance components, the relative change (impact of agroforestry) was larger at Nyangores sub-watershed compared to the larger MRB. This can be attributed to the differences in the ratio of area simulated with agroforestry to the total sizes of respective watersheds (Brown *et al*., 2005; Bruijnzeel, 2004). The proportion of watershed areas simulated with agroforestry were 1.8%, 3.3% and 6% of the watershed area respectively for the three scenarios for the MRB compared with 6.4%, 14.4% and 27.9% respectively for Nyangores sub-watershed. It is therefore apparent that watershed scale has a profound effect on the impact of agroforestry on watershed hydrology. Comparison of relative impact of ratio of watershed under agroforestry on water yield between the two watersheds reveals interesting effect of scale (Figure 6). It can be seen that although the impact of each of the agroforestry scenarios on water yield was higher for Nyangores sub-watershed, the slope was higher for the MRB than for Nyangores. This may have been caused by climate variability within the MRB (Brown *et al*., 2005). From Tables IV and V it can be seen that whereas the average precipitation and potential evapotranspiration are the same across the three scenarios in each of the two watersheds, the values are different for the two. The average rainfall is higher for the upstream Nyangores sub-watershed (1430 mm) than for the larger MRB (1045 mm). This is because the lowlands (Maasai Mara-Serengeti region) experience lower rainfall compared with the upper Mara (Mau Forest). On the other hand, average temperatures are higher in the lowlands than highlands and consequently the potential evapotranspiration is slightly higher for the larger Mara (1629 mm) than for Nyangores (1605 mm). This implies

that generalisation or extrapolation of impact of agroforestry (or any other forest-related land-use change) of a small catchment to the larger watershed may not be practical without considering the effect of climate variability within the watershed (Brown *et al*., 2005).

3.4 Implication for water resources management

The main finding of this study is that agroforestry would increase water demand and hence evapotranspiration and reduce the water yield (streamflow) of the Mara River. Reduced flows may be a concern by water managers who are tasked with managing the resources against an increasing demand (Dessu *et al*., 2014). However, these findings should be viewed within the broader context of environmental services provided by agroforestry. This is necessary because in the last few decades there has been a paradigm shift on how water resources should be managed. Integrated Water Resources Management (IWRM) has now been accepted worldwide as an effective management approach of water resources (UNEP, 2010; GWP, 2000). IWRM advocates for a holistic approach in water management where water, land and other resources (e.g. forestry) are managed in an integrated manner- because they are interlinked (Mwangi *et al*., 2015a). Agroforestry, for example, additionally provides other environmental services e.g. soil erosion control, provision of wood products such as timber and fuelwood, carbon sequestration, modification of microclimate (Ong *et al*., 2006; Nair, 1993). Soil erosion control is directly related to the findings reported here. The decrease in surface runoff due to agroforestry as reported in this study would consequently reduce soil erosion which is still a major problem in the MRB (Defersha and Melesse, 2012; Defersha *et al*., 2012; Kiragu, 2009). Reduced soil erosion would essentially reduce loss of top fertile soils in farmlands and hence control decline in land productivity for improved crop production. Decline in land productivity in the upper Mara has led to increased encroachment of the Mau forest by the local communities whose main economic activity is subsistence

farming (Mati *et al*., 2008). Reduction in soil erosion would also minimize sedimentation in the rivers and thus improving the water quality. This is very important because majority of people living in the watershed consume the water directly from the stream without any form of treatment (Ngugi *et al.*, 2014; Dessu *et al*., 2014). For the few who live in towns within the watershed and who have the privilege of taking treated water, reduced sediment loads would lower the water treatment costs. Another key benefit of agroforestry is the provision of timber and fuelwood which would lower the pressure on the forests. In Kenya, about 89% of people living in rural areas rely on fuelwood for their energy needs (World Resources Institute, 2007; Nyaga *et al*., 2015) which shows the importance of agroforestry in the livelihoods of rural communities.

It is also worth mentioning that the results reported here are based on annual averages. Water resources management should go beyond the annual averages and consider the intra-annual flows. This is because streamflow seasonality is a key determinant of water availability (Hoekstra *et al*., 2012) particularly for an unregulated river like Mara (Young, 2014). River Mara is only 395 km long from the source to its mouth in Lake Victoria. This means it only takes a few days for water from the headwaters to drain in the Lake and therefore most of the streamflow especially in the two wet seasons ends up in the Lake and would still be the case even in case of implementation of agroforestry. Flood water harvesting for the Mara would therefore be a very practical management strategy to ensure temporal distribution of water availability throughout the year.

The effect of watershed scale may be of interest to Tanzania considering that MRB is a trans-boundary between Kenya and Tanzania on the downstream end where there has been concern of the impact, on hydrology, of upstream watershed activities (Gereta *et al*., 2009, 2002). It may be interesting to note that though there may be some reduction of streamflow in the Mara by implementation of agroforestry, the impact would be lower on Tanzanian side of the

Mara compared to the Kenyan side. Integration of management of trans-boundary basins is also emphasised in IWRM and therefore the more need for a holistic view of watershed management in the MRB. Therefore, our findings viewed in the lens of IWRM would provide crucial information for watershed management in the greater basin. The three scenarios further provide some guidelines on trade-offs that can be made between streamflows and other environmental services especially by the Kenyan government that is keen on increasing the tree cover of the heavily deforested upper Mara basin and Mau Forest in general (GoK, 2009).

At a global level, SWAT is increasingly getting wide application in land-use and water resources studies (Gassman *et al*., 2010). Because agroforestry is also a common land-use practice worldwide especially in the tropical Africa, Asia and America (World Agroforestry Centre, 2009), there is need to provide ways/methods of modelling agroforestry in SWAT. We have provided a simple approach to model agroforestry in SWAT using the current model structure, with good results. However, more needs to be done to make the model structure flexible to enable modelling different systems of agroforestry e.g. allow intercropping in the same HRU.

4 CONCLUSIONS

SWAT model was used to simulate the impact of agroforestry on the hydrology of the MRB. Prior to simulation of agroforestry scenarios the model was successfully parameterized, calibrated and validated. We have provided a simple approach for simulating agroforestry in SWAT using the current model structure. We however note that more needs to be done on the model structure to make it flexible to incorporate different systems of this important land-use. Another contribution of this study was to provide a simple way in which the model can reasonably simulate tree growth in the tropics without changing the source code. Though simple, this kind of parameterization, which involves adjusting the minimum LAI and

fraction of tree heat unit to initiate growth, was considered better than the use of the default parameters that are better suited for temperate. Use of this approach of parameterization can greatly improve SWAT land-use modelling in tropical countries of the world.

Model simulation scenarios showed that agroforestry would generally reduce the surface runoff, lateral flow, groundwater contribution to streamflow and the water yield while the evapotranspiration would increase. The relative change in water balance components is proportional with increase in area under agroforestry. The decrease in surface runoff was mainly attributed to improved water infiltration conditions offered by the trees while decline in baseflow and overall water yield was attributed to the extra water use by trees that are not only able to extract water from shallow aquifer storage owing to their deep rooting system but also transpire more due to their bigger aerodynamic conductance. This suggests that the gain aquifer storage, made by increased infiltration, is outweighed by extra water removal by agroforestry trees; the net effect being decline in both baseflow and total water yield.

Spatial scale was found to have a significant role in determining the magnitude of change in hydrology; the impact of agroforestry was bigger for the smaller up-stream Nyangores sub-watershed compared with that of the entire MRB. This shows that the impact on hydrology is directly related to the fraction of the watershed implemented with agroforestry. It was also found that the slope of change of water yield with increase in tree cover was different for the MRB compared to that of one of its upstream sub-watershed (Nyangores). This was attributed to the spatial variability of climate within the MRB. This implies that generalization or extrapolation of effect of agroforestry (or any other change in tree cover) from small to larger watersheds may not be accurate without eliminating or taking into account the climate variability within or between the watersheds. This information is particularly important for scientific community working on small experimental study sites with an aim of extrapolating the results (or modelling) to large watersheds.

We conclude/suggest that these findings would be more beneficial to water resources managers when viewed from a broader perspective of IWRM. Agroforestry has many other related ecosystem services e.g. soil erosion control, which is directly related to our findings of reduction in surface runoff. We have shown how reduced surface runoff, and by extension soil erosion control, may also have multiplication of other benefits such as drinking water quality improvement and enhanced crop production for the subsistence farmers in the watershed. Owing to the high levels of competition for land between forestry and crop production in the basin, the results of the three agroforestry scenarios that are based on tree cover increment, may be used as a guideline to assist water resource managers and policy makers in making practical trade-offs between change in water yield and other benefits of agroforestry.

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Table I: Calibrated SWAT model parameters

Parameter		Calibrated parameter values			Parameter range used for calibration	Description	
		common	Upper Mara	MRB			
Surlag		3.74			0 - 4	Surface runoff lag coefficient	
AWC*		0.14			-0.20 – 0.20	Available water capacity of soil	
CN	FRSE	35			35 - 40	Initial Soil conservation service (SCS) runoff curve number for moisture condition II	Forest 'evergreen'
	FRST	36			35 - 40		Mixed forest
	AGRR	60			60 -75		Agriculture
	SWHT	71			60 - 75		wheat
	RNGE	36			35 - 45		rangelands
CH_N			0.12	0.09	0.01-0.3	Manning's "n" value for the main channel	
CH_K			3.23	2.98	0-10	Effective hydraulic conductivity in main channel alluvium (mm/hr)	
ALPHA_BF			0.75	0.98	0.6 - 0.99	Base flow alpha factor (l/days)	
GW_delay			31.0	4.91	0 - 31	Ground water delay time (days)	
GW_Revap			0.14	0.10	0.02 - 0.15	Groundwater "revap" coefficient	
GWQMN			200	1869	150 - 2000	Threshold depth of water in the shallow aquifer required for return flow to occur (mmH_2O)	
Rchrg_dp			0.25	0.10	0.02 - 0.25	Deep aquifer percolation fraction	

*percent of the parameterized soil awc for layer of each soil

Table II: size of the watershed converted to forest under the three agroforestry scenarios

Mara River Basin (area = 10,550 km^2)			
Scenario	Lower slope threshold (%)	area (ha)	% of watershed area
S1	20	18,559	1.8
S2	15	34,321	3.3
S3	10	63,810	6.0
Nyangores sub-watershed (area = 692 km^2)			
Scenario	Lower slope threshold (%)	area (ha)	% of watershed area
S1	20	4,420	6.4
S2	15	9,965	14.4
S3	10	19,380	27.9

Table III: Daily and monthly Nash-Sutcliffe efficiencies (NSE) and Klingupta efficiencies (KGE)

Calibration				
	Daily		Monthly	
Gauging station	NSE	KGE	NSE	KGE
Nyangores	0.65	0.81	0.77	0.88
Maramines	0.46	0.72	0.78	0.89
Validation				
Nyangores	0.63	0.80	0.74	0.85
Maramines	0.56	0.52	0.79	0.63
Amala	0.67	0.67	0.75	0.68

Table IV: Water balance (in mm) of the Nyangores sub-watershed for the three agroforestry scenarios

	Base	S1	S2	S3
Precipitation		1429.6		
Surface runoff	29.7	25.5	20.6	13.8
Lateral flow	29.2	28.0	27.5	27.0
Groundwater flow (GwQ)	295.4	281.4	263.9	235.7
Revap	0.45	0.46	0.47	0.48
Total water yield	354.3	334.9	311.9	276.5
Evapotranspiration (ET)	1057.8	1076.4	1098.6	1133.1
Potential ET (PET)		1605.9		

Groundwater flow (GwQ) is the groundwater contribution to streamflow.

Table V: Water balance (in mm) of the MRB for the three agroforestry scenarios

	Base	S1	S2	S3
Precipitation		1044.6		
Surface runoff	23.8	22.9	22.1	20.8
Lateral flow	10.3	9.9	9.8	9.7
Groundwater flow (GwQ)	106.1	103.8	101.2	96.9
Revap	124.4	123.9	123.5	122.8
Total water yield	140.1	136.6	133.2	127.3
Evapotranspiration (ET)	750.9	755.0	758.8	765.6
Potential ET (PET)		1628.9		

Groundwater flow (GwQ) is the groundwater contribution to streamflow.

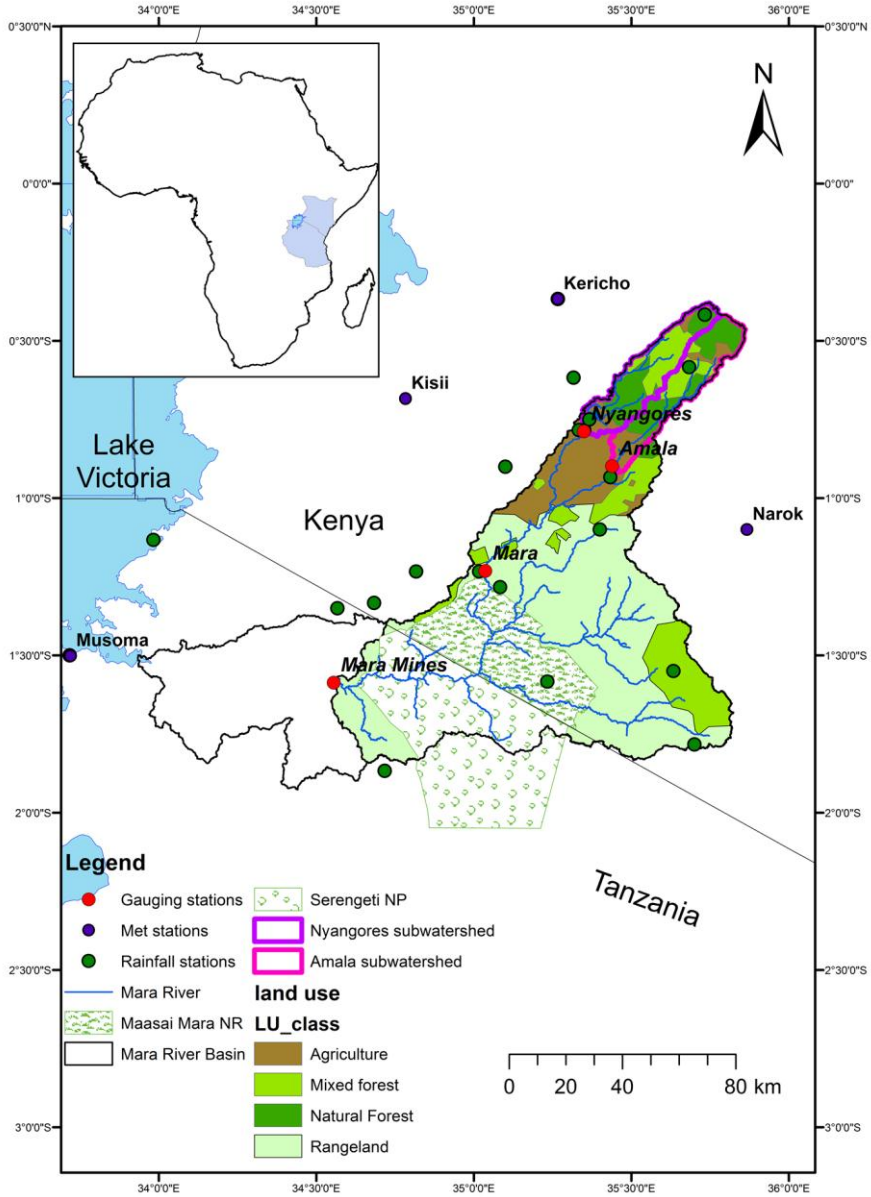

Figure 1: Mara River Basin

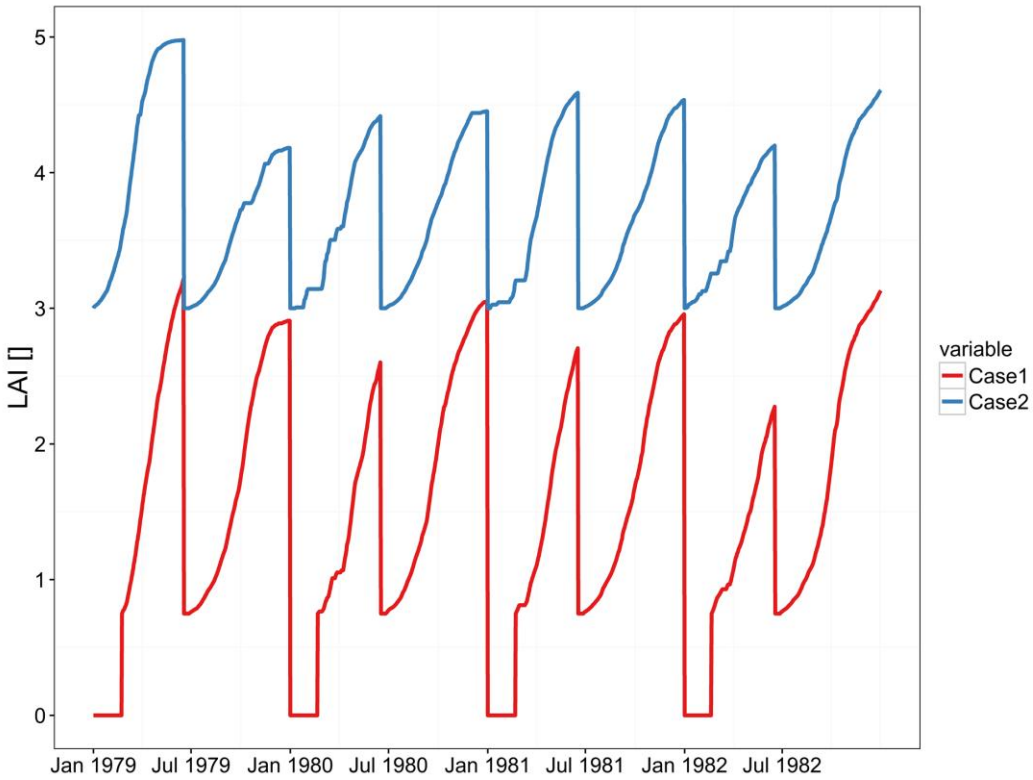

Figure 2: LAI simulated using a) case 1: the default setting in SWAT (Minimum LAI = 0.75; 'start growing season' PHU fraction = 0.15) and b) case 2: adjusted values (Minimum LAI = 3.00; 'start growing season' PHU fraction = 0.001). PHU = 3500

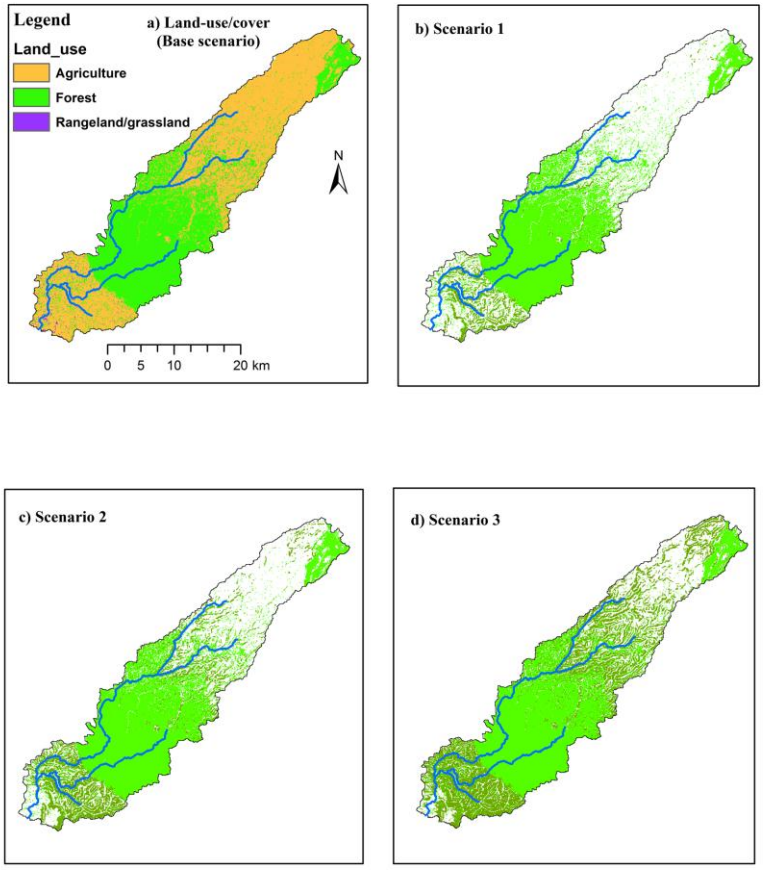

Figure 3: Land–use and agroforestry scenario maps (for Nyangores sub-watershed only): (a) Land–use/cover map (2014); also represents the base scenario. (b, c, and d) Agroforestry scenarios 1, 2, and 3 respectively (showing the forest cover in the base scenario (light green) and additional areas simulated with woodlot agroforestry (dark green).

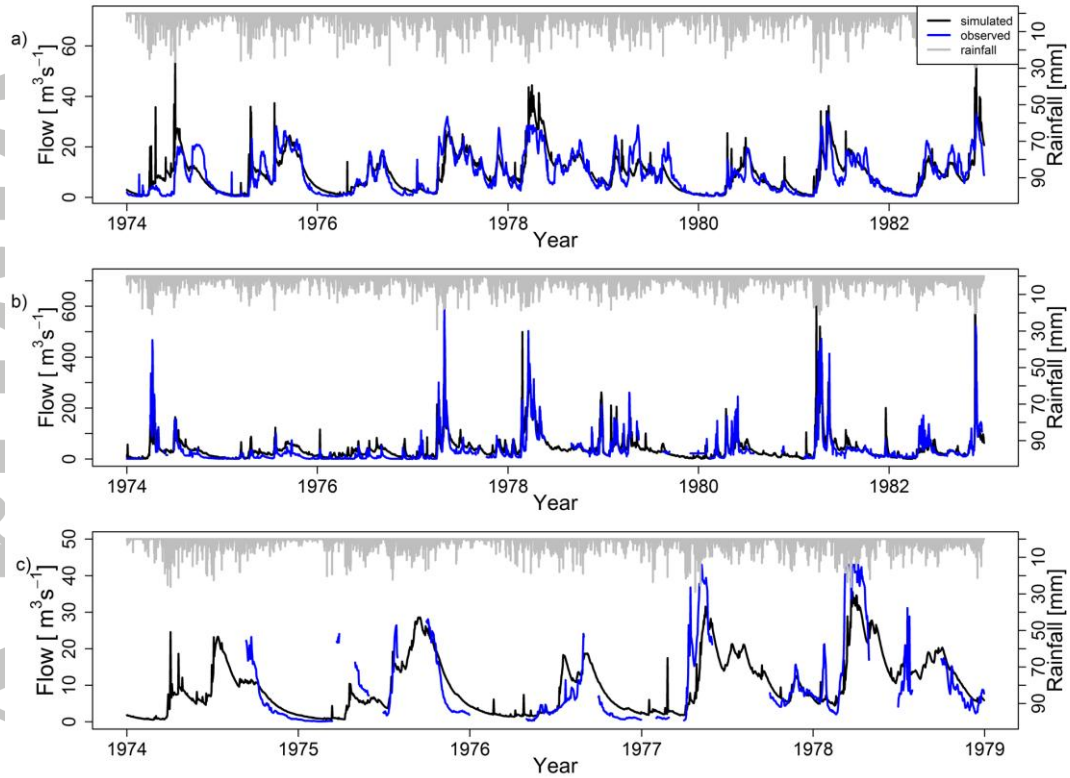

Figure 4: Daily hydrographs for observed and simulated streamflow of: a) Nyangores River at Bomet, b) Mara River at Mara mines and c) Amala River at Mulot

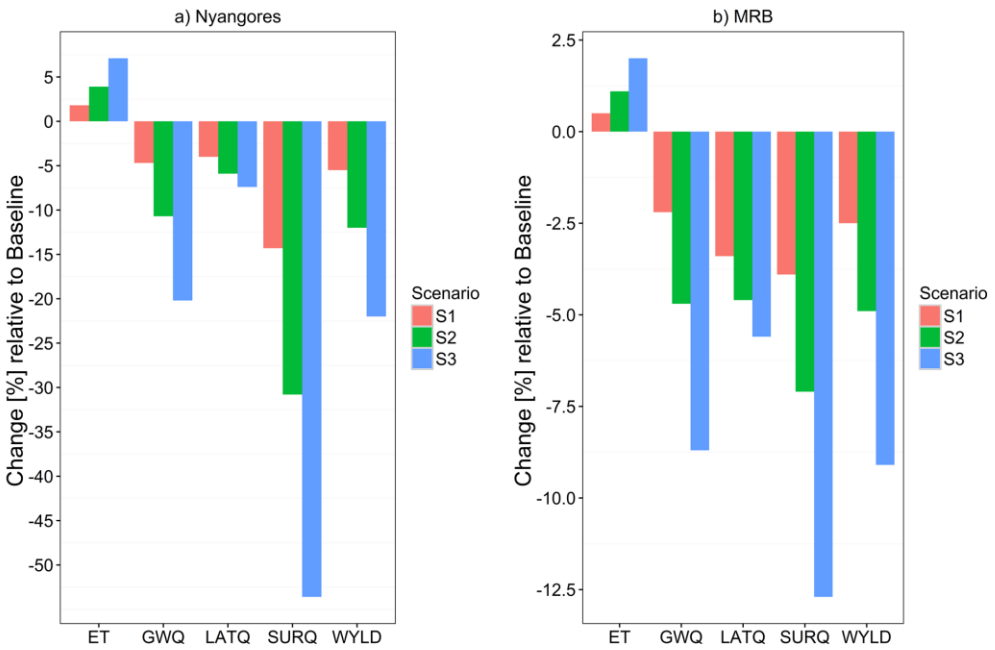

Figure 5: Relative impact of increasing area under agroforestry on water balance of: a) Nyangores sub-watershed and b) larger MRB. SurQ is the Surface runoff, LatQ is the lateral flow, GWQ is the groundwater contribution to streamflow, Total WYLD is the total water yield and ET is the evapotranspiration

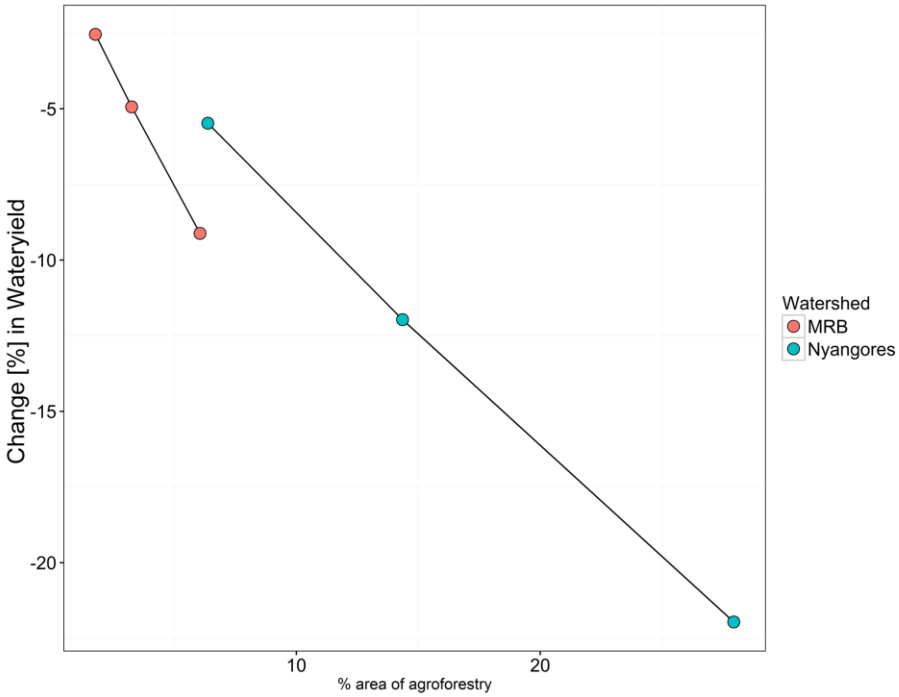

Figure 6: Relationship between ratio (%) of watershed (simulated with agroforestry) and percent change in water yield for MRB and Nyangores