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Assessing the Effects of Land Use/Land Cover Change on Discharge Using SWAT Model in River Ruiru Watershed, Kiambu County, Kenya

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Abstract Watersheds and water resources are highly vulnerable to land use/land cover changes (LULCC) as they directly influence hydrological characteristics in terms of water quantity. This study aimed at assessing the effects of land use/land cover changes (LULCC) on Surface runoff contribution to discharge (SURQ), lateral flow contribution to discharge (LATQ) and groundwater contribution to discharge (GWQ) of River Ruiru watershed, Kiambu County. The study integrated the use of remote sensing, GIS and hydrological modeling to collect and analyze data. Results of the study indicated that built-up areas, annual crops (mixed farming) and perennial crops (Tea and coffee farming) increased by 1.83%, 15.05% and 10.90% from 1984 to 2017 while grassland, shrubland and forestland decreased by 6.21%, 11.92% and 10.06%. Consequently, SWAT model results indicated that land use/land cover changes that occurred in River Ruiru watershed between 1984 and 2017 had effects on Surface runoff (SURQ), lateral flow (LATQ) and groundwater contribution to discharge (GWQ) which increased from 30.25 mm/yr, 8.48mm/yr and 9.95mm/yr to 181.25mm/yr, 11.44mm/yr and 10.66mm/yr respectively. The results from this study will help in understanding the effects of LULCC on the quantity of discharge which is one component of the knowledge base required in applying the principles of integrated water resources management (IWRM) thus providing critical input to the decision making on water resources management and planning.

Keywords: *land use change, land cover change, discharge, River Ruiru watershed, SWAT model*

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1. Introduction

The hydrological cycle of a basin is a complex process influenced by climate, physical characteristics of the basin and human activities [1,2]. Effects of Land use changes on the water cycle are usually reflected in the long-term spatial and temporal variation of water balance components such as surface runoff, soil moisture, evapotranspiration, groundwater and streamflow [3,4,5]. Thus, [6] in their study on the impacts of human activities on the water-land environment of the Shijang river basin conclude that while striving towards sustainable development, it is important to analyze the consequences of water-related human activities so as to improve the existing water management practices.

In recent years, there has been a rapid declining availability of usable freshwater in terms of water quality and quantity due to unsustainable land use practices in catchments [7,8,9]. The increase in population, declining land available for cultivation due to land sub-division coupled with unsustainable land management practices have also affected land productivity, forcing communities to intensify cultivation into water catchment areas (WCAs) in search of more land which ultimately affect the catchment water functions (CWFs) [10].

Modification of natural land cover has brought about changes in the river flow regime such as high peak flows, reduced base flows, enlarged river channels and silt deposition downstream [11]. It also affects river discharge implying changes in the hydrological characteristics of the watershed [12,13]. In addition, urbanization and agricultural expansion lead to an increase in impervious surface area which may lead to an increase in surface runoff and decrease in infiltration [14,15]. These changes have a substantial impact on the hydrological compartment and have become a central component in current strategies for managing natural resources and monitoring environmental changes [16]. According to [17] natural and human-induced environmental changes are of concern today because of deterioration of the environment and human health. Thus, [18] concluded that there is a need for efficient watershed management which requires a rational and efficient decision support system for tackling a wide range of environmental and resource management issues.

In Kenya, land use changes in various catchments and water towers have been increasingly characterized by human settlement, deforestation, wetland reclamation and unsustainable agricultural activities [19]. The upper Athi Catchment which includes River Ruiru watershed has been experiencing land cover and land use changes due to agricultural expansion and urbanization and these changes are distributed according to agro-ecological zones [3]. River Ruiru traverses rural, urban and peri-urban areas and therefore the watershed is characterized by high population growth, demographic changes as people move from rural to urban environment especially in Ruiru Municipality, higher demands for food security and agricultural, industrial and quarrying activities. Moreover, the influence of the city of Nairobi has also led to tendency towards land use change from agricultural to commercial and settlement, especially within the urban centres [20]. Thus, the watershed has undergone many land use/land cover changes due to population pressure which may have affected discharge.

2. Materials and Methods

2.1. The Study Area

River Ruiru watershed has an area of 484.515 km^2 and a population of 671,646 persons [21]. It lies between longitude 36°40’E and 37°00’E and latitude 1°20’S and 0°.50’S. River Ruiru originates from Kikuyu escarpment and is the boundary between Lari and Githunguri sub-counties. Administratively, Ruiru River watershed traverses through Ruiru, Githunguri and Lari sub-counties and is fully located in Kiambu County (Figure 1). The watershed is located in a medium rainfall potential area with moderate and reliable rainfall. It has two distinct rainy seasons: The long rains are experienced in March-April-May (MAM) and short rains are experienced in October and November. The mean temperature is 26°C with temperature ranging from 17.1°C in the upper highlands to 34°C in the lower midlands and shows an increasing trend in the recent past. July and August are the months during which the lowest temperatures are experienced while January, February and March are the hottest months [20]. It is hydrologically located within the Athi Basin, 3BC sub-basin administered from upper Athi Water Resource Authority (WRA) in Kiambu. The watershed is covered by a well distributed dense lateral river network. Ruiru River is the major river in the watershed with its main tributaries being Makuyu, Gatamaiyu and Komothai. It has four dominant land cover types which include trees, settlements, grasslands and croplands. The land cover has high temporal variations with the wet season exhibiting high vegetation cover and the dry season exhibiting very low vegetation cover. The upper part is predominantly forested but is currently threatened with pockets of farmlands. The land use potential may be described according to the country’s agro-ecological zones which may be categorized as medium to high potential falling under zones UM3, UM2, UH1, UH0, UM1, UM5, UM4 and LH1 as shown in Figure 1 [22].

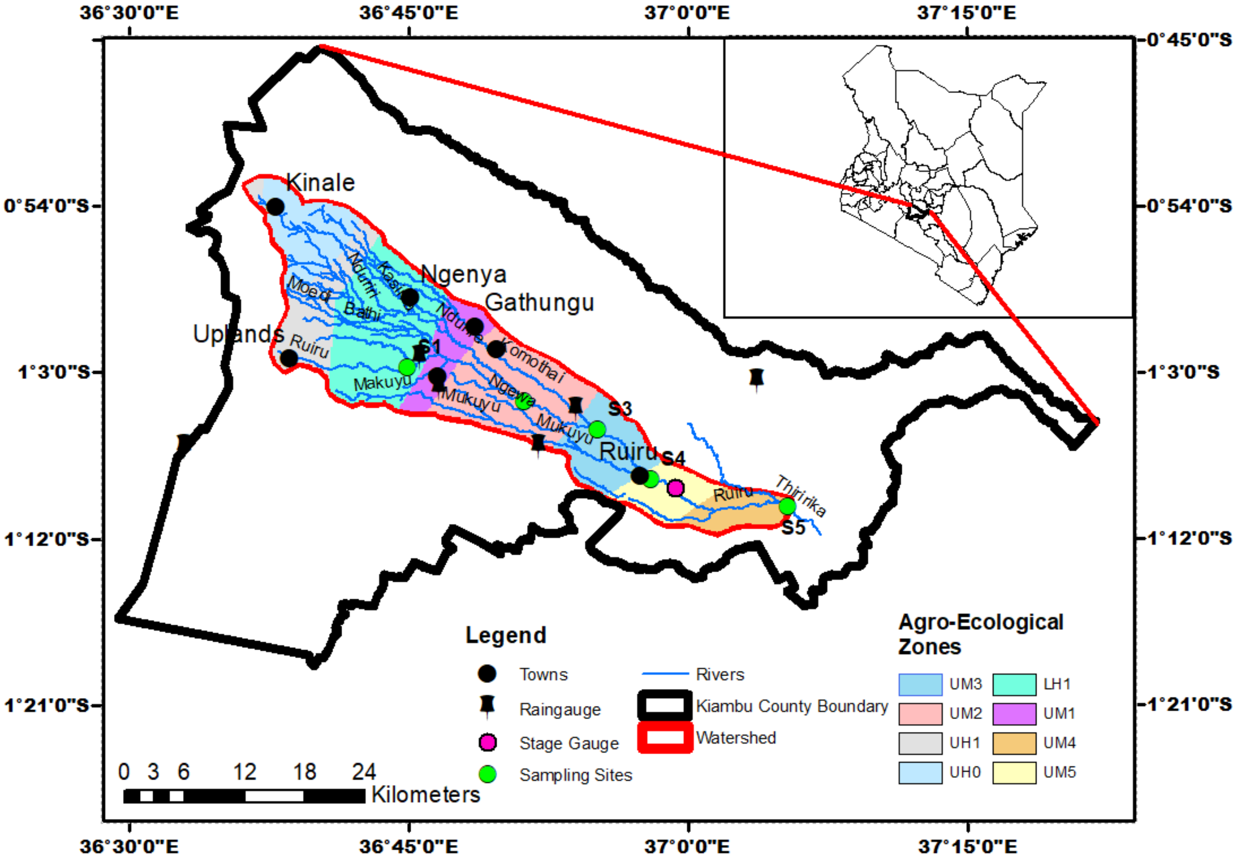

Figure 1. River Ruiru watershed

2.2. Data Collection Techniques

2.2.1. Land Use/Land Cover Data

Land use/land cover data of two multi spectral landsat images TM and OLI/TIRS images for 1984 and 2017 were acquired from USGS-Earth explorer (http://www.earthexplorer.usgs.gov/) website as shown in Table 1. These landsat images were chosen based on available cloud free landsat images, available SWAT input weather data and also a time interval that is long enough for land use/land cover change to have measurable impacts on hydrologic response. To avoid uncertainties, clouds and possible errors resulting from seasonal differences between time points, the selected images were acquired within the dry seasons of the year (December). It has been suggested that by using dry season images, there will be decreased confusion at forest edges between dense forest vegetation and small-scale agricultural plots [23].

2.2.2. Weather Data

Rainfall data from five weather stations shown in Table 2 and minimum and maximum temperature data from Thika Agro-meteorological station were acquired from Kenya Meteorological Department. Wind speed, solar radiation and relative humidity data were obtained from global weather data set of the National Centre for Environmental Prediction (NCEP) (http://globalweather.tamu.edu/) Climate Forecast System Reanalysis (CFSR). The weather data was prepared according to the SWAT model ASCII (.txt) table format and used for weather data definition in SWAT model.

2.2.3. Discharge Data

Mean daily river discharge data in cubic meters for River Ruiru was obtained from Water Resources Authority (WRA) in Kiambu for the period between 2007-2013 for the gauge station 3BC8 located in Ruiru Bridge. This data was used during calibration and validation of the SWAT model. The discharge data for the period from 2007-2013 was chosen as it was complete with no gaps.

2.2.4. Soil Data

The SWAT model requires different soil textural and physico-chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. This study used the digital soil data acquired from the Kenya Soil and Terrain Database (KENSOTER) soil classification system that describes soil types for Kenya that are linked to FAO soil classification system which was then manually linked with the SWAT database.

2.2.5. Digital Elevation Model (DEM)

A Digital Elevation Model (DEM) with a spatial resolution 90m of 3-arc second was derived from SRTM satellite data in GEO TIFF file format. This resolution is generally consistent for most regions of the globe and sufficiently allows for quantification of landscape features influencing hydrological processes [24]. The DEM was used to delineate the watershed into sub-basins and then into smallest representative unit of the watershed, the Hydrologic Response Units (HRU's) based on specific land use, soil and slope characteristic features, compute the outlet point of the watershed and to compute the drainage and stream density of the entire watershed.

2.3. Data Analysis Techniques

2.3.1. Land Use/Land Cover Change Analysis

Land use/land cover change analysis was done using ArcGIS 10.4 functions. Three bands B2, B3 and B4 representing the RGB colors were imported into the ArcMap. A composite of the three bands was formed using the image analysis tool. The study area was extracted through masking in the arctool box then projected into UTM WGS 1984 southern hemisphere zone 37S. Training samples were then created based on different colors of the study area Landsat images and the signature file. Land use/land cover classification was done using image classification tool -maximum likelihood classification method. False color composites (Bands 432) were used for the visual examination and interpretation of the images and maximum likelihood classification method was used as recommended by [25]. The maximum likelihood classification method is the most widely used per-pixel method which takes into account spectral information of land cover classes [26]. The maximum likelihood decision rule is based on the probability that a given pixel belongs to a particular class [27] and that the statistics for each class in each band is evenly distributed.

Table 1. Metadata for the Landsat Images

Year	Acquisition data	Sensor ID	Path	Row	Producer	Resolution
1984	17/12/1984	TM	168	061	USGS	30m
2017	28/12/2017	OLI-TIRS	168	061	USGS	30m

Table 2. Rainfall Stations in River Ruiru Watershed

Station Name	Station ID	Data available	Altitude	Geo-coordinates	Status of the data
Githunguri Agricultural station	9136098	1970-2017	1999m	36°47'E, 01°04'S	Complete
Jacaranda Coffee Research	9136084	1970-2017	1608m	36°54'E, 01°05'S	Complete
Tatu City	9136092	1970-2017	1554m	36°47'E, 1°08'S	Complete
Ndoondu Estate- Kiambu	9136018	1970-2017	1655m	36°52'E, 01°07'S	Complete
Thika Agro-Meteorological Station	9137048	1970-2017	1463m	37°06'E, 1°01'S	Complete

Table 3. Reclassification of Land Use/Land Cover Types to SWAT Land Use/Land Cover Classes

User land use/land cover	SWAT land use/land cover	SWAT land use/land cover code
Built-up areas	Residential	URBN
Annual crops(mixed farming)	Agricultural land-Generic	AGRL
Perennial crops (Tea and coffee)	Forest-mixed	FRST
Grassland	Range grasses	RNGE
Shrubland	Range-grasses	RNGB
Forestland	Forest-evergreen	FRSE
Waterbody	Water	WATR

The images were classified into seven land use/land cover types using supervised classification based on [28] land use/land cover classification system as shown in Table 3. Ground truthing of the major land uses/land cover within the study area was done according to [29] guidelines. These land use/land cover types include built-up areas, annual crops, plantation (tea and coffee), grassland, shrubland, forestland and waterbody. They were further reclassified to match classes that are comparable to the SWAT land use and land cover data as shown in Table 3.

2.3.2. Hydrological Modeling

The effects of land use/land cover change on discharge were assessed by integrating remotely sensed data, GIS and the Soil and Water Assessment Tool (SWAT) model. The integration of SWAT model with GIS and remote sensing tool are helpful in analyzing and evaluating spatio-temporal land use/land cover dynamics [30,31]. ArcSWATv2012.10.1.18 was downloaded from the SWAT model website (http://swat.tamu.edu/software/arcswat) and installed in ArcGISv10.4.

The SWAT [32] is a physically-based semi-distributed hydrological model developed by the USDA-ARS (Agricultural Research Institute). It has been widely used to examine the hydrological impacts of land use/land cover change in various U.S agencies, universities and research institutes. The model is capable of describing the various components of the hydrological process and is considered to be the most rational way to investigate the hydrological response to LULCC [33]. It operates at a wide range of scales with complex terrain features including various soils, land use and management conditions over a daily time-step. The model has gained international acceptance as a robust interdisciplinary watershed modeling tool as evidenced by international SWAT conferences, hundreds of SWAT-related papers presented at numerous other scientific meetings and dozens of articles published in peer reviewed journals [34].

The SWAT model sub-divides a basin into sub-basins connected by a stream network and further delineates such sub-basins into Hydrologic Response Units (HRUs) consisting of unique combinations of land use and soils. Areas with the same soil type and land use form a HRU, a basic computational unit assumed to be homogenous in hydrologic response to land cover change. The model application can be divided into the following steps; data preparation, sub-basin discretization, Hydrologic Response Unit definition, parameter sensitivity analysis, calibration and validation and uncertainty analysis.

The model simulates the hydrology into land and routing processes. In the land phase, the amount of water sediment and other non-point loads are calculated from each HRU and summed up to the level of sub-basins. Each sub-basin controls and guides the loads towards the basin outlet. The routing phase defines the flow of water sediment and other non-point sources of pollution through the channel network to an outlet of the basin. The hydrological routines within SWAT account for snowfall and melt, vadose zone processes (infiltration, evaporation, plant uptake, lateral flows and percolation and groundwater flows [35].

The interface in GIS (Arc-SWAT) is convenient for the definition of watershed hydrologic feature and storage, as well as the organization and manipulation of the related and tabular data [36]. Arc-SWAT environment also provides the facility to input spatially referenced data and thereby enhances its capability to represent spatial heterogeneity. Being a semi-distributed, continuous time model, it requires numerous spatial and attribute inputs that represent weather, hydrology, soil properties, plant growth, nutrients, pesticides, bacteria and pathogens and land management. Arc-SWAT breaks the preprocessing into four main steps; watershed delineation, HRU analysis, weather data definition and SWAT simulation. ArcSWAT is also an effective tool in analyzing the impacts of land use/land cover changes on streamflow in areas with limited data [30]. The model also utilizes Geographic Information System (GIS) and Digital Elevation Model (DEM) to delineate watersheds and extract networks.

The model offers continuous-time simulation, high level of spatial detail, unlimited number of watershed sub-divisions, efficient computation and capability to simulate changes in land management. SWAT also runs with minimum data inputs, which is advantageous when working in areas with limited data especially when modeling ungauged watersheds [37]. Daily climatic inputs such as daily precipitation, maximum and minimum air temperature, solar radiation, wind speed and relative humidity can be generated internally in the model using monthly climate statistics that are based on long-term weather records. It is also computationally efficient and therefore able to run simulations of large basins or management practices without consuming large amounts of time or computational resources.

Another basis for the selection of SWAT model was due to its worldwide use for variety of application. The model has in the recent past gained significant publicity having been used widely for various applications world over with notable success [38]. SWAT applications for flow and pollutant loadings have compared favourably with measured data for a variety of watersheds scales [39,40]. The model also integrates functionalities of several other models, allowing for the simulation of climate, hydrology, plant growth, erosion, nutrient transport and transformation, pesticide transport and management practices [41]. The model software is freely available for download on the SWAT website. There is also a large amount of user support available on its site-including user forum, educational videos and user manuals. More detail about the SWAT theory one can refer to the theoretical documentation available online (http://swat.tamu.edu/).

Classified land use/land cover data, soil data and weather data were input into the Soil and Water Assessment Tool (SWAT) [32] hydrological model and run to analyze the effects of land use/land cover change on discharge. Two independent SWAT model runs were carried out on a monthly basis using the 1984 and 2017 ArcGIS generated land use/land cover maps. Consequently, the following discharge components were compared for the two years; surface runoff contribution to discharge (SURQ), lateral flow contribution to discharge (LATQ), groundwater contribution to discharge (GWQ).

3. Results

3.1. Land Use/Land Cover Types for 1984 and 2017

Figure 2 and Figure 3 show the two land use/land cover maps of 1984 and 2017 that were generated from landsat TM and OLI/TIRS classification respectively. Results of the study indicated that built-up areas, annual crops (mixed farming) and perennial crops (Tea and coffee farming) increased by 1.83%, 15.05% and 10.90% from 1.9%, 31.6% and 5.3% to 3.8%, 46.6% and 16.1% respectively from 1984 to 2017. Area under water bodies also slightly increased by 0.095% from 0.22% to 0.31%. On the other hand, grassland, shrubland and forestland decreased by 6.21%, 11.92% and 10.06% from 11.2%, 13.0% and 36.7% to 5.0%, 1.4% and 26.6% respectively within the same period as shown in Figure 4 and Table 4.

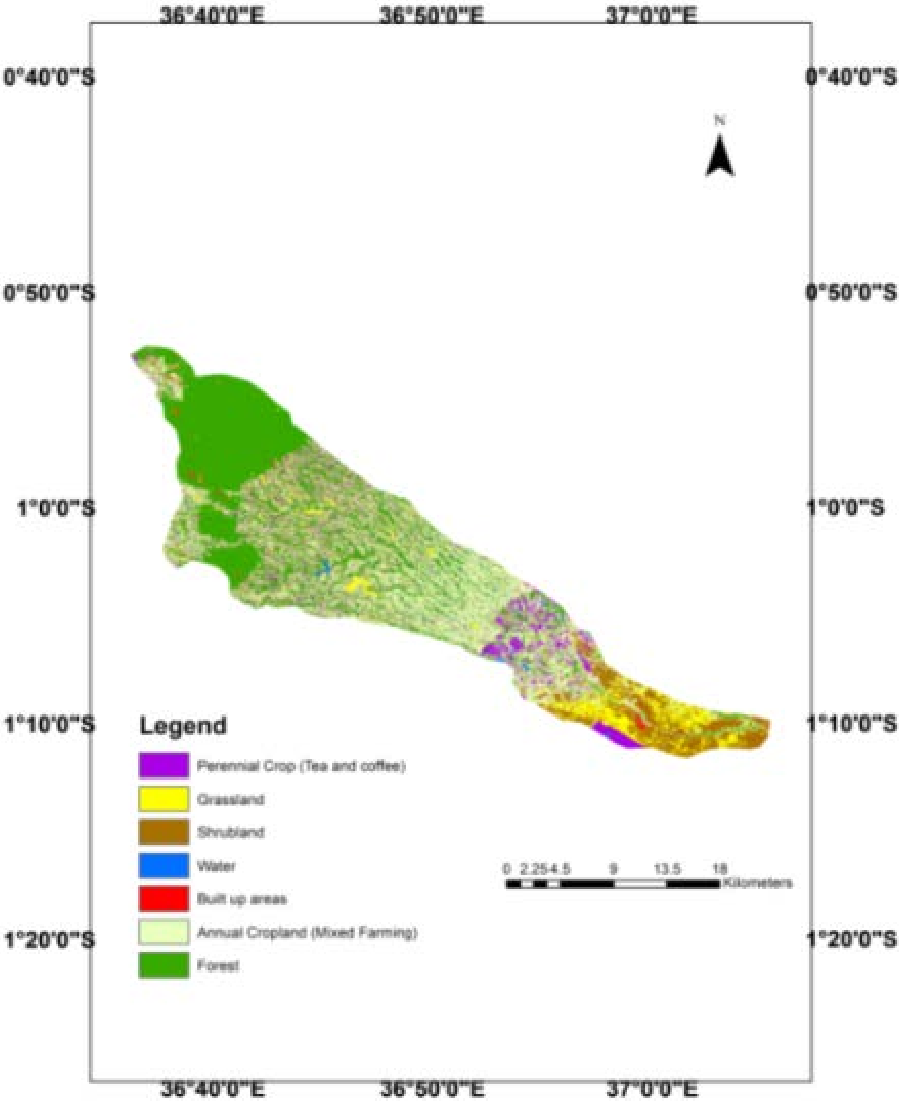

Figure 2. Land use/cover map computed from TM 1984

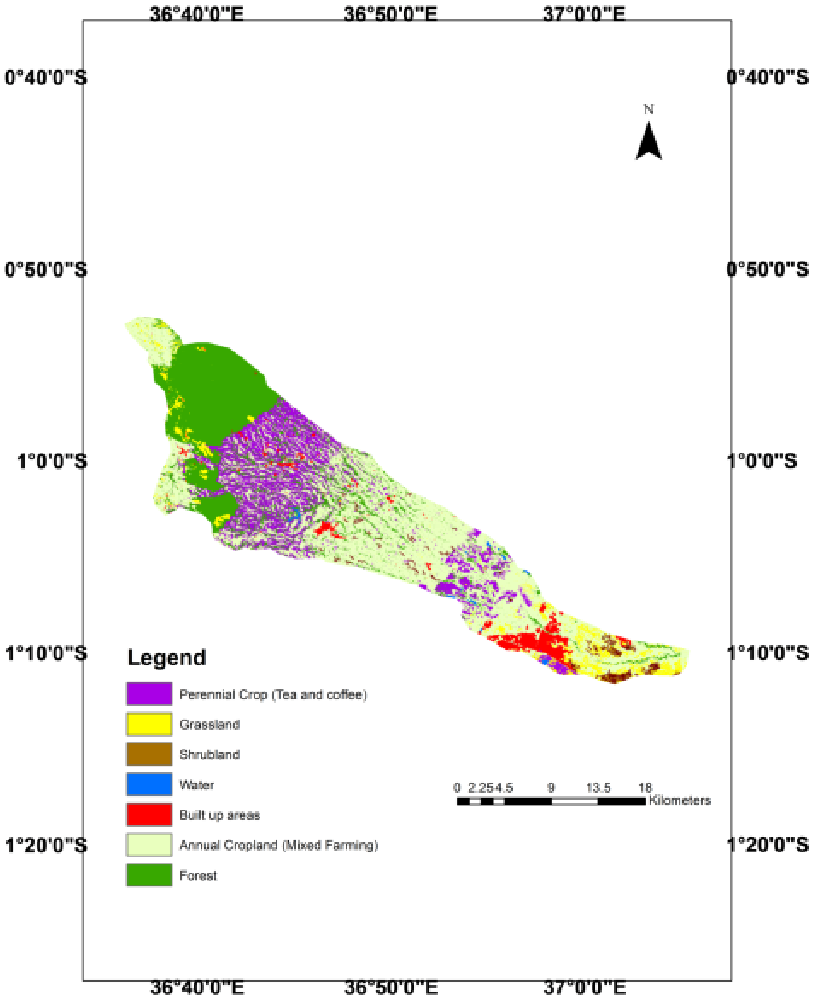

Figure 3. Land use/cover map computed from OLI/TIRS 2017

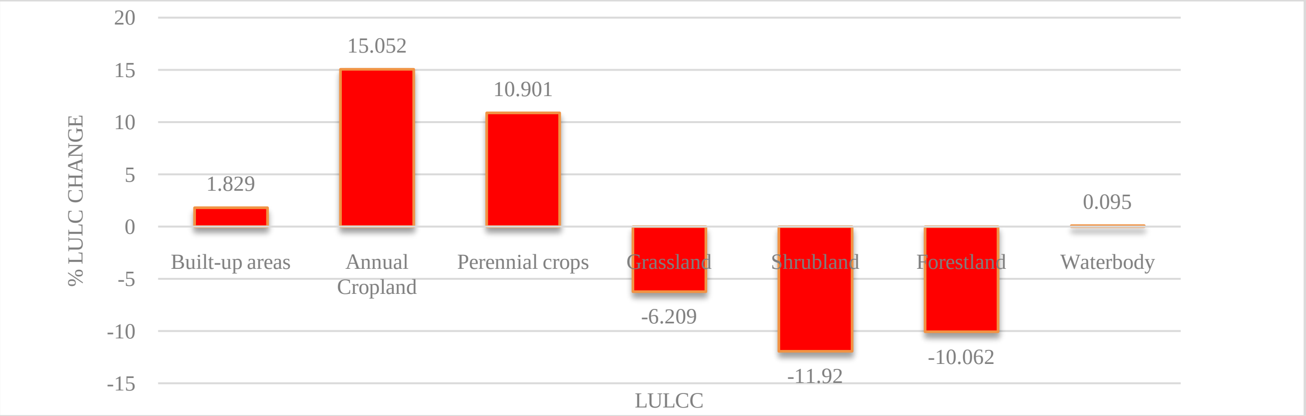

Figure 4. Percentage land use/land cover change between 1984 and 2017

Table 4. Land Use/ Land Cover Change in River Ruiru Watershed between 1984 and 2017

	AREA IN HA					
LULC	1984		2017		CHANGE IN LULC(1984-2017)	
	Area(ha)	%	Area(ha)	%	Area in ha	%
Built-up areas	11,271.00	1.929	21,951.00	3.758	10,680.00	1.829
Annual crops/Mixed farming	184,519.00	31.586	272,449.00	46.638	87,930.00	15.052
Perennial crops/Tea and coffee zone	30,739.00	5.262	94,420.00	16.163	63,681	10.901
Grassland	65,871.00	11.276	29,598.00	5.067	-36273.00	-6.209
Shrubland	76,148.00	13.035	8,355.00	1.430	-67,793.00	-11.920
Forestland	214,373.00	36.697	155,595.00	26.635	-58,778.00	-10.062
Water bodies	1,257.00	0.215	1,810.00	0.310	553	0.095

3.2. SWAT Model Results

3.2.1. Sensitivity Analysis

Following calibration, the overall effect of each parameter used was ranked using global sensitivity function within SWAT-CUP. From the analysis, the most sensitive parameters to discharge were CN^2.mgt and ALPHA.BNK. The CN^2.mgt (SCS runoff curve number for moisture condition II) is an empirical parameter used to predict direct runoff and infiltration from rainfall excess. The curve number estimates runoff based on the relationship between precipitation, hydrologic soil group and land uses. Therefore, the parameter reflects soil permeability, land use and antecedent soil water as it is a function of these conditions [42]. ALPHA-BNK is the baseflow alpha factor bank storage [43].

3.2.2. Model Uncertainty Analysis

The model was able to bracket 67% of observed data and a large uncertainty band (r-factor=1.12) during calibration. During validation, the model bracketed 96% of the observed data with a slightly larger uncertainty band (r-factor=1.33) as shown in Figure 5 and Figure 6 and Table 5. The mean simulated and mean observed monthly discharge was 0.89 and 1.10 respectively during calibration and 0.64 and 0.65 respectively during validation (Table 5).

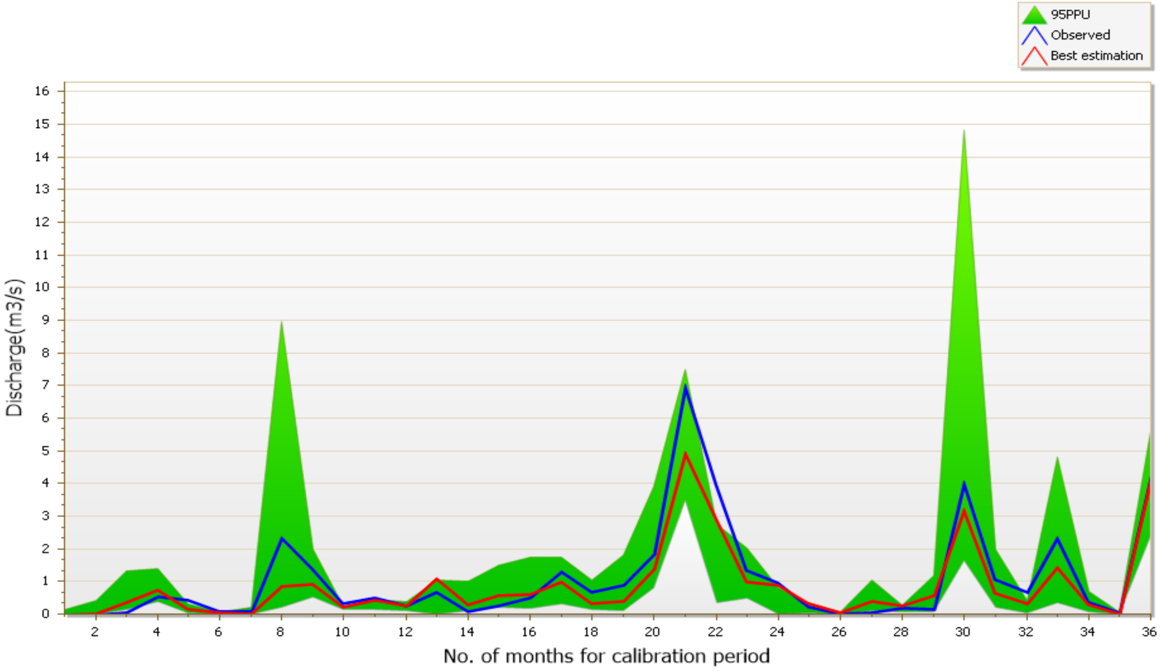

Figure 5. Model uncertainty output expressed as 95PPU for calibration period

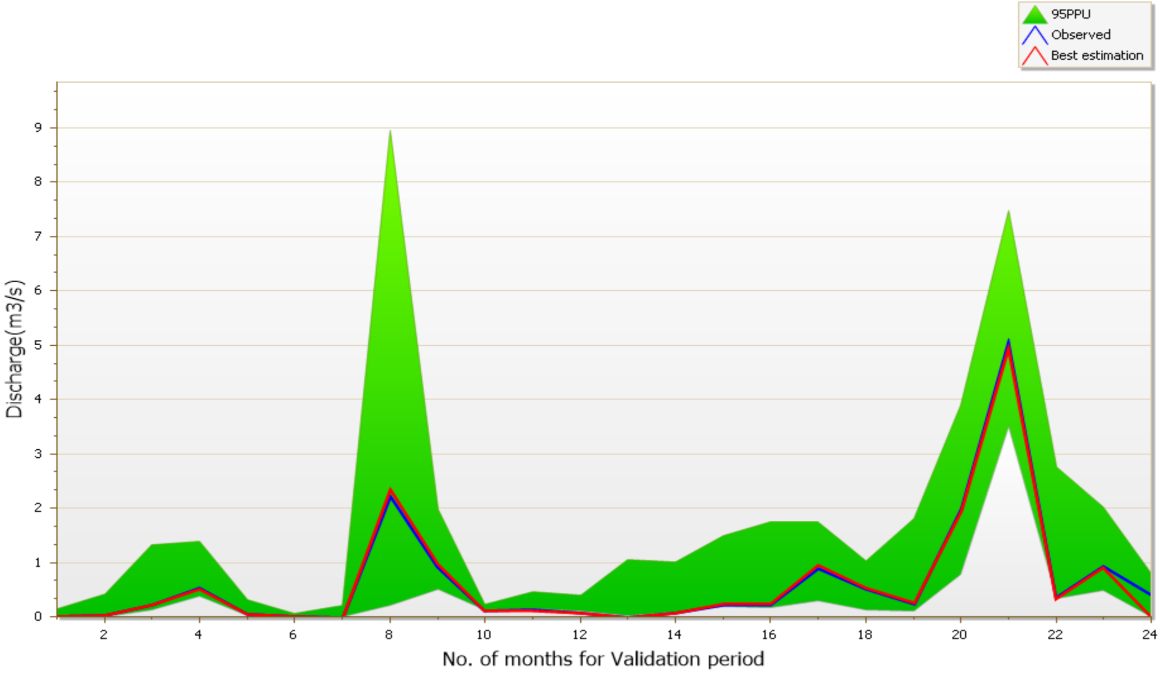

Figure 6. Model uncertainty output expressed as 95PPU for validation period

3.2.3. Model Performance Evaluation

Calibration and validation outputs for the period 2007-2009 and 2012-2013 showed a good correlation between observed and simulated discharge values with NSE=0.86, PBIAS=19.4, R^2=0.93 and RSR=0.37 during calibration and NSE=0.99, PBIAS=2.0, RSR=0.08 and R^2=0.99 during validation as shown in Table 4 and Figure 7 and 8.

Table 5. Performance Evaluation Indicators

	NSE	PBIAS	RSR	R^2	Mean_sim(Mean_obs)	Stddev.sim(obs)	P-factor	R-factor
Calibration (2007-2009)	0.86	19.4	0.37	0.93	0.89(1.10)	1.14(1.52)	0.67	1.12
Validation (2012-2013)	0.99	2.0	0.08	0.99	0.64(0.65)	1.09(1.10)	0.96	1.33

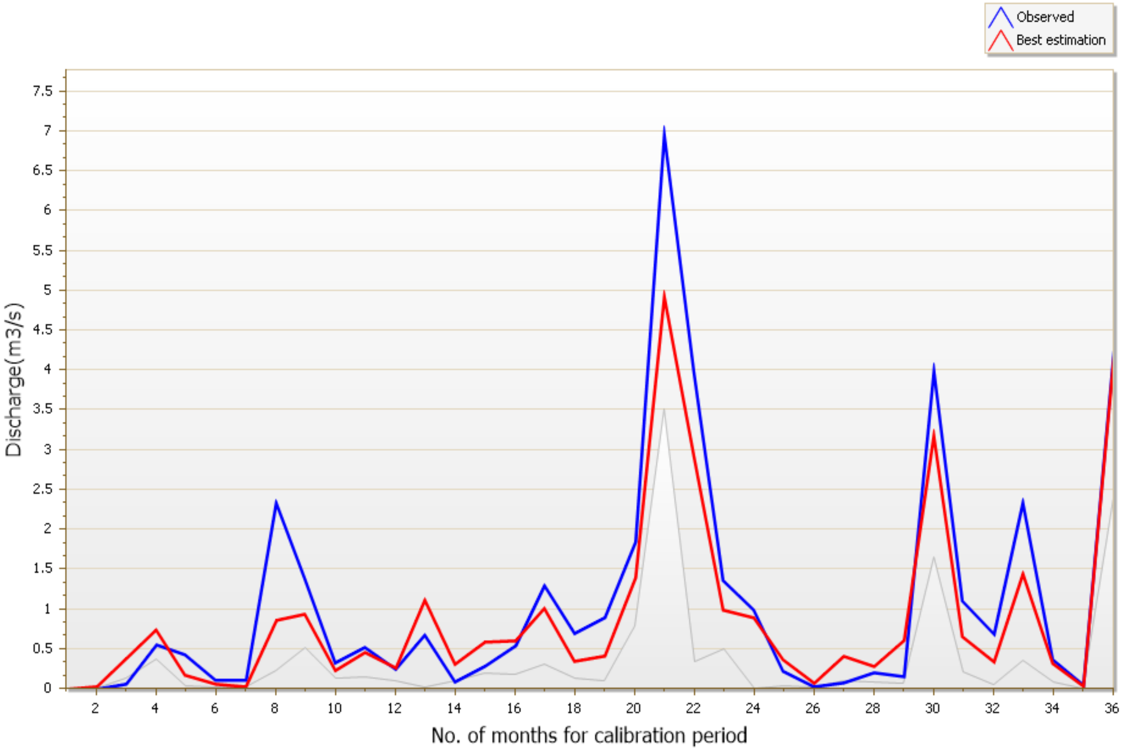

Figure 7. Observed and simulated flow hydrograph for calibration period

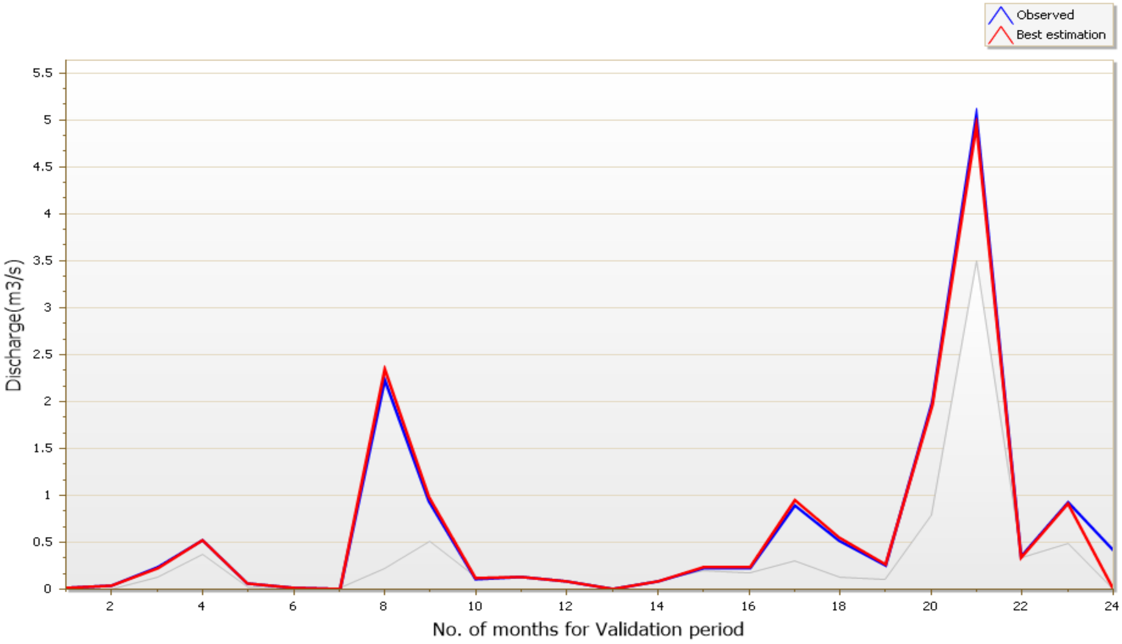

Figure 8. Observed and simulated flow hydrograph for validation period

3.3. Effects of Land Use/Land Cover Change on Discharge

Findings from the study indicated that River Ruiru watershed experienced land use/land cover change over the last 33 three years (1984-2017). An increase in the built-up areas, annual and perennial crops by 1.83%, 15.05% and 10.90% respectively and a decline of the grassland, shrubland and forestland by 6.21%, 11.92% and 10.06% respectively led to a great increase in surface runoff (SURQ) from 30.25mm/yr in 1984 to 181.25mm/yr in 2017.Results also indicate a slight increase in lateral runoff (LATQ) and groundwater contribution to discharge (GWQ) from 8.48mm/yr and 9.95mm/yr respectively in 1984 to 11.44mm/yr and 10.66mm/yr respectively in 2017 as shown in Table 6.

Table 6. Effects of Land Use/Land Cover on Discharge Components in 1984 and 2017

Discharge component	1984	2017
Surface runoff contribution to discharge (SURQ)	30.25mm/yr	181.25mm/yr
Lateral flow contribution to discharge (LATQ)	8.48mm/yr	11.44mm/yr
Ground water contribution to discharge (GWQ)	9.95mm/yr	10.66mm/yr

4. Discussion

An increase in built-up areas, perennial and annual crops by 1.83%, 10.9% and 15.05% respectively and a decline in forestland, shrubland and grassland by 10.06%, 11.92% and 6.21% respectively between 1984 and 2017 led to a change on the discharge components of River Ruiru watershed. Surface runoff greatly increased from 30.25mm/yr to 181.25mm/yr between 1984 and 2017. This increase could have been attributed to the reduction of the forest cover, grassland and shrubland and increase in built-up areas in the area leading to reduced infiltration and high surface runoff while the slight increase in LATQ and GWQ could have been attributed by the increase in perennial farming. Similarly, [44] in their study on the impact of land cover change on runoff in the Nzoia catchment also concluded that land use and in particular agricultural land use has a strong effect on hydrological regime of the Nzoia catchment in Kenya. They observed that changes in LULC over the period of 1973 and 2001 have been significant and have contributed to a considerable increase in runoff. Reference [45] in their study on flow simulation based on land use change simulations concluded that overall, the model outcomes indicated that land use changes lead to increase in the average runoff in their study area. Similarly, [46] in their study in the upper Brantas Basin in Indonesia also concluded that land use/land cover change has a significant impact on the watershed hydrology by affecting the magnitude and pattern of surface runoff, groundwater and soil moisture content. Reference [3] in their study on the hydrological impacts of land cover changes in upper Athi catchment also observed that changes in land use/land cover led to a general increase in runoff depths and peak flows associated to increase in agricultural and built-up areas.

Study results by [47] who assessed the impacts of land use changes on the hydrology of a lowland rainforest catchment in Ghana indicated that peak and dry season streamflow between 1990 and 2011 have increased by 21% and 37% respectively under the current land use in comparison with the baseline due to a decrease in evergreen and secondary forests by 18% and 39%. Reference [48] also observed that a decline in tree plantation by 9.4% and forest by 1.2% and an increase in farmland by 8.7% and shrubland by 1.2% led to an increase of streamflow by 3%. Similarly, [49] observed that land use trends between the year 2000 and 2013 show that bare lands, urban areas, water bodies, agricultural lands, deciduous forests and evergreen forests have increased respectively by 67.06%, 33.22%, 7.62%, 29.66%, 60.18% and 38.38% while only grassland decreased by 44.54% within that period. This land use/land cover change led to an increase in surface runoff and lateral runoff by 27% and 19% respectively while ground water recharge decreased by 6%.

Moreover, [50] while simulating land use change scenarios using SWAT model indicated that runoff volume increased by 3% and 14% when 50% of pasture and grasslands are converted to agriculture and also increase by 15% and 32% when the entire sub-watershed is converted to agricultural land. From their modeling, [51] concluded that clearing of forests generated an increase in runoff to approximately 40%. Reference [52] in their study in the Muchison Bay in Uganda, noted that surface runoff increased from 101mm/yr to 128mm/yr (26.7% increase) when the forestland declined from 31.15% to 13.91% and built-up areas increased from 26.53 to 39.09%. Reduction in forest cover and rangeland resulted to an increase in surface runoff and decrease in baseflow or groundwater recharge [14,53,54].

Reference [55] in their study concluded that land use change especially agricultural area affects runoff. They observed that from 1980 to 2008, forest area declined from 28.01% to 17.94% while agricultural area, urban area and water resources increased from 63.92%, 7.47% and 0.61% to 69.72%, 10.14% and 2.19% respectively. Other results showed that urban area has increased during the last 11 years (2002-2013) resulting to 5-40% increase in surface runoff [56]. Land use/land cover analysis revealed that there was considerable increase in the built-up area and barren lands at the expense of forest and other dense vegetations, leading to an increasing pattern of peak flow and decreasing pattern of low flow values [57]. Since 1980's, land use in the Dongjiang basin have experienced significant change with a prominent increase in urban areas, a moderate increase in farmlands and a great decrease in forest area overall, runoff change was contributed half and half by climate change and human activities respectively, in which 20%-30% change was contributed by land use change [58].

According to [59], land use change resulted in the decrease of 4×106m3 of yearly groundwater recharge in their study area, with a spatially averaged rate of 100.48mm/yr and 98.41 mm/yr in 1980 and 2005 respectively While [60] observed that increase of settlement directly led to decrease in groundwater level. Reference [61] in their study assessed the effects of land use/land cover on runoff characteristics of two watersheds in Kerara, India and found a reduction in forest area amounted to 60% and 32%. Changes in the surface runoff of these watersheds were not comparable with the changes but were within 20%. Maximum (peak) value of runoff increased by 15% and this could be due to the fact that forest had been converted to agricultural purpose with major proportions as plantations which have comparatively similar characteristics of the forest.

Reference [62] in his findings concludes that land use change is the main driver of the change in streamflow accounting for about 97.5% of the change. Forest removal and conversion to cropland agriculture caused the increase in streamflow due to reduced water use of crops as compared to forests. While modeling the effects of historical and future land cover changes on the hydrology of the Amazonian Basin [63] concluded that increased deforestation will intensify floods and low flow events. On the contrary, a study by [64] showed that two-thirds of the annual streamflow decreased and the change in streamflow was different among different types of land use. However, overall, 30-year averages of the streamflow decreased on agricultural land but increased in forest areas.

5. Conclusions and Recommendations

An increase in built-up areas, perennial farming and annual crops by 1.83%, 10.9% and15.05% respectively and a decline in forestland, shrubland and grassland by 10.06%, 11.92% and 6.21% respectively between 1984 and 2017 led to a change in the quantity of discharge in River Ruiru watershed. Surface runoff greatly increased from 30.25mm/yr to 181.25mm/yr. This increase could have been attributed to the reduction of the forest cover, grassland and shrubland and increase in built-up areas in the area leading to reduced infiltration and high surface runoff. This could be the course of floods in some areas of the watershed.

There is therefore a need to develop strategies for sustainable water and environmental resources in the watershed. Water and land use planners need to consider future possible response of hydrological processes to land use/land cover change by carrying out integrated water and land use management. Remedial actions to address the effects of land use/land cover change on discharge are required both by the county and the national governments These may include site selection for different activities such as agriculture, urban, industrial and residential and commercial development. In addition these development activities must be integrated with water resource considerations and watershed protection.

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