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Modelling Surface Water Potential of Somodo Watershed Using SWAT Model

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Abstract: Despite increased worldwide water demand, freshwater availability is decreasing as a result of population expansion, industrialization, land use, and climate change. As a result, in order to provide strategic information for long-term water security planning, it is required to quantify the water resources potential. The objective of this study was to determine the surface water potential of the Somodo watershed. GPS, GIS, Arc SWAT, and SWAT-CUP software were all utilized to collect data. Secondary data, such as DEM, land use/land cover maps, soil maps, stream flow, and meteorological data, were collected from appropriate institutions. We investigated the model's sensitivity, calibration, and validation. According to the findings, surface runoff and base flow were the most sensitive parameters of stream flow in the Somodo watershed. The statistical results for model performance revealed a very good agreement (R^2 of 0.795 and NSE of 0.68) between the simulated and observed flow for calibration, and a very good agreement (R^2 of 0.821 and NSE of 0.7) between the observed and simulated stream flow for validation. The catchment, with a total watershed area of 19860 hectares, generated 56.75 million cubic meter (MCM) surface runoff per year, according to the model. The watershed's surface water potential of 56.75 MCM is sufficient to meet a variety of water demands.

Keywords: Arc SWAT, Model, Somodo, Water Balance, Water Potential

1. Introduction

As a result of population growth, industrialization, land use changes, and climate change, freshwater supply is predicted to decrease in many areas [1]. Unfortunately, the world's water demand is growing [2]. Climate change, which is a result of the greenhouse effect, has a huge impact on freshwater availability and is merely one of the present water resource constraints [3]. On the other hand, rapid population increase, urbanization, and industrialisation have had a significant impact on the hydrological cycle [4-6]. As the world's population expands, it becomes more challenging to provide clean water in megacities in developing countries [7]. Quantifying the water resources of a watershed is essential for providing the strategic information needed for long-term planning of water security.

Conventional water resources planning and management have mostly been based on blue water resources, which serve the needs of engineers who are responsible for coping with infrastructure projects for water supply [8]. Blue water is known that the sum of river discharge and deep groundwater recharge. Green water, however, is differentiated according to Falkenmark et al. [9] as green-water resources and green-water flows. According to their definition, green water resource is the moisture in the soil. This is the renewable part that can potentially generate economic returns and the source of rainfed agriculture. Green-water flow, however is the actual evaporation (the non productive part) and the actual transpiration (the productive part), commonly referred together as the actual evapotranspiration [10]. Thus, it is vital to study the blue and green water potential for effective water resources planning and management.

Water resources development, integrated water resources management, and water resources utilization are the best options and are recognized as a tool for sustainable economic growth, poverty reduction, and water-related conflict management in developing countries [11, 12]. Most commonly, land and water, which are the major assets for the majority of rural people who depend on agriculture and livestock production for their livelihood, require effective management.

Irrigation development is also necessary for sustainable and reliable agricultural development in Ethiopia by meeting the demands of food security and poverty reduction [13]. These sustainable developments will be ensured by assessment of the potential of available resources and designing the best utilization mechanisms at a watershed level.

The Somodo watershed, which is a tributary of the Abay River basin, is a high-potential area suitable for the cultivation of coffee (Coffea arabica L.). Even though it is a high potential area for the cultivation of coffee, there are other activities in the watershed that demand water that drains from the watershed, mainly domestic water supply, livestock consumption, and irrigation for the cultivation of vegetable crops. Though there were the above-mentioned different water demands in the watershed, their quantity was not determined by the current and future demands. Local farmers in the watershed use irrigation for coffee and vegetable crop production, but they never realize the exact quantity of irrigation water, rather they apply water by physical observation. For water resources management, it is better to begin with the available quantity of water. Therefore, this study was initiated with the objective of assessing the surface water resources potential of the Somodo watershed.

2. Materials and Methods

2.1. Description of the Study Area

The Somodo watershed is one of the major coffee producing areas in the Manna district of the Jimma Zone, which is located 368km South-West of Addis Ababa and 15km West of Jimma town. It is 5 km from the main road from Jimma to Gambella and 20 km from the district center of Yebu town. The climate is weyna dega and very favorable for crop production and animal and human health. It is geographically located between 7°46′00″-7°47′00″N latitude and 36°47′00″-36°48′00″E longitude and the altitude ranges between 1900-2050 meters above mean sea level. The minimum and maximum temperatures of the watershed are 13°C and 25°C, respectively, and the average annual rainfall is 1500mm. Nitosols and Orthic Acrisols are the dominant soil types with a slightly acidic PH, which is suitable for coffee and fruit production.

2.2. Materials

The materials used for conducting the study were the GPS, GIS, SWAT, and SWAT-CUP software.

GPS was used to collect the geographic information of the study area and to select the outlet of the watershed. The coordinate which was recorded using GPS was also used to delineate the watershed from the DEM, which was used as an input data for further use in SWAT model. SWAT was used to simulate the quantity of surface water in the watershed. SWAT-CUP software was used for calibration and validation of the SWAT model.

2.3. Data Collection and Sources of Data

The following secondary data was used for conducting the study, namely DEM, land cover map, land use map, soil map, stream flow and meteorological data as shown in Table 1.

Table 1. *Collected data and their source.*

No	Data	Source	Scale/period	Purpose
1	DEM	MoWIE	30x30	For SWAT model
2	Land use/Land cover map	MoWIE	2014	Land use/cover classification
3	Soil map	MoWIE	2014	Soil classification
4	Meteorological	NMSA	1997-2016	Weather data
5	Stream flow	MoWIE	2011-2016	For calibration/validation

2.4. Methodology

The missing values were filled using the excel stat software before applying the meteorological and stream flow data. The long-term meteorological data, namely precipitation, maximum and minimum temperatures, wind speed, solar radiation, and relative humidity, were then generated in a SWAT-compatible format, as well as stream flow data for use by SWAT-CUP software.

The SWAT model was built up to delineate the watershed into multiple hydrologically related sub-watersheds for watershed delination. This was accomplished by extracting the predicted DEM from the DEM of the Abay Riber basin using GIS and loading it into Arc SWAT for further analysis. The non-draining zones were removed from the grid DEM map. The drainage area thresh hold approach was used to establish the stream network and sub-basin outlets. The threshold area is the smallest drainage area required to produce a stream's genesis. A minimum, maximum, and proposed threshold area are listed on the interface. Based on the lowest analytic distance, a 2500 ha threshold area was employed in this investigation.

The delineated watershed's hydraulic response unit (HRU) was constructed using the Land use/land cover, soil, and slope map, followed by HRU definition. The SWAT model was run after the metrological data, such as rain fall, maximum and minimum temperatures, relative humidity, solar radiation, and wind speed, was organized daily in ASCI-format as per the SWAT model's requirements, and the simulation was completed.

The soil water content of the delineated watershed was analyzed by using

$$SW_t = SW_o + \sum_{i=1}^{t} (R_{day} - Q_{sur} - E_a - W_{seep} - Q_{gw}) \quad (1)$$

Where: SWt -is the final soil water content (mm),

SW_o -the initial soil water content,

R_{day}- the amount of precipitation,

Q_{sur}- the amount of surface runoff,

E_a-the amount of evapotranspiration,

W_{seep}- the amount of water entering the vadose zone from the soil profile and

Q_{gw}- the amount of return flow on day i (mm), and t - is time (days).

The model sensitivity analysis, calibration, and validation were used to assess the model's performance for the specified watershed. Stream flow recorded data from a stream gauging station was used to calibrate and validate the system. To calibrate and validate the model employing flow sensitive parameters, the determination coefficient R^2 and NSE (Nasch cliff simulation efficiency) were utilized as objective functions. SWAT-(SUFI-2) CUP's technique was used to calibrate and validate the model.

3. Result and Discussion

3.1. Sensitivity Analysis of the Model

Surface runoff and base flow were the most sensitive parameters of the stream flow in Somodo watershed. The most sensitive parameters when calibrating the model were curve number (CN2), base flow alpha factor (ALPHA_BF), ground water delay (GW_DELAY), ground water “revap” coefficient (GW_REVAP), initial depth of water in the shallow aquifer (SHALLST), threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN), irrigation efficiency (IRR_EFF), effective hydraulic conductivity in main channel alluvium (CH_K2), manning's "n" value for the main channel (CH_N2), base flow alpha factor for bank storage (ALPHA_BNK), soil evaporation compensation factor (ESCO), saturated hydraulic conductivity (SOL_K), moist bulk density (SOL_BD) and snowfall temperature (SFTMP).

Similarly Duguma [14] also estimated the following sensitive parameters for modelling Abay river basin a case study in Dedessa sub-basin and get the sensitive parameters mainly curve number (CN2), available water capacity (SOL_AWC), saturated hydraulic conductivity (SOL_K), ground water re evaporation coefficient (GW_REVAP), threshold water depth in the shallow aquifer for flow (GWQMN), and base flow alpha factor (ALPHA_BF).

Cuceloglu et al. [15] also obtained similar sensitive parameters for determining the surface water resources potential of Istanbul, namely; r_CN2.mgt, r_OL_AWC (…).sol, r_ESCO.hru, r_GW_REVAP.gw, r_GWQMN.gw, r_REVAPMN.gw, r_ALPHA_BF.gw, r_SOL_K (…).sol and r_SOL_BD (…).sol.

The sensitivity given were estimates of the average changes in the objective function resulting from changes in each parameter while other parameters are changing. This gives relative sensitivities based on linear approximations and provides partial information about the sensitivity of the objective function to model parameters.

3.2. Calibration and Validation

The statistical results for the model performance displayed satisfactory (R^2 of 0.795 and NSE of 0.68) between the simulated and observed flow, respectively for calibration. However, the simulated stream flow was higher than the corresponding observed values during periods with high rainfall.

During the validation period, the observed and simulated monthly stream flow nearly matched for the most part, with the exception of a few high-flow occasions where the model under-estimated the flow. The statistical analysis findings indicated very strong agreement between the observed and simulated stream flow, with an R^2 value of 0.821 and an NSE value of 0.7 for validation. Despite the statistical study yielding outstanding results for both calibration and validation periods, SWAT tended to overestimate stream flow during high-flow periods and underestimate it during low-flow periods.

This could be because the present curve number technique was unable to create trustworthy stream flow forecasts for a stormy day. When several storms occur on the same day, the soil moisture level and the accompanying stream flow curve number fluctuate from storm to storm. However, because SCS-CN techniques assume a rainfall event to be the sum of all rainfall that falls on a single day, runoff may be underestimated. The previous results showed that both calibration and validation performed well, with R^2 and NSE values of 0.795, and 0.68 for calibration and 0.821, and 0.7 for validation, respectively. As a result, the SWAT model may be implemented in the Somodo watershed.

3.3. Water Balance and Surface Water Potential

Important model performance indicators of the water balance for correct representation of flow are evapotranspiration (ET) and soil water content (SWC) through infiltration (lateral, groundwater flow) and surface run-off. As evapotranspiration is a function of crop (tree) growth, only a proper simulation of crop growth and management can ensure realistic modelling of evapotranspiration within a river catchment. Evapotranspiration is a primary mechanism by which water is removed from the catchment. It depends on air temperature and soil water content. The higher the temperature, the higher the potential evapotranspiration (PET) and consequently, evapotranspiration, if there is enough water in the soil.

After running (simulating) the SWAT model, calibrating the result with the gauged stream flow data, validating from and checking the R^2, NSE and p-test, the following result was obtained. The surface water runoff depth of the watershed was 285.78 mm, rainfall was 1556.3mm and lateral soil flow was 47.65mm annually (table 3). From a total watershed area of 19860 ha, a total of 56.75MCM surface runoff was generated by the model from the catchment annually. The watershed has a maximum runoff volume of 11.23 MCM and a minimum runoff of 0.502 MCM in August and December, respectively.

The contribution of the water balance during 'Kiremit' season (June, July, August and September) is high with a total surface runoff of 203.85mm depth, rainfall of 907.14mm, and lateral soil flow of 29.82mm. From this result 58.28% of the rain fall contribution is during 'Kiremit' season. The water balance is low during 'Bega' season (October, November, December, and January) with a total surface runoff depth of 44.58mm, rainfall of 258.5mm, and lateral soil flow of 10.81mm. The water balance during the 'Belg' season (February, March, April and May) the contribution is relatively higher than 'Bega' season with a total surface runoff of depth 37.33mm, rainfall of 390.5mm, and lateral soil flow of 7.01mm (table 2).

Table 2. *Average monthly water balance values of the watershed.*

No	Month	Rainfall (mm)	Surface discharge (mm)	LAT discharge (mm)	Water yield (mm)	ET (mm)	PET (mm)
1	January	31.87	3.10	0.68	14.60	30.85	114.83
2	February	39.34	2.90	0.63	5.96	38.84	118.30
3	March	93.33	8.26	1.43	11.47	101.83	128.02
4	April	115.43	11.48	2.02	16.12	96.71	122.69
5	May	142.20	14.69	2.93	21.40	81.07	122.16
6	June	225.0.1	49.89	5.85	70.42	68.19	108.48
7	July	235.34	52.26	7.93	106.56	65.37	92.36
8	August	236.36	56.46	8.24	139.97	66.31	93.30
9	September	210.33	45.24	7.80	140.84	73.68	107.23
10	October	151.21	30.72	6.24	124.70	68.78	117.15
11	November	47.63	8.23	2.72	74.67	39.14	109.21
12	December	27.64	2.53	1.17	38.16	33.42	110.15

Table 3. *Average annual water balance values of the watershed.*

No	Water balance	Depth (mm)
1	Precipitation	1556.3
2	Surface runoff (Q)	285.78
3	Lateral soil (Q)	47.65
4	Total water yield	764.87
5	Evapotranspiration	764.5
6	Potential evapotranspiration	1344.8
7	Return flow	408.94
8	Recharge to deep aquifer	22.94
9	Percolation to shallow aquifer	458.77
10	Re-evaporation from shallow aquifer	26.9

4. Conclusion and Recommendation

4.1. Conclusion

Estimating the runoff potential of a watershed is important for water resources planning. The runoff was estimated by simulating a distributed SWAT hydrological model that requires soil, land use/land cover, topographic slope and metrological data as basic inputs. After correcting and simulating the SWAT model using meteorological data for a period of 20 years from 1997-2016, the DEM of the Abay river basin, soil and land use/land cover map of the study area, checking of the sensitivity analysis, calibration and validation of the model using stream flow, the surface water potential of the watershed was 56.75 million cubic meter (MCM) annually from a total area of 19860 ha.

4.2. Recommendation

Even though in deep study of the surface water potential of the watershed was studied the following works need a further investigation.

a) The study assessed surface water resources only, so groundwater availability of the watershed should be studied and supply enhancement and demand management options can be considered to balance future water resources and demands.
b) Construction of soil and water conservation structures, wise management of the grazing land and construction of water harvesting structures at the upstream of the watershed is recommended to increase the water potential and to use the water during the dry period respectively.

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