# SURFACE WATER POTENTIAL ASSESSMENT OF WABISHEBELE BASIN, ETHIOPIA

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**Abstract**
*The objective of this study was to quantify the surface water resource potential of Wabishebele River Basin using soil and water assessment tool (SWAT). The SWAT model was successfully calibrated and validated for measured stream flow at Gode gauging station. Flow calibration gives coefficient of determination (R2) and Nash-Sutcliffe simulation efficiency (ENS) of 0.70 and 0.82 respectively. Flow validation gives 0.70 and 0.87 for R2 and ENS values respectively. Model performance evaluation statistics (R2 and ENS) values were in the acceptable range. Therefore, the SWAT model yields average annual runoff of 3.67 Billion m3 at Gode stream gauging station.*

**Keywords:** Calibration, surface water, SWAT, validation, Wabishebele basin;

## 1. INTRODUCTION

Water, like the air we breathe, is a basic requirement for all life on Earth. It is vital for many aspects of economic and social development, e.g., for energy production, agriculture, domestic and industrial water supply, and it is a critical component of the global environment. There is growing awareness that development, including development of water resources, must be sustainable, which implies that the world's natural resources must be managed and conserved in such a way that meeting the needs of present and future generations.

Water is the most complex natural resource correlating its availability from the atmosphere to lithosphere through hydrosphere. The availability of water is highly uneven in space and time. Improper assessment of water resources is potentially disastrous (Fekadu, 1999). For instance, under estimation of flood can lead to overtopping of dam and consequent failure of its structure. On the other hand, for projects where water potential is overestimated, the system may not come to a position to fill up to the full reservoir level.

Water-resources information is useful for regional and national assessments of water availability. Therefore, collection and analysis of long term hydrological and meteorological data like rainfall, runoff, infiltration characteristics,temperature, humidity, wind-speed and others for the area are essential.

A systematic assessment of water resources availability with high spatial and temporal resolution is essential in basin for strategic decision-making on water resource related development projects. Hence, a comprehensive understanding of hydrological processes in the watershed is a pre requisite for successful water management and environmental restoration.

Wabishebele River Basin is the largest basin in Ethiopia' with low water resources' potential, very little of which has been developed for agriculture, hydro power, industry, water supply and other purposes. Apparently, there has not been any in-depth study done to address surface water potential in the basin with up-to-dated information and suitable methods. River flow data are limited to the upstream and rarely available to downstream part of the basin as there are no evenly distributed hydrometric stations, large areas lack gauging stations, and only a few years of data are available.

The basin water resources are under pressure by increasing population, new infrastructure and new large scale irrigation projects development. Therefore, determination of the surface water potential of the basin is fundamental to sustainable water allocation and conflict management (Adane, 2009).

The general objective of this study was to come up with better estimates of available surface water which are key tools to sustainable water management.

In the Wabishebele River Basin, Integrated Master Plan Study carried out over years with different Phases. In the master plan the total mean annual flow from the river basins is estimated at about 3.49 BMC.

Many studies have successfully applied the SWAT model in Ethiopia, on different river basins.

Examples include, among others: calibration of the SWAT model on the Nile basin, the Awash basin and the Omo gibe Basin. However there are no published works on the application of the SWAT model on the Wbishebele River Basin.

## 2. METHODOLOGY

### 2.1. Study Area Descriptions

Wabishebele river basin is situated between 4045'N to 9045'N latitude and 38°45'E to 45°30'E longitude. Wabishebele river basin has an area of 188,320 square kilometer, covering parts of the. Somalia, Oromia, Harari and a small area at the source of the Wabi River in South Nations Nationalities and Peoples (SNNPE)

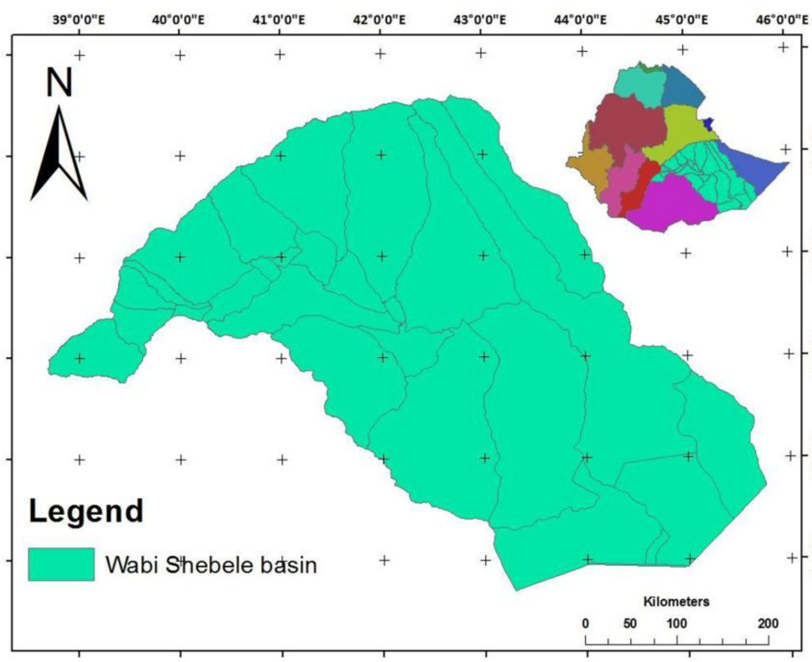


**Figure 1:** Location map of Wabishebele Basin, Ethiopia

## 2.2. Method

Meteorological, hydrological and spatial data were prepared as per the requirement of the model and SWAT model application was followed with calibration and validation after re-adjusting the model parameter at sub catchment. The model computes the surface flow of the Wabishebele River Basin.

The Soil and Water Assessment Tool (SWAT) model (Neitsch, 2005) is a distributed parameter and continuous time simulation model. The SWAT model has been developed to predict the response to natural inputs as well as the manmade interventions on water and sediment yields in un-gauged catchments (SCS, 1972). The SWAT model is a long-term, continuous model for watershed simulation. It operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields. Major model components include weather, hydrology, soil temperature, plant growth, nutrients, pesticides, and land management. The model has been validated for several watersheds. In SWAT, a watershed is divided into multiple sub-watersheds, which are then further subdivided into unique soil/land-use characteristics called hydrologic response units (HRUs). The water balance of each HRU in SWAT is represented by four storage volumes: snow, soil profile, shallow aquifer and deep aquifer. Flow generation, sediment yield, and non-point-source loadings from each HRU in a sub watershed are summed, and the resulting loads are routed through channels, ponds, and or reservoirs to the watershed outlet.

Thus, the lumped conceptual model selected for use in this study is SWAT 2005. It is chosen because it suits the interfaces of Arc GIS 9.3, which is not difficult for the classification of spatial data, the most versatile and ease of use

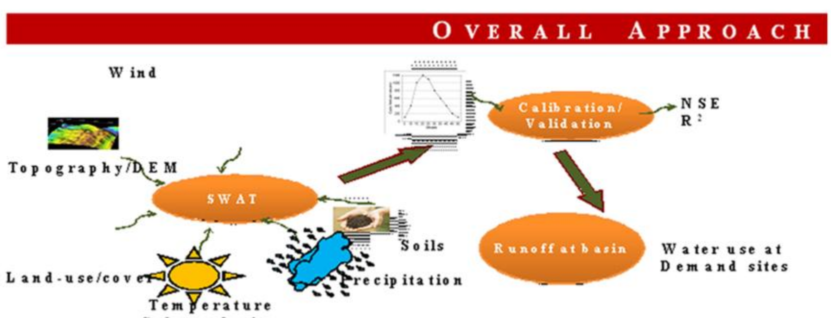


Figure 2: Conceptual frame works

### *2.2.1. Input data/database*

Data was collected from various sources Ministry of water, Irrigation & Electricity, Ethiopian Mapping agency, National Meteorological agency and some literature. The following basic primary and secondary data sets were necessary for the modeling work: Meteorological (rainfall, temperature, relative humidity and solar radiation), hydrological data and spatial data (topographic map, soil, land use/cover, digital model (DEM)) and were prepared as per the requirement of the model.

### *2.2.2. Swat Model parameterization*

#### *Watershed delineation*

The watershed delineation interface in Arc-View is separated into live sections including model Set Up, Stream Definition, Outlet and Inlet Definition, Watershed Outlet(s) Selection and Definition and Calculation of Sub basin parameters. In order to delineate the networks sub basins, a critical threshold value is required to define the minimum drainage area required to form the origin of a stream.

After the initial sub basin delineation, the generated stream network can be edited and refined by the inclusion an outlet. Adding an outlet at the location of established monitoring stations is useful for the comparison of flow concentrations between the predicted and observed data. Therefore, one sub basin outlet was manually edited into the watershed based on known stream gage location that had sufficient stream flow data available from 1976-2005.

#### Hydrologic response unit definition

Hydrologic response units (HRUs) are lumped land areas within the sub - basin that comprised of unique land cover, soil and management combinations. HRUs enable the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers and soils. The runoff was estimated separately for each HRU and routed to obtain the total runoff for the watershed. This increases the accuracy of inflow prediction and provides a much better physical description of the water balance, the land use and the soil data in a projected shape file format. These shape files were loaded into the SWAT interface to determine the area and hydrologic parameters of each land-soil category simulated within each sub-watershed. The land cover classes were defined using the look up table. A look-up table that identifies the 4-letter SWAT code for the different categories of land cover/land use was prepared so as to relate the grid values to SWAT land cover/land use classes. After the land use SWAT code was assigned to all map categories, calculation of the area covered by each land use and reclassification were done. As for the land use, the soil layer in the map was linked to the user soil data base information by loading the soil look-up table and reclassification was applied for it. The DEM data used during the watershed delineation was also used for slope

**Weather data definition**

Available meteorological records (i.e. precipitation, relative humidity, minimum and maximum temperature, solar radiation and wind speed) and locations of meteorological station were prepared based on SWAT CN table format The applicability of the model for intended purpose should be evaluated through the process of sensitivity analysis, calibration and validation (White and Chaubey, 2005) for further analysis of the result. After the model setup has been completed, the model was run and the simulation result was analyzed.

Sensitivity analysis evaluates the influence of different parameters on simulation result, the response of output variable to a change in input parameter (White and Chaubey, 2005) Sensitivity analyses were conducted using the entire flow parameters. In this research, model sensitivity and calibration were performed using the output of SWA T-CN method. A SWAT model was calibrated and validated on a monthly basis to estimate the flow using a time series dataset of 10 years from 1990 to 2000 and only a

classification. After the reclassification of the land use, soil overlay operation was performed. The second step in the HRU analysis was the HRU definition. The HRU distribution in this study was determined by assigning multiple HRU to each sub-watershed. In multiple HRU-definition, a threshold level was used to eliminate minor land uses, soil or slope classes in each sub – basin. Land uses, or soils which cover less than the threshold level were eliminated. Soil was reapportioned so that 99.93% of the land area in the sub- basin is modeled. The threshold levels set is a function of the project goal and amount of detail required and integrated with the model using weather data input wizards. Gode meteorological station data were used as weather generator.

### 2.2.3. Sensitive analysis, calibration and validation

few years of data are available. The first year of the modeling period was used for model "warm-up". Data for the period 1991 to 1996 were used for calibration and the remaining part of the dataset was reserved for validation. The watershed was subdivided into 15 sub basins based on a chosen threshold area of 700,000 ha. The overlay of land use, soil and slope maps resulted in the definition of 270 HRUs. The simulated stream flow at the outlet of the watershed gauging station was compared with the observed stream flow.

Stream flows, measured at Gode stream gauges were used for calibrating and validating the model. This stream gauge is not affected by reservoirs, diversions, or return flows that is why it was selected for model calibration and validation.

## 3. Results and Discussion

### 3.1. Stream flow calibration and validation

Model calibration involves adjustment of parameter values of models to reproduce the observed response of the Wabishebele basin within the range of accuracy specified in the performance criteria. After the sensitive parameters were identified using sensitivity analyses, a combination of manual and automatic calibration method were used to calibrate the model using the observed monthly stream flow for a flow calibration period (1991-1996). Calibration resulted in Nash-Sutt cliffe simulation efficiency (ENS) of 0.81 and correlation coefficient (R2) of 0.70 showing a good agreement between measured and simulated monthly flows. The result has shown in table below also indicated that model was calibrated satisfactorily to simulate monthly stream flows adequately. The calibration result demonstrates the SWAT's ability to predict steam flow.

Some stream flow events are still not completely represented by the calibrated modeled. This may be due to inaccurate representation of the spatial distribution of precipitation within the watershed by the available rain gages used as model input.

**Table 1: Calibrated and default SWAT parameter value**

| No. | Parameter | Description | Initial value | Calibrated value |
|---|---|---|---|---|
| 1 | Alpha_Bf | Baseflow alpha factor | 0.00 | 0.00 |
| 2 | Biomix | Biomass | 0.20 | 0.20 |
| 3 | Ch_K2 | Effective hydraulic conductivity in main channel alluvium | 0.00 | 0.00 |
| 4 | Cn2 | Moisture Condition of Curve Number | 94.00 | 57.00 |
| 5 | Epco | Plant uptake Compensation Factor | 0.00 | 0.00 |
| 6 | Esco | Soil Evaporation Compensation Factor | 0.90 | 0.31 |
| 7 | Gw_Delay | Groundwater Delay | 31.00 | 31.00 |
| 8 | Gw_Revap | Groundwater Reavap Coefficient | 0.02 | 0.02 |
| 9 | Gwqmn | Threshold Water Depth in the Shallow Aquifer for Flow | 0.00 | 5000.00 |
| 10 | Revapmn | Water in shallow aquifer | 1.00 | 1.00 |
| 11 | Sol_Alb | Soil albedo | 0.13 | 0.13 |
| 12 | Sol_Awc | Available Water Capacity of the soil layer | 0.15 | 0.10 |

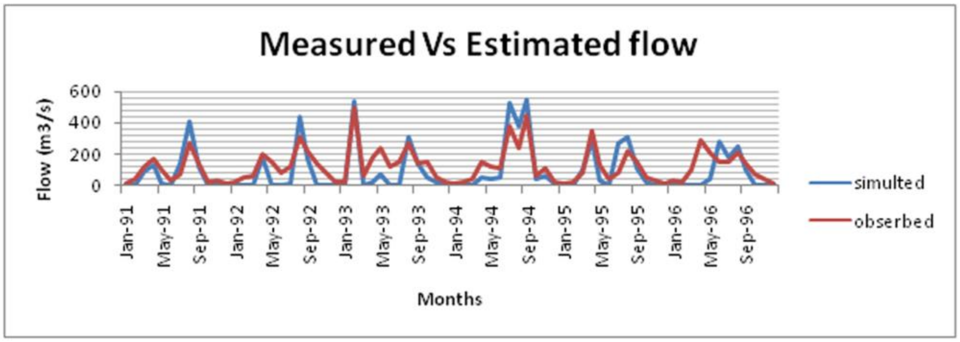


**Figure 3**: Monthly Measured Vs Estimated flow

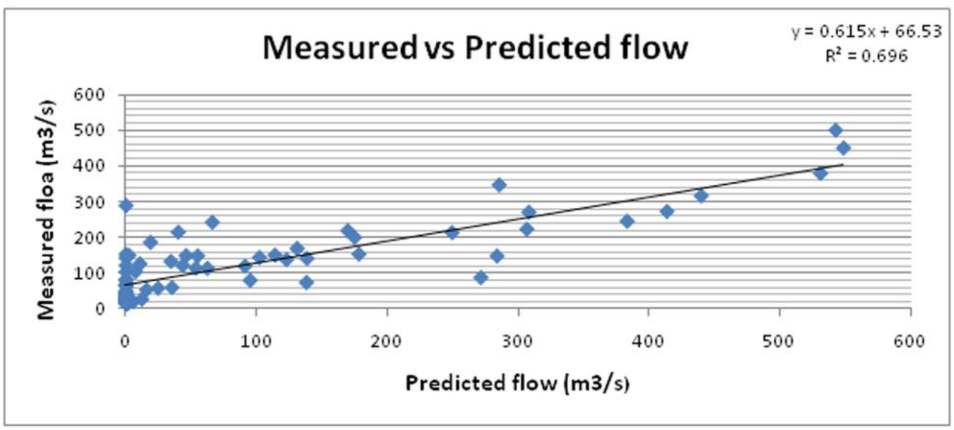


**Figure 4**: Monthly measured vs. estimated flow, calibration

In order to utilize any predictive watershed model for estimating the effectiveness of future potential management practices the model must be first calibrated to measured data and should then be tested (without further parameter adjustment) against an independent set of measured data. This testing of a model on an independent data set is commonly referred to as model validation. Model calibration determines the best or at least a reasonable, parameter set while validation ensures that the calibrated parameters set perform reasonably well under an independent data set. Provided the model predictive capability is demonstrated as being reasonable in both the calibration and validation phase. The model can be used with some confidence for future predictions under somewhat different management scenarios (Kassa, 2009)

Calibrated parameters were validated for the period of (1997-2000) and the model results are then compared with observed stream flow values measured at Gode gauging station

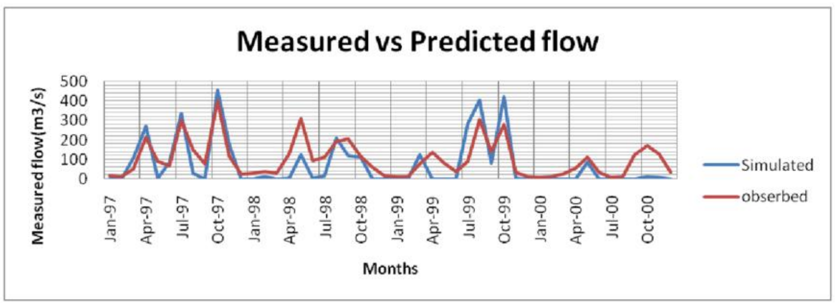


**Figure 5:** Monthly measured vs. estimated flow, validation

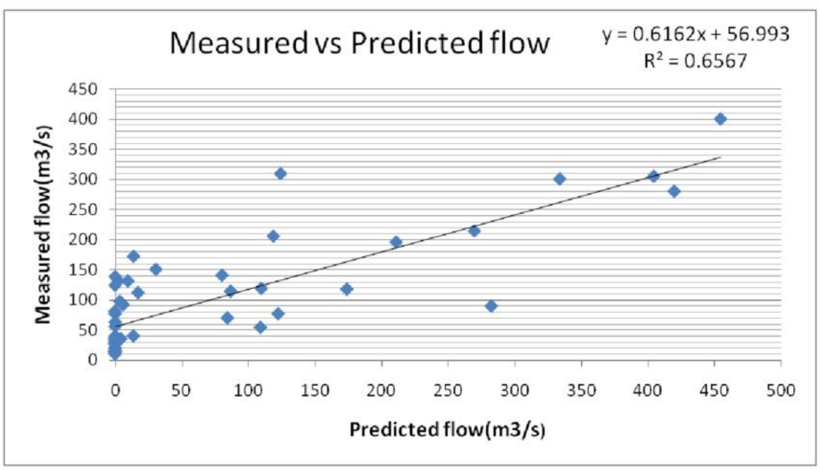


**Figure 6:** Measured Vs Predicted flow

### 3.2. Output of the model/stream flow simulation

After compiling all data, several simulations were carried out. The model computes the surface flow of the Wabishebele River Basin, the flow rate, the pick runoff rate, potential and actual evapo-transpirations, and water yield, some of the simulated parameters were compared with their corresponding measurements available in the existing master plan of Wabishebele River Basin.

**Table 2:** Comparison between model annual output and previous study in the master plan

| Parameters | Own result | Previous result | Remark |
|---|---|---|---|
| Surface runoff($BM^3$) | 3.765 | 3.49 | |
| Rainfall(mm) | 468.1 | 425 | |
| Actual evapo-transpiration(mm) | 374.2 | | |
| Potential evapo-transpiration(mm) | 1503.1 | 1500 | |
| Water yield ($BM^3$) | 3.154 | | |
| Area ($km^2$) | 188818.89 | 200000 | |

Water yield (mm H2O) is the net amount of water that leaves the sub basin and contributes to stream flow reach during the time step. Surface runoff contribution to stream flow during time step (mm H2O) for each sub basin spatially clearly shown in the following figure.

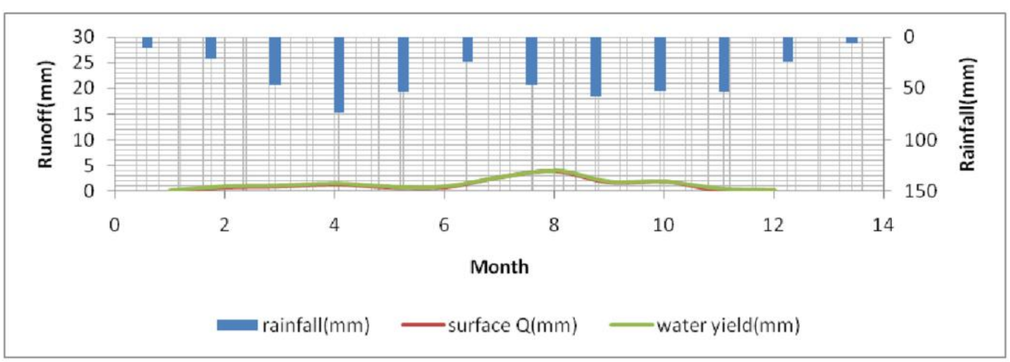


**Figure 7:** Monthly rainfall, runoff and water yield of the basin

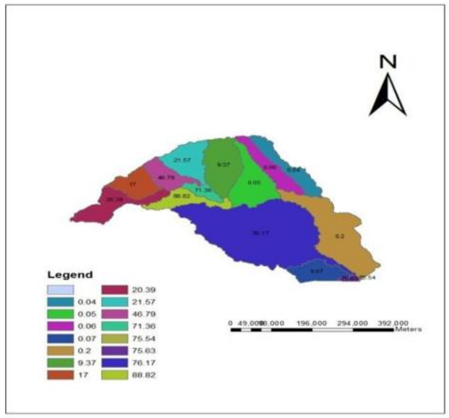


**Figure 8:** Surface runoff results for each sub basin

**4. Conclusions and Recommendations**

Sensitivity analysis is performed to select important model parameters. Both manual and automatic calibration was performed for stream flow using measured data at Gode gauging station for a period of 1991 -1996. The result has shown that the model performed well with ENS and R2 of 0.81and 0.70 respectively. The model was validated for the stream flow for the period of 1997-2000. The model performed well for monthly time steps with ENS and R2. 0.87 and 0.65 respectively. The simulate basin yield at the gauging station is 3.154 BM3.

In general, the SWAT model performed well in predicting the flow from the study watershed and its simulation results were acceptable. Therefore, it is a capable tool for further analysis of the hydrological responses in the watershed.

The calibrated model can be used for further analysis of surface water potential and to investigate the effect of different management scenarios on stream-flows in the watershed.

Data quality and availability should be stressed much more while using distributed hydrological models. The applications SWAT 2005 models were very challenging and a lack of appropriate data was one of the biggest concerns throughout. Without proper data, model implementation is very difficult.

The use of new data gathering techniques should be envisaged for developing countries so that local and regional authorities can be involved in integrated and coordinated data compilation.

A complete study should also take into consideration of integrating other factors such as existing infrastructure development within Wabishebele basin, industrial growth in the basin, and the groundwater recharge within the basin to produce more realistic water resources / availability scenarios.

Further runoff data from field sized plots for dominant land use / cover types in the watershed may help to characterize and validate generation mechanism as well as for better improvement to the model

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