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Estimation of Water Balance Components for the Watershed of Ghataprabha Sub-Basin

Akshata Bandi H.*† and Nagraj S. Patil**
*Department of Civil Engineering, SDM College of Engineering, Dharwad-580002, Karnataka, India
**Department of Civil Engineering, Visvesvaraya Technological University, Centre for PG studies, Belgaum, Karnataka, India
†Corresponding author: Akshata Bandi H.; akshatabandi9090@gmail.com

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ABSTRACT

Evaluation of hydrological components in the water balance study is important in planning and maintaining a sustainable watershed to understand the hydrology of the river sub-basin/watershed. This study was carried out to estimate the water balance components in the watershed of the Ghataprabha sub-basin using the hydrological model SWAT (Soil and Water Assessment Tool). The river watershed was further delineated into 35 sub-basins comprising 542 hydrological response units (HRUs). A monthly calibration and validation study has been performed. Statistical model performance indicators, coefficient of determination (R^2), and Nash & Sutcliffe (1970) efficiency (NSE) were used to correlate the monthly observed discharge data and monthly simulated discharge data. R^2 of 0.75 and NSE of 0.63 for calibration and 0.7 and 0.65 for validation respectively, indicated the satisfactory performance of the model simulation on monthly simulation of flow. Monthly average water balance components (Precipitation, Evapotranspiration, Stream flow, Water yield) were estimated for the watershed.

INTRODUCTION

The geographical variations, lands use land cover changes, water usage policies and strategies, and climatic variations along with uneven distribution of rainfall with irregular frequency influence the driving mechanism of water resource planning and management, quality and quantity of water body spatially and temporally. The rise in population exerts pressure on the demand for production of more yield, and rising temperature day by day causes an inadequate supply of water for various needs such as irrigation, drinking purposes, domestic usage, manufacturing, and treatment sites. In this respect, it is necessary to quantify the geographical changes and demographical changes spatially and temporally in the study area to understand the hydrology in the watershed to meet the various objectives set to fulfill the need for domestic and commercial purposes and to achieve sustained management of water resource spatially and temporally. The present study made utilization of remotely sensed tools with geographic information system (GIS) techniques for hydrological modeling and water resource assessment with an evaluation of water balance components. Models are classified into three types; empirical, conceptual, and physical models based on the model structure, algorithm, and data availability. Models are also categorized based on the spatial variability of the catchment area which is lumped, semi-distributed, and distributed. The model has to be chosen based on the objective of the study, data availability, and model simplicity (Sitterson et al. 2014). The physically-based hydrological model considers the land use land cover, topography, and management practices spatially and temporally, thus it makes it easy to interpret the effects of various driving factors on the hydrological system in the study area. SWAT is one such a physically-based continuous time scale, a semi-distributed model which has been widely used as a hydrological model to simulate climate change, surface runoff, sediment transportation, and nutrients loading (Arnold et al. 2012, Moriasi et al. 2007, 2012, Neitsch et al. 2002). Many studies have been performed to estimate the average annual and monthly average flows (Erhui et al. 2016, Rederick et al. 2018 Xu et al. 2013).

One of the studies calibrated and validated the hydrological model SWAT using performance indicators and estimated the average annual water balance components and concluded that there was variation in the soil storage and evapotranspiration caused more loss of water from the watershed (Shawul et al. 2013, Gupta et al. 2020). It was found that 57% of precipitation melted into the lake and it was a major cause of expanding the catchment. Glaciers melt for lesser evaporation (Adnan et al. 2019). The researcher carried out a water balancing components study using SWAT and SWAT CUP for hydrological simulation in the Tandula (India) reservoir catchment to overcome the lack of water supply for the paddy growth, which boosts the economy of the people in the area since it was known for the cultivation of paddy and covering 86% of the area of the catchment (Jaiswal et al. 2020). Evaluation of snowmelt in the river was one of the great works to estimate the water balance components at mountain glaciers and 25% was lost as evapotranspiration from the river (Dhami et al. 2018). The objectives of the study were to standardize the SWAT model and to estimate the water balance components for the monsoon season in the watershed of the Ghataprabha sub-basin.

MATERIALS AND METHODS

Study Area

The sub watershed lies between 15°45' to 16°20' N & 74°0' to 75°5' E in the Ghataprabha basin, India (Fig. 1). Common soil types are gravelly sandy clay loam and clay. The area of the watershed is 4717 km^2. The average slope is 22°. The climate in the watershed is typical of a semiarid environment. . Most of the basin receives monsoon rainfall. Rainfall shows high seasonal variability. The average annual precipitation is 633.07 mm.

Datasets

The various types of data to be given as input to the model were digital elevation model (DEM), Soil data, land use/ land cover, and weather data like precipitation, temperature, and discharge data. A 32 m DEM tiles were obtained from the Bhuvan website, India. Land use/ land cover data was obtained from the Arc-SWAT website (Indian dataset for SWAT 2012). Soil data (Soil HWSD FAO (worldwide data)) was derived from the Arc-SWAT website (Indian dataset for SWAT 2012). Weather Data includes Precipitation, Temperature, relative humidity, solar radiation, and wind speed data obtained from the Arc-SWAT website. Daily river discharge data from 1990-to 2011 is collected from the water resource information system (WRIS), India.

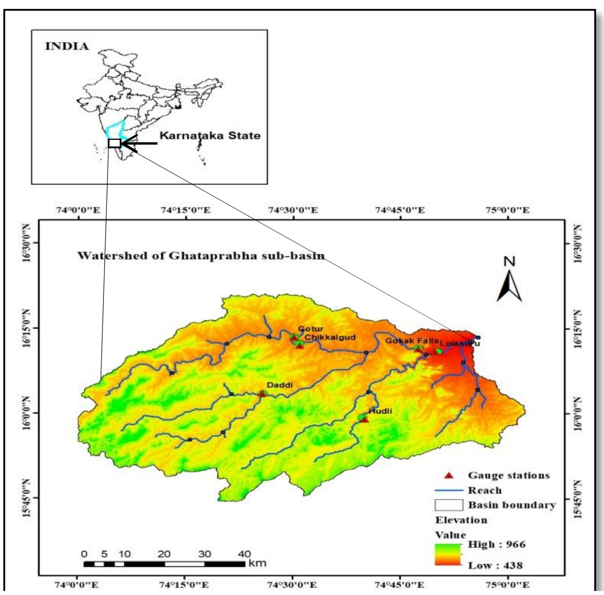

Fig. 1: Study area of the watershed.

Methods

The Soil and Water Assessment Tool (SWAT) was used for hydrological simulation of the flow in the study (Arnold et al. 2012). The model setup involved preparation of data, formation of sub-basin, defining HRUs, analysis of sensitive parameters, calibration, and validation. The river sub-basin was further delineated into 35 sub-basins comprising 542 hydrological response units (HRUs) Using the DEM (Fig. 2(a)). The soil data, land use land cover data, and the meteorological data between 1975 and 2016 were given as input to the model, SWAT model was run to simulate the monthly stream flow from 1990 to 2016. Soil, Land use land cover, and slope maps were prepared (Fig. 2(b), 2(c), 2(d) 2(e)). The simulation period was split as spatially to perform the validation at a different site (Arnold et al. 2012). The calibration period was from 2007 to 2011 for the Lolasuru station and the validation period was from 2007–to 2011 for Hudli. The sensitivity of the parameters was tested by using ArcSWAT during the calibration of the model. The calibrated parameters were used during the validation of the model.

The simulated and observed flow were compared and the model performance was evaluated using R^2 and NSE [12].

$$R^2 = \frac{[\sum_i (O_i - \bar{O})(S_i - \bar{S})]^2}{\sum_i (O_i - \bar{O})^2 \sum_i (S_i - \bar{S})^2} \qquad \ldots(1)$$

$$NSE = 1 - \frac{\sum i\,(O - S)_i^2}{\sum i (O_i - \bar{O})^2} \qquad \ldots(2)$$

Where O_i and S_i are observed flow and simulated flow values in the month i, respectively, $\bar{O}$ and $\bar{S}$ are the average values of observed flow and simulated flow respectively. Model performance was accepted as satisfactory if NSE > 0.55 and R^2 > 0.7 for monthly flow and as good if NSE > 0.7 and R^2 > 0.8 (Moriasi et al. 2015).

RESULTS AND DISCUSSION

The simulated results were compared with observed data as shown in Fig. 3. The simulated flow peaks were not properly matching with observed datasets. The value of R^2 for observed and flow-out discharge from the scattered plot is 0.71 (Fig. 4). Comparatively lesser R^2 indicates the scope for model tuning is available to ensure accurate hydrological data for the study area.

Calibration was done for five years starting from -2007 to 2011 to match simulated results with observed data values. The sensitive parameters were identified and adjusted to obtain better calibration (Fig. 5). This is confirmed by knowing the R^2 and NSE values between observed values and simulated results and must be within the allowable limits. Table 1 shows the adjusted parameters during the calibration of the model.

Table 1: Sensitive parameters and best-fitted values for calibration.

S 1 . No.	Sensitive Parameter	Fitted Value	Min. Value	Max. Value
1	CN2	86	35	98
2	SOL_AWC	0.13	0	1
3	ESCO	1	0	1
4	EPCO	0.95	0	1
5	SURLAG	0.5	0.1	24

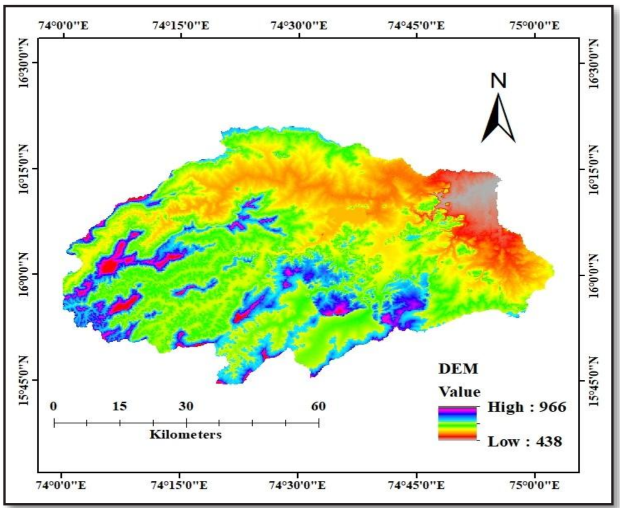

Fig. 2(a): Digital elevation map.

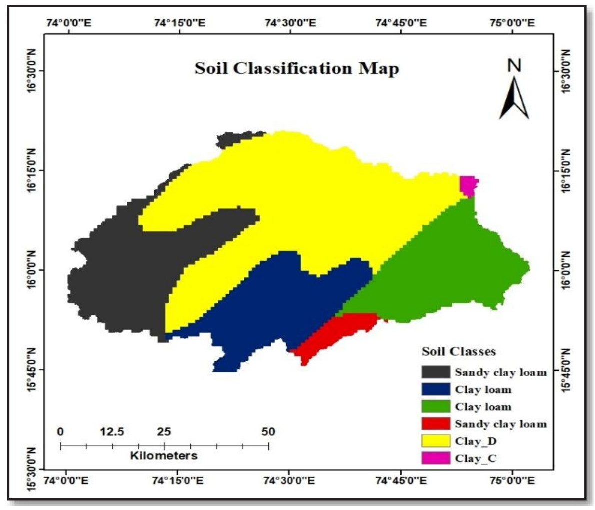

Fig. 2(b): Soil classification map.

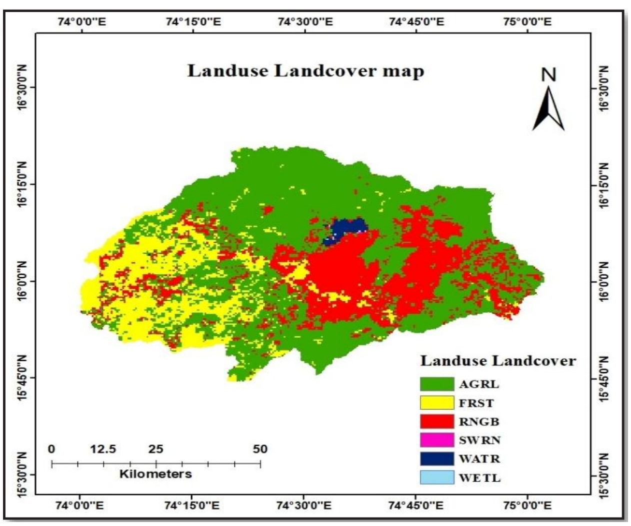

Fig. 2(c): Land use the land cover map.

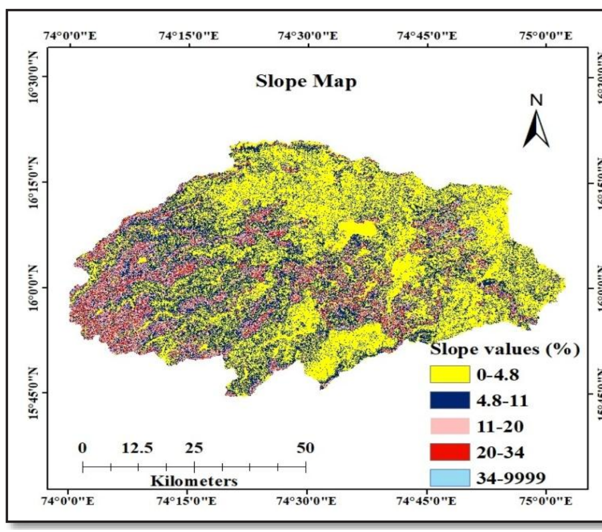

Fig. 2(d): Slope map.

The sensitive parameters were identified during the calibration of a model and adjusted to rate the performance of the model using R^2 and NSE. R^2 of 0.75 (Fig. 6), the NSE of 0.63 for calibration and 0.7 (Figs. 7 & 8), and 0.65 respectively for validation as shown in Table 2, Statistical parameters indicated the satisfactory performance of the model simulation on the flow of monthly time period (Moriasi et al. 2015).

Water Balance Components

Variation in the hydrological process of any system contributes to the difference in impoundment of storage in the watershed. Water balance is the driving mechanism for these variations to take place in the study area. SWAT model was simulated again after the calibration and validation to ensure the best simulation available to carry out the water balance study. The SWAT output file provided the monthly average of various water balance components. The comparison study of various hydrological components such as precipitation, evapotranspiration, stream flow, and water yield for the monsoon season is represented graphically (Fig. 9). Estimated water

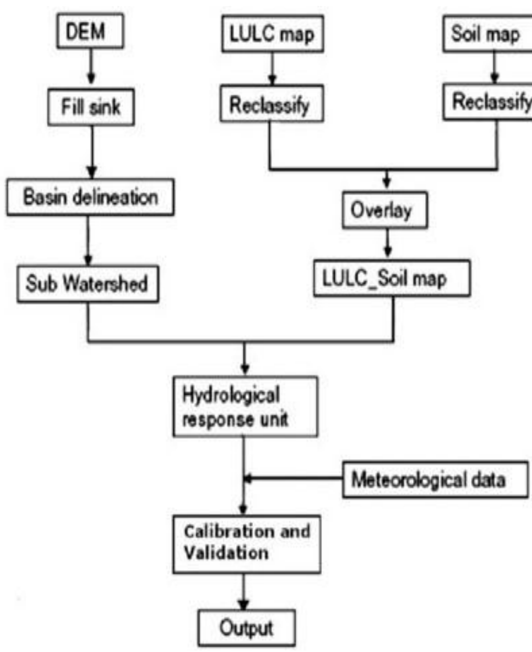

Fig. 2(e): Flowchart of SWAT methodology.

Table 2: Performance ratings of model.

S.No	Model	R^2	NSE
1	Calibration	0.75	0.63
2	Validation	0.7	0.65

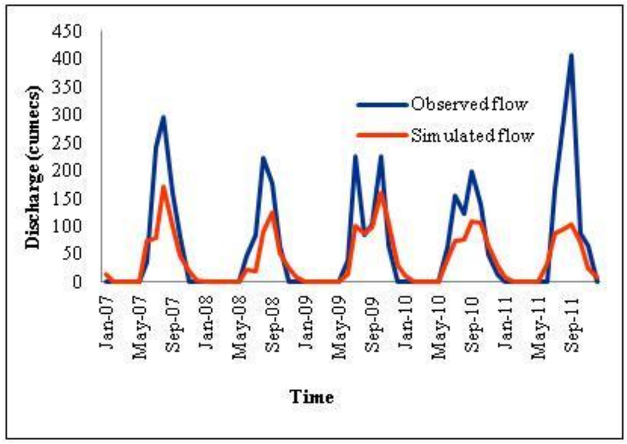

Fig. 3: Comparison of observed flow with the simulated flow before calibration.

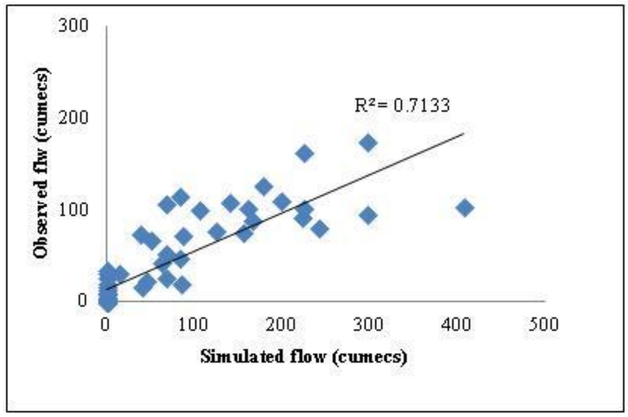

Fig. 4: Scatter plot of simulated versus observed flow before calibration.

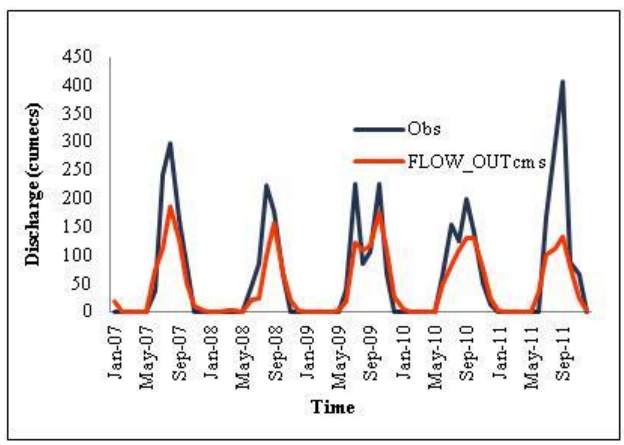

Fig. 5: Comparison of observed flow with the simulated flow after calibration.

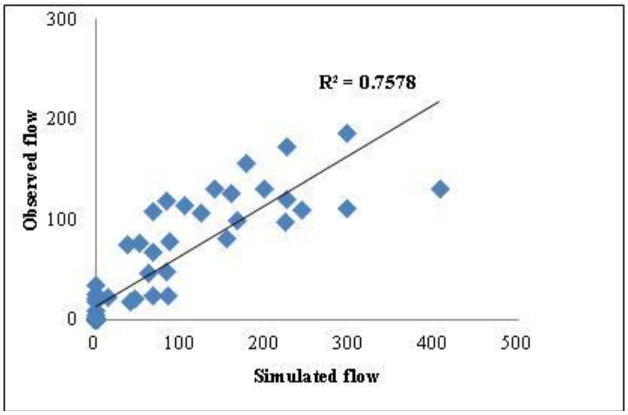

Fig. 6: Scatter plot of simulated versus observed flow after calibration.

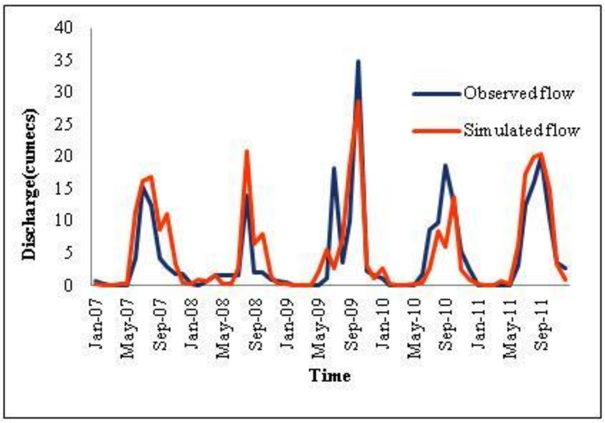

Fig. 7: Comparison of observed flow with the simulated flow for Hudli station.

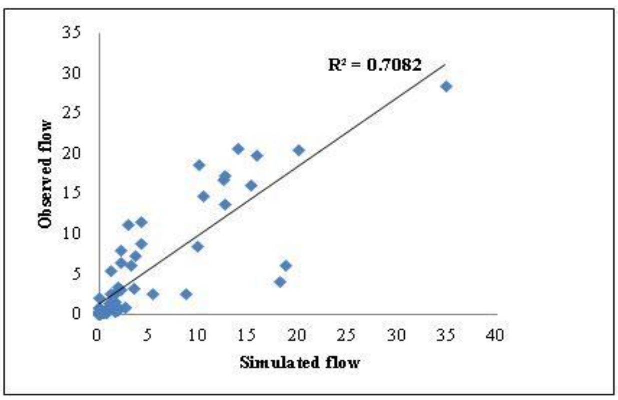

Fig. 8: Scatter plot of simulated versus observed flow after validation.

balance components accounted for 53% of precipitation, 10% of evapotranspiration, 32% of stream flow, and 13% of water yield (Fig. 10).

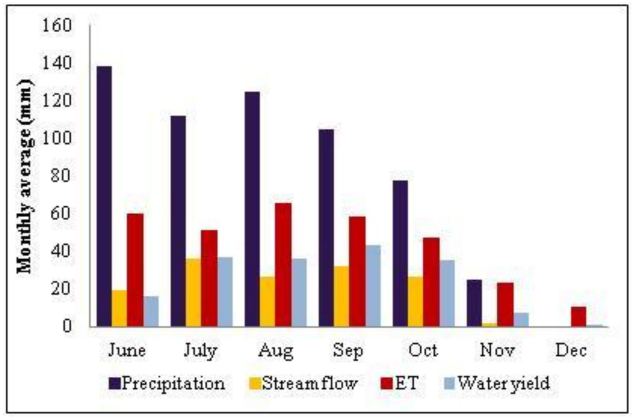

Fig. 9: Monthly average of Stream flow, Precipitation, and Evapotranspiration, water yield for the watershed.

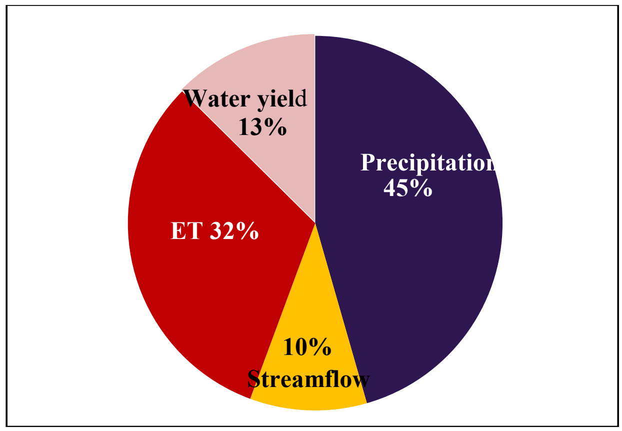

Fig. 10: Contribution of monthly average stream flow, precipitation evapotranspiration, and water yield for the watershed in percentage.

CONCLUSION

The model was calibrated and validated. The calibration and validation of the model for the study area were done with reference to observed data obtained from WRIS, CWC, and the Government of India. The calibration was carried out for the year 2007- 2011 for Lolasuru station and the period from 2007-to 2011 was used to validate the process for Hudli station. The model was also simulated with only default parameters, and it showed satisfactory results before calibration. Still toning of the model was available to ensure the best simulation to carry out the water balance study. During calibration, it was found that CN2, SOL_AWC, ESCO, EPCO, and SURLAG were the most sensitive parameters in the study area. With the default parameters, the results were found to be reasonable, and they improved after calibration, the R^2 and NSE values for calibration were 0.75 and 0.63 and for validation, it was 0.7 and 0.65 which indicates that The model's performance was satisfactory. Further water balance components study was done. The monthly average contribution of precipitation was 53% causing the stream flow of 10%, with the loss of water due to evapotranspiration was 32% and water yield was accounted for 13% through the estimation of mean monthly stream flow. The result showed that there was more loss of water due to evapotranspiration due to rising temperature. It also means that there was enough water accumulation in the area due to the precipitation. To avoid more evapotranspiration losses, the best watershed management practices can be installed to store this water as groundwater storage through infiltration. The study of the water balance components helps in accounting for inflow and outflow of water, estimating the proper water supply, also estimates the future supply for the agricultural, commercial, or domestic purposes, and in the assessment of the hydrological study.

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