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PREDICTION OF STREAMFLOW IN UNGAUGED CATCHMENT USING HYDROLOGICAL MODELLING

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Abstract - *The urbanization process transforms riverine resources, which constitute the foundation of life. In order to revitalize riverine ecosystems, this has to be well analyzed. Using hydrological modelling, which is used in this work, makes it easier to analyzed the consequences of land-use dynamics. The Soil and Water Assessment Tool (SWAT), which has the capacity to quantify the alternative input data supplied to the model, is a useful tool for modelling the river basin. The given model, which had a warm-up time of two years, was used to replicate 14-years' worth of monthly data. The investigation yielded a coefficient of determination of 0.93 and a Nash-Sutcliffe efficiency (NSE) of 0.88, both of which show that the simulated values are within good ranges. Curve number, soil water holding capacity, groundwater delay, Manning's n, and plant uptake compensation are found to have the most effects. The SWAT Calibration and Uncertainty Procedures (SWAT-CUP) accuracy was improved by using the fitted range, which was discovered. Because it takes into account all potential uncertainties in the mode and has effective uncertainty consideration criteria, Sequential Uncertainty Fitting ver. 2 (SUFI2) has been widely accepted. We may evaluate the effect of alternate input data on the stream flow by using hydrological modelling of a river basin.*

1. INTRODUCTION *(Size 11 , cambria font)*

Large affects on the availability of water resources have been seen over time as a result of rising human activity and modifications to land use. The primary component that keeps life on earth alive is water. It is a natural resource with a variety of applications. The nation's industrial operations, hydropower generation, agriculture, forestry, leisure pursuits, fisheries, navigation, etc. depend on groundwater and surface water supplies. People may get water and use it in a variety of ways thanks to rivers, streams, and other water-transporting infrastructure. This is advantageous for the physical environment, which contains all types of living things. Overfishing, water pollution, and habitat loss as a result of dams, sedimentation, and diversion networks are some of the elements that have an impact on the ecological integrity of an aquatic environment. Urbanisation has an ongoing negative impact on the quality and quantity of the hydrological cycle. With changes in land-use patterns, watersheds that carry streamlines see a change in their properties. Quantifying hydrological factors including surface runoff, groundwater recharge, evapotranspiration, water needs, etc. yields the water balance parameter, a crucial aspect in assessing a catchment basin's efficacy. Watersheds must be maintained to meet the demands of the surrounding physical environment. The challenge is to satisfy the requirements of the present generation without jeopardising those of the next generation. Land-use dynamic patterns were connected with changes in rivers and watersheds. The dynamics of the watershed are impacted by changes in urban settlements in order to sustain the hydrological conditions. Another research analyses the water balance parameter of a watershed and correlates it with land-use patterns. By measuring hydrological variables including groundwater recharge, evapotranspiration, surface runoff, etc., the water balance parameter was computed. The agricultural metrics and variations in land use were compared. Crop parameters turn into a side route to watershed effectiveness. The region with a high vegetative cover during the post-monsoon period appears to demonstrate improved water balance in the corresponding watershed, according to land-use responses in relation to water demands.

Hydrological Modeling

One of the key factors in a river's creation is surface runoff. In order to evaluate a river basin's efficacy, the flow from the basin must be calculated. A river basin has a variety of land uses, soil types, slopes, and weather patterns. For its analysis, proper factor parameterization and consideration are necessary. The significance of hydrological modelling is now apparent. We can trace the development of hydrological modelling back to the logical approach. The novelty in this area was the transition from the rational method to distributed hydrological models. A basin hydrological model is a conceptual model that allows us to enter the land use, soil, slope, and climatic data to simulate the flow. In order to create hydrographs, which in turn help with the construction of sewage systems and other hydrologic structures, the flow characteristics must be ascertained.

Soil and Water Assessment Tool (SWAT)

The hydrologic model used for the soil and water assessment tool is continuous, conceptual, semi-distributed, deterministic, and runs on a daily time step. The model's purpose is to mimic how different land management techniques affect agricultural watersheds' hydrology, sedimentation, and nutrient transfer. Hydrology, soil management erosion, weather, plant growth, pesticides, nutrients, land management, and reservoir routing are among the model's eight main components. The sub-basins that SWAT created from the specified river basin are connected geographically. The smallest geographical unit in SWAT is called a "hydrologic response unit," and it is made up of sub-basins that have uniform soil, slope, land cover, and management characteristics. To determine the overall output from the sub-basin, the output from each HRU is added.

SWAT Calibration and Uncertainty Procedures (SWAT-CUP)

An interface created for SWAT is called SWAT-CUP. This programme is used to calibrate SWAT models. Sequential Uncertainty Fitting version 2 (SUFI2) is a process that is supported by SWAT-CUP and is linked to SWAT. With this, the user may calibrate, validate, and do sensitivity analysis on SWAT models.

Sequential Uncertainty Fitting Version 2 (SUFI2)

All sources of uncertainty are taken into consideration by the Sequential Uncertainty Fitting version 2 programme, including uncertainty in the conceptual model, the driving variables (such as rainfall), the parameters, and the observed data. The P-factor, which is the proportion of measured data enclosed by the 95% prediction uncertainty (95PPU), is a metric used to quantify the extent to which all uncertainties are taken into consideration.

Statistical Criteria for Assessing the Performance of the Models

Coefficient of Determination (R2)

The percentage of the variance that can be explained by fitting a regression line is known as the coefficient of determination. The main result of a regression analysis is this. The fitted regression line effectively demonstrates how the dataset is represented. R2's value ranges from 0 to 1.

$$R^2 = \frac{\sum(((Q_i - Q_{\text{mean}})(P_i - P_{\text{mean}}))^2)}{\sum(Q_i - Q_{\text{mean}})^2 \sum(P_i - P_{\text{mean}})^2}$$

Nash–Sutcliffe Efficiency (ENS or NSE)

The effectiveness of hydrological models as predictors is measured by Nash-Sutcliffe efficiency. It establishes the residual variance's relative size in relation to the variance of the measured data. The value reflects how closely the measured value vs the simulated value correspond with the 1:1 line and runs from -1 to +1.

$$E_{\text{NS}} = 1 - \frac{\sum((Q_i - P_i)^2)}{(Q_i - Q_{\text{mean}})^2}$$

2. STUDY AREA

For this study, the Nethravathi river basin in Karnataka, which is located on the west coast of India, is chosen. The river's exact position is between latitudes 12° 29′ 27.9′′ and 13° 10′ 58.7′′ and longitudes 74° 51′ 35.36′′ and 75° 47′ 13′′. It rises 1,000 metres above mean sea level in the Western Ghats (mountain range), an evergreen tropical rain forest on India's west coast, and flows west to enter the Arabian Sea. The river's 3,657 km2 CWC basin drains into a total length of around 103 km. The Nethravathi river basin has an elevation range of 0 to 1619 metres and an undulating landscape with a slope of 0% to 71%. The sandy clay loam, sandy loam, and loamy soils are the predominant soil types in the basin. Forest covers the majority of the basin, followed by orchards and agricultural crops. At Manglore, it merges with Arabian Sea. The Nethravathi basin receives 3721 mm of rain annually on average. The temperature in this area ranges from a minimum of 17°C in December and January to a maximum of 37°C in April and May. In general, the relative humidity is relatively high, exceeding 85% from June to September during the southwest monsoon. The Nethravathi River supplies water to the basin's agriculture, industry, businesses, and city of Mangalore.

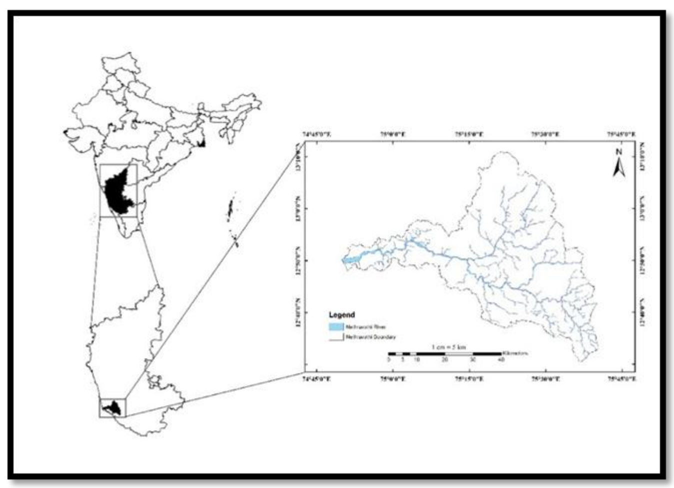

Fig.2.1 Location of study area

3. MATERIALS AND METHODS

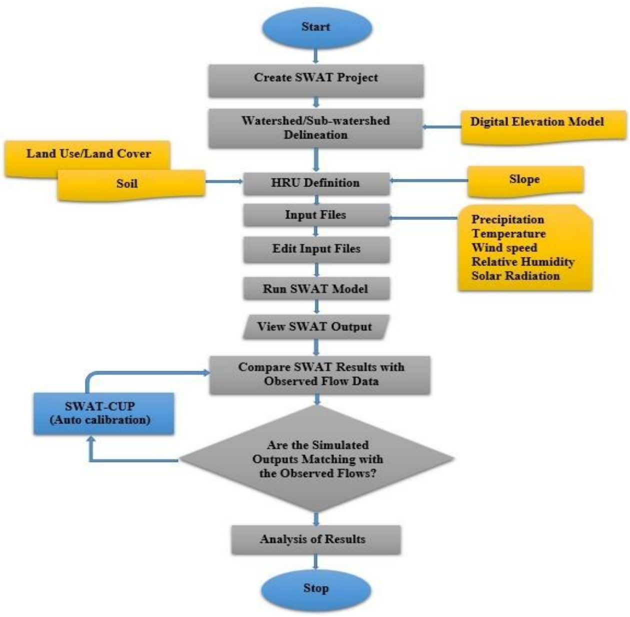

Fig.3.1 Methodology Flow chart.

Digital Elevation Model

The United States Geological Survey (USGS) provided the Shuttle Radar Topography Mission (SRTM) 30 m digital elevation model (Fig. 3), which was utilised to create slope maps in the research region. In SWAT, the DEM was used to define the river and its basin.

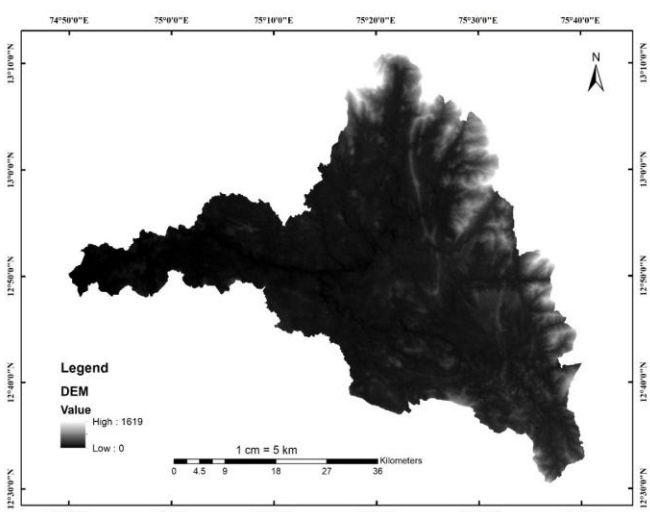

Fig 3.2 DEM for the study area

Land Use

Esri satellite image categorization was used to build land-use maps. A satellite picture from December 2000 was retrieved, processed, and subjected to supervised classification. Six classifications were found at Level 1 categorization, as indicated in Fig.3.3, including Agricultural land Generic, Agricultural land Row Crops, Forest Deciduous, HAY, Orchard, and Wetlands-non-forested.

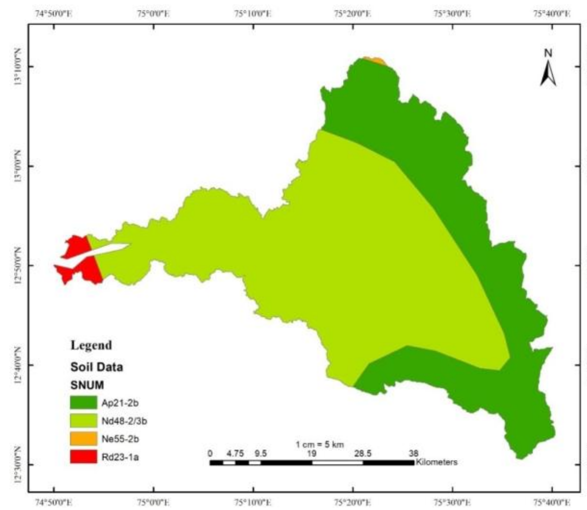

Fig. 3.3 Land use Land cover map for the study area.

Soil Map

The Food and Agricultural Organisation (FAO) Geo network was used to get the soil map. Using the characteristics, a SWAT model database was developed for the FAO soil map. According to the FAO statistics, the basin has three classifications, as seen in Fig.3.4 These three soil classifications will serve as the foundation for the HRU development.

Meteorological Data

Daily meteorological data are input by SWAT. The input data (weather stations) include information on temperature and precipitation. The additional meteorological information that may be entered into SWAT include wind speed, relative humidity, and sun radiation. We do not take the variations in relative humidity, solar radiation, and wind speed into account since rainfall and temperature fluctuations have a significant impact on the Netravathi basin.

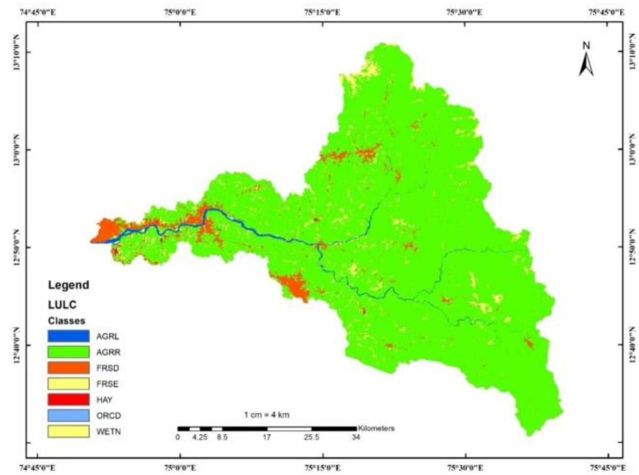

Fig.3.4 Soil map for the study area.

Rainfall Data

For this investigation, daily rainfall information was gathered from seven distinct sites (Fig. 6) throughout the river basin. Data on rainfall from 2000 to 2012 was utilised. It was acquired from the Irrigation Department and Statistical Department in Mangalore. The geographical and elevation parameters of the rain gauge stations located inside the basin.

Temperature

Data for five sites inside the basin were recovered using interpolated 1-degree resolution gridded India Meteorological Department (IMD) temperature data. The gridded data were used to derive the greatest and lowest daily temperatures .The monthly average maximum and lowest temperature variance over a period of 13 years.

Hydrological Data

The Water Resource Information System of India (WRIS) portal was used to determine the river basin's actual discharge at Bantwal station. The Bantwal gauging station was continually monitored by CWC (Table 3), and outflow data for the relevant time period was collected. For graphical depiction, the observed daily stream flow measurements at the Bantwal gauging stations were converted to monthly values.

4. METHODOLOGY

Steps of SWAT model simulation

The SWAT-based hydrological modelling involves the following steps:

(1) Setup of SWAT project,
(2) Watershed/sub-watershed delineation,
(3) HRU analysis,
(4) writing and editing input tables,
(5) model run,
(6) calibration and validation of model.

The ArcSWAT interface in ArcGIS is used to control the SWAT model. Choosing the directory that contains all the relevant databases and files for data storage is the first step in setting up a SWAT project. A threshold must be specified for the delineation of sub-basins in the second stage of catchment delineation. There are many subbasins within the Netravati watershed region. All of the geographical inputs (LULC, soil, and slope maps) are classed in the HRU definition stage to make them compatible with the Arc SWAT environment. A total of 27 sub-basins over the watershed have HRUs once the thresholds for each input are defined and overlaid. The subbasin 14 with a total contributing area is where the basin's exit is located. SWAT is characterised as a semi-distributed model since it operates at the HRU level. The meteorological data (from IMD and CFSR) are fed into the model as inputs after the HRU analysis stage. The IMD rainfall and temperature data are structured with regard to the CFSR data format since it is most compatible with the SWAT model; in other words, the IMD rainfall and temperature input tables are substituted with those from IMD. The model receives these meteorological inputs, and the database is updated.

The model is run and the result (i.e., streamflow at the sub-catchment outlets) is simulated when all the meteorological inputs have been provided. In general, a model's default simulation does not yield adequate results, hence the model should be calibrated and validated in relation to the observed hydrologic data. In order to create the best model structure feasible that is appropriate to the local hydrological circumstances, calibration tries to determine the parameters that have the most impact on the catchment's hydrologic processes and their ideal values. Software called SWAT-CUP (SWAT-Calibration and Uncertainty Procedures) is used to automatically calibrate the SWAT-simulated flows. Calibration may also be done manually by examining each parameter's impact on the model and repeatedly testing to determine its optimal value. However, this technique is time-consuming and demanding. The SWAT-CUP gives the user a lot of alternatives, which gets around the problems with manual calibration and produces a more accurate result with less time and effort. Sequential uncertainty fitting (SUFI2) tool is the most often used algorithm in SWAT-CUP, and it is also employed in this work. The model is verified to support its future application throughout the area.

Table-4.1Statistical criteria for the calibration of the model

Statistical criteria	Stream flow
R 2	0.91
NSE	0.88
PBAIS	13.5
RSR	0.35

Table-4.2 Statistical criteria for the validation of the model

Statistical criteria	Stream flow
R 2	0.96
NSE	0.88
PBAIS	13.5
RSR	0.35

5. RESULTS AND DISCUSSIONS

This study's goal is to predict the hydrology of the Netravati basin using high-resolution images that were obtained from NRSC (ISRO). The categorization of LULC and slope over the research region must be done with the remotely sensed products before they are utilised as geospatial inputs for HRU analysis. Fig.3.3 displays the Netravati catchment's categorised LULC map. Seven different LULC classes are recognised within the catchment based on LULC categorization. Generic agricultural land, agricultural area used for row crops, deciduous forest, HAY, and orchard. The normalised difference vegetation (NDVI) map for the Netravati Catchment was created using the 2017 LULC imagery and is shown in Fig. 4. The presence of lush vegetation is preferred in the areas close to the reservoir since it is situated in the lower catchment areas, where it can aid with soil and water conservation. Fig.3.4 displays the Netravati catchment's categorised soil map. Three separate soil types—clayey loam, gravelly loam, sandy loam, and sandy clayey loam—can be clearly seen across the watershed. It may be deduced from Figs. 4 and 5 that soil types with sandy loam, clayey loam, and sandy clayey loam have plant cover. The SWAT model generates a number of outputs at the outlet of each sub-catchment, however this research focuses on the streamflow at the outflow of the whole catchment because data on the observed streamflow into the Netravati reservoir is available. The discharge within reported by SWAT should be calibrated with regard to the matching observed data, since it was previously noted that the outflow of the entire catchment lies in sub-basin 14, which has a total contributing area of 7268 km2. The period of 2002–12 is separated into three parts: the year 2000–02 is considered as the warm-up phase, 2002–2008 is selected as the calibration period, and 2009–2012 is taken as the validation period. This is done since the observed discharge data for the years 2000–2012 was available at the Netravati catchment outlet. In other words, a model's warm-up is an adjustment procedure that raises the internal stores (such as soil moisture) from the estimated beginning condition to an optimal level, placing the model in an ideal state. The model is then calibrated using the observed flows for the years 2002–2008. It should be noted that the SWAT model has a monthly time step for calibration. The mode was calibrated at monthly time increments since the observed flows are, nevertheless, accessible at a daily scale. In order to do this, the observed 10-day data were scaled up to the monthly level and entered into the SWAT-CUP model with the goal function of maximising NSE. The various sensitive parameter ranges are used to simulate the SWAT-CUP 500 times. Based on the SWAT calibration and validation literature, the list of parameters and their ranges were chosen. More simulations aid in enhancing the model's performance. Out flow 14 shows the outcomes of the best simulation (based on efficacy metrics on a monthly size) and a comparison to the actual flows and rainfall at a daily scale during a period of four years, from 2009 to 2012. It is evident that there is good agreement between the best-simulated flow and the observed flow. The pattern of the flow is well reproduced by the model. The SWAT model may be used to simulate discharge throughout the watershed since the R2 and NSE efficacy values at the monthly scale were determined to be 0.93 and 0.88, respectively. A competent hydrological model will produce results that are roughly commensurate to rainfall quantities. In order to assess their influence on the discharge at the catchment outflow, a list of 17 parameters was selected for the uncertainty analysis. These factors were discovered to significantly affect streamflow from the pertinent SWAT calibration literatures. Knowing their ideal value might help you better comprehend the catchment's hydrology. Table 8 lists the variables taken into account for the uncertainty analysis of the discharge modelling for the Netravati catchment, as well as their calibration range (minimum and maximum) and best-fit values. Literature may be used to find a full explanation of these and other SWAT model parameters. You may learn more about these characteristics' specifics and their significance from the papers already mentioned as well as the SWAT website (https://swat.tamu.edu/). Additionally, Table 8's parameters may be shown to have prefixes (R_, V_) and suffixes (.mgt,.hru,.bsn,.sol,.gw). The suffixes identify the category to which the parameters belong; for example, management, hydrologic response units, basins, soil, and groundwater are denoted by.mgt,.hru,.bsn,.sol, and.gw, respectively. On the other hand, "relative" and "replace" are represented by the prefixes R_ and V_ in the SWAT-CUP. In the SWAT model, the V_ prefixed parameters' optimal values should be changed, and the R_ prefixed parameters' starting values should be multiplied by the best-fit value.

6. CONCLUSIONS

The conclusions of this study, which were summarised, can be applied to a variety of situations.

• SWAT Sensitivity analysis in SWAT identifies the sensitive parameters using p-value and t-stat value. Modelling for the study has supplied the model parameters which represent the efficacy of the model. The parameter that had a higher t-statistic and a lower p-value was discovered to be sensitive to the model.

• SWAT's parameterization tool enables us to identify and modify the parameters that have the greatest effect on simulation quality.

• This model's calibration depends heavily on variables like curve number, groundwater delay, soil accessible water capacity, Manning's n, and plant uptake compensation.

• R2, NSE, and PBAIS all fall within acceptable ranges.

• For higher amounts of stream flow, the scatterplot's dispersion is shown to increase.

• The validation output may be too optimistic given that the validation result indicates that the PBAIS value is high. The calibrated and verified model may be used to determine the effects of land-use changes on stream flow. The model may accept alternative input data so that the answer can be quantified using actual numbers.

REFERENCES

1. Dos Reis, A. A., Weerts, A., Ramos, M. H., Wetterhall, F., & dos Santos Fernandes, W. (2022). Hydrological data and modeling to combine and validate precipitation datasets relevant to hydrological applications. Journal of Hydrology: Regional Studies, 44, 101200.
2. Darbandsari, P., & Coulibaly, P. (2020). Inter-comparison of lumped hydrological models in data-scarce watersheds using different precipitation forcing data sets: Case study of Northern Ontario, Canada. Journal of Hydrology: Regional Studies, 31, 100730.
3. Juma, L. A., Nkongolo, N. V., Raude, J. M., & Kiai, C. (2022). Assessment of hydrological water balance in Lower Nzoia Sub-catchment using SWAT-model: towards improved water governace in Kenya. Heliyon, 8(7), e09799.Shivhare, N., Dikshit, P. K. S., & Dwivedi, S. B. (2018).
4. Lirong, S., & Jianyun, Z. (2012). Hydrological response to climate change in Beijiang River Basin based on the SWAT model. Procedia Engineering, 28, 241-245.Darbandsari, P., & Coulibaly, P. (2020).
5. Mourad, K. A., Nordin, L., & Andersson-Sköld, Y. (2022). Assessing flooding and possible adaptation measures using remote sensing data and hydrological modeling in Sweden. Climate Risk Management, 100464.

6. Mtibaa, S., & Asano, S. (2022). Hydrological evaluation of radar and satellite gauge-merged precipitation datasets using the SWAT model: Case of the Terauchi catchment in Japan. Journal of Hydrology: Regional Studies, 42, 101134.Guug, S. S., Abdul-Ganiyu, S., & Kasei, R. A. (2020).
7. Osei, M. A., Amekudzi, L. K., Wemegah, D. D., Preko, K., Gyawu, E. S., & Obiri-Danso, K. (2019). The impact of climate and land-use changes on the hydrological processes of Owabi catchment from SWAT analysis. Journal of Hydrology: Regional Studies, 25, 100620.
8. Oleyiblo, J. O., & Li, Z. J. (2010). Application of HEC-HMS for flood forecasting in Misai and Wan'an catchments in China. Water Science and Engineering, 3(1), 14-22.
9. Perez-Valdivia, C., Cade-Menun, B., & McMartin, D. W. (2017). Hydrological modeling of the pipestone creek watershed using the Soil Water Assessment Tool (SWAT): Assessing impacts of wetland drainage on hydrology. Journal of Hydrology: Regional Studies, 14, 109-129.Vilaysane, B., Takara, K., Luo, P., Akkharath, I., & Duan, W. (2015).