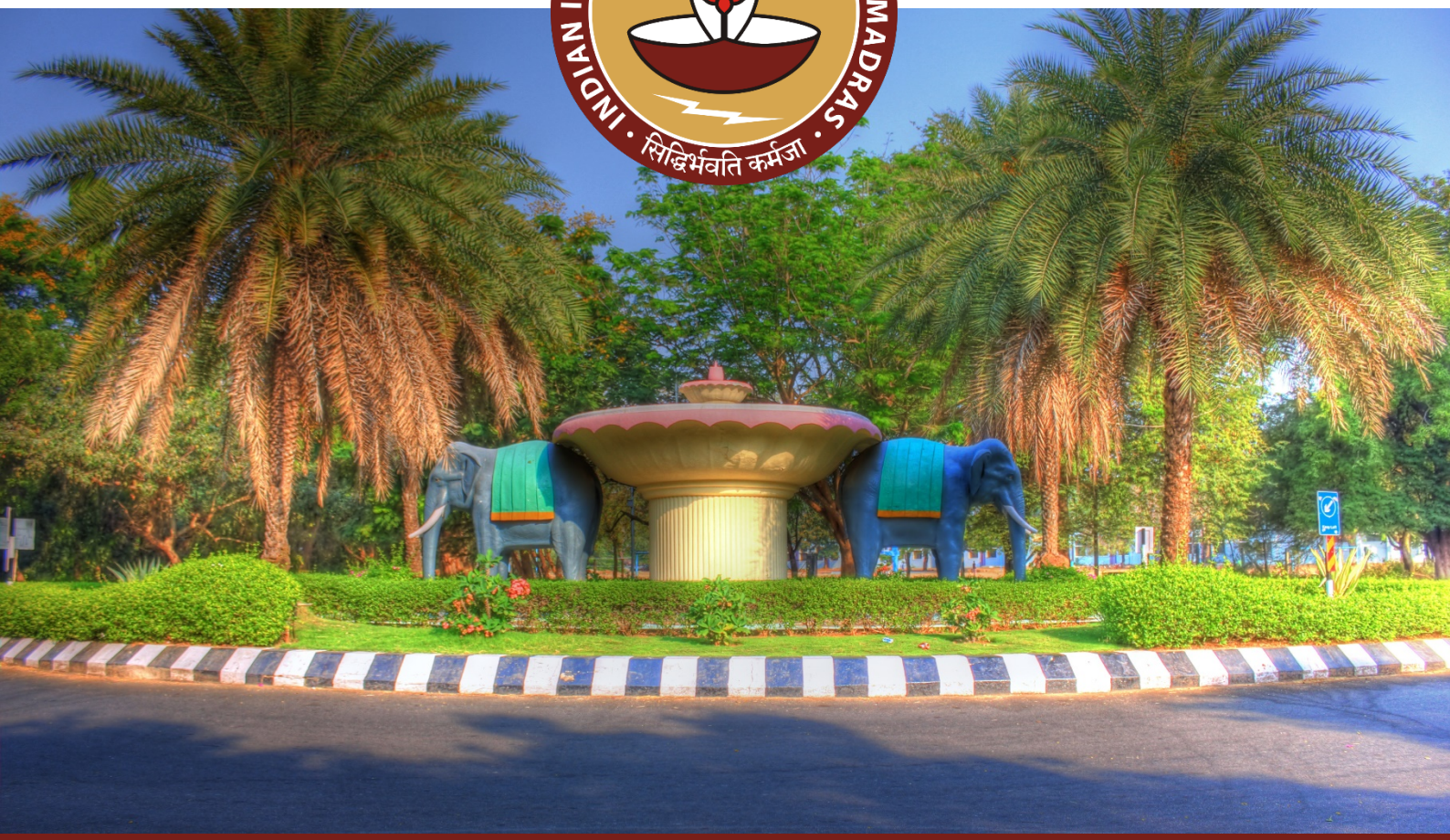
INTERNATIONAL SOIL AND WATER ASSESSMENT TOOL CONFERENCE

SWAT

CHENNAI, INDIA

JANUARY 10 - 12

2018



Book of Abstracts

The Soil and Water Assessment Tool (SWAT) is a public domain model jointly developed by USDA Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research, part of The Texas A&M University System.

SWAT is a small watershed to river basin-scale model to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change. SWAT is widely used in assessing soil erosion prevention and control, non-point source pollution control and regional management in watersheds.

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Contents

Foreword

The organizers of the 2018 International SWAT Conference want to express their thanks to the organizations and individuals involved and their preparation and dedication to coordinate a successful conference. We would also like to thank the Scientific Committee for their support in preparing the conference agenda and allowing for scientists and researchers around the globe to participate and exchange their scientific knowledge at this conference.

A special thank you to the Indian Institute of Technology - Madras along with Balaji Narasimhan, K.P. Sudheer, and the rest of the local organizing committee in Chennai for their countless hours and efforts to host the SWAT Community. On behalf of the SWAT Community, we extend our sincere gratitude to you and your university for the kind invitation and welcoming hospitality.

The following Book of Abstracts contains abstracts for presentations covering a variety of topics including but not limited to large scale applications; climate change applications; model development; database and GIS application and development; environmental applications; hydrology; best management practices (BMPs); sensitivity, calibration and uncertainty; SWAT remote sensing applications; sediment, nutrients, and carbon; the EPIC/APEX modeling system; and more.

The Conference Organizers hope you enjoy the conference and continue to view these SWAT gatherings as a positive opportunity for our international research community to share the latest innovations developed for the Soil and Water Assessment Tool.

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Hydrologic Modelling in India: Current Status and Way Forward

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Abstract

Most hydrologic systems are extremely complex and it is quite difficult to understand them in all the requisite details. Main objectives of catchment modelling are to gain a better understanding of the hydrologic processes operating in a catchment, examine how changes in the catchment and hydromet inputs may affect these processes, generate synthetic sequences of hydrologic data for project design, and forecast future hydrologic inputs for management of hydro-infrastructure. Different hydrological models provide diverse perspectives of the catchment system and are simplified representations of the reality as visualized by the modeller.

A wide range of hydrological models are being used in India, ranging from simple regression models to physically-based distributed models and purposes of application range from simple rainfall-runoff modelling to study of impact of climate change. With wider availability of hardware and software, applications of the models is growing rapidly but the use of models for addressing real-life problems leaves much scope for improvement.

Considering the current water related problems of the India, and indeed of many other countries, the main issues that need to be addressed include water resources assessment in gauged and ungauged basins, integrated water resources management, water quality management, flood and drought management, and impact of landuse-land-cover and climate change on catchment response. This requires better quality and coverage of data and trained manpower to rightly apply the models. Serious efforts are to be made to take the models from the academia into the fields. Innovative ideas and comprehensive models are needed to make use of ever increasing information. Further, model calibration and operational implementation are complex tasks and pool of well-trained scientific manpower is needed to complete them.

The present talk will discuss some of these ideas in the backdrop of emerging hydrological problems and sub-optimal use of hydrological models to address these with particular reference to India.

SWAT 2018: Global Impacts and Future Horizons

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Abstract

The Soil and Water Assessment Tool (SWAT) has emerged as one of the most widely used ecohydrological models in the world. SWAT has proven to be a very flexible tool for investigating a broad range of hydrologic and water quality problems across different watershed scales and environmental conditions. The use of SWAT was initially concentrated in North America and Europe but has since expanded dramatically in other countries and regions during the past decade including across much of Africa, Asia and South America. This is evidenced by over 3,000 peer-reviewed SWAT-related articles that have been published in hundreds of reputable journals and by thousands of other studies which have been published in conference proceedings and other formats. The influence of SWAT within water resources research and related disciplines is further confirmed by a variety of recent bibliometric analyses, which reveal the impact that the model has had across a broad spectrum of the scientific community. The impact of SWAT globally can also be seen in the ever increasing types of applications that the model is being applied for including dozens of studies that report some type of code modification, most of which have not been ported to the main SWAT code at present.

Broad indicators of SWAT use are reviewed here including relative use among different countries in Asia as well as dominant trends in the peer-reviewed literature including assessment of leading journals and disciplines that are the forefront of publishing current SWAT literature. Key trends in SWAT use are also reviewed including emerging application subcategories such as regionalization approaches and evaluation of SWAT output using statistical criteria and various “soft data” sources. Applications of modified SWAT codes for improved representation of various physical processes are further explored including a broad overview of SWAT adaptations across North America and specific modifications to better represent variable source area hydrology and rice paddy dynamics. Finally, the potential to incorporate some of these modifications as well as well as other potential advancements in future versions of the SWAT+ code are discussed.

SWAT+, Restructured routing, input and output file structure in a modular format

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Abstract

SWAT+ is a completely restructured version of the Soil and Water Assessment Tool (SWAT) that was developed to face present and future challenges in water resources modeling and management. SWAT+ makes extensive use of FORTAN data structures and modules. The modular structure facilitates maintenance, adding process modules, and linkage to other models. Each spatial object (hru's, landscape units, channels, reservoirs, and point sources) are modules within SWAT+ and are linked with connect files. The connect files for each object specify multiple hydrographs (surface runoff, lateral flow, percolation, tile flow, total outflow) that can be routed to any other object(s). This increases flexibility of connections and allows pollutant routing across the landscape. Input files have been restructured into a relational format, reducing the number of input files, decreasing run time, and allowing data files to be maintained and supported. A calibration file was added to speed calibration, track modified parameters, and support conditional changes based on land use and soil texture. Decision tables were added to SWAT+ as a precise, compact way to model complex rule sets and their corresponding actions. Decision tables are currently used for reservoir releases and land management including irrigation, fertilization, drainage water management, and land use change. We are currently applying SWAT+ in our USDA national conservation assessment called CEAP (Conservation Effects Assessment Project). In CEAP, we are modeling representative fields, each channel (gully/ditch) leaving the field, each first order channel, higher orders, and main routing channel in each subbasin (approximately 75 km^2). Release of a QGIS interface and SWAT+CUP are planned for 2018.

High-End Climate Change for Specific Warming Levels and Their Implications in the Ganga River Basin

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Abstract

The High-End cLimate Impacts and eXtremes (HELIX), a European Union Collaborative project focused on the creation of future implications under varied levels of global warming. The rate of future climate change will be a critical factor in the vulnerability or resilience of societies to the changing climate, because ongoing economic development will affect the sensitivity of societies to weather and climate, and adaptation measures will require time to be identified, planned and implemented. Interdependencies between different impacts, both biophysical and socio-economic, shall make the problem even more complex.

HELIX has addressed this situation by providing a clear, coherent, internally-consistent view of a small, manageable number of "future worlds" under higher levels of global warming reached under a range of physical and socio-economic circumstances, including consideration of different adaptation scenarios, supported by advice on which aspects are more certain and which less certain.

The research has focused on addressing the questions "What do 4ºC and 6ºC worlds look like in comparison to 1.5ºC and 2ºC?" and "What are the consequences of different adaptation choices?" The core of HELIX work is at the global scale, (https://www.helixclimate.eu/) but there is an additional focus on three key regions (Europe, northern sub-Saharan Africa, and Indian sub-continent) . The work presented here is about the application of HELIX philosophy to the Ganga River Basin.

Eleven high resolution RCM models with data from 1980-2100 have been used to identify the Specific Warming Levels (SWLs) of SWL1.5, SWL2, SWL4, SWL6. These SWLs have then been used to derive impacts on the water resources of the Ganga Basin. The well-known distributed hydrological model SWAT has been deployed to run with the climate data of the identified eleven regional climate models for the 30 year period around each one of the SWL1.5, SWL2, SWL4 levels for each of the models.

The outputs of these scenarios have been analysed to evaluate the possible impacts on some of the important hydrological entities such as the runoff, baseflow, soil moisture, ground water recharge and actual evapotranspiration. The impacts have been expressed as change under various SWLs with respect to the baseline. The question of how this information can feed into the policy formulation so as to help the policymakers in making choices is also discussed.

Water is the next GOLD rush: a case study in Iraq

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Abstract

Water is critical for everyday life. International water sharing and its conflict are becoming increasingly prevalent now in Africa, Asia, Middle East, and in Europe.

The Al-Hawizeh marsh is located east of the Tigris River in lower Iraq between the cities of Amara and Basra and extends over the international border into the Islamic Republic of Iran. The marsh has been designated as Ramsar wetland of international significance to migratory birds. The marsh is dependent on water contribution from the Tigris and Karkheh rivers within the Tigris and Euphrates basin. Currently, the marsh is facing the greatest danger and is becoming hydrologically and ecologically stressed because of decreased water inflows.

A hydrology model of the Tigris Euphrates basin with emphasis on flow contributing to marsh was developed. The SWAT (Soil and Water Assessment Tool) model was used to simulate the hydrology of the basin, as it allows simulation of runoff in the ungauged stream network because feeder streams into the marsh are unmetered. The SWAT model is calibrated using long-term monthly average water flow data collected from existing stream flow monitoring stations. The presentation overviews the hydrological analysis (flood/drought frequency, intensity, and the probability of exceedance) of flow in the Tigris and its tributaries (including Karkheh river flowing from Iran) feeding the marsh using calibrated SWAT model. Also, the impacts of current and future dams on flow contributions are explored.

How parameter value identification is impacted by the selection of performance criteria – A SWAT study in four contrasting catchments in Germany

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Abstract

SWAT model parameter values are identified by calibrating them to the conditions of study catchments using performance criteria. In recent years, the benefit of using multiple performance criteria and in particular signatures measures was shown. Since each performance criterion is focused on different parts of the hydrograph, the selection of a certain performance criterion impacts also the identification of optimal parameter values.

In this study, the SWAT model is applied to four contrasting catchments in Germany along an elevation gradient from alpine via mid-range mountainous to lowland catchments. We used here the SWAT3S-version with two active and one inactive groundwater component. For this analysis, twelve SWAT model parameters were selected and 2000 model simulations were carried out based on an identical parameter sampling for all catchments. Ten different performance criteria were calculated for each model simulation. These are: Nash-Sutcliffe Efficiency (NSE), Kling-Gupta-Efficiency (KGE) as well as separately its three components (KGE_alpha (variability), KGE_beta (bias), KGE_r (correlation)). Moreover, the RSR is calculated for five segments of the flow duration curve (FDC), namely very high, high, mid, low and very low flows.

Next, parameter values are related to the best values of each performance criterion. It is demonstrated that both the sensitivity of model parameters as well as the optimal parameter values can largely change when using different performance criteria. The results moreover vary between the four contrasting catchments.

Thus, for each model parameter, a specific decision on appropriate performance criteria is required. Based on this, a refinement of parameter ranges is possible to constrain the model parameters individually for each catchment.

Keywords

performance criteria, parameter identification, lowland, mountainous, alpine

How well does a model reproduce hydrologic response? Lessons from an inter-model comparison

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Abstract

A wide variety of hydrologic models are available to simulate the rainfall runoff response for a catchment. Users are generally presented with the challenge of choosing an appropriate model structure for simulating the rainfall runoff relationship in their study area. A common approach to do this is to compare the simulations of streamflow and other hydrologic variables at daily or monthly time scales to observed data and estimate a statistical error metric, typically based on squared errors. While useful, this has several disadvantages. First, a statistical error metric condenses information of errors in a time series in a single value. This leads to loss of information about time varying nature of errors. Second, squared error metrics tend to focus on fitting the peak flows; high performance in these metrics may still be accompanied by poor prediction of low to medium flow values. Third, there are no clear guidelines for cutoffs of high versus low performance of these statistical metrics. Therefore, each study may choose to define different thresholds of performance as acceptable. Fourth, it is possible for model structures to perform similarly in statistical error metrics making it hard to understand which model truly represents catchment processes. This is also known as the problem of equifinality in hydrologic modeling.

We present a model comparison framework that showcases means to overcome the aforementioned disadvantages to some extent. We compare three rainfall runoff models in their ability to effectively simulate streamflow. Each of the three models has the same runoff generation scheme but differs in their routing structures. The first two model structures employ two variants of a recently proposed geomorphological hydrologic routing routine while the third employs a commonly used routing routine – two linear reservoirs in parallel. To overcome the second limitation, i.e., focus on high flows, we applied statistical error metrics to Box-Cox transformed streamflow time series, allowing fair weightage to performance in both high and low flows. To overcome the third disadvantage, we tested the models not only on commonly employed root mean squared error metrics but also on ecologically relevant metrics such as ability to reproduce duration of low flows. Thus, a total of eight quantitative statistical and ecological performance measures were employed. Consequently, instead of choosing a single best performing parameter set, we obtained a Pareto front of non-dominated parameter sets by comparing performance across parameter sets from all three model structures for all eight metrics. The ability of each model to contribute to the Pareto set is thus a measure of overall performance of a model. We found that Pareto-optimal parameter sets belonging to different model structures represented very different dominating catchment processes. In order to overcome this fourth challenge, we employed a qualitative performance measure: the ability of each model structure to simulate the dynamic storage-discharge relationships of catchments. It was found that assessing performance qualitatively helped to partly reduce the uncertainty in identifying dominating catchment processes. By applying this framework across 71 catchments across the continental United States, we learnt that developing blueprints of qualitative model performance measures is perhaps as important as having robust measures of quantitative performance.

Is there a 'universal' calibration-free continuous hydrological model? Testing a dynamic Budyko model in multiple continents

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Abstract

Traditional continuous hydrological models have large number of free parameters whose values need to be determined through calibration, and thus their applicability is limited to gauged basins. For prediction in ungauged catchments, hydrologists generally follow regionalization methods to develop calibration-free models, for e.g., by relating model parameters with easily observable catchment characteristics. However, no regionalization method so far has helped us to construct a universal calibration-free model applicable to all real world catchments. An alternative attempt was made recently to develop a calibration-free continuous model by proposing a 'decay function' that offers definition of *instantaneous dryness-index* as a function of antecedent rainfall and solar energy as inputs. The model was applied to 63 US catchments and the median Nash-Sutcliffe efficiency (NSE) was found to be 0.41. Recently, the model was tested in 40 catchments in south India with the main question in mind if the instantaneous-dryness-index based model is universally applicable. The median NSE. Furthermore, significant improvement in model performance was observed upon Box-Cox transformation of discharge (NSE_{BC} is 0.44), indicating that the model simulates discharge well in general but does not route well flood peaks. Results here to a large extent seem to suggest that the instantaneous dryness-index based calibration-free model is universally applicable. The model can thus potentially be used for predicting discharge in ungauged catchments for which no regionalization based modelling option is available as well as helping us in providing a more accurate description of catchment hydrological processes.

Keywords

Universal calibration-free continuous hydrological model, instantaneous dryness-index, Budyko function, prediction in ungauged catchments

Optimal Estimation of SWAT Model Parameters using Adaptive Surrogate Modelling

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Abstract

A major challenge in calibration of Soil and Water Assessment Tool (SWAT) is identification of optimal model parameters and its sensitivity analysis. In general, the accuracy of estimation of SWAT model parameters depends on: (i) the number of parameters available, such as hydro-meteorological data and catchment characteristics; (ii) objective functions; and (iii) structural complexity of SWAT. Further, in SWAT model, the choice of the calibration period and its length can have a significant impact on the estimated model parameters. In general, estimation of SWAT model parameters is complex and demands significant computational cost. The surrogate models are best alternative choice to represent the response surface of the complex simulation models such as SWAT. These models are shown to be very efficient and reduces number of simulations in obtaining optimal model parameters. In addition, surrogate models are used to identify the most sensitive parameters for complex simulation models. In this study, the adaptive surrogate modelling based optimization (ASMO) framework is adopted for reducing the number of SWAT model runs as well as identification of sensitivity parameters for Peachtree Creek watershed, USA. For the selected watershed, 16 SWAT model parameters related to streamflow generation were considered for optimization. Preliminary results indicate that adaptive surrogate modelling is able to effectively reduce the number of simulations and resulted in higher modeling accuracy. However, ASMO can provide only approximate optimal solutions, whose precision is limited by surrogate modeling methods and problem-specific features. Further, the identifiability of model parameters is correlated with parameter sensitivity.

Keywords

SWAT, Adaptive Surrogate Modelling, Sensitivity Analysis, Optimization

Hydrological Modelling of Narmada basin in Central India using Soil and Water Assessment Tool (SWAT)

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Abstract

The study is an attempt to understand and quantify the hydrological processes in a Narmada River basin which has undergone changes owing to the developmental activities with the proposed water resources development activities planned for future. Modelling the hydrology of a watershed is important for understanding and predicting the potential hydrological consequences of changes in the system inputs. The SWAT model has been applied for simulating the hydrology of Naramada River upto the Barmanghat gauging site with a catchment area of 25862.53 sq. km. The modelling exercise has been performed using the virgin conditions during 1971-88 as well as incorporating the existing dams during 1988-05. The performance of the model application based on the multi-site calibration and uncertainty analysis using SUFI-2 algorithm in SWAT-CUP ,is encouraging and the performance based on the model evaluation statistics varied between good and very good at all the six gauging sites except Mohgaon whereas during validation the performance varied between satisfactory and very good at all the gauging sites. The SWAT model can be applied hereafter for the simulating the hydrology of the study area for the assessment of the impacts of climate change, land use change and future development scenarios.

Keywords

Narmada,

Modeling sustainability of water resources in Tuul River watershed in Mongolia

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Abstract

In many parts of the world, freshwater source is getting depleted due to extensive rise in demand for water for agriculture, industries and growing urban and rural population. With climate change and land use alterations, sustaining of water resources is a major challenge. There is a need for watershed scale assessment and planning to address this problem.

Watershed models are useful tools to investigate effects of hydrologic responses at various scales under climate change conditions, and to simulate effects of the management decisions in order to support sustainable water management.

The main objective of this study is to evaluate ecohydrological processes at subbasin scale for sustainable water management using physically based Soil and Water Assessment Tool(SWAT) for the Tuul River Basin in Mongolia. This watershed is an important region for social and economic development of Mongolia and undergoing rapid depletion in water resources due to overexploitation of groundwater resources and uncertainty of climate change.

We use SWAT model to simulate ecohydrological processes influencing water resources and see the potential effect of different management practices. Based on the assessment of water supply and demand dynamics, a water sustainability index is calculated using water supply-demand metrics for each subwatersheds and then ranked for sensitive areas. The sustainability index is used to evaluate and prioritize most vulnerable subwatersheds to support decision makers and identify optimal management practices to sustain water resources in the watershed.

Keywords

SWAT, sustainable water management, sustainability index, water supply and demand, Tuul River

Surface Water and Groundwater Interactions in Kosi River Basin using Surface and Subsurface Hydrological Modelling

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Abstract

In hydrological cycle, Surface water and Groundwater (SW-GW) interaction is one of the important components. It is a natural process and complex phenomenon to understand its physical dynamic processes. Many processes such as natural and anthropogenic processes (climate change, population growth, industrial growth and landuse/landcover change, etc.) effect this interaction exchange patterns. In this article, the study has focused on the effect of landuse/landcover changes on SW-GW interactions in Kosi River basin, India. In order to achieve this, the present study has divided into two parts. In the first part, surface water hydrological model (SWAT) has been used to get monthly water availability of the watershed at river reach scale. Using simulated and observed flow discharge series, a simple water balance study is carried out as a primary tool to investigate SW-GW interactions along the course of Kosi River for monthly level. Gaining and losing zones are identified by this analysis along the river reach and it is also noticed that there are significant changes in the interaction exchange pattern during the analyzed period along the river reach. In the second part, sub-surface hydrological model (MODFLOW) has been used to identify the zones of gaining and losing reaches along the reaches. Landuse/landcover changes are also incorporated in the model using temporal evapotranspiration data information and significant changes in interaction exchange patterns are observed. Finally, SW-GW interaction zones identified with water balance study are verified with zones identified with groundwater flow model. From this study, it is concluded that combination of surface and sub-surface hydrological models can be used to understand the effect of landuse/landcover on SW-GW interaction exchange process.

Keywords

Surface Water-Groundwater Interactions, Hydrological Modelling, Landuse/Landcover Changes

Validity of Top Soil Moisture Estimation Using SAR Data in a Rainfed Region

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Abstract

Soil moisture is a crucial parameter in many fields such as crop yield estimation, drought forecast, hydrological and climatic studies, and it can be retrieved from Synthetic Aperture Radar data at very high spatial resolution. The Radar backscattering coefficient has a linear relation with the soil moisture if roughness and other contributions are absent. The backscattering coefficient (σ^0) is the ratio of amount of energy backscattered to the amount energy transmitted and it is the function of target parameters of soil moisture, roughness, vegetation, soil texture and sensor parameters of wavelength, incidence angle, and polarization.

In this study, soil moisture was derived from RISAT-1 dual incidence angle and dual polarisation SAR data for the rainfed region of Vidarbha, India. Higher incidence angle data was used for retrieval of roughness component, and low incidence angle data was used for retrieval of soil moisture. A Radar vegetation Index was developed using higher incidence data to account vegetation influence in the soil moisture retrieval. The derived soil moisture was validated using in-situ soil moisture measurements and correlated well with R^2 value of 0.74 with the error in soil moisture retrieval of 0.40 cm^3/cm^{-3}. The derived soil moisture maps were compared with Soil moisture and Ocean Salinity (SMOS) data using temporal stabilization method. The soil moisture derived from RISAT-1 soil moisture was downgraded into 1km spatial resolution. Then the mean value of RISAT-1 pixel was calculated concerning SMOS spatial resolution of 25 km. The SMOS and RISAT-SM were correlated with R^2 value of 0.407 with error of 0.68 cm^3/cm^{-3} respectively. The result of the analysis shows that SAR with dual incidence angle and dual polarisation can be used for top soil moisture estimation at a finer scale with the error up to 5%.

Keywords

Soil moisture, SAR, RISAT-1, SMOS

Prediction of low flow using GRACE derived daily TWSA.

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Abstract

One of the most challenging jobs in Hydrology is to plan water management in low flow scenario. We need to understand the behaviour of the river basin in the recession flow when discharge from the basin is mainly controlled by the amount of water it stores. Measuring water storage in a comprehensive way beyond the point scale is a challenging task. The same has been resolved by the successful mission of NASA, i.e, "GRACE MISSION" which gives us information about total water storage changes occurring. TWSA (total water storage anomaly) data have been widely used for large river basin analysis. In our study, we have used GRACE derived daily TWSA for 30 mid-sized river basins in the United States. And we found a good relationship between the power law recession coefficient k (in -dQ/dt = kQ^α), Q being discharged at the basin outlet) and past average TWSA, which further has indications of predicting discharge from TWSA. The same was done by integrating power law equation. By knowing peak discharge of each recession event and taking α as 2, we predicted discharge in the recession period after six days of peak flow. The model efficiency was evaluated using Nash–Sutcliffe efficiency and coefficient of correlation, which is upto 0.58 and 0.66 respectively. This study shows that GRACE derived daily TWSA potential to predict low flow discharge.

Keywords

Daily GRACE derived TWSA, low flow, recession flow.

A framework for ensemble streamflow forecast using improved post-processed precipitation forecasts

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Abstract

In Canada, floods occur frequently along large river systems causing devastation to lives and infrastructures. One of the most common reasons for flooding in Canada is heavy rainfall during the snowmelt period. The flood forecast centers, responsible for providing flood warnings, rely heavily on the forecasted precipitation from the numerical weather prediction (NWP) model output from the Environment Canada and the National Oceanic and Atmospheric Administration. The uncertainty in NWP model output is enhanced by the physiography and orographic effects due to large diversity in landscape, especially in the Western catchments in Canada. Therefore a post-processing of NWP model output is necessary to obtain better forecast of rainfall amount, location, timing and intensity.

In this study, the performance of a Rainfall Post Processing (RPP) approach developed by Shrestha et al. (2015) in Australia is evaluated for improving the precipitation forecast in southern catchments in Alberta. The RPP relates raw quantitative precipitation forecasts and observed precipitation using a Bayesian joint probability (BJP) modeling approach followed by the Schaake shuffle. The precipitation forecast from two NWP models, the NCEP's Global Ensemble Forecasting System (GEFS Reforecast 2 project) and Canadian Meteorological Center's Global Deterministic Prediction System (CMC-GDPS) are analysed in this study. The study period spanning Jan 2012 to Dec 2015 covers a major flood event in Calgary, Alberta. Observed data was collected from the provincial River Forecast Center. Since the hydrological model need precipitation in subareas, the rain-gauge observations and forecast grid points are interpolated to obtain an aerial average precipitation in subareas. The BJP model is applied to the subarea observed and the forecasted precipitation. The success of RPP approach is evaluated by its ability to reduce the forecast errors, and to capture rare events well in advance. The generated ensembles of subarea-averaged precipitation forecasts are provided as input to a hydrological model based on Soil and Water Assessment Tool (SWAT). The generated ensembles of streamflow will be suitable for estimating the likelihood of occurrence of any future hydrological event and thus allowing water managers to prepare for the risks involved during low and high flow events, at least a few days in advance. The study is still underway and results will be presented at the conference.

Keywords

Rainfall post-processing, Precipitation forecast, Bayesian Joint Probability

Assessing Impact of Ridge to Valley Scenarios on Soil and Water Processes in relation to Land cover Seasonality

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Abstract

Water conservation and its management is considered as a highest prioritised Programme, by the Government of India. Integrated Watershed Management Programme (IWMP) is one of such programmes which is formulated to improve water conservation as well as Rural Development. Construction of water conservation structures and watershed development with ridge to valley treatment is the main aim of Rural Development. A Micro watershed, Prakasam-IWMP-36/2011-12 in the Prakasam district, Andhra Pradesh is selected as study area. Check dams, Percolation Tanks and Farm ponds are planned in the study area as conservation structures. The influence of the existance of these structures is analysed in the terms of hydrological parameters. A hydrological Model SWAT is used to obtain the essential outputs. These Hydrological outputs are obtained by incorporating the conservation structures into Land use. The respective seasonal change in the land cover is mapped for three seasons in a typical year. A SWAT Model is run separately for three seasons with variations in land use accordingly. The comparative studies of the three seasons are made to understand the significance of these interventions on the Hydrological Outputs.

Keywords

Water Conservation, SWAT, Hydrological Parameters, IWMP.

The effect of water resources management on uncertainties inherent in climate change impact studies – case study of the Lusatian river basins (Central Europe)

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Abstract

Climate change impact assessments are characterized by error/uncertainty propagation and amplification through the modelling chain of global climate to impact (e.g. hydrological) models. The potential of societies to cope with climate change impacts by managing water effectively is often not considered in hydrological modelling studies. Here, we investigated the influence of water resources management on discharge variability and uncertainty by combined analyses of observed flow records and model-based climate change impact simulations. The neighbouring watersheds of Schwarze Elster (Germany) and Spree (Germany and Czech Republic) serve as study areas. The watersheds are similar in terms of climate, topography and land use, but different in water resources management and reservoir storage capacities. Extensive water resources management takes place in the Spree River watershed including operation of seven large reservoirs (current total storage capacity of 94 hm^3), water diversions, feed-in discharge (mostly pumped groundwater) and withdrawals (for power plant operation) most of which are related to former and present lignite mining activities.

Variability indices formed the basis for historical flow records analysis (Parde Index, Richards-Baker-Flashiness Index, Interquartile Ratio and Baseflow Index). The climate change impact simulations were carried out using a model cascade of (i) the statistical regional model STAR, (ii) the hydrological model SWIM, and (iii) the water resources management model WBalMo. The STAR climate scenarios consist of 100 stochastically generated realizations which are based on three positive linear air temperature trends (+0K, +2K, +3K) and decreasing precipitation.

Our results reveal that the annual observed discharge variability is dominated by mining activities rather than natural rainfall-runoff processes in the Spree watershed. The large reservoir capacity of the Spree watershed reduces the discharge seasonality and short-term variability considerably. SWIM forced by the climate scenarios simulates a considerably reduction in mean annual natural discharge (-20% to –50% (2048-2052 compared to the reference period 1961-1990)) with only marginal differences between the watersheds. In the Schwarze Elster watershed, the managed discharges simulated by WBalMo are comparable to the simulated natural discharges in terms of annual means, distribution and seasonal variability. For example, the interquartile ratio of natural discharge at the outlet of the Schwarze Elster River is 1.3 compared to 1.6 for managed discharge (scenario STAR 2K, period 2048-2052 based on weekly values). In the Spree River, however, water management reduces the discharge variability as visible from an interquartile ratio of managed and natural discharge of 0.5 and 1.6, respectively (scenario STAR 2K, period 2048-2052 based on weekly values).

The results of the study imply that considering water resources management in model based climate change impact assessments reduces uncertainties and associated discharge variability. Watersheds with a high storage ratio are potentially are less vulnerable to changing climate conditions as periods of high and low natural discharge can be balanced more effectively. However, reservoir management alone can compensate changes in climate conditions only to a certain degree. Long term water availability and reservoir level reductions need to be addressed using a more holistic water resources management approach.

Keywords

reservoir management , mining, variability indice

The role of time scale in bias correction and its impact on hydrologic simulations

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Abstract

Regional climate model (RCM) output often requires bias correction before it can be used for climate change impact assessment studies. This has led to development of various bias correction methods. The bias correction techniques aims on the corrections of statistical properties of climate model data with those of the observations. However, the improvements of statistical properties of the data achieved are limited to the specific timescale chosen for the bias correction. Most of the existing methods use correction statistics derived using monthly data for correcting daily precipitation data. The main objective of the present study is to evaluate the effectiveness of bias correction at daily timescale compared to monthly time scale. In this study the existing bias correction methods of precipitation such as linear scaling, local intensity scaling, power transformation and distribution mapping methods along with the modified power transformation method is applied to daily precipitation data using monthly correction factors and daily correction factors on a daily time scale with a moving window approach techniques using a 31 day moving window approach. Further, to study the effect of time scale on bias correction method on generated runoff is investigated using hydrological model, Soil and Water Assessment Tool (SWAT) for current climate. The study is carried out in two watersheds; Achankovil and Vaippar basin which belongs to different climate zone. The performance of bias correction techniques were assessed by evaluating the quantile - quantile plots and Nash Sutcliffe efficiency. The performance of daily based correction methods was better than the monthly based bias correction methods. The modified power transformation method proposed in this study and distribution mapping method exhibited consistently good statistics among the models and watersheds compared. Further, the hydrologic simulations based on daily correction factors using distribution mapping method compared well with the simulations driven by the observed rainfall data for the watersheds compared.

Keywords

Bias correction, hydrological simulation, SWAT, RCM

An investigation on the frequency and intensity of extreme precipitation in Chennai city in the context of climate change

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Abstract

Urban flooding is common in most of the Indian cities due to inadequate drainage capacity and frequent occurrence of extreme precipitation events. Climate change is one of the major causes for changes in the frequency of extreme precipitation events. In the context of changing climate scenarios, the urban drainage infrastructures designed with the assumption of stationarity in climate needs to be revisited. General Circulation Models (GCM) projections are the major source of climate variables for studying future consequences of climate change. In this study, the future possible occurrences of extreme precipitation and their frequencies at Chennai city, are examined using GCM projections. The study considered precipitation projections from MOHC-HadGem2-ES model. The projections were statistically downscaled to the city scale for rcp2.6, rcp4.5, rcp6.0 and rcp8.5 scenarios, and Generalized Extreme Value (GEV) distribution was fitted to the downscaled extreme precipitation. The frequency analysis of the precipitation data indicated an increase in the frequency of future occurrences of extreme precipitation, and also a higher intensity as compared to historical precipitation. The results suggested that the rainfall in Chennai during December 2015 (348.1 mm/day), which caused a heavy flood, had a return period of 166 years. However, this 166 year event is expected to become 30, 31, 26 and 37 year event respectively under rcp2.6, rcp4.5, rcp6.0 and rcp8.5 scenarios. It is also noted that the design intensity of rainfall that is used to design drainage structures (currently 39 mm/h, 2 year event of 1 hour duration) has changed to 50 mm/h in the recent years (1969-2015), and may even increase to 54 mm/h in the near future under rcp4.5 scenario. Therefore, appropriate changes in the design values and procedures need to be taken up so as to make the city sustainable under the changing climate scenario.

Keywords

Climate Change, Extreme Precipitation, Downscaling.

Impact of projected climate change on sediment yield in the Chaliyar River Basin, India

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Abstract

Excessive sediment load in streams impair water quality due to increase in turbidity, making penetration of sunlight into the water difficult. This can adversely affect aquatic flora and fauna. Also, it will reduce the capacity of the river channel and increase chances of flooding. Streamflow and sediment yield can be affected by changes in climate. In this study, the sediment yield of the Chaliyar river basin in Kerala was estimated for the present climate conditions and future climate conditions using the Soil and Water Assessment Tool (SWAT). The model was calibrated and validated for sediment yield using observed data for the periods of 1990-1997 and 2001-2005 respectively. Future climate was obtained from the output of the regional climate model (RCM) REMO2009. Projection of sediment yield for the decade 2050-2060 under extreme RCP (RCP8.5) (Representative Concentration Pathways) and an intermediate condition(RCP4.5) was performed. Results of the study reveal that water quality would be adversely affected during the monsoon season (June-August) in the decade 2050-2060 as the concentration of sediments is showing an increase. This may be due to the occurrence of heavy precipitation events during the monsoon season due to climate change. Mitigation measures have to be adopted to prevent the negative impacts of increase in sediment yield on aquatic flora and fauna and also to reduce chances of flooding.

Keywords

Climate change, SWAT, RCP,sediment yield

Comparative analysis of SWAT model with Coupled SWAT-MODFLOW model for Gibbs Farm Watershed in Georgia

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Abstract

In recent years, rapid world population growth has led to increased water demand. For efficient water resource management, a clear understanding of the linkages between the Surface Water (SW) and Ground Water (GW) is essential. The most commonly used watershed scale SW model is the Soil and Water Assessment Tool (SWAT) while the most commonly used GW model is the Modular Three-Dimensional Finite-Difference Groundwater Flow Model (MODFLOW). SWAT does not simulate the distribution and dynamics of GW levels and recharge rates. The major drawback of integrating SWAT with MODFLOW is the conversion from SWAT's HRU's/sub-basins to grids for compatibility with MODFLOW. SWAT uses a one-dimensional empirical equation called Hooghoudt's equation for simulating base flow contribution. Many studies have integrated the SWAT and MODFLOW models successfully for comprehensive assessment of (SW-GW) water resources. By integrating these two models, the spatial and temporal patterns of the interactions are better captured and assessed. This paper demonstrates the comparison of results of the SWAT model with the newly developed SWATMOD-Prep, graphical user interface, that couples a SWAT watershed model with a MODFLOW groundwater flow model. GW levels in the surficial aquifer and stream flow were examined and tested for a seven-year period at the University of Georgia Coastal Plain Experiment Station Gibbs Farm watershed (115 ha) near Tifton, Georgia. Spatial and temporal patterns of SW-GW interactions were studied throughout the watershed by comparing the results of the SWAT model with the coupled SWAT-MODFLOW model. Both the models were calibrated with observed values to replicate the responses of the SW and GW interactions in a reasonable way.

Keywords

SWAT, HRU, SW, GW, MODFLOW, SWATMOD-Prep

Performance Evaluation of SWAT Model for groundwater variability analysis in Venna river basin of central India

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Abstract

Monitoring of groundwater level fluctuation is important for water resource management practices in a region. The objective of this study is to find out the performance of SWAT hydrologic model in groundwater level variability studies of a watershed. This study has been performed in Venna river basin Maharashtra, India. Groundwater level monthly data for calibration and validation was obtained from CGWB. Other data such as precipitation data from Indian Meteorological Department (IMD), soil data from NBSS-LUP, and weather data from National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) has also been used to run the SWAT model. The agreement of the model output groundwater level with observed groundwater level data was tested using RMSE R^2, PBIAS, and Nash Sutcliffe methods. Calibration has been done for the period 1995 to 2005 and validation for the period of 2006 to 2015. The result indicates that there is a good correlation between the SWAT- output and observed groundwater level data for the study region.

Keywords

Groundwater, SWAT, SWAT-CUP

SWAT-MODFLOW and an Optimization Model for Conjunctive Use of Surface and Groundwater of Nagarjuna Sagar Catchment

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Abstract

Low water use efficiency and groundwater overexploitation are threatening the sustainable development of the Khammam and Guntur districts. The major problem in the Khammam district is water scarcity, whereas Guntur district is facing the waterlogging problem. In the present study, hydrological modelling of Guntur and Khammam districts of South India along with Nagarjuna Sagar catchment releases has been carried out using Soil Water Assessment Tool (SWAT) for better understanding of hydrological regime of these regions. Model calibration and validations (R^2 and NSE) has been carried out using SWAT-CUP with the help of observed streamflow data. It is observed that there surface runoff in Guntur district shows high when it is compared to Khammam district. The integrated surface-groundwater model was then set up using SWAT-MODFLOW and an optimization model was developed to find optimal cropping pattern with and without the conjunctive use of surface and groundwater. This assessment is useful for water management strategies as the study area lies on left and right side of Nagarjuna Sagar and it belongs to different states of South India.

Keywords

Conjunctive use, Hydrological modelling, Management strategies, SWAT-MODFLOW, Optimization model.

Implementation of Solute Transport in the Vadose Zone into the 'HYDRUS Package for MODFLOW'

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Abstract

The 'HYDRUS package for MODFLOW' was developed by Seo et al. (2007) and Twarakavi et al. (2008) to simultaneously evaluate transient water flow in both unsaturated and saturated zones. The package, which is based on the HYDRUS-1D model (Šimůnek et al., 2016) simulating unsaturated water flow in the vadose zone, was incorporated into MODFLOW (Harbaugh et al., 2000) simulating saturated groundwater flow. The HYDRUS package in the coupled model can be used to represent the effects of various unsaturated zone processes, including infiltration, evaporation, root water uptake, capillary rise, and recharge in homogeneous or layered soil profiles. The coupled model is effective in addressing spatially-variable saturated-unsaturated hydrological processes at the regional scale, allowing for complex layering in the unsaturated zone. It can also consider spatially and temporarily variable water fluxes at the soil surface and in the root zone, and alternating recharge and discharge fluxes (Twarakavi et al., 2008).

One of the major limitations of this coupled model is that it could not be used to simulate solute transport simultaneously. Solute transport is highly dependent on water table fluctuations due to temporal and spatial variations in groundwater recharge. This is an important concern when the coupled model is used for analyzing groundwater contamination due to transport through the unsaturated zone. The objective of this study is to integrate the solute transport model (the solute transport part of HYDRUS-1D for the unsaturated zone and MT3DMS (Zheng and Wang, 1999; Zheng, 2009) for the saturated zone) into the existing coupled water flow model. The unsaturated zone component of the coupled model can consider solute transport involving many biogeochemical processes and reactions, including first-order degradation, volatilization, linear or nonlinear sorption, one-site kinetic sorption, two-site sorption, and two-kinetic sites sorption. Due to complex interactions at the groundwater table, certain modifications of the pressure head (compared to the original coupling) and solute concentration profiles were incorporated into the HYDRUS package. The developed integrated model is verified using HYDRUS (2D/3D) and analyzed for its computational time requirements.

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Keywords

HYDRUS-1D, MODFLOW, MT3DMS, Unsaturated and saturated soil zone

Integrating urban growth predictions and climate change for hydrologic assessment in Chennai basin

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Abstract

Urban expansion in Chennai basin significantly affect the hydrological components. The Chennai floods in 2015 imply the unguided and uncontrolled large-scale urban sprawl. Impact of urban growth on hydrological assessment provides insight for future water management at the basin scale. Under this background, the present study is aimed to predict urban sprawl in Chennai basin for 2036 using urban growth and land use model SLEUTH. The breed coefficient increased significantly indicating the organic growth within the watershed. Similarly, road gravity coefficient also increased progressively indicating the road influenced growth. The rate of increase of breed coefficient is more than the road gravity coefficient revealed that the urban sprawl of Chennai basin is more affected by new spreading center growth rather than edge growth during 2036. The projected land-use with IPCC A1B scenario climate change projections of CMIP5 data in SWAT model assessed the hydrological implications in the Chennai basin. The urban growth model simulated an increase of 23.4 % urban extent between 2016 and 2036 in the western part of the watershed. Simulation of the water balance components for the year 2036 compared with 2016 showed an increase of 17 % surface runoff which accounts for 35 mm during monsoon season due to the increased impervious area. The annual average runoff has increased from 450 mm to 700 mm due to effects of the increased impervious surface area typically result in higher peak flow and larger streamflow volume. There is also a reduction in the percolation water to the aquifer from 110 mm to 88.16 mm annually. The decline in the vegetative cover at the fringe of the basin showed a decreased evapotranspiration loss up to 15.2 mm per month. There is a drastic reduction in the groundwater flow to 21.01 mm from 96.08 mm. The study demonstrated that integrating projected urban extent along with climate change predictions on rainfall and temperature can pave the way for better planning and management of water resources in the Chennai basin.

Keywords

SLEUTH, Climate change, Chennai basin

Uncertainties in climate change projections – impact of model selection and methods

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Abstract

Climate change predictions are subject to various uncertainties. The choice of the climate models, bias correction method, emission scenario selection as well as the ecoregion of interest can cause different hydrological responses to projected future climate.

We analyse these uncertainties using data from the coordinated regional downscaling experiment (EURO-CORDEX), which currently provides the most advanced downscaled climate change scenarios for the European continent on an 11km-grid. All 16 combinations of available global circulation models with their respective regional climate models (GCM+RCM) for the two emission scenarios RCP 4.5 and 8.5 were processed. The resulting raw time series were corrected using four common bias correction (BC) methods. The 160 raw as well as bias corrected CORDEX combinations were then run in three well-calibrated SWAT models of three mesoscale catchment located in the lowlands, mid-range mountains and alpine region of central Europe.

Agreement of the hindcasted CORDEX simulations with simulations of observed historical climate were assessed comparing hydrological indicators of monthly means, magnitude, duration, rate, and timing of discharge events (IHA). Groups of best performing simulations were selected by minimizing the Euclidean Distance between the IHA.

The selected groups contained combinations from different GCM+RCM, BC and RCP in the different catchments, indicating that the one best performing combination does not exist. Despite this pre-selection, predictions of future changes for the 2050 and 2090 decades in the IHA still showed considerable uncertainties and needed to be tested for significance using ANOVA and Tukey tests. The results indicate an ecoregion-specific significant change in hydrological indicators, affecting both extremes and mean flows.

The study shows that robust climate change projections are only possible if the various uncertainties inherited in the choice of models and methods are considered and analysed.

Keywords

uncertainty, CORDEX, climate change, lowland, mountainous, alpine

Fuzzy Cognitive Mapping (FCM) application to Climate Change and Water Resources Engineering

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Abstract

Fuzzy Cognitive mapping (FCM) is cognitive based technique that model complex real life problems into a simplified mapping. Weights [varies from -1 to 1] inferred from the data collected are input to FCM. Resulting adjacency matrix is used as the basis to simulate possible scenarios as well as strength of chosen elements. FCM is applied to climate change and irrigation planning situations. In the climate change situation, suitability/stability of global climate model (GCM) is studied. Some of the factors considered in this process are surface temperature, population, precipitation, tidal waves, error in historic data, global warming etc. Interdependency between these factors in the form of connections are studied. Process was modelled using Mental Modeler software to capture knowledge that can be used for scenario analysis. Simulation helped to visualize how climate change is affecting the society as a whole.In the irrigation planning problem, total factors/ components chosen are 18 (that affect the efficiency of irrigation) such as crop productivity, employment opportunities, salinity, groundwater levels, environment, flora and fauna, aquatic etc. Challenges in implementing FCM is also discussed, namely, variation of the outcomes in terms of individual knowledge of expert, tedious process of collecting the information and possible improvements.

Keywords

Fuzzy Cognitive Mapping, Climate Change, Irrigation

Assessment of Streamflow Variability in Thamirabarani River Against Climate and Land-Use Change Dynamics Through Geo-Spatial Modelling Approach

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Abstract

According to the IPCC report, the global temperature may increase between 1.1° C to 6.4° C by 2100. Climate change is going to affect the developing countries like India rigorously, where large population depends on a climate-sensitive sector like agriculture which mostly depends on monsoon-driven water resources for their sustainability. Additional to climate change, the growth of population, rapid urbanization and socio-economic development often lead to an increase in water demand in last few decades. Impacts of land use and climate changes on the stream flow of river basins are the main concern. The assessment of the impacts of climate change and land use change on the water resources is highly relevant and prior knowledge required for water management adaptation and for the preparation of suitable mitigation plans, especially in regions with water scarcity issues, high climate variability and sensitivity, and a rapid socio-economic development.

The study area namely Thamirabarani river basin in Tamilnadu, Southern India experiences an increase in population, wasteland and loss of agricultural land and in terms of climate variables, increasing and decreasing trend in temperature and rainfall respectively. This research investigates the effect of Land Use and Land Cover (LULC) and the climate change on the water resource components of the basin and the future trends. CLUE-S model is used to simulate land use change, in space and time. Auto-Regressive Integrated Moving Average (ARIMA) time series model is used to analyze the temporal pattern of the climate data. Soil and Water Assessment Tool (SWAT) integrated with Geographic Information System (GIS) is applied to predict the future impact of the projected land use and climate changes on the hydrological component.

The results of ARIMA indicate that monthly precipitation predicted value increases in northeast monsoon and decreases in southwest monsoon. It also suggests an increase in annual rainfall by 108cm in 2018 and internal variability indicates a changed seasonal peak discharge. Time series analysis of temperature shows an increasing trend in temperature; increase in monthly average temperature during south-west monsoon and decrease in monthly average temperature during the northeast monsoon. Up to 2^0C increase in temperature is predicted for the year 2018.

The CLUE-S model is used to predict the land use as on 2020 with past land use data of 1996, 2006 and 2012 as input and validated with the land use data of the year 2006 and 2012. Here, agriculture land use area is predicted to decrease by 4.27%, while wasteland, built-up and wetland area were predicted to increase by 1.93%, 1.84% and 0.5% respectively, based on baseline data of 1996. Peak discharge has been estimated using GIS-enabled SWAT for years 1996, 2006 and 2012. When the land use change has been included in the model, it is found that there is a decrease of 12.4% as against 10.8% with climate parameters alone.

The analysis of model results indicates that predicted increase in precipitation will have a greater impact on streamflow than the predicted land use changes, but land use change also plays an important role because it can magnify these impacts. The result shows that the man-made land use change has a greater influence on the stream flow of the river basin. In addition, harvesting of surplus water during monsoon season could alleviate drought problems that may be occurred with a changing climate and land use.

Keywords

Geographical Information System (GIS), Climate Change, Land Use Change. SWAT, CLUE-s

Assess the Impact of Calibration Data Length on the Performance of SWAT Model

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Abstract

In the recent times, the researchers have focused on understanding the significance of variation in the climate (Wet and Dry periods) on the model performance and optimal parameters. Several studies have concluded that, the model performance can be significantly improved when only the data length representing the wettest or dry period are used for calibration. This raises the following questions, viz., (i) How the model perform, when the entire length of data available is used for calibration; (ii) what will be the effect of using Wet period data for calibration and it effect on validation under the drier condition; and (iii) How different are the model parameters when Dry period data used for calibration and its effect on validation under the wetter condition. The answer to these questions will help us to decide whether or not the future prediction should be carried out using the parameter values obtained from calibration against a historical period that is similar to the GCM's projections or parameter values from calibration against the entire historical dataset.

Here, the Malaprabha river basin which has data for 21 (1980-2000) years covering both wet and dry year hydrological and meteorological data has been selected for the study. The objectives of the study is (i) to gain insights into hydro-climatic behaviour of the model in dry and wet years which are the climatic extremes; and (ii) to understand the uncertainty of the model prediction. In order to achieve purpose set above, the SWAT rainfall-runoff model is used. The study used the following strategies; i.e., (i) the model was calibrated using the longer period of data; (ii) calibrated using the wet period data and validated for dry period data; and (iii) calibrated using the dry period and validated for wet period data. The calibrated model was used to project the runoff under different RCP's scenarios. The results indicated that, though the optimal model parameters are differing, the difference in runoff responses from different model calibration considered in the present analysis is likely to be small relative to the uncertainty/ range in the future rainfall projections.

Keywords

SWAT, Wet and Dry period, GCM, Malaprabha, calibration

A generalized methodology for identification of threshold for HRU delineation in SWAT model

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Abstract

Many hydrological models are developed considering simplified representation of the complex hydrological processes. Among those, Soil and Water Assessment Tool (SWAT) developed by the United States Department of Agriculture-Agricultural Research Service (USDA-ARS), is a widely used model. The model is physically based, computationally efficient and capable of continuous simulation over long periods. The distributed hydrological model, subdivides the watershed to sub watersheds and each sub watershed is then further divided into hydrologic response units (HRUs). The hydrologic response units are defined based on the land use, soil and slope. Since a large number of HRUs would end resulting in more computational time, they are minimized by a thresholding approach to finalize a reasonable number of HRUs in each sub watersheds. The threshold percentage of land use, soil and slope is subjective, as it is defined by the user. In the current HRU delineation practice within SWAT, the land use, soil and slope of the watershed, which are less than the predefined threshold will be surpassed by the dominating land use, soil and slope classes. This procedure of reducing the number of HRUs introduces some level of ambiguity in the computations in terms of inappropriate representation of the area. Therefore, the threshold values have to be chosen in such a way that the loss of information should be minimum, which is highly subjective to the purpose of the study. This research explored the effects of threshold values of HRU delineation on the hydrological modeling of SWAT on sediment simulations, and suggests guidelines for selecting the appropriate threshold values considering the sediment simulation accuracy. The preliminary study was done on Illinois watershed by assigning different thresholds for land use and soil. The proposed methodology was accomplished with a zero threshold run and would apply to any watershed irrespective of its diverse nature. Graphical guidelines are suggested for identifying an appropriate threshold for HRU delineation in SWAT model with minimal computational time and reasonable accuracy in the simulation.

Procedure for identifying the triggering point to dynamically vary the parameter values of a hydrologic model

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Abstract

Distributed hydrologic models are being extensively used for watershed modeling these days as they can account the heterogeneity of the catchment to a great extent. The large number of parameters that need to be calibrated, however, increases the complexity of the modelling. The various parameters may be representing a physical process that can have seasonal variability. However, most of the hydrologic models assume temporal invariability of the model parameters and their respective optimal values. This assumption, though, helps in reducing the computational burden, may compromise the ability of the model to extract information from the observed data having seasonal changes. In addition, the model may not simulate acceptable watershed responses during wet and dry seasons of the year if the same value for parameters is employed. Consequently, this study aims at developing a procedure for identifying the point of time (triggering point) at which the model needs to change the parameter values along the period of simulation. Considering varying values for parameters along the seasons in an year, may lead to a better performance of the model. A demonstrative case study is conducted using SWAT model considering the data pertaining to Mississinewa watershed, Indiana, USA. The seasonally sensitive parameters of the model are identified, and are varied during the four different seasons of the year considering the antecedent moisture conditions. The model is expected to simulate the high and low flows more accurately compared to the conventional method of using a single set of parameter values for the entire simulation.

Keywords

Dynamic variability, triggering point, SWAT parameters

Sediment yield Modeling with Parameters Sensitivity Analysis of a River basin using SWAT Model.

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Abstract

Generally due to sparse data, and uncertainty in climate (e.g.rainfall and temperature), accurate prediction of hydrologic parameters in a mountainous river basin, highly depends on how well spatial input data describe real and relevant characteristics. With the significant development in hydrologic modeling, such as Soil and Water Assessment Tool (SWAT) model, the over-parameterization is usually a critical issue in the calibration process. For a trained hydrologist, it requires too much time with good knowledge of the relationship between model parameters and physical characteristic of the river basin.To deal with this problem, global sensitivity analysis methods are developed which can reduce the number of parameters to be adjusted during calibration and simplify the use of the model. The objective of this study is to perform a sensitivity analysis for sediment yield in a small mountainous river basin, located in Western Ghats India using the SWAT model for simulation withSWAT-CUP for calibration. Calibration of sediment yield facilitated by sensitive analysis was performed for the period of 1995 to 2000. Initially, the simulation run in SWAT underestimated values of peak sediment yield. However, the peaks were minimized and minimum sediment yield was adjusted to the observed sediment yield after global sensitivity analysis.The multi-objective functions were used to evaluate the model performance. The Nash-Sutcliffe efficiency (NSE), coefficients of determination (R^2) and percentage bias (PBIAS) were obtained as 0.79, 0.95 and 10.24 respectively for sediment yield. The simulation results revealed that among eleven selected parameters for sediment yield, curve number (CN2), USLE equation support parameter (USLE_P), Base flow alpha factor (day) (ALPHA_BF), USLE soil erodibility factor (USLE_K), Average slope steepness (m/m) (HRU_SLP), Linear parameter for calculating the maximum amount of sediment load that can be re-entered during channel sediment routing (SPCON), Manning's "n" value for the main channel (CH_N2) was found to be most sensitive parameter. The sediment parameters from the landscape are more sensitive in comparison to channel parameters.

Keywords

Sensitivity analysis, SWAT, SWAT-CUP, sediment yield

Effect of spatial and temporal discretizations on the simulations using constant-parameter and variable-parameter Muskingum methods

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Abstract

Though it is well-known in the literature that flood wave movement is a nonlinear process, many process-based models used for catchment runoff simulations still employ linear theory based models for runoff simulations. The focus of this study is concerned only with one of the component processes, namely, the channel routing component using the Muskingum method. The proposed study is relevant for improving those process-based hydrological models, which employ a constant parameter Muskingum method for modelling channel routing, by advocating the use of a mass-conservative variable-parameter Muskingum method. It is pertinent to point out that the SWAT model employs the linear Muskingum method as one of the channel routing models with its constant parameters estimated based on Cunge's diffusion analogy theory. Perhaps the reason behind the use of a constant parameter Muskingum method over the available nonlinear process based variable-parameter Muskingum methods could be due to the problem associated with the conservation of mass by such models. While the former method is invariably volume conservative, the latter is not. However, the mass-conservative variable parameter simplified routing methods reported in the current literature overcome this deficiency

The objective of this study is to explore the impact of spatial and temporal discretization on the routing simulations of constant-parameter and variable-parameter Muskingum methods. The mass-conservative variable-parameter McCarthy-Muskingum (VPMM) method proposed by Perumal and Price (2013) is used for this study. The VPMM method has been developed directly from the Saint-Venant equations and its development adheres to the theory proposed by McCarthy in 1938, namely, that the reach storage consists of prism and wedge storages. The same method is used to arrive at the constant parameter Muskingum method by estimating its two constant parameters using a reference discharge. The study uses hypothetical channels and a given hypothetical inflow hydrograph for arriving at the benchmark solutions as well as the simulations using the considered candidate methods. The benchmark solutions were obtained using the HEC-RAS model. The numerical experiments deal with the routing of a four-parameter Pearson type distribution in ten trapezoidal channels for a reach length of 40km. Each of the ten channels are identical in shape and size, but characterised by a unique set of Manning's roughness coefficient and bed slope values. A preliminary investigation carried out with the considered objective shows that the routing solution obtained using a longer routing time interval induces significant numerical diffusion of the routed hydrograph leading to over attenuation of the inflow flood peak and, thereby, resulting in poor reproduction of the benchmark solution. Further details will be reported in the full paper.

Keywords

Muskingum, Routing, discretization

Incorporation of GIUH into the SWAT model

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Abstract

In this study, the incorporation of flood computation using Geomorphological Instantaneous Unit Hydrograph (GIUH) into the SWAT model is carried out. Different morphological parameters like bifurcation ratio, length ratio, area ratio, travel time parameters, path probability are required for the computation of GIUH ordinates and are estimated. Further, GIUH and corresponding unit hydrograph ordinates were also calculated. These are saved as text input along with the SWAT text input-output folder. SWAT source code is then modified to read this input data on an hourly scale and incorporate the convolution part utilising the rainfall excess available from the surface runoff module using Green Ampt method. Additional three subroutines are added to the SWAT for this purpose. In addition, a few more changes were carried out in already existing subroutines. Further, the simulations were carried out to see whether the SWAT can be utilised as an event model. A few events of Manali Watersheds of Kerala were selected for the application. From the application of the model in different events, the performance of the modified SWAT model is marginally better than that from the original SWAT model. In these applications, the proper distributions of rainfall within the basin are not taken into account, owing to lack of sufficient spatially distributed data. Hence the performances are to be further evaluated by utilising spatially distributed rainfall data.

Keywords

GIUH, model development, Event model

Streamflow Routing in Perspective of Muskingum Scheme

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Abstract

In this current study, Muskingum scheme i.e. Muskingum Routing Scheme (MRM) used in the SWAT model is being compared with a less parametric Muskingum scheme. The Muskingum scheme proposed by Perumal and Price (2013) also known as Variable Parameter McCarthy-Muskingum (VPMM), has an advantage of inherent physically based routing parameters while accounting for the nonlinear characteristics of flood wave movement in steep, intermediate and small slope channels and rivers, although having the limitation of the inflow hydrograph being characterized by the criterion $(1/So)\partial y/\partial x<0.5$, where $\partial y/\partial x$ denotes the slope of the longitudinal water surface gradient. A watershed in the Vansadhara basin of the Odisha state in India is studied to demonstrate the routing capability of the VPMM scheme in comparison with the MRM scheme using measures of evaluation like the Nash-Sutcliffe efficiency (NSE), coefficient of determination (R^2). The NSE estimates for VPMM and MRM routing schemes for the calibration and validation period are estimated to be 0.89 and 0.92, and 0.72 and 0.71, respectively; similarly, the R^2 estimates for VPMM and MRM routing schemes for the calibration and validation period are estimated to be 0.89 and 0.93, and 0.71 and 0.70, respectively. As the VPMM model has less calibration parameter along with sound physically based routing structure, it may be suitable for incorporating in the SWAT model with the current MRM scheme which suffers the problem of over-parameterization. Moreover, the estimation of stage along with discharge in the VPMM scheme may also enhance the utility of SWAT model for sediment transport, in-stream nutrient and other such operational purposes.

Keywords

Soil and water assessment tool (SWAT); Variable parameter McCarthy-Muskingum (VPMM); Muskingum routing method (MRM); Vansadhara basin; Streamflow

A Bivariate SWAT-Copulas-based Approach for Detection of Agricultural Drought Year in a Tropical Canal Command

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Abstract

Since drought is a natural disaster that causes significant loss to society and the agrarian economy, detection of drought period is very important for different drought management strategies involving irrigation scheduling, canal scheduling and reservoir operation. For estimation drought, although there are a number of drought indices, viz., univariate Standardized Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI), Palmer Drought Severity Index (PDSI), and Soil Moisture Stress Index (SMSI) existing in the literature, they are not fully effective for early warning and onset detection of drought events due to the scarce-knowledge of interdependency among the drought-causing factors. As an indirect method, the hydrological Soil Water Assessment Tool (SWAT) alone cannot be used for drought assessment. Hence, in this study, the SWAT is coupled with the multivariate copulas to effectively predict the drought years. The specific objectives of this study are: 1) To develop a multivariate standardized drought index (MSDI) using SWAT-copulas based approach by combining SPI and SMSI to predict the agricultural drought year in the study area; and 2) To inter-compare the performances of the MSDI and SPI based drought indices considering the observed datasets.

The developed approach is tested in the Kangsabati River basin (12,014 km^2) having about 48% of area under paddy land use. The SWAT model is setup for the study area at daily time-scale with the Nash-Sutcliffe Criterion (NSC) of 0.60 and R^2 of 0.60 during the calibration period. The 32 years (1979 – 2010) time series data of the soil moisture and streamflow are extracted from the SWAT-simulated outputs for the upstream catchment area of the Kangsabati reservoir, and for the command areas of the left bank feeder canal (LBFC) and right bank main canal (RBMC). The SPI and Standardized Streamflow Index (SSI) are calculated for all the selected areas at four time-scales of 3-months, 6-months, 9-months and 12-months using the time series data from 1982 - 2010. For identification of drought year, the multivariate distribution of SPI and SMSI are constructed using the members of Archimedean copula family. Out of all the members of copula family, Frank copula gave the best joint probability distribution function. Subsequently, the hydrological fluxes of evapotranspiration, deep aquifer recharge and shallow aquifer recharge are derived at annual time-scale from the SWAT model simulation for both the LBFC and RBMC. When analyzed with the 12-monthly MSDI value, all the three hydrological fluxes show a very good agreement during the drought period. The MSDI is capable of identifying nine drought years out of 11 observed drought years with very good accuracy; whereas the SPI-based approach could predict only five drought years successfully. Hence, the results reveal that the developed SWAT-Copulas based approach has the potential to be implemented in data-scarce regions for effective drought monitoring with the minimum observed inputs.

Keywords

Agriculture; Copulas; Drought index; MSDI; SWAT

Uncertainty in calibration of large-scale watershed models

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Abstract

A few issues are hindering calibration of large-scale watershed models by substantially increasing prediction uncertainty. These include increasing availability of input databases for soil, land use, crops, and climate, and existence of different calibration algorithms and objective functions. Multiple database are now available from different sources for the same region. As the correct database is not known, their impact on model outputs has largely been ignored. Furthermore, there are many different calibration/uncertainty analysis algorithms that could be run with different objective functions. In this talk, I highlight the fact that each combination of optimization algorithm-objective functions may lead to a different set of optimum parameters, while having the same calibration performance. This makes the interpretation of dominant hydrological processes in a watershed highly uncertain.

How to improve the representation of Nitrate processes and their temporal patterns

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Abstract

Nitrate is one of the most important nutrients in predominantly agricultural catchments. Its excessive presence can result in serious negative impacts on water resources and ecosystems. Mostly, agricultural activities are responsible for this water quality degradation by nitrates due to intensive fertilization and cattle grazing. This is currently a relevant topic in many countries.

The transport of nitrate and its transformations are influenced by many interacting processes. Acknowledging current research in hydrological consistency, the different hydrological and nutrient processes need to be considered at the same time in the model calibration. To achieve this, a two-step procedure is provided consisting of a temporally resolved sensitivity analysis of discharge and nitrate parameters and a joint multi-calibration of discharge and nitrate. For these analyzes, the ecohydrological model SWAT is used in an agricultural dominated catchment (Treene river, Northern Germany). A better understanding of the modelled nitrate processes can be achieved by analyzing the temporal variations of dominant nitrate parameters with a temporal parameters sensitivity analysis (TEDPAS). TEDPAS provides daily sensitivities for the nitrate parameters. The temporal sensitivity analysis shows that the dominant parameters vary in the annual cycle due to seasonal varying dynamics in nitrate transport and plant uptake. Following an improved understanding of dominant nitrate parameters and related processes, a new calibration method is proposed which takes all relevant processes controlling nitrate loads into account. For this, a nitrate duration curve (NDC) is constructed and used in addition to the flow duration curve (FDC) in the calibration method. Separate performance metrics are calculated for five segments of FDC and NDC to examine the different magnitudes of discharge and nitrate loads separately. Through this separate assessment of discharge and nitrate segments, a model run is detected that represents all phases simultaneously well.

The combination of a better understanding of the modelled nitrate processes by a temporal parameter sensitivity analysis and an adequate representation of all processes through a segmented calibration of discharge and nitrate leads therefore to a better control of how nitrate dynamics are represented in models.

Keywords

Nitrate simulation, temporal sensitivity analysis TEDPAS, advanced calibration techniques

Development Efforts in Soil Hydrology and In-stream Water Quality

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Abstract

Appropriate mathematical representation of ecohydrologic processes is critical to providing results that can be used to understand those processes and to make effective watershed management decisions. Continued developmental efforts are necessary to improve model skill in parallel with advances in conceptual and practical understanding of the natural and anthropogenic processes being modeled. We have identified two key processes in the SWAT model for potential improvement, including 1) soil water hydrology and 2) instream water quality. Currently, SWAT simulates soil water movement utilizing a reservoir cascade scheme, whereby soil water is transported only when a threshold storage is exceeded. Alternatively, we have developed new approach that defines soil water movement as a function of the degree of saturation of the soil profile using established concepts from Richards equation. The approach was tested in two experimental watersheds, the Little River (GA, USA) and Cedar Creek (IN, USA), where results were compared to observed soil moisture measurements. Results indicate that choice of soil hydrology scheme can greatly impact model predictions beyond accuracy in capturing soil water dynamics and underscores the importance of soil water effects in not only hydrologic, but water quality predictions. In terms of improving the stream water quality sub-routines in SWAT, we have developed a new model using knowledge from existing solute transport models. The model incorporates important in-stream processes (advection, dispersion, transient storage exchange and biochemical reactions) affecting the fate of nitrogen, phosphorus and algae. Tracer tests were conducted in Kielstau Catchment (Germany) to validate the model with the field data. Efforts are also being made to generalize the model over a wide range of streams by avoiding reach-specific parameter calibration. Preliminary results indicate that the model can simulate nutrient processes and solute breakthrough curves with a reasonable accuracy. We plan to incorporate this improved in-stream model into SWAT for enhanced water quality predictions at watershed scale. Overall, we anticipate that potential improvements in soil hydrology and instream water quality will provide more representative predictions to allow increased confidence in modeling as a decision support system for managing and mitigating negative environmental impacts.

Keywords

Soil moisture, hydrology, in-stream processes, water quality

SWAT-DEG App- A Cloud Based Tool for Headwater Streams

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Abstract

A simple small watershed hydrologic model for assessing the time rate of degradation and channel widening was developed based on the architecture and inputs of the SWAT Model. This model allows continuous simulation of small watershed (< 20 sq. km.) water and sediment budgets including channel erosion and changes in channel morphology (width, depth, slope), and water budget output including, soil moisture, infiltration, lateral flow, deep percolation, evapotranspiration, surface runoff, and baseflow. The model runtime is fast which allows for decadal impacts of various land use changes to be assessed in a matter of minutes. Output includes time series graphical or tabular summations on a daily, monthly or annual basis, as well as flow duration curves. To facilitate use of the model, the model has been incorporated into a cloud based platform (eRAMS), which enhances use, facilitates model updates as well as offers other symbiotic data analysis and geospatial tools for watershed assessment.

Modelling stream flow rate and sediment concentration for Seonath Subbasin using Arc-SWAT model

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Abstract

This research study deals with the major aim to test and apply a hydrologic and water quality model to simulating stream flow rate and sediment concentration with least uncertainty among the parameters. Soil and Water Assessment Tool (SWAT) model integrated with Geographic Information System (GIS), known as ArcSWAT was used to simulate the stream flow rate and sediment concentration of Seonath subbasin of upper Mahanadi basin for the period from 2003 to 2013. Model was calibrated and validated on monthly basis for simulating the discharge and sediment concentration. Other than climatic parameters, most of the input parameters were extracted automatically using ArcGIS which is integrated with the model and by providing different thematic maps. The calibration results of the model showed the very good performance for the simulation of monthly flow rates and sediment concentration for the years from 2003 to 2009. The calibration results for simulating flow rates were found to be satisfactory since Nash-Sutcliffe coefficient (E_{NS}), PBIAS, coefficient of determination (r^2), Modified Nash-Sutcliffe coefficient (E), Index of Agreement (d) and Modified Index of Agreement (d1) were found to be 0.78, 13.28, 0.893, 0.67, 0.961 and 0.82, respectively. Also a good model performance for sediment concentration was found for validation period i.e. from 2010 to 2013 with E_{NS} = 0.889, d = 829, PBIAS = 5.586, r^2 = 0.814, E = 0.897 and d1 = 0.942. During validation period for monthly time step E_{NS} = 0.91, PBIAS = 9.14, r^2 = 0.930, E = 0.69, d = 0.97 and d1 = 0.84 was found to be very good for flow rates. Similarly, for sediment concentration E_{NS} = 0.92, PBIAS = 5.9, r^2 = 0.979, E = 0.89, d = 0.91 and d1 = 0.90 was found, which indicate very good model performance. On the basis of results of this study it can be concluded that the ArcSWAT model can simulate stream flow rate and sediment concentration accurately and can be applied for effective planning and management of soil and water resources of Seonath subbasin.

Keywords

ArcGIS, Hydrologic modeling, ArcSWAT, Sediment concentration, Stream flow.

Simulation of Nitrates Pollution in Agricultural Watershed

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Abstract

Agricultural usage of fertilizers is one of the prime factor for Nitrates pollution in watershed. As the runoff moves, it picks up and carries away excessive nitrogen which remained, finally deposition them into lakes, rivers, wetland, coastal waters and ground waters. The Nitrates pollution in water resources has become a major problem in recent years due to more human interactions to natural landscapes. The focus of the present work is the assessment of Nitrates concentration in the surface water flow of Munneru watershed, a sub-basin of Krishana River, located in Andhra Pradesh, India. SWAT model is used to simulate the pollutants due to fertilizers usage in the agricultural watershed to the sub watershed level. The R^2value for runoff and Nitrate are 0.81 and 0.56. Whereas the NSE value for flow and Nitrate are 0.88 and 0.68. Based on the observations from simulations, flow during the August increase tremendously than June and July months. It is observed that maximum nitrate concentration can be seen in monsoon months such as August, September and October months due to excessive flows and flooding condition in various parts of the watershed. Nitrates also presented more in November month which is harvesting season for the watershed.

Keywords

Nitrates, SWAT, Watershed, Simulation

Application of SWAT for the modelling of sediment yield at Pong reservoir, India

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Abstract

The estimation of sediment yield from watershed is very important for ascertaining the useful life of reservoir for meeting its intended purposes. The sediment process in a watershed is highly random and depends upon the characteristics of basin and river which include climate, land slope and topography, land cover and pattern of land use. The sediment yield can be modelled efficiently by Soil and Water Assessment Tool (SWAT) provided all required data are available. SWAT is a conceptual, time continuous and physically based simulation model to model the discharge, sediment yield and water quality. The modelling capability of SWAT for the sediment yield from Beas Catchment up to Nadaun bridge (Pong reservoir) is presented with the input data available from different sources such as NASA, National Bureau of Soil Survey and Land Use Planning (NBSSLUP) and NRSC. Grid based meteorological data such as daily rainfall, minimum and maximum temperatures are obtained from Indian Meteorological Department (IMD) and European Centre for Medium-Range Weather Forecasts (ECMWF) (ERA Interim data). The parameters of SWAT for the modelling discharge and sediment yield are calibrated manually (trial and error method) by considering the data from 1993 to 1996 for calibration and 1999 to 2002 for validation. The coefficient of determination for simulation of sediment yield during calibration and validation are 0.95 and 0.92 respectively. The results clearly demonstrate the capability of SWAT for simulating the sediment yield at Pong reservoir.

Keywords

Watershed, sediment yield, SWAT, Beas catchment, Pong reservoir, India

Development of a near real time hydrologic modelling system for India based on ensemble of SWAT model simulations

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Abstract

Estimation of hydrological fluxes such as evapotranspiration, surface runoff and baseflow play a major role in redistributing the water over space and time. Assessing water availability across the country on a regular basis is useful in water resources planning and management. In this context, the study is proposed to develop a hydrologic model in SWAT modeling framework to compute water balance components such as surface runoff, soil moisture, percolation and streamflow, etc. The output of the model is helpful in monitoring and identifying the extreme hydrological conditions in the country. It is proposed to develop the SWAT model for the entire country at three different spatial resolutions: 1) 9min (16.5km) 2) 3min (5.5km) and 3) 1km. The SWAT model will be set-up in a gridded architecture with each grid simulated as a sub-basin. For the 9min and 3min resolutions, every grid will be simulated with multiple hydrologic response units (HRU's). For the model set-up at 1km resolution, each grid (sub-basin) will be modelled with a single dominant HRU within the grid. The surface water will be routed between the grids based on the digital elevation model conditioned using the stream network of India developed for India-WRIS. SWAT has a crop growth model embedded within the hydrologic model. It is proposed to make use of the district wise crop calendar developed by the National Sample Survey Organization (NSSO). Based on this and the NDVI seasonal profile (MODIS 16-day composites) grid wise approximate planting dates and harvest dates can be identified. It is proposed to use an automated algorithm based on Lagrangian interpolation to derive crop phenological stages at regional scale. These dates along with the crop details from NSSO can be used to set-up the crop growth model within SWAT for every grid across the country. It is proposed to calibrate every single grid (sub-basin) across the country using the energy balance actual ET from MODIS (MOD16) and surface soil moisture from AMSR2 and comparing it with SWAT estimates within a recursive autocalibration framework. This autocalibration framework will help us in arriving at a suite (range) of sensitive model parameters and their different combinations (for every grid) that give us the same level of acceptable performance (e.g. R2 > 0.7 or Nash-Sutcliffe E > 0.6). Hence, it is possible to arrive at a set of parameter combinations (say 25 acceptable parameter realizations that give us a similar level of model performance) which can be used to get an ensemble of model output (Surface runoff, ET, soil moisture, percolation and streamflow). These ensembles will help us to provide an uncertainty band around the median simulation to help us improve the confidence in the model results. Further, ingesting in-season satellite data based geo-physical data sets, such as, NDVI, Vegetation Fraction, Soil moisture would account for seasonal variations in parameterization leading to improved water balance components estimations supporting water management decisions.

Keywords

Hydrological Fluxes, Gridded SWAT, Crop Phenology, Ensemble simulation, autocalibration

Application of Remote Sensing derived land surface information to enhance implementation of management practices in SWAT

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Abstract

Soil Water Assessment Tool (SWAT) is a physically based, daily time step hydrologic model capable of simulating the complex hydrological processes and water balance at regional scale. In the case of watersheds dominated by agriculture, in addition to the degree of calibration, the effectiveness of SWAT simulations will be decided by the extent to which the unique land cover and management practices are represented at the scale of individual Hydrologic Response Units (HRUs). Conventional methods of acquiring land management related information through field scale surveys, cropping related reports etc., are appropriate for model simulations at a field scale. However at a regional scale where individual HRUs represent distinct agricultural practices and cropping schedule, field based data collection techniques will not be able to capture the spatial and temporal information related to crop/ land management. In this context time series of data acquired from remote sensing satellites can be employed to extract distributed crop phenological information that are crucial for parameterization of SWAT. The proposed study utilizes time series of Moderate Resolution Imaging Spectroradiometer (MODIS) derived Normalized Difference Vegetation Index (NDVI) composites from 2000 – 2015 at 250 m. An automated algorithm based on Lagrangian interpolation is used to derive crop phenological stages at regional scale. The smoothened NDVI profile of agricultural pixels is processed to get the derivative values. The maxima and minima of the derivative values are analysed to get the sowing and harvesting dates for each pixel. The results are verified with ground truth information and the feasibility of the methodology is assessed at Krishna basin, South India.

Keywords

SWAT, Crop Phenology, MODIS and NDVI

Improved ensemble representation of soil moisture in SWAT for data assimilation applications

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Abstract

Soil moisture is one of the essential climate variable. Although it holds negligible part of overall water cycle on earth, its small fluctuations greatly impact the underlying ecology and agriculture. Traditionally the soil moisture across larger areas is being estimated by running hydrological models. These estimates are often erroneous due to errors in the input forcing including rainfall and temperature and model parameter uncertainties. Another way of estimating the spatial variation of surface soil moisture is from satellite based retrievals. However, these estimates are insufficient because these are limited to top 5 cm only. Therefore, while using these products for assimilation in hydrological models, appropriate ensemble representation of soil moisture forecasts is a major concern. In order to overcome this issue, in the present study, a new approach for appropriate ensemble representation of soil moisture forecasts in SWAT hydrological model framework is demonstrated. The new approach is based on the perturbation of soil moisture field capacity in SWAT without altering the model physics. The results indicate that the proposed approach can represent soil moisture ensemble in more realistic manner than running the ensemble model run with static model parameters.

Keywords

Data Assimilation, SWAT

Hydrological modeling of a semi urbanized catchment with limited data availability using SWAT model

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Abstract

The Adyar river is one of the two important rivers flowing in the heart of Chennai metropolitan city. The Chembarambakkam reservoir located in the Adyar river basin is the major drinking water contributor to the city. The Chennai city receives around 1200 mm of annual rainfall but still faces water scarcity during summer. The objective of the study is to analyze the hydrology of the Adyar river system and estimate the water balance of the catchment which can be helpful in the water resources management. The land use land cover changes during analysis period have been accounted in the analysis. For calibration and validation of the model, the Chembarambakkam reservoir data from 2003 to 2007 and 2008 to 2016 were used respectively. The Chembarambakkam sub catchment is validated and the parameters have been distributed to other parts of the catchment and the model results shows good tendency towards the approach. Based on the results, suggestions to improve the basin hydrology are derived. Based on the hydrological analysis and the simulated hydrological response of the catchment, the surface water-groundwater interaction were recognized for the future study, which in turn useful for simulating the surface water and groundwater dynamics of the hydrological system using SWAT-MODFLOW.

Keywords

hydrological modeling, SWAT, land use change

Comparative study of Evapotranspiration estimation using SWAT model and MODIS NDVI data

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Abstract

Evapotranspiration on the earth's surface cannot be predicted directly and exactly to estimate the water and energy balances. But it is very important to estimate evapotranspiration for the purpose for various hydrological models, management of water supply for irrigation and water and energy balance estimations.In the present study, the evapotranspiration estimation has been carried out using SWAT model and it has been compared with evapotranspiration obtained from MODIS NDVI data. SWAT requires various parameters which are required to be considered while estimating the potential and actual evapotranspiration, such as precipitation,soil moisture content and land use pattern. In SWAT, three methods have been used to estimate the evapotranspiration viz. Penman Monteith method,PriestleyTaylor method and Hargreaves method.Remotely sensed MODIS NDVI data has been used for the estimation of spatial evapotranspiration. MODIS NDVI data and MODIS images over the study area were obtained.The relationship between actual evapotranspiration estimated from MODIS NDVI data and evapotranspiration calculated from SWAT were correlated with some coefficients.The results of this paper may be tested and utilized under different environmental conditions and different land use patterns.

Keywords

Evapotranspiration, MODIS NDVI Data, SWAT model.

Runoff Prediction in the Ghataprabha Subbasin using Hydrological Model SWAT

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Abstract

Efficient Water Management is an important factor for regional development and requires a set of actions in order to manage water resources in a sustainable way. Ghataprabha sub-basin is selected as the study area, which covers an area of about 8829km^2 located between latitude of 16.25N and longitude of 74.75E in a Krishna river-basin. This paper describes a methodology of water resources exploitation, with the potential of creating small watersheds and reservoirs. This can be done with the integration of Geographic Information Systems (GIS), using the Soil and Water Assessment Tool (SWAT) hydrological model including Reservoir operation. The various data used for execution of SWAT model viz. Digital Elevation Model (DEM), Land use Land cover, Soil, Meteorological data etc. The Multisite calibration and validation for the basin carried out with SWAT-CUP using four discharge gauges from 1981-2005 on daily basis and the model performance checked with statistical measures such as coefficient of determination (R^2) and Nash-Sutcliffe efficiency (NS). The future downscaled results from GCM model BCC CSM 1.1 for the four future scenarios of RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5, are used in the SWAT model for prediction runoff from 2021-2100. The model results which helps in understanding the changes in runoff for the future time period and to manage the water resource objectives.

Keywords

Ghataprabha Subbasin, Geographic Information System, Runoff, SWAT, SWAT-CUP.

Evaluation of SWAT for modelling the water balance and water yield of Yerrakalva river basin, A.P.

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Abstract

The knowledge of water balance and water yield of a river basin is an indispensable prerequisite in the sustainable management of water resources at basin level. The components of water balance of a basin are influenced by climate, the physical characteristics of the watershed such as morphology, land use and soil. Therefore, understanding the relationship between these physical parameters and hydrological components is necessary to assess the hydrologic response to climate and land cover variability in determining the water availability. Major hydrological processes can be quantified with the help of a water balance equation. Since the hydrologic processes in a natural watershed are very complex, watershed models are widely used for proper comprehension of water balance components. The watershed models partition rainfall into various hydrological processes such as surface runoff, evapotranspiration, percolation, lateral flow and base flow etc. with the constraint to account for all water entering, leaving and being stored in a catchment. This adaptation of the principle of conservation of mass constrains the potential for error.

In the present study, SWAT was used to quantify and analyze the annual water balance and water yield of the Yerrakalva river basin located in Andhra Pradesh. The hydrologic cycle simulated by SWAT is based on the water balance equation. Also, it uses physically based inputs such as weather variables, soil properties, topography, land use characteristics and land-management practices occurring in the catchment. The model was calibrated and validated for daily river flows at Ananathapalli G-D site (1662 sq km) which is located downstream of Yerrakalva reservoir. Since the flows at G-D site are regulated by the reservoir, the reservoir is also incorporated in the model to take into account the effect of reservoir on flows at G-D site. The results exhibited fairly good agreement between observed and simulated daily values with coefficient of determination (R^2) of 0.65 and Nash–Sutcliffe coefficient (E_{NS}) of 0.64 for calibration and 0.62 and 0.62 respectively for validation. The monthly values, aggregated from daily values, indicated a very high performance with R^2 and E_{NS} of 0.98 and 0.95 for calibration and 0.87 and 0.87 respectively for validation. Overall, the model demonstrated good performance in capturing the patterns and trend of the observed flow series, which confirmed the appropriateness of the model for future scenario simulation. The water balance components namely, surface runoff, lateral flow, base flow and ET were computed as 16.6%, 3.1%, 22.4% and 55.7% of average annual rainfall during calibration and 16.2%, 2.8%, 19.5% and 56.9% respectively during validation. The annual water yield was computed as 580 mm (41.8%) and 536 mm (38.3%) during calibration and validation respectively. The study suggests that SWAT model, embedded in GIS environment, is highly prospective in its usage as a tool to support policies and decision making for the sustainable water management at basin level.

Keywords

SWAT, Water balance, reservoir, Calibration

Impact of Climate change on the hydrology of Ponnaniar Reservoir system using SWAT

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Abstract

Ponnaniar dam has been constructed across Ponnaniar river, a tributary to Cauvery at longitude 78° 16'20" E and Latitude 10° 34'55" N in Manapparai Taluk in Trichy district during the period 1970-74. Ponnaniar river originates from Kadavur hills and after running for 32km towards east, it reaches the Koraiyar river on its right near its confluence with Cauvery.

The hydrology of the Ponnaniar Reservoir system was studied in a detailed manner during the last year. The rainfall, inflow, outflow, releases from the reservoir, cultivation details etc were collected and analysed and found that:

In respect of rainfall

- Out of 39 years of the data collected, 11 years experienced normal rainfall, 12 years had excess rainfall and 13 years received deficit rainfall.
- No definite periodicity is observed, but, raising and falling epochs are observed in the collected data.
- After 2000, in a span of 12 years (from 2000 to 2012,) deficit rainfall is experienced in 7 years.
- Worst drought hit was experienced during 1980, 1990, 2000 to 2003, 2006, 2012 and 2013.
- For 12 years, the rainfall was more than 1000 mm.
- The South West monsoon is having a declining trend and especially after 2000, the contribution of South West Monsoon to agricultural activities has considerably reducing.
- The North East Monsoon at the same time is having an upward trend there by contributing to the agricultural activities.
- These are also established in the number of rainy days of the irrigation system.

In the case of inflow into the reservoir,

- The inflow into the reservoir was studied and it clearly established that the inflow into the reservoir after 2000 is poor and from 2000 to 2012, only in one year the reservoir has reached its full reservoir level.

The hydrology of the Ponnaniar Reservoir System for understanding the impact of Climate change in Ponnaniar Reservoir System using SWAT had been done.

Impacts of Climate Change in Water Resources in Ponnaniar Reservoir System using Soil Water Assessment Tool (SWAT)

In this study, a hydrological model Soil and Water Assessment Tool (SWAT) was used to simulate runoff in the Ponnaniar basin for current climatic conditions, and for prescribed hypothetical climatic conditions that represent a range of possible climate changes that is likely to be expected in the current century.

Annual summary of hydrological outputs of Ponnaniar basin for the year 2008 (representing 75% dependability of rainfall) as simulated by SWAT model has been worked out and the monthly hydrology of Ponnaniar basin has also been calculated.

The model was run for two climatic conditions, i.e. 1^0 incremental change in temperature from the base temperature and changes in precipitation with -40%, -20%, and +20%, +40%. Totally eight scenarios were considered for the study to assess the impact of climate change in Ponnaniar Reservoir System. The paper discuss the effect of Climate change on the hydrology of the Ponnaniar system and the challenges to be faced and actions to be taken to mitigate the possible challenges.

Keywords

Ponnaniar reservoir - hydrology of the system - impact of Climate change - hypothetical climatic conditions - possible climate changes - model run in SWAT - mitigation arrangements

Extreme event analysis of Krishna river basin under future scenarios

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Abstract

One of the most important aspects of climate change related to water resources management is the occurrence of climate events and weather extremes have a significant impact on water availability and agricultural production. In the present study Soil and Water Assessment Tool (SWAT), has been used for the assessment of water resources of Krishna river basin, fourth largest river basin in India. SWAT-CUP has been used for the calibration and validation of the model, the R^2 value varies from 0.72 to 0.5 and NSE values vary from 0.67 to 0.43 for calibration and for validation these values vary from 0.8 to 0.54 and 0.62 to 34 respectively, indicate satisfactory results. SWAT simulations have been carried out for the observed, downscaled historical and future data of rainfall, maximum and minimum temperature of nine climate models such as CSIRO-QCCCE-CSIRO-Mk3-6-0, MOHC-HadGEM2-ES, NOAA-GFDL-GFDL-ESM2M, ICHEC-EC-EARTH, MPI-M-MPI-ESM-MR, IPSL-IPSL-CM5A-MR, MIROC-MIROC5, CNRM-CERFACS-CNRM-CM5, and NCC-NorESM1-M. To reduce the uncertainties associated with the climate models linear scaling bias correction method has been used. The results indicate that the frequency of extreme weather events increases under future climate especially in the end century (2071-2100) than early (2006-2040) and mid-century (2041-2070) and also it indicates the number of rainy days decreases in the future even though the rainfall increasing. Understanding the climate variability and its influence on the occurrence of extreme events such as floods and drought under future scenarios will help in better planning and management of water resources.

Keywords

Climate change, Extreme events, Bias correction, Water balance components

Climate Change Impact on Water Resources of Phakal Lake using SWAT model

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Abstract

Tank irrigation is significant in arid and semi-arid regions due to the contribution to water resources development, agricultural production, livelihood security and environmental sustainability. This study was carried out for Phakal watershed, which is situated in the Krishna River Basin, India. This part of the basin is very important as the catchment provides water for Phakal lake – a medium irrigation project. So it is crucial to study and evaluate the potential impacts of climate change on the hydrology and water resources availability. The assessment of future climate change impacts on Phakal lake has been carried out using the Soil and Water Assessment Tool (SWAT). The present and future climate model data is obtained from the Coordinated Regional climate Downscaling Experiment (CORDEX) climate data repositories. SWAT Model has been run for IMD (Indian Meteorological Department) data for the period of 1970-2005 for Konduru watershed which is downstream of the study area due to the lack of gauge station at the Phakal lake. SWAT model calibration and validation is carried out for monthly simulated stream flow using observed stream flow data from the Purushothamagudem gauging station present in Konduru watershed and the model parameters are transferred to Phakal watershed. The calibrated and validated SWAT model has been applied to simulate hydrologic components of three future periods 2006–2040, 2041-2070 and 2071–2099 and the impact of climate change on the water resources availability is studied.

Keywords

Climate Change, CORDEX, SWAT, Tank Irrigation, Water Resources.

Long Term Trends in Intensity and Distribution of Hydrological Components of Brahmani & Baitarani Basin using SWAT Hydrological Model

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Abstract

Increasing concentration of atmospheric GHGs shows unprecedented warming of the earth's atmosphere in last few decades which can substantially impact the hydrological cycle and precipitation patterns over the globe. The annual average temperatures over the Indian landmass have shown an increasing trend of about 0.6^0C (100 yrs) during the period 1901-2010 (IITM, 2017). The annual as well as seasonal (June through September) monsoon rainfall over India shows significant decreasing trend over the core monsoon zone, with intensification of both dry and wet periods. These climate changes is coupled with significant socio-economic developments resulted noticeable land use/land cover change over the last three decades across different landscapes over India. These are the most direct contributors that alter hydrological behavior the river catchments.

The present study is to investigate the long-term trends in catchment scale hydrological response of Brahmani-Baitarani river basin. Soil and Water Assessment Tool (SWAT) continuous simulation based hydrological model, has been employed for the study. SRTM DEM of 90m resolution, Land Use/Land Cover map derived from AWIFS data, Soil texture data obtained from National Bureau of Soil Sciences and Land Use Planning (NBSS&LUP), weather data from Indian Meteorological Department (IMD) are used. In this study runoff is estimated using modified version of SCS Curve Number method and evapotranspiration by Penman-Monteith method for a long period of 28 years from 1985 to 2013. The model performance was determined using standard statistical methods. The hydrological modeling is calibrated at the outlet point of Jenapur and Anandpur station of the Brahmani & Baitarani basin. Steady increase in basin runoff is observed during the recent decade from Brahmani & Baitarani catchment progressively in the last three decades. Run Coefficient is observed to be higher, which induce higher exposure of flood hazard in the downstream delta districts. Spatial trends in runoff and evapotranspiration are captured across different regions of the basin. The results indicated the long-term trends in hydrological response of the catchments and enabled characterizing the spatial changes actuated by climate and land use/land cover change.

Keywords

Climate change, Hydrological model, Land use, SCS Curve number, SWAT

Chemical weathering of continental rocks and its impact on global climate: A review

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Abstract

This paper reviews on the consumption of atmospheric CO_2 through continental rock weathering and its impact on global climate. Chemical weathering is one of the major part of earth surface processes which links between the solid earth, the atmosphere and the ocean. Over geologic timescales, chemical weathering of continental rocks is an important sink of atmospheric CO_2 and have a major control on global climate and carbon cycle. It is a major source of elements transported by rivers to the ocean. The carbon cycle is important to the maintenance of life, climate, and the composition of the atmosphere and oceans. Rivers are the major geological agents which mainly transports weathering products of terrestrial rocks. Therefore, the chemistry of river water can be used for the chemical weathering rates in a river basin. The total global flux of atmospheric CO_2 consumed by rock weathering is 24×10^{12} mol yr^{-1} (0.288 Gt C yr^{-1}). This value is close to the net uptake of CO_2 by the terrestrial biosphere in pre-industrial condition (0.4 Gt C yr^{-1}). The increased chemical weathering as a consequence of uplift of the Himalaya Mountains considered as a principal cause of late Cenozoic cooling due to drop in atmospheric CO_2. Chemical weathering and associated CO_2 consumption is a complex process that regulated by multiple co-dependent factors such as climate (temperature, rainfall and runoff), lithology, physical erosion, rainfall pH, soil temperature, vegetation cover, soil cover, relief, tectonic and anthropogenic activities.

Keywords

Chemical weathering; Atmospheric CO2 consumption; Global climate; Carbon cycle; River

An integrated dynamic hydrological model for prediction of discharge in data-poor large river basins

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Abstract

Rainwater does not transform into streamflow and evapotranspiration immediately. The catchment first stores rainwater and then releases it as streamflow and evapotranspiration at rates that may vary significantly over time. For a small timespan, it is important to consider storage fluctuation, which is the main reason why it is so difficult to perform dynamic hydrologic modelling. Most dynamic hydrological models keep multiple free-parameters, whose values need to be determined through calibration, which is, of course, not easy in data-poor basins. Hydrologists, therefore, have developed several regionalization approaches to predict discharge for data-poor basins. By definition, regionalization approach based models are not universally applicable. However, a recent study has opened up an alternative avenue for calibration-free dynamic hydrological modelling by introducing the concept of *instantaneous dryness-index* with the help of an empirically derived *universal decay function*. Essentially, the decay function characterizes the effects of antecedent rainfall and solar energy inputs on the dryness state of a catchment at an instance of time. Instantaneous dryness-index determines hydrologic partitioning at a small timescale; i.e., it tells us how much proportion of rainfall occurring at a particular time is *effective rainfall*, the part of rainfall that eventually transforms into streamflow. The same decay function is then used to transform effective rainfall time series into discharge time series. The model was tested in small to medium sized 63 US catchments where its performance was found to be encouraging. However, the model cannot be applied to large river basins where delays due to the flow of water in channel networks are significant. In this study, we develop a simple channel routing model and integrate with the instantaneous dryness-index based model to predict discharge in large river basins. The integrated model is tested in Krishna and Godavari basins using gridded rainfall and temperature data, and the model's performance is found to be satisfactory. Our proposed model is thus suitable for prediction of discharge in data-poor large river basins.

Keywords

Budyko model, callibration-free, channel routing, hydrological model, large river basins

Quantifying the water footprint of an urban agglomeration in developing economy

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Abstract

Managing water resources in large urban centers have become challenging due to the rapid increase in population and standards of living. Globally, urban centers host more than 50% of the population which is projected to increase 70% by the year 2050 [UNDP, 2012], but occupy only a little above 2% of the global land area. Cities are consumption hotspots as they consume more water per capita than rural regions as part of urban metabolism. Cities are similar to organisms, they consume resources from their surroundings and excrete waste [*Kennedy et al.*, 2011]. While there is significant work done to assess the physical water consumption of urban centers both in India and globally, there is a large gap in our understanding of how water is consumed in the form of embedded products.

This water embedded in the form of goods, products and services consumed by the consumers of a region to satisfy the water thirst of a particular region is termed as water footprint of that region [Mekonnen and Hoekstra, 2011]. Generally wealthier regions are dominant water consumers directly, indirectly and they consume more water through water embedded goods, due to their food habits and lifestyle [Vanham and Bidoglio, 2014]. Typically, most of these water-intensive goods are imported from the state or national boundaries, thus it becomes challenging to trace the source of virtual water across a variety of products being consumed in an urban area. The water embedded in these imported goods/services is also called 'indirect' or 'virtual water'. The concept of the water footprint is an important planning tool that can be used to understand the flow of virtual water across a cities boundary. However, only a handful of studies has attempted to apply this concept for urban centers in India.

The goal of this research is to develop a general method to assess the water footprint of a typical city in India using existing databases. A secondary goal is to estimate the extent to which collection of new data can reduce uncertainties in water footprint assessment. We adopt a consumer-centric approach to assessing water footprint in Hyderabad Metro Development Area (HMDA), with publically available data. We also analyze the variation of the water footprint across economic gradients of consumers. This assessment helps to know water dependability of a region on external sources, to plan an annual water budget of region or urban and to plan water intensive trade between the regions. We estimate the flow of water footprints into the HMDA in four broad categories: food consumption, physical water, energy (coal, kerosene, power) and fuel (petrol and diesel) by applying consumer-centric approach and average per capita water footprint of HMDA region is 1041 m^3/Year, with annual per capita footprint of food consumption is 725 m^3, 270 m^3 in electric power consumption, 44 m^3 in physical water consumption and with lowest water footprint of 0.62, 0.30 m^3 in fuel (petrol, diesel) and energy (coal, kerosene and LPG) consumption.

Keywords

Water footprint, water management, urban

Hydrological Stream Flow Modelling for Snow and Glacier fed Mountain Basin using SWAT Model

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Abstract

Many Himalayan rivers have their upper catchment in the ice and snow covers area and water allied movement which take place in a part of the basin may have consequences in the other basin. Soil and Water Assessment Tool (SWAT) has been applied to simulate stream flows in Beas Basin up to Bhunter site, located in Himachal Pradesh in N-W Himalayan region, India. The study was carried out to test the performance and feasibility of SWAT by examining the influence of topography, land use, soil and climatic condition on stream flow. The model was simulated on a daily basis for the period of 1990-2010. The simulated stream flow was calibrated and validated with discharge data measured at the outlet of the basin. As it is difficult to manually calibrate such complex model with many parameters, the Sequential Uncertainty Fitting (SUFI 2) was used for calibration and to quantify uncertainty. Performance of SUFI2 model was evaluated using a Statistical function. As a result, observed and simulated flows were not considerably diverse at the 95% level of confidence (95PPU) and demonstrate a good agreement between observed and simulated discharge/flow of the stream on a daily basis (R^2= 0.60, NSE= 0.60 for Calibration Period and R^2= 0.57, NSE= 0.48 for Validation Period). It demonstrates the efficiency and suitability of the SWAT & SUFI 2 method for the hilly catchment.

Keywords

Hydrological Modeling, Stream Flow, SWAT, SUFI-2, Beas basin

Hydrological Simulation of Projected High Flows over a Flood-prone River Basin under Data-scarce Condition

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Abstract

It is evident that changes in climate alter the incidence of hydro-climatic extreme events; particularly, floods and droughts that are likely to cause substantial socio-economic and ecological damage. To understand the hydrological response at watershed-level, it is important to comprehend the changes in several hydro-meteorological variables. Under data-scarce conditions, poorly gauged watersheds across a majority of the Indian river basins make the quantification of changes in river flow even more challenging. The Mahanadi River Basin (India) has been selected as the study area to investigate the impacts of simulated meteorological extremes on different flood variables. The major objective of the study was to propose a framework to improve the estimation of flood variables (in terms of runoff and streamflow) with refined simulations of hydro-meteorological variables, particularly under data-scarce scenario. This has been achieved by implementing a newly developed Modified Statistical Downscaling (MSD) approach for projecting precipitation extremes. The simulated precipitation outcome serve as an input to a hydrological model, Soil and Water Assessment Tool (SWAT) that simulates the flood variables. Statistical analysis has been performed with mean, high and low flows to quantify changes in the projected flows in comparison to observed ones, at monthly, seasonal and annual scales. Additionally, it was observed that the contribution of LULC changes during the period 1992-2005 have no significant impact on the watershed's hydrology. Therefore, attribution of individual impacts of climate and LULC change on runoff (or streamflow) has not been quantified. Furthermore, the above simulated hydro-climatic variables can be used as an input to a 3-way coupled flood model, which can further quantify the changes in watershed hydrology and flood potential under changing climate. Such reliable estimates of simulated hydrological variables during hydro-climatic extreme events can also facilitate the implementation of structural measures, like flood plain zoning/planning under data-scarce condition.

Keywords

Data scarcity, Hydrologic modeling, Modified statistical downscaling, SWAT

Impact of Climate Change on the Water Availability in Snow Dominated River Basins in Bhutan

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Abstract

Climate change may have profound implications on water availability in the snow-dominated river basins in Bhutan. Changes in water availability under the projected future climate can have implications for hydropower production and agriculture in Bhutan. In this study, we examined the impact of the projected future climate on streamflow of five river basins (Amochhu, Wangchhu, Punatshangchhu, Mangdechhu, and Drangmechhu) in Bhutan. Streamflow for each basin was simulated using the Soil and Water Assessment Tool (SWAT) for the observed and projected future climate after calibration and evaluation at a number of gauge stations. The analysis for the projected future climate was performed for near (2011-2040), mid (2041-2070) and end (2071-2100) periods of the 21st century using the downscaled and bias-corrected precipitation and temperature forcing. Daily precipitation and temperature data for Representative Concentration Pathway (RCP) 4.5 and 8.5 scenarios were obtained from six General Circulation Models (GCMs) from the Coupled Model Intercomparison Project Five (CMIP5), which were bias-corrected and downscaled using Princeton University dataset by the equidistance quantile mapping technique. Apart from the use of the elevation bands, parameterizing sub-basins separately with the help of multiple gauge stations in a basin helped in improving the SWAT model calibration. It was found that streamflow in all the five river basins is projected to increase in the 21st century with a higher increase under the RCP 8.5 than that of RCP 4.5 scenario. The increase in mean annual streamflow during the end period with respect to the historical reference period (1981-2010) was estimated to range between 10.76 % (± 16.74 %) and 43.26 % (± 26.29 %) under the RCP 4.5 scenario in the five river basins. The increase in streamflow under the RCP 8.5 is ~1.5 times higher than the projected increase in streamflow under the RCP 4.5 at the end of 21st century. Projected increase in streamflow in the snow dominated river basins can have implications for floods, landslides, reservoir operation, and hydropower production in Bhutan.

Keywords

Climate Change, Hydrology, Streamflow, Bhutan

Application of SWAT model to study hotspots of 1960s Green revolution in India

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Abstract

Since the advent of Green Revolution, India has seen remarkable growth in agriculture. From a major food importer in 1970s to a net exporter today, the food grain production has increased from 83 million tonnes in 1960-61 to about 252.7 million tonnes in 2014-15. Moreover, the Department of Agriculture Research and Education stated that about 50% increase in agriculture production during the green revolution is attributed to the use of fertilizers. Ministry of Agriculture in India further reported that country will require about 300 million tons of food grains by 2025 which requires around 45 million tons of nutrients. Considering the excessive use of chemical fertilizers and nutrients deficiency in Indian soils post green revolution, it is important for policymakers to come up with effective measures to improve soil health and augment agricultural production and productivity. The present study is aimed at analyzing changes in nutrients, biomass yield, soil production potential in agriculture soil under different land management scenarios using SWAT model. SWAT which was originally developed in the United States, however now widely used all over the world. The limited availability of good quality data in India and challenges in training, testing, and validation of the model is also highlighted in this paper. The study is performed on a small watershed in a prominent Green revolution hotspot in India with SWAT interface in QSWAT. The modeling results are compared with available literature to test the performance of SWAT model on impacts of 1960s Green revolution in India.

Keywords

food production, Green revolution, nutrient deficiency, SWAT

What controls the Recession flow exponent?

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Abstract

Recession flows of a basin provide valuable information about its storage-discharge relationship as during the recession periods stream-flows is driven by the depletion of storage. For the natural basins, the degree of storage-discharge non-linearity can be quantified as the exponent (α) of the power-law equation $-dQ/dt = kQ^{\alpha}$ (Q being discharge at time t) governing the recession flows. Recently, it was discovered that the power-law equation is dynamic in nature i.e., k significantly varies with the recession events and α needs to be computed separately for each event. The median α can then be considered as the representative α for the basin. The question that arises here is: what are the basin characteristics that influence the value of α? Studies based on a small number of basins (up to 50 basins) reveal that α has good relationship with several basin characteristics. However, whether such a relationship is universal remains an important question, since a universal relationship would allow prediction of the value of α for any ungauged basin. To test this hypothesis, here we study data collected from a relatively large number of basins (358 basins) in USA, and examine the influence of 35 different physio-climatic characteristics on α for different regions. The results indicate that α is not identically influenced by basin characteristics in different regions. In future, a better estimate the recession flow exponent can lead to improved modeling of base flow and low flow in the SWAT model.

Keywords

Recession flows, Brutsaert-Nieber analysis, storage-discharge relationship, basin characteristics, step-wise multiple linear regression.

Impacts of On-site System Status: Water Quality and Quantity in Micro to Macro Scale

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Abstract

Nationwide, the number of decentralized wastewater treatment system (also called on-site system or septic system) users increases every year as a result of continuous urban and suburban sprawl, rural development and the high cost of central sewer systems. On-site wastewater treatment systems, can be environmentally friendly, safe to human health and provide permanent wastewater treatment solutions if closer attention is provided to use, inspection, operation and management of the systems. If systems are not properly maintained, they will not function adequately, and malfunctioning systems have the potential to result in negative impacts to public health as well as to the environment. The Soil and Water Assessment Tool (SWAT), a comprehensive watershed modeling tool capable of simulating OWTS biozone processes, was applied to the Lick Creek Watershed in North Carolina, USA to evaluate the impact of on-site system status (properly functioning vs. malfunctioning) on ten water quality and quantity parameters at micro- and macro-scales. The parameters under consideration were: evapotranspiration (ET), soil water content (SW), surface runoff (SURQ), groundwater discharge in to reach (GW_Q), net water yield to reach (WYLD), organic nitrogen (ORGN), organic phosphorus released into reach (ORGP), nitrate released into reach (NSURQ), soluble phosphorus released into reach (SOLP) and mineral phosphorus attached to sediment released into reach. Impacts of malfunctioning systems in measured water quality and quantity parameters were noticed only at micro-scale.

Keywords

On-site systems, nutrient, failing system, water pollution

Application of ANN and SWAT Models for Daily Streamflow Prediction in different climatic zones in Spain

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Abstract

Streamflow estimation is essential for planning, operating, and management of water resources. Sometimes, streamflow records suffer from missing observations and it is necessary to use models for its estimation. For this purpose, two models, soil and water assessment tool (SWAT) and artificial neural network (ANN), were evaluated and compared in two basins with different climates, Ladra River Basin (NW Spain) and Headwater of Segura Basin (SE Spain). ANN is chosen for being a powerful learning machine technique which is capable of identifying complex nonlinear relationships between input and output. The selection of inputs to ANN involved a study of quantification of cross-correlation of the data series that best represent the hydrological response of the watersheds. In addition, we divided the flow direction curves (FDC) into five segments of flow phases (very high [>Q5], high [Q5-Q20], medium [Q20-Q70], low [Q70-Q95], and very low [<Q95]) for a better evaluation of accuracy and skill of these estimation techniques. The performance of the models in these segments was evaluated separately with root mean square error (RMSE). Both models, SWAT and ANN, provided good results in the simulation of daily streamflow during calibration and validation phases based on four statistical measures (the coefficient of determination (R^2), the Nash-Sutcliffe efficiency (NSE), percent bias (PBIAS), and RMSE. We can conclude that SWAT and ANN can be powerful tools in daily streamflow modelling. Comparing both models, the results of this study indicate that ANN was more successful than SWAT in relation to better simulation of very high flows [>Q5], while SWAT was superior at estimating flows of the rest of segments of flows in both studied basins. Therefore, the combined use of both models may be useful to improve the accuracy of daily streamflow estimations.

Keywords

soil and water assessment tool (SWAT); artificial neural network (ANN); streamflow; hydrological modelling

Evaluation of SWAT Model for Streamflow and Sediment Yield Simulation in the Bandon River (Ireland)

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Abstract

The Soil and Water Assessment Tool (SWAT) was tested for modelling the streamflow and sediment yield in the river Bandon, in the south of Ireland, as the first step in the assessment of Best Management Practices (BMPs) scenarios related to the effects of climate change on water, sediment and nutrient in this watershed. The river catchment area is 415 km^2 and is occupied mainly by agriculture and some rural areas. The river is prone to flooding on specific stretches and also contains the fresh water pear mussel, an endangered species protected under the Habitats Directive, especially sensitive to suspended sediments and flows irregularity due to land-use changes. Thirty-seven years of daily/monthly flow data (1979-2015) and one year of sediment data (February 2010 – January 2011) were used in this study. We employed three years for warming up in flow modelling. The data series from 1982 to 2015 (34 years) were divided into two sets. The first 19 years (1982–2000) were used for calibration, and the remaining 15 years (2001–2015) were used in model validation. A Sequential Uncertainty Fitting (SUFI-2) procedure was used to auto-calibrate unknown parameter values in the SWAT model. Nash Sutcliffe efficiency (NSE) and R^2 (coefficient of determination) for monthly flow were computed as 0.60 and 0.78, respectively; and as 0.81 and 0.90 for monthly flow during the calibration. Daily flow results were 0.53 for NSE and 0.71 for R^2. Statistical comparisons of sediment yield produced values for NSE and R^2 of 0.70 and 0.71, respectively. The results showed that sediment simulation presented greater uncertainty than stream flow. ESCO, GW_DELAY and CN2 were identified as the most sensitive parameters in flow modelling and LAT_SED, CH_N2, USLE_K and OV_N in sediment modelling. SWAT satisfactorily simulated hydrology and sediment yield and will be implemented in BMPs schemas for long-term.

Keywords

Streamflow modeling, sediment yield, SWAT, Bandon River basin

SWAT model assessment of runoff variation and reservoir impact in Manjira river Basin, India.

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Abstract

Freshwater discharge is a key component of the terrestrial hydrologic cycle. Variations in climate and land use have profound impact on surface runoff generation in arid and semi-arid regions of the world. Further, increased urbanisation and construction of dams and reservoirs play a major role in regulating discharge in rivers and streams. This study aims to simulate runoff using Soil Water Assessment Tool (SWAT) model over the Manjira basin (sub-basin of the Godavari river basin) for the period of 1996 to recent. The SWAT hydrologic model is driven by meteorologic, hydrologic and land use data. Additionally, for more accurate representation of runoff while accounting for controlled flows from the study area, we have incorporated major reservoirs in the model. Hence, reservoir regulation data of Nizam Sagar and Singur reservoirs in the Manjira river basin is also utilized in this study. The focus of this study is to develop a process based hydrologic model SWAT and calibrate it with observed gauge data from multiple sites, using SUFI2 mechanism present in SWAT-CUP. Being a large sub basin it possess spatial heterogeneity which would be ignored if single site calibration is used. Incorporation of reservoirs can help us in proper estimation of discharge, which will be crucial for evaluating the impact of dams and reservoir on the hydrologic regime of the study area. The results of the hydrologic model can be further used to study the impact of urbanisation on flooding potential in the lower reaches of the basin, which has witnessed rapid growth in population in recent years.

Priotization of critical sub-watershed of Hamp Watershed in Upper Mahanadi Basin using SWAT and Morphometric Analysis

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Abstract

Hydrologic and water quality investigations are fundamental to any watershed management programme. Surface hydrologic modelling of watershed mainly includes processes like runoff and transport of sediment as well as pollutants from the watershed. The recent version of Soil and Water Assessment Tool (SWAT) interfaced with ArcGIS and called as ArcSWAT, being used widely and successfully in different countries including India is adopted for simulating the hydrological behaviour for watershed management in upper Mahanadi basin of Chhattisgarh state. The current study was under taken with the use of a distributed parameter model interfaced with GIS *i.e.* ArcSWAT to estimate the surface runoff, sediment yield and nutrient losses from a critical agricultural sub-watershed of Hamp watershed for development of effective management plan. The study area was subdivided into 14 sub-watershed considering topographical parameters derived from DEM and drainage network. The land cover, soil layers, and DEM were used to generate 207 HRUs to analysis of daily and monthly seasonal precipitation, runoff, sediment yield and nutrient losses, for 2004- 2008 (calibration period) and 2010-2013 (validation period). Simulated daily and monthly runoff and sediment yield for the monsoon period for both calibration and validation period compared well with their observed counterparts. In daily runoff (E_{NS} = 0.638, PBIAS = 1.147, R^2 = 0.748, Modified E_{NS} = 0.506 and Modified Index of Agreement = 0.896) and monthly runoff (E_{NS} = 0.942, PBIAS = 1.147, R^2 = 0.943, Modified ENS = 0.760 and Modified Index of Agreement = 0.984) showed a good agreement with the observed data for the calibration period of 2004 to 2008. During validation period the daily runoff (E_{NS} = 0.646, PBIAS = 2.206, R^2 = 0.700, Modified E_{NS} = 0.612 and Modified Index of Agreement = 0.909) and monthly runoff (E_{NS} = 0.914, PBIAS = 5.80, R^2 = 0.923, Modified E_{NS}= 0.808 and Modified Index of Agreement = 0.975) also showed close relation. Similarly the model was calibrated and validated for daily and monthly sediment loss and seasonal nutrient loss also. The model was run for the four consecutive years (2010 – 2013) and annual watershed yield including runoff, sediment yield NO_3-N and soluble - P were considered for each sub-watersheds. The morphometric analysis of the Hamp watershed was carried out based on linear and shape parameters. Linear parameters have a direct relationship with erodibility whereas shape parameters have inverse relation to erodibility. Out of the fourteen sub-watersheds, the WS3, WS6, WS9, WS12, WS13, WS14 fell under moderate soil loss group of soil erosion classes (5 to 10 t/ha/yr). The WS4, WS8, WS10 and WS11 fell under high soil loss group of soil erosion classes (10 to 20 t/ha/yr), whereas other sub-watersheds fell under slight erosion classes. Looking at the annual soil loss (18.18 t/ha), runoff (245.97 mm) and nutrient losses (1.62 kg/ha NO_3-N and 0.19 kg/ha Soluble-P), the most critical sub-watershed (WS4) which was even beyond the national average limit of soil loss was considered to adopt the management measures in order to reduce the sediment and nutrient losses and to conserve the rainwater within the watershed for sustainable crop production.

Keywords

SWAT, Morphometric Analysis, Mahanadi Basin, Calibration, Validation

Modelling Runoff and Sediment Yield from a Small Watershed Using ArcSWAT for Identification of Critical Sub-watersheds

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Abstract

A model called ArcSWAT was tested on daily and fortnightly basis and applied for identification and prioritization of critical erosion prone areas of Dhangaon watershed located in Bemetara district of Chhattisgarh (India). In this study, model was calibrated and validated for estimation of surface runoff and sediment yield and used for identification and prioritization of critical sub-watersheds. The watershed and sub-watershed boundaries, DEM, drainage networks, slope and soil texture maps were generated using ArcGIS. Supervised classification method was adapted for land use/cover classification from satellite imageries of the years 2009 and 2012, respectively for calibration and validation. Hydrological and meteorological data recorded during the monsoon seasons of the 2007 to 2012 were used. Manning's roughness coefficient 'n' for overland flow and channel flow, Fraction of Field Capacity and ET methods were calibrated for monsoon season of the years 2009-2010. The model was validated for the years 2011and 2012 using the respective rainfall and temperature data. Calibration and validation results revealed that the model was predicting the daily and fortnightly surface runoff and sediment yield quite satisfactorily. Capability of model for generating rainfall was also evaluated for the period of 2007 through 2012. The model was able to simulated monthly rainfall close to the observed monthly rainfall. Also the model predicted monthly runoff and sediment yield using generated daily rainfall compared well with observed runoff and sediment yield during the simulation period of the monsoon season of the year 2007 through 2012. The adequately tested model was applied for identification of critical sub-watersheds of Dhangaon watershed. The critical sub-watersheds were identified on the basis of average annual sediment yield during the period of 2007 through 2012 using observed daily rainfall and temperature data. The priory of different critical sub-watersheds was done according to the annual sediment losses for developing the management plans. The sub-watershed SW3 was found to be most critical on the basis of soil loss, however other sub-watersheds including SW4, SW9, SW7, SW5, SW8 and SW1 were also found to be critical, hence suggested to adopt recommended management practices on the order as mentioned.

Keywords

ArcSWAT, Modelling, Runoff, Sediment Yield, Watershed

Development of an Operational forecasting and Decision Support System (DSS) for effective management of reservoir systems: Case study of Lunugumwehera reservoir, Kirindi Oya basin, Sri Lanka

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Abstract

The lack of available, reliable and timely rainfall data is a major constraint in the development of flood forecasting and early warning systems in many regions across the globe. This in turn forms a significant input to inflow forecasting with enough lead time that will enable the Engineers/ Decision makers to manage the reservoir operations in an effective manner and ensure minimum impact resulting from extreme flows downstream of the reservoir. The proposed study region, Kirindi Oya basin lies within the dry zone of Sri Lanka with a catchment area of 1157 km^2. The basin, being located in the semi-arid tropics; onset and withdrawal of monsoon varies from year to year; often making it difficult to manage inflows to the Lunugumwehera reservoir system that represents the mainstay of Kirindi Oya irrigation system. Kirindi Oya receives much of the rainfall within 3 to 4 months in a year and this contributes a major share of the reservoir inflows. However, uncertainty involved in the quantity and timing of the rains and inflows make planning and operation of the reservoir a difficult task resulting in contrasting issues of drought and floods affecting the basin. In this context, short term or seasonal forecasts become crucial in managing the available water resources and further assist in addressing the hydrological extremes in terms of drought and floods faced by the basin. Therefore, the objective of the proposed study is to develop and implement an integrated Decision Support System (DSS) to facilitate enhanced operation of Lunugumwehera reservoir while ensuring the daily and hourly releases through downstream channel within acceptable limits. The study employed HEC-HMS as the modelling tool that simulates the rainfall-runoff process to capture the hydrological response of the basin. The hydrological model was calibrated with respect to the historical inflows available at the gauging sites distributed within the basin. The decision support system further integrates numerical weather predictions with the calibrated hydrological model to generate short term inflow forecasts upto 3 days ahead for the Lunugumwehera system. Performance of the model in predicting the volume and pattern of the inflow hydrograph at the reservoir further demonstrates the potential of rainfall forecasts from weather models in the development of real time flood forecasting systems.

Keywords

HEC-HMS, Decision Support System, flood forecasting

Modelling nitrous oxide (N2O) emission from soils using the Soil and Water Assessment Tool (SWAT)

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Abstract

Identification of the nitrous oxide (N_2O) emission hotspots has gained increasing attention in recent years due to its higher global warming potential compared to other trace gases. Estimates showed that the N_2O concentration in the atmosphere has reached to 325 parts per billion, a level 20% higher than that before the pre-industrial era. Interestingly, the N_2O emission from soils accounts almost 70% of the global N_2O emission. Hence, it is of paramount importance that we keep track of the N_2O emission from different soils. The N_2O measurements from experimental sites offer an option but the measurements are often sporadic, cumbersome and costly. Use of modelling tool, therefore, seems a more viable option. Here, we present a new module complementing the Soil and Assessment Tool (SWAT) to simulate N_2O emission from different soils. We consider the N_2O fluxes from nitrification and denitrification. The fluxes are based on the empirical equations, which considers the nutrients, carbon, soil moisture, temperature and pH levels in the user-specified soil layers. We tested the module against the N_2O emission from three different experimental sites – an agricultural and a shelterbelt site in Saskatchewan, Canada and a grassland site under light grazing in Alberta, Canada. We validated the module against the sporadic dataset of water filled pore space (WFPS), soil temperature and N_2O fluxes. Results showed that the model is able to represent the dynamics of WFPS and soil temperature with 'Good' to 'Very Good' accuracy at all sites. Besides, the N_2O flux has been simulated with 'Very Good' accuracy at the agricultural site where detailed information of irrigation and fertilizer application were available. However, at the shelterbelt and grassland sites, the accuracy remained low (satisfactory). The yearly average N_2O emission from the agricultural, shelterbelt and grassland sites was found to be 2068 g/ha, 572 g/ha and 94 g/ha, respectively showing the high variability of emission amongst the soils under different management practices. The N_2O flux from denitrification dominated the flux from nitrification especially from the soils laden with fertilizers. With robust simulation of the variables affecting the N_2O flux, especially the soil moisture, and detailed information of management practices, this module can be used to estimate N_2O emission from any soils. We believe that availability of such modules would help in identifying the N_2O emission hotspots, and would be useful tool for the integrated biogeochemical modelling of watersheds.

Keywords

global warming, SWAT, nitrous oxide, nitrification, denitrification

Assessment of precipitation effects on hydrological characteristic and nitrogen loss under different land use types in southern China

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Abstract

Land use and land cover (LULC) is considered to have important influence on the hydrological cycle and non-point sources (NPS) pollution. Precipitation also plays an important role in hydrological cycle, which would affect the water allocation and NPS pollution discharge. Therefore, understanding the hydrological characteristic and nitrogen losses from different land uses and comparing their response to different precipitation condition are urgent needed. In this study, the Soil and Water Assessment Tool (SWAT) model was used to simulate the hydrological response and nitrogen losses from different land uses (including forest, paddy fields, dry lands, pasture and urban lands) in a watershed in southern China. Results showed that hydrological parameters and nitrogen losses were highly correlated to land uses and rainfall. Runoff and nitrogen load intensity decreased in an order of dry lands, paddy fields, urban lands, pasture and forest lands. Larger percentages of runoff generated in in forest and pasture lands were transferred into lateral flow, while agricultural and urban lands generated more surface runoff. Extreme rainfall events had severely influence on the generation of water yield (22.17%), surface runoff (54.10%) and nitrogen losses (34.52%). More than 40% water yield in urban lands were generated under extreme rainfall conditions, followed by more than 33% in agricultural lands. The lowest percentage was observed in forest lands (17.80%). Extreme rainfall events had more serous influence surface runoff and nitrogen losses in forest and pasture, with more than 60% and43% occurring during ERC, respectively. Although forest contributed large amounts of water yield, surface runoff and TN and TN_{ERC}nutrient losses due to large area proportion, agricultural lands (especially paddy field) were the main pollution loading sources, with higher NPS and NPS_{ERC} nutrient loadings and unit contribute index (UCI) on $TN_{ERC}$and TN_{ERC} losses. Forest was more influenced by annual precipitation variance than other lands, with much higher TN and TN_{ERC} nutrient losses in wet yeas than that in normal years. These results revealed that forest and pasture could potentially reduce surface runoff and nitrogen in normal days, but the effects would be reduced under extreme rainfall conditions. These finds can be useful for land use planning and heavy rainfall management.

Environmental Impact Assessment of Current and Potential Additional Water Abstraction from the Badas (Belait) River, Brunei

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Abstract

An Enironmental Impact Assessment study was undertaken for two (2) scenarios namely: an increase of withdrawal from the Belait River located in Brunei, above current uses; and the longer term sustainability of the river to provide water for both current uses plus future anticipated increase. Increased withdrawal can result in a multitude of downstream effects including reduction in water levels that could reduce available habitat, reduction in flow rates resulting in reduced water availability for downstream users as well as a reduce assimilation capacity (dilution capability) for any downstream discharges.

Using global datasets, long-term (19 years) natural river flows at a daily scale was simulated using Soil Water Assessment Tool (SWAT). Seasonal and annual variability of flow was estimated using the long term flow obtained from SWAT. Variability in flow for events such as flood was validated using secondary data research. It was found that these flow rates in the Belait River are significantly higher than the current and projected demand.

Low flow statistics such as 7Q10, 7Q20 and 7Q30 were used to assess the changes in the assimilative capacity downstream. To assess water availability and downstream effects from various withdrawals, a probabilistic approach was adopted. Use of a probabilistic approach was necessary as forecasts of actual conditions in Belait River could not be made due to uncertainties related to weather patterns. Probabilistic approach is a common methodology for these assessments as it provides an indication of the probability (percentage of likelihood) of a defined outcome.

The assessment indicated that minimal loss in assimilative capacity will occur for increased abstraction; even after taking into account the future demands that are higher.

Keywords

Environmental Impact Assessment, SWAT, Belait River, water availability

Measuring effectiveness of practices for knowledge co-production around hydrological modelling: need for a framework?

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Abstract

Stakeholder participation in water management has considerably increased over the last decades due to the ever-increasing challenges water managers face in implementing more Integrated Water Resources Management (IWRM) and developing adaptation strategies to climate and land use changes. It is now widely recognized that long-term feasibility of any proposed adaptation strategies hinges on appropriate stakeholder engagement. Knowledge co-production therefore, has become a key area of concern with its objective, on one hand, to leverage expert driven hydrologic models for climate change impact assessments; while on the other hand, to engage local stakeholders in incorporating local knowledge/values, developing meaningful scenarios, etc. The state-of-the-art in assessing the hydrological response to climate and land use changes is using complex model chains where climate and/or land use change scenarios force an impact model (hydrological model, e.g. SWAT/SWIM), sometimes resulting in a large model ensemble. To enable a truly effective two-way communication between scientists and stakeholders around results from model-based climate/land-use change impact assessments, scientists need to engage stakeholders at an early project stage and onwards iteratively. Scientists also need ensure that modelling results are accepted, trusted and understood despite the complexity of the approach (e.g. modeling tools involved, large ensembles consisting of many different models and complex statistical analysis) and a potentially large variability or even ambiguity in final results. Despite growing attempts for stakeholder engagement, a concise and robust mechanism to measure and improve quality of interaction is not yet well established. Here, based on case studies in different geographical and societal settings and using different methodological approaches (e.g. structured versus unstructured workshops, SWOT analysis, etc.), we propose a framework that can be used to synthesize effective practices. The framework can help contribute towards establishing Best Management Practices for knowledge co-production.

Keywords

stakeholder engagement, climate change impact assessments

Identifying physio-climatic controls on watershed vulnerability to climate and land use change

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Abstract

As projections of future water resources are uncertain for many parts of the globe, we provide a framework that would be useful to water resource managers for understanding a watershed's vulnerability to environmental change despite large uncertainties. Our proposed framework quantifies the relationship between watershed's vulnerability to climate and land use change and its physio-climatic characteristics. We developed this framework by combining strengths of recently developed exploratory modeling frameworks and comparative hydrology to quantify the relationship between watershed's vulnerability and its physio-climatic characteristics. The framework can be implemented independent of future projections of change drivers and can use varying definitions of vulnerability making it a useful tool for water resource management in watersheds.

We apply this framework on 77 United States watersheds using four different indicators of vulnerability that denote water availability, extreme flow conditions (droughts and floods) and ecological function of streams. Application of this framework to the US revealed exciting relationships between watershed's physio-climatic characteristics and chosen vulnerability indicators. For example, we found evidence to indicate that watersheds with low baseflow index, high topographic wetness index, and low average permeability tend to have more significant reductions in long-term streamflow for relatively smaller decreases in precipitation, and vice-versa. In this way, we can quantify the vulnerability of watershed to climate and land use change. Implementation of this framework to a large number of watersheds in a region can also help to quantify the vulnerability of ungauged watersheds to uncertain environmental change.

Keywords

Climate change, land use change, vulnerability assignments, physio-climatic characteristics, CART

Assessment of Runoff Generation at Rift Valley Lakes Basin of Ethiopia for present and future climate scenario

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Abstract

The water yield of a basin is significantly altered by the undergoing dynamics of weather variables and catchment characteristics. Such climate and catchment driven influences could legitimately be captured at small spatial scale through process based hydrologic models. SWAT model is calibrated and validated in two snow free agricultural watersheds of Rift Valley lakes basin of Ethiopia. The impact of topographical, weather and catchment parameters on runoff generation is investigated. In view of this, initial curve number for average soil moisture condition, deep aquifer fraction, minimum water depth in the shallow aquifer for flow and available soil water holding capacity parameters have been found either to attenuate or accentuate the resulting runoff more significantly than others in the watersheds. Model performance indices have shown that runoff at desired outlet is simulated at acceptable range of closeness to observations. The overall Nash-Sutcliffe and coefficient of determination model performance indices ranges between 0.79 and 0.96 during calibration and validation period at both watersheds. Approximately 80% of measured data is bracketed by the 95 percent prediction uncertainty at both watersheds. It has been estimated that the simulated average annual water yield is 425 Mm^3 and 47.8 Mm^3 at Bilate and Hare gauge sites respectively. The simulated annual water yield is within ±3.4% error to the observed annual stream flow volume at the same outlet. Potential monthly evapotranspiration magnitude exceeds the total rainfall during critical soil moisture season (November – March) of the year.

The impact of large-scale atmospheric-ocean variables on local-scale hydrology is investigated through Global Climate Model (GCM) outputs under different greenhouse gas emission scenarios. Statistically downscaled and subsequently bias corrected daily temperature and precipitation variables are used to simulate runoff for present and two future (A1B and A2) greenhouse gas emission scenarios at Bilate and Hare watersheds. of Rift Valley lakes basin of Ethiopia. Future implications of extreme precipitation and runoff events are discussed from GCMs outputs for varied greenhouse gas emission scenarios. Simulated future runoff events are characterized by increased extreme events that ultimately resulted in increase in the gross annual runoff volume from the watersheds. The simulated runoff varies from -4% to 18 % at Hare watershed and is within the range of -4 % and 14 % at Bilate watershed. Simulated average annual water yield shows slight variation between GCMs. It lies within ±10 % at Bilate basin and ranges from -17% to 12% at Hare basin. Future water resources planning and management could likely be affected by such variability and hence existing design methods could expand their scope to account for these extreme events.

Keywords

Climate Change, SWAT model, Runoff, GCM, statistical downscaling, Ethiopia

Assessing Impact of landuse/Land cover Changes on Stream flow in Noyyal River catchment using ArcSWAT model

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Abstract

Water is one of the most important natural resources of any country, which determines all the development activities. Accurate determination of streamflow is required for water resources planning, design and management of all hydrological structures. Catchment hydrology and its local ecosystem are highly affected by the changes in the landuse and climate pattern in the catchment. In this study, we developed a hydrologic model for Noyyal catchment which is highly urbanized and rapid changes in is landuse land cover (LULC) pattern. The hydrologic model was created using the Geographical Information System (GIS) supported Soil and Water Assessment Tool (SWAT) model for forecasting the streamflow in the river basin. The daily observed streamflow data at the catchment outlet from 1999 to 2010 were employed for calibration and validation. By calculating the coefficient of determinacy (R^2) and Nash–Sutcliffe efficiency (NSE) are used to determine the model efficiency. Shuttle Radar Topography Mission (SRTM) DEM 30 meter resolution and hydro-meteorological data used for preparation of the model. Hydrological modeling was conducted for each of the LULC map in four time periods (2000, 2006, 2010, and 2015) in the Noyyal catchment using LandSat TM and ETM images. Changes in hydrological components between two simulations using LULC maps in 2000 and 2015, respectively, were related to changes of LULC in a multiple regression to quantify the effect of changes in LULC to that of hydrological components at the sub basin scale. From this study, it is concluded that future changes in the LULC are most likely to produce significant impacts on the surface runoff and water yield in the study area.

Keywords

ArcSWAT, GIS, hydrological model, landuse and land cover change, Streamflow

Effects of land use change on the water resources of the Basoda basin using the SWAT model

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Abstract

Indian river basins are among the most sensitive natural systems. However, in many parts of India rapid land use changes alter the natural environment, resulting in pronounced impacts on the water balance. In the Basoda basin, water resources are increasingly used for agriculture production. Moreover, urbanization nearby the capital city Bhopal affects the vegetation cover. This study uses the semi-distributed hydrological model SWAT for sustainable management of land resources in the Basoda river basin of Central India. The SWAT Calibration and Uncertainty Programs (CUP) Sequential Uncertainty Fitting (SUFI-2) algorithm has been used for sensitivity analysis, calibration, and validation of the model. The SWAT model performance was satisfactory R^2 = 0.90, NSE = 0.88, PBIAS = -14.2 and RSR = 0.34 in calibration, and R^2 = 0.90, NSE = 0.84, PBIAS = -13.6 and RSR = 0.41 in validation on a monthly scale. Further, the land use change analysis indicates a decrease in dense forest from 24.76% to 14.50%, a decrease in degraded forest from 13.23% to 9.25%, an increase in agriculture area from 59.50% to 71.19%, an increase in barren land from 0.31% to 1.33%, an increase in water bodies from 1.46% to 2.57%, and an increase in settlement area from 0.74% to 1.16% during 2001-2013. The effect of these changes on the water balance has been analyzed employing the SWAT model. Results show that the major land use changes in the dense forest (decreased by 10.26%) and agriculture area (increased by 11.69%) have significant impacts on the runoff simulation. At sub-basin level, the effect of land use change on runoff varied depending on changes in the vegetation cover. This study reveals that land use change is an important driver for changes in the water balance of Basoda basin. Thus, proper management is required to conserve and sustain the land and water resources in Central India.

Keywords

Land use change, water balance, SWAT model, Basoda basin, agriculture, sustainable management

Evaluation of Daily TMPA Rainfall for Rainfall-Runoff Modelling Using SWAT in Indravati River Basin, India

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Abstract

Abstract: Rainfall being a major driven force in hydrological modelling, plays a prominent role in the estimation of surface runoff at large river catchments. Recently, application of remote sensing rainfall datasets in hydrological modelling is increasing, especially in data scarce regions. Among all remote sensing rainfall datasets, researchers show great interest in Tropical Rainfall Measuring Mission (TRMM) Multisatellite Precipitation Analysis (TMPA) data due to its improved rainfall magnitude by merging with gauge rainfall data. The present study aimed to evaluate the daily TMPA rainfall for rainfall-runoff modelling using Soil and Water Assessment Tool (SWAT) model in Indravati river basin, a sub-basin of Godavari river, India. The daily TMPA rainfall available from 2001 to 2013 is used in this study. The uncertainty of SWAT model parameters during calibration period from 2001 to 2008 is carried out using Sequential Uncertainty Fitting version 2 (SUFI-2) algorithm of SWAT-CUP. The performance of SWAT model is evaluated with the coefficient of determination (R^2) and Nash Sutcliffe coefficient (NSE). The runoff estimations of SWAT model forced with TMPA daily rainfall show R^2 and NSE values 0.35 and 0.3 respectively during the calibration period, 0.51 and 0.45 respectively during the validation period. The results indicate that SWAT model forced with TMPA rainfall is underestimated surface runoff during the calibration period. Whereas validation period results showed good agreement with daily observed runoff obtained from Central Water Commission (CWC). Overall, TMPA rainfall, an open source data with global coverage is a promising dataset for estimating surface runoff at large river catchments, especially in data scarce regions.

Keywords

Hydrological modelling, Rainfall-Runoff modelling, TMPA rainfall, SWAT model, SWAT-CUP.

Hydrological Modelling of Goi River Watershed of Narmada Basin using Soil and Water Assessment Tool (SWAT)

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Abstract

The present study is carried out with an established aim and objectives to know the hydrologic response of Goi watershed of Narmada river basin using SWAT hydrological model and its impact with the various hydrological parameters responsible for runoff. The physical and the functional characteristics of watershed led many to suggest that it is the basic natural hydrological unit for any water resources management studies (Winpenny, J.T. 1991). With advancement in computer technology, the use of hydrological modelling tools such as SWAT which has an interface with GIS environment, helps to model the hydrological unit in a better way. Here, the runoff yield and sediment yield of the watershed is estimated using the SWAT model on daily and monthly basis for a period of 2003-2010. The study area is divided into number of sub-watersheds and Hydrological Response Unit's (HRU's) for the modeling purpose. Physical properties such as landuse, soil and elevation are very important in determining the hydrologic response of watershed in association with the climatic behavior of the region. The discharge data at the outlet of the watershed is obtained from Central Water Commission (CWC). The simulated flow is calibrated for a period of 2004 - 2007 and validated for a period of 2008 - 2010 with the help of SWAT Calibration and Uncertainty Programs (SWAT-CUP). Statistical analysis is carried out using the quantitative parameters such as coefficient of determination (R^2) and Nash-Sutcliffe Efficiency (NSE) followed by the sensitivity analysis. This gives confidence on the performance and reliability of the model in this kind of terrain and physical conditions. Hence, the SWAT model helps to better examine, monitor and simulate the hydrological process within the watershed in accordance with the given input parameters. This in turn helps many watershed management activities such as prioritization of watershed, other planning, development and action, etc., to be implemented with focusing the sustainable land and water resources management on one side with climate change initiatives on the other.

Keywords

SWAT, GIS, SWAT-CUP, Calibration and Validation, Sensitivity Analysis, Nash-Sutcliffe Efficiency

Calibration and evaluation of the efficacy of Xinanjiang Model in a watershed in the USA

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Abstract

The Xinanjiang hydrological model has been widely used in the humid and semi-humid region of the China for streamflow forecast. The same model is employed in this study for the Riesel watershed, (USA) to test its efficacy. Most of the parameters of the Xinanjiang model can only be determined by calibration due to the presence of uncertainty in the soil characteristics. Although all these parameters have clear physical meanings, their determination by field measurement is quite difficult. In the present study, the Genetic Algorithm (GA) is used for optimizing the model parameters and split sample method is used for the validation of the model. Essentially, the effectiveness of the calibration and validation is evaluated based on the comparison of different criterion between simulated and observed discharge. From the performance evaluation criterion of the model, it is observed that that the model is capable of forecasting the streamflow in the study watershed.

Keywords

Xinanjiang model, streamflow forecast, GA, Calibration

Soil moisture variability correlation with remotely sensed GLDAS Data using SWAT-model output data for Upper Godavari River basin.

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Abstract

Monitoring of temporal and spatial soil moisture variability of different layers at different depths is important to understand surface water and groundwater hydrology of the region. The objective of this study is to analyze the spatial variability of soil moisture at different depths. The study has been performed for the Upper Godavari river basin of India. The monthly observed data of soil moisture has been taken from Global Land Data Assimilation System (GLDAS) NOAH model of 0.25^0 spatial resolution at different depths of 0-10cm, 10-40cm, 40-100cm, 100-200cm and at the root zone depth. The soil moisture anomalies were calculated for available observed monthly data sets and correlated with derived soil moisture from SWAT model output. The Pearson Product-Moment Correlation and Spearman's rank correlation coefficient have been used for establishing the spatial correlation between soil moisture and SWAT model output of the region. The results of the study indicate that correlation of soil moisture and output soil moisture from SWAT of the study area harmonize well with each other.

Keywords

Soil Moisture, GLDAS NOAH, SWAT

SWAT Tools- An Innovative CyberInfrastructure for Watershed Modelers

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Abstract

SWAT is one of the most actively used watershed model in the world. My lab has been actively engaged in developing desktop-based tools, namely LUU Checker, Field_SWAT, SWAT_LUU, LUU Uncertainty, etc., for a variety of purposes such as quick and reliable processing of large, input data sets for land use change scenario evaluation studies, explaining the model results to common public, and assessing the impact of land use classification uncertainty on hydrologic responses. The tools mentioned previously were originally developed using MATLAB software and distributed to interested users in the form of a MATLAB executable program. However, over a period of time, distribution of the tools proved challenging for a variety of reasons. Therefore, all the four tools have been redeveloped using open-source cloud technologies and placed under a prototype cyberinfrastructure named SWAT Tools ((https://saraswat-swat.rcac.purdue.edu/). SWAT Tools was recognized with 2017 American Society of Agricultural and Biological Engineers (ASABE) Blue Ribbon Education Aids Award in recognition of its usefulness for meeting the needs of relevant audience beyond a classroom setting. The objective of the talk is to present the functional capabilities of two of the tools namely LUU Checker and SWAT_LUU included in SWAT Tools. The two tools have great potential to be adopted for long-term watershed modeling studies in those areas that are undergoing regular land use changes, a scenario quite common in India due to increased urbanization in response to increasing population. Some of the common mistakes that modelers have made while using the two tools and capability enhancements that have been undertaken to accommodate needs of power users will be discussed. SWAT Tools is appropriate to be used as an educational aid within a classroom setting for a variety of purposes outlined above. The utility of LUU Checker and SWAT_LUU will be demonstrated by using a couple of case studies. Even though this presentation focuses on the SWAT model, the architecture used for the tools may be adapted for other models with capabilities similar to SWAT.

Keywords

SWAT Tools, SWAT model, land use change, model uncertainty

Impact of Climate Change on Hydrology of Watershed

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Abstract

Climate change is expected to have significant impact on the water sector. Rising temperatures would increase the evaporation from water bodies and soil surface and might lead to increases in precipitation. The IPCC (2007) report indicates that there would be increase in frequency extreme events including droughts and floods. Change in climate would alter the components of hydrological cycle including water availability, water demand, and water allocation at the global, regional, basin, and at local level. A study was undertaken using Soil and Water Assessment Tool (SWAT) to assess the impact of climate change on hydrology, focusing on trends of precipitation, evapotranspiration and water yield in NOYYAL Basin. From the model, for the current climate,it was observed that annual average rainfall of Noyyal sub basin is 936.1mm.Future climate scenario over the Noyyal sub basin derived from 16 GCM ensemble at 60 % probability indicate that the annual rainfall, evapotranspiration surface flow and soil water storage would decrease with the advancement of time, whereas lateral flow groundwater flow is expected to increase. In the mid century, there is no change in precipitation(936 mm), Soil water storage(150.6 mm), surface flow(146 mm) and Evaoptranspiraion (675 mm) from the baseline. Water yield during Monsoon (South West Monsoon) and post monsoon (North East Monsoon) seasons are predicted to increase towards mid and end century. In end-century, the annual soil water storage is expected to decrease by 5 per cent from the baseline. The evapotranspiration is expected to increase in mid century and gradually decrease towards end century compared to current conditions indicating more water requirement for cultivation of crops. Hence, research towards economizing water to increase crop productivity is need of the hour.

Keywords

Climate change,Hydrology,SWAT

Assessing the impact of climate change for Mahanadi basin using SWAT model

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Abstract

As water resources become further stressed due to increasing levels of societal demand, understanding the effect of climate change on various components of the water cycle is of strategic importance in management of this essential resource. Climate change will affect water resources through its impact on the quantity, variability, timing, form, and intensity of precipitation. Gaining knowledge on potential climate change impacts on water resources is a complex process which depends on mathematical models capable of describing these processes in quantitative terms. The Mahanadi is one of the major rivers of the country and among the peninsular rivers, in water potential and flood producing capacity, it ranks second to the Godavari. The normal annual rainfall of the *Mahanadi* catchment is 141.7 cm. The main objective of the study is to investigate the climate change related uncertainty in the estimation of extreme flood flows for the middle Mahanadi using a wide range of climate model scenarios. The historical trends of hydrological variables, such as number of rainy days, magnitude of intense rainfall and variation of runoff for four sub-basins of Mahanadi were detected using a non-parametric statistical test. Variation of rainfall shows that numbers of rainy days and total annual rainfall is decreasing. Kesinga sub-basin exhibited highest decrease in rainfall events in the Mahanadi basin. Analysis of daily rainfall intensities indicated more frequent and larger-intensity floods in the Mahanadi basin. The trends of these meteorological variables were then employed to generate runoff in future climatic conditions using a SWAT continuous rainfall–runoff model. Statistical downscaling approach has been applied for downscaling the precipitation data. For downscaling, GCM data (RCP 2.5, 4.5 and 8.5) was downloaded from Environment Canada, Canadian Centre for Climate Modelling. Decadal rainfall projection shows that there is decrease in rainfall for some of the sub-basins. SWAT model projections reveal that there is an increase in flood in the future. It is also found that the RCP-2.6 and RCP-4.5 show moderate increase in the rainfall, whereas RCP-8.5 shows significant increase.

Keywords

climate change, downscaling, SWAT Model, future projections

Impact of Climate Change on Munneru River Basin Using SWAT

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Abstract

This study is an attempt to quantify the impact of climate change on Munneru sub basin in Krishna river basin, Telangana, India. The flow in this river greatly varies due to the high variation of rainfall during monsoon and dry season. A well-documented, well tested GIS based semi-distributed hydrological model, Soil and Water Assessment Tool (SWAT) has been used to estimate future runoff using slope, Soil Map, Land Use Land Cover Map for historical time period (1971-1999) and for future climate emission scenarios i.e. RCP4.5 and RCP8.5 for three future period's base century (2006-2034), mid-century (2041-2069) and end century (2071-2099). Most critical parameters are found by performing sensitivity analysis using SUFI2 algorithm. SWAT is calibrated using 11 years (1975-1985) of streamflow data and validated with 8 years of data (1989-1996) for the streamflows measured at Keesara station and a satisfactory goodness of fit was found. The performance of the model is calculated for daily streamflow, which yielded a Nash-Sutcliffe efficiency (NSE) value of 0.72 and Percent Bias (PBIAS) of ± 4% value for calibration period, 0.63 and ±12% for validation period. Bias corrected climate data from four Regional Climate Models (RCMs) under two emission scenarios of IPCC Assessment Report 5(AR5), namely RCP4.5 and RCP8.5 were used to forecast future runoff in this sub basin. For comparing bias correction, three correction methods have been used for correcting RCM simulated base line period data (1971-1999), i.e. Linear Scaling, Local Intensity Scaling and Quantile Mapping. Comparing the statistical measures (mean, median, standard deviation, 99 percentile) and by observing cumulative distribution, Quantile Mapping is found to be the best among the methods, for bias correction and hence it is used for bias correction of future time periods. For evaluation of future streamflows and their changes based on observed streamflows, flow duration curves are prepared for wet period. Mean monthly flow curves are also prepared for two emission scenarios i.e. RCP4.5 and RCP8.5 and three time periods i.e. base century, mid-century and end century.

Keywords

SWAT, FLOW DURATION CURVES, RCP4.5, RCP8.5 QUANTILE MAPPING, RCM, NSE, PBIAS

Groundwater Profile Prediction of Kechery Watershed

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Abstract

Groundwater is a finite water resource and it gets recharged mainly by infiltration and percolation from precipitation, and seepage from surface water bodies. Understanding the trend of groundwater level and response of aquifer to groundwater extraction and climate should serve as the basis for framing water utilization policies to avoid irreparable negative consequences. The combination of Soil and Water Assessment Tool (SWAT) and a suitable forecasting model appears to work out a good strategy to model spatial and temporal variations of groundwater depth.
SWAT, a deterministic hydrologic model, is utilized indirectly to generate a long time series of groundwater depth, since groundwater table depth is not directly obtainable from SWAT output file. Hence a procedure to compute groundwater table depth using SWAT is used here, based on the relationship between ground water depth and amount of recharge entering the aquifer beneath. The simulation of groundwater table depth using SWAT showed good performance with Coefficient of determination (R) and Nash-Sutcliffe model efficiencies in the range of 0.7 to 0.9.
For forecasting the ground water depth, Empirical Mode Decomposition (EMD) method is used, which is an adaptive time series decomposition technique. In this method, groundwater depth is decomposed into a set of non-linear Intrinsic Mode Functions (IMF's) and a residual component. Each IMF and the residual component are then forecasted using Neural Network Tool in MATLAB and the principle of superposition is applied. After forecasting the ground water depth in the observation wells, Inverse Distance Weighting (IDW) method is used to develop the temporally varying groundwater profile using GIS. This information can be used as a valuable input for the development of appropriate water conservation and management strategies.

Keywords

GROUNDWATER DEPTH,SWAT,Empirical Mode Decomposition (EMD),MATLAB

Assessment of groundwater flow process driven by geomorphology in the Godavari river basin

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Abstract

The present study is an attempt to understand the surface water and groundwater flow process at the Godavari river basin scale by considering individual sub-basins as a unit namely Indravathi, Weignganga, Warda, Pranahita, Majeera, Middle Godavari, Upper Godavari and lower Godavari. The river flows across six states viz., Maharastra, Madhya Pradesh, Orissa, Chhattisgarh, Telangana and Andhra Pradesh. The majority of the area in the basin is occupied by hard rocks and the basin experiencing intensive irrigation driven by supplemental groundwater source. In general the groundwater flow process and its distribution driven by geology, geomorphology and hydrometeorology. The groundwater recharge primarily controlled by weathering, thickness of the formation and fracture/lineaments density in hard rock regions. The sustainable water resources management required to estimate the renewable groundwater/recharge and available surface water for agricultural development. In the present study we evaluated available surface water at different sub-basins and estimated groundwater recharge for the same basins from 1996-2016 using observed groundwater levels and surface discharge collected from different sources. The analysis of surface water flows over the two decades revealed that no major change of surface water flows in the upstream river basins, on the other side a drastic decrease in surface water flow in the downstream sub-basins. The average water yields for the Godavari basin is 332054 MCM and it ranges from 25980 MCM in Upper Godavari and 61093 MCM in the Weinganga. The estimated average groundwater recharge for whole basin is 25930 MCM and it ranges between 611 MCM in the upper Godavari to 7910 MCM in the lower Godavari. The morphometric analysis of the sub-basins shows that inverse relationship between drainage density and groundwater recharge.

Keywords

Godavari basin, groundwater recharge, surface water flows, Manjeera river, Weinganga river and irrigation

Prediction of flow duration curve for ungauged catchments in south India with calibration free dynamic Budyko model

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Abstract

In view of rapid population growth, increasing industrial requirements and economic development, developing country like India need to strategies and plan for long-term sustainable water resources management schemes. Many practical problems like monitoring reservoir sedimentation, managing stream water quality, and hydro-power generation can be solved by understanding the flow duration curve (FDC) which is a good place to start and can be well-defined as the probability of streamflow exceeding a certain desired discharge values. Regardless of their practical relevance, continuous historical streamflow information required for construction of FDC. Although past studies on ungauged basin prediction mainly focused on the use of statistical based regionalization method but often results in observational errors and biases in the prediction. Furthermore, the applicability of the statistical method is limited to only hydrologically similar catchments. In the present study, we use a recently proposed calibration free process-based dynamic Budyko model to predict FDCs for 40 sub-basins of Krishna and Godavari basins of India and compared the results, obtained from a standard regionalization method. Model is based on the concept of *instantaneous dryness-index* which helps in the simulation of continuous discharge using the original Budyko function. Predictive performance of the model is evaluated using Nash Sutcliffe efficiency (NSE) and coefficient of determination (R^2). The median NSE for dynamic Budyko model and the regionalization method respectively are 0.77 and 0.43 whereas the median of R^2 is found to be 0.95 and 0.88. The underestimated results by the statistical method are preferably due to some observational errors in the dataset. Result suggests that dynamic Budyko model is performing significantly better compared to the statistical method which recommends the use of calibration-free dynamic Budyko model for prediction of FDC in ungauged basins with inadequate data.

Keywords

Calibration free Dynamic Budyko model; Flow Duration Curve; Instantaneous Dryness Index; Statistical based Regionalization method; Ungauged Basin

Management of Storm Water Flooding in Metropolitan Cities of India

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Abstract

Management of quantity and quality of storm water runoff from urban areas is a complex task which has become an increasingly important environmental issue for urban communities in India. In an ideal situation, storm water systems would be designed and analyzed with catchment modeling systems which fully replicated the important processes involved with the generation and transmission of storm water. This realization has prompted increasing use of physically based urban watershed models such as the Environmental Protection Agency (EPA) storm-water management model (SWMM). In order to understand runoff process, efficiency of existing storm water drains and flood mitigation measures, SWMM model has been applied to sub basins of Chennai and Hyderabad metropolitan cities in India. The sub basin geographical areas of Chennai and Hyderabad are 30 and 84 sq km respectively. Due to lack of short interval rainfall and water level data in these sub basins, field instruments (Tipping bucket rain gauges and automatic water level recorders) have been installed at various locations. The SWMM model has been calibrated using observed field data. Based on hourly rainfall data the IDF curves have been developed for both sub basins. The present storm water net work efficiency in both the cities is limited to drain 2 to 5 years return period storm only. The flood hydrographs at outfalls in these sub basins have been developed for various return periods. Few flood management scenarios have been developed based on the calibrated model. The data monitored in these sub basins may act as benchmark dataset for further research and to explore other flood mitigation measures.

Keywords

Storm, Drains, Flood, Urban

Uncertainty in the SWAT Model Simulations due to Different Spatial Resolution of Gridded Precipitation Data

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Abstract

Gridded precipitation data are being increasingly used as input to watershed hydrological models for better representation of spatial variability of the precipitation. The spatial variability of gridded data is best utilized by distributed and semi-distributed hydrological models, compared to the lumped models. Among the numerous watershed hydrological models, Soil and Water Assessment Tool (SWAT), owing to its better computational efficiency, is being widely used for practical applications of water resources management. SWAT model delineates the watershed into sub-basins and subsequently to hydrologic response units (HRU's) on the basis of slope, soil and land use/ land cover. In the context of increasing use of gridded precipitation products with the SWAT model, it is important to assess the variability induced by the spatial resolution of precipitation data on the model simulations. An experiment was conducted on Krishna River Basin (India), with catchment area of nearly 2,60,000 km^2, using precipitation data sets pertaining to three spatial resolutions (1°x1°, 0.5°x0.5°, and 0.25°x0.25°) from India Meteorological Department (IMD) to evaluate the variability induced in the SWAT model outputs. Model output from the 1° spatial resolution data was considered as the reference to compare the variability from other resolutions. SWAT, a semi-distributed model, considers uniform precipitation input for the whole sub-basin. Under this assumption, an experiment was performed by varying the sub-basin sizes in the SWAT setup to study the combined effect of spatial extent of sub-basins and spatial resolution of the precipitation data on the model simulations. The simulations were run for a period of 35 years from 1971-2005. The comparison of the output hydrographs at the watershed outlet for the three input data showed that the peak flows were significantly reduced when the input resolution becomes finer. The sediment yield at the watershed outlet also had a significant reduction for finer resolution data, compared to the coarser resolution precipitation data. For any given sub-basin, cross-examination of discharge and sediment yield among simulations of different input data showed significant variability. It was also observed that for larger sub-basins in the watershed, the variability in flow and sediment yield is less. Such variations could invariably affect the decision making process by using the hydrological model and different resolutions of input data. Hence, it is recommended that the choice of the spatial resolution of the gridded precipitation data should be done carefully by considering the size of the watershed under investigation.

Keywords

Gridded Precipitation, Input Uncertainty, Large River Basin

Investigating the effect of calibration objective function on a flood forecasting system

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Abstract

Accurate and reliable flood forecasting is essential for effective management and mitigation of floods. This is generally achieved by applying various hydrological models, and through hybrid models which combines the strength of different modelling aspects in hydrology. For the calibration of these hydrological models, modellers employ different objective functions. However, objective function employed may capture an only certain amount of information, which might be detrimental to model performance. Thus, it is essential to understand the impact of objective function on the model performance and the parameters. In this study, a hybrid model combining HEC-HMS and ANN was considered for flood forecasting in a small watershed located in northern portion of Greenville County in the state of South Carolina in the USA. The purpose of application of the hybrid model is to give accurate flow forecasting for increased lead time and also get accurate hydrograph for preparing flood inundation maps. For understanding the impact of objective functions on the model performance, different indices were used for model calibration. The objective functions considered for the model training were Mean Squared Error (MSE), Nash Sutcliffe Efficiency (NSE) and Modified Peak Difference (MPD) and Relative Volume Error (RVE). AMALGAM optimizer was used to calibrate the model using these performance measures. A numerical exercise was planned to evaluate the impact of different objective functions individually as well as combinations of it with the characteristics of the model parameters and associated uncertainty. The results showed that multi-objective calibration improves the model performance compared to single objective calibration method. The combination of the NSE and MPD yielded best results by simultaneously capturing the peak and shape of the hydrograph. The model parameters were also found to be varying significantly for different objective functions used for training the hybrid model.

(Any hydrological model can be used for developing this hybrid model including SWAT. The purpose of using the hydrological model in this study is to take an account of the physical processes happening in the watershed during a rainfall event. SWAT is a distributed hydrological model which is commonly used in continuous simulation and gives a detailed representation of the watershed processes but in this study, we required a model which can represent the watershed process in a simple manner. For that, we adopted a semi-distributed model HEC-HMS which represents the watershed process using conceptual and empirical methods.)

Keywords

Flood forecasting , Hybrid model, Model Calibration, Performance indices, AMALGAM

Hydrological Assessment of Gridhamal Basin and Sensitivity Analysis using SWAT

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Abstract

Water an essential element for the survival of all organisms and occupies a vital position in the hydrological cycle, also a necessary factor for economic-development and agricultural-growth with rapidly increasing population and urbanization. Madurai has been selected as the urban area, and it generates a vast amount of wastewater daily. While considering the sustainability concept, one should reuse this wastewater after proper treatment. Gridhamal basin within Madurai urban area which is suffering from the water crisis was selected. The objective of this study is to find out the hydrological processes and how best the treated wastewater can be used to enhance the urbanization in the context of sustainability and also to find the sensitive parameters which are having more influence on our study area. SWAT a semi-distributed hydrological model is chosen, and the model has been simulated with collected data, and the characteristics of treated wastewater are estimated under laboratory condition. As a preliminary study, rice has been chosen as the initial crop, and plant growth was based on both precipitation and treated wastewater with the estimated water quality. The groundwater recharge, plant growth, ET, outflow are simulated for 35 years with available 40 years data (5 years base period). For calibration and validation ET values have been chosen, in the 25 years observed information ten years has been used for calibration and another 10 for validation and initial five years as base period and 11 sensitive parameters had been identified. The calibration shows R^2 as 0.86 and NS as 0.72, and the validation shows R^2 as 0.85 and NS as 0.61 in SWAT-CUP with the SUFI2 algorithm.

Keywords

Hydrological processes; Urban; Reuse; Simulation; SWAT; SUFI2

Performance Evaluation of Swat with a Conceptual Rainfall-Runoff Model GR4J a Catchment in Upper Godavari River Basin

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Abstract

Due to high spatial variability of monsoon rainfall, water resources management issue is utmost requirement in the upper Godavari river basin(UGRB). Despite the presence of several dams in this region, the availability of water resource is not evenly distributed. For studying the efficiency and suitability of hydrological models for stream-flow prediction, a semi-distributed model SWAT (Soil Water Assessment Tool) and a conceptual model GR4J (Genie Rural 4 parameters Journalier) is compared at catchments in UGRB. GR4J model, working in Source modeling platform developed by eWater Australia, is used in this study. The main objectives of the study include: 1) Identify the advantages and disadvantages of the SWAT over GR4J 2) Performing sensitivity analysis and uncertainty analysis in SWAT for determination of sensitive parameters and their ranges. The UGRB is divided into many sub catchments due to presence of dams in the area. In this study, one catchment Mula (2292 km^2) is considered. Based on the data availability and quality it was observed that the GR4J performed better than SWAT in terms of Nash Sutcliffe Efficiency (NSE) and R^2 for small catchments at a daily time scale. However, for monthly calibrations the SWAT model produced better results compared to GR4J with p-factor0.77, r-factor0.49, NSE 0.78 and R^2 0.78. The physically based parameters in SWAT helps in understanding the important hydrologic processes better compared to lumped parameters in GR4J. The range of parameters obtained after stochastic calibration in SWAT gives an idea about prediction uncertainty. GR4J is recommended in data scarce regions due to its minimal input requirements. SWAT is more suitable where data availability is not a constraint.

Keywords

SWAT, GR4J, Hydrologic Modelling, Water Resource Management

Soil Water Balance model over the Chittar Subbasin, Tamilnadu using SWAT

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Abstract

Water balance model is one of the effective management tool for flood control and management, rainwater harvesting, groundwater recharge sites, drought analysis, irrigation management, land and soil conservation and its management, design of hydraulic structures in the river basin. A water balance model, also called a mass balance model, is an application of conservation of mass to a particular spatial unit. The law of conservation of mass states that in a closed system, the total mass in the system is always constant over specific period. Water balance model is developed by assuming the river basin is a closed system, the change in water storage over specific period should be equal to difference between inflow as rainfall and outflow as surface runoff, infiltration and evapotranspiration. The Water Balance models have been developed at various temporal levels (e.g. hourly, daily, monthly and yearly) and to varying degrees of complexity. There are available to develop water balance model also many theoretical and experimental studies has been carried out in the past years. In this study an attempt will be to develop monthly water balance model for the chittar subbasin, Tamilnadu. The model development will be carried using SWAT. Then the understanding of spatial and temporal distribution with the Evapotranspiration, Infiltration, Surface runoff, Soil moisture and Groundwater level fluctuation over the catchment area. It will be useful for developing integrated water resources management policy over the catchment area.

Keywords

Water balance model, Surface runoff, Infiltration, Evapotranspiration, Soil moisture, Groundwater

Hydrologic Response of Bhavani Sagar Reservoir Watershed Using SWAT

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Abstract

Planning of water resources projects depends on the hydrologic response of a watershed. Therefore, hydrological modeling at a watershed level is very important. This paper describes the application of the Soil and Water Assessment Tool (SWAT) Model to the Bhavani Sagar reservoir watershed, located in Southern India, Tamil Nadu. The SWAT model was developed based on SRTM DEM 30 m resolution and land use of 10 km resolution and soil maps of 30 arc-second raster resolution. The model was calibrated using streamflow for the period 2007-2009 and validated with data for the period 2010 to 2011. The simulated values of streamflow were found to be in good agreement with the observed values. The values of coefficient of determination (R^2), Nash-Sutcliffe efficiency (NSE) and Percent BIAS for streamflow were found to be 0.75, 0.72 & 12.4 % for calibration period and 0.72, 0.07 & 44.5% for validation period. Further, the developed model is being simulated to understand the impact of sediment erosion from the watershed on the Bhavani Sagar reservoir. The sedimentation survey (2006) by CWC reported that the reservoir has lost its gross capacity around 159.21 M.cum from 975.18 M.cum with an average rate of siltation is 3.643 M.Cum/yr over 53 years**.** So controlling the sedimentation in reservoir is important and it depends upon prevention upland watershed and channel erosion. Hence this study we are focusing on estimating the sediment yield from Bhavani Sagar reservoir watershed, identifying the erosion-prone areas in the watershed and proposing best management practices to minimize erosion rate in the watershed.

Keywords

Sediment Erosion, Reservoir Sedimentation, Watershed-scale Hydrological Model

Streamflow quantification using SWAT in a catchment of Coastal Odisha

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Abstract

Odisha is a state which is liable to various natural disasters due to its geographic location. Large areas of coastal Odisha are affected by floods every year resulting in huge loss of life and property. Hence, accurate quantification of the water resources in a monsoon-dominated area is a top priority. In the current study, a semi-distributed, physically based hydrological model, i.e., Soil and Water Assessment Tool (SWAT) is applied for the assessment of streamflow at a daily scale in the Budhabalanga river, a tributary of Subarnarekha river. The calibration and validation of the model were carried out using SWAT-Calibration Utility Programs (SWAT-CUP) with Sequential Uncertainty Fitting (SUFI-2) algorithm. The time-period of the analysis was divided into three sections, i.e., calibration (2000-2010), with an initial warm-up period of 3 years, (2000-2002) and validation (2011-2014). The uncertainty associated with the model prediction is presented in the form of 95PPU. Three statistical indicators, i.e., Nash-Sutcliffe efficiency (NSE), Coefficient of determination (R^2) and Percentage Bias (PBIAS) were used to assess the model performance. The obtained values of NSE, R^2 and PBIAS values are 0.61, 0.71 and -12 during the calibration and 0.57, 0.66 and 14.2 during validation period respectively. Since SWAT model performed satisfactorily for the identified study area as per the goodness of fit values, this model can be implemented in similar hydrologic conditions.

Keywords

SWAT, SUFI-2, Daily streamflow, Goodness of fit, Uncertainty

Parameter Optimisation of runoff model using Particle Swarm Optimisation

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Abstract

Watershed is a basic scientific unit for studying various hydrological processes in a region. Runoff measurement helps in water management practices within a watershed. A distributed event based rainfall runoff model with Kinematic Wave-Finite Element Method (KW-FEM) is chosen to simulate the runoff in a watershed. Infiltration being the key part of hydrologic process, GAML infiltration model is used in the runoff simulation. GAML model parameters are manually calibrated for each event in the watershed runoff model. This process is tedious and laborious and needs human intervention to run the iterations. The KW-FEM model can be used for real time forecasting if the parameters are automatically optimized on real time. Hence, in this study, infiltration model parameters that are saturated hydraulic conductivity (K_s), average suction head (S_{av}), saturated water content (θ_s) and initial water content (θ_i) are optimized using Particle Swarm Optimisation (PSO) technique. Parameter tuning is minimal in PSO and it considers real numbers as particles. The proposed model is applied on Banha and Khadakohol watersheds in India. It is observed that the simulated hydrograph is improved by optimizing the parameters of the runoff model. The optimized model can further be applied for real time scenario.

Keywords

Infiltration, Particle Swarm Optimisation (PSO), Runoff, Watershed

Hydrological Modeling of Upper Tapi River Sub-Basin, India using QSWAT Model and SUFI2 Algorithm

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Abstract

Hydrological modeling of a sub-basin is a must to evaluate the impact of land use land cover changes and to study the impact of climate change on sub-basin. In this study QSWAT model is used to simulate the hydrology of the Upper Tapi River Sub-Basin of India. The study area is a sub-basin of Upper Tapi River Basin covering the area of 10,595 km^2. The datasets used in this study include the daily climate data of Climate Forecast System Reanalysis (CFSR), collected for the period 1980 to 2013 from SWAT website. The daily observed discharge data (1980-2013) is obtained from India Water Portal (India-WRIS) for Bhuranpur gauge station. The Upper Tapi River Sub-Basin and the drainage pattern of the land surface terrain is delineated in QSWAT using the SRTM DEM. Consequently, the sub basin is divided into 9 watersheds and it is further sub divided into 150 hydrologic response units (HRUs) based on the land use, soil type and slope of the area. The model was calibrated for the period 1987 to 2005 including three years warm up period (1987-1989) with Sequential Uncertainty Fitting (SUFI-2) algorithm in SWAT CUP (Calibration and Uncertainty Program) and validated for the period 2006 to 2013 on monthly bases. Global sensitivity analysis was performed to identify the most sensitive parameters for stream flow based on t-state and p-value. It was found that SCS run-off curve number for moisture condition II (CN2), Soil evaporation compensation factor (ESCO), Base flow alpha factor (ALPHA_BF), were the most sensitive parameters for the sub basin followed by Manning's "n" value for the main channel (CH_N2), Manning's, "n" value for overland flow (OV_N) and Soil available water storage capacity (SOL_AWC). The calibration and validation results show satisfactory model performance and the QSWAT model is applicable to the catchment for the hydrological analyses. Developed model could be used for analysis of different scenarios based on expected changed land use land cover or climate.

Keywords

Basin, Hydrology, Land use/Land cover, Model, SUFI2 and QSWAT

A Study On The Impact Of Errors In Weather Parameters Generated By Stochastic Weather Generators In Hydrologic Simulations

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Abstract

Hydrological model simulations require time series of daily weather information; however availability of reliable and accurate weather data continue to pose a challenge in modelling studies carried out in many parts of the world. Hydrological models such as Soil Water Assessment Tool (SWAT) address this issue through stochastic Weather generators that are capable of generating synthetic time series of weather variables such as precipitation, temperature, relative humidity, solar radiation and wind speed based on the statistical characteristics of historical weather related observations available at the locations. Hence accuracy and reliability of observed data is critical in generating realistic sequences of weather information from stochastic weather generators. Lack of accurate observed data causes uncertainty in the weather generator simulations in the form of over prediction or under prediction of weather sequences which subsequently affects the performance of hydrological models. In this context, the proposed study aims at assessing the sensitivity and performance of the weather generator CLIGEN in deriving time series of weather information, namely relative humidity and solar radiation. Bias corrected precipitation and temperature data along with relative humidity, solar radiation and wind speed from the CFSR data set was used as input for SWAT and was considered as the pseudo observed data. The sensitivity of CLIGEN was evaluated by further simulations of SWAT carried out using different sets of relative humidity (RH) and solar radiation (SR) varied from +/- 10% to +/-25% along with random noise. The derived weather datasets were employed for hydrological modelling of five basins namely Birhidang, Ken, Subarnarekha, Achankovil and Vaipar which belong to distinct climatic zones and hydrological response. The results from the study indicated that the degree of sensitivity of the predicted streamflows with respect to different sets of RH and SR derived from CLIGEN were different for basins belonging to distinct climatic zones.

Keywords

CLIGEN, Weather Generator, SWAT

Calibration & Validation of MWSWAT Hydrological Model to Estimate Hydrological Parameter of Sabarmati River

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Abstract

The present paper is focused on Sabarmati River which is passing through states of Rajasthan and Gujarat and meets Gulf of Cambay. The study area is covering Gujarat Portion up to Vasna barrage which is situated downstream of Ahmedabad city. Daily rainfall and maximum and minimum temperature data of eight years (1998-2005) are used in the study. "SWAT" (Soil and Water Assessment Tool), a distributed hydrological model, is a public domain model actively supported by the USDA has been applied for this research work. The main components of SWAT include weather, surface runoff, return flow, percolation, Evapotranspiration, transmission losses, pond & reservoir storage, crop growth & irrigation, groundwater flow, reach routing, nutrient & pesticide loading, and water transfer. The study adopts a Map-Window (GIS software) interfaced SWAT based distributed model for the study of watershed to estimate the Precipitation. The soil data, land use data, DEM and drainage map of study area are used in the study a geographical information system (GIS) is used for generating drainage networks, land cover/land use data and soil series. The SWAT model is made to run and results are measured by applying appropriate methods. The outputs are then calibrated and validated with the observed values to improve the results.

Keywords

MWSWAT, Sabarmati River, Precipitation

Isolating the impacts of climate change using QSWAT model on Uguem river stream-flow at Goa, India

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Abstract

Climate change studies predict intense impacts on water resources in India. These impacts include higher annual average rainfall as well as increased drought. This can have negative impacts on the water supply. Considering that the political and technical measures to adapt to climate change take place at a regional/local level, site-specific studies on climate change are much needed. In Goa, an assessment of the impact of changing climate on streamflow has not been addressed. It is in this context, that this study was undertaken at a watershed level for the Uguem River in South Goa.

The future climate variables of precipitation and temperature were generated using the regional climate model PRECIS. A 30-year baseline data, climate scenario A1B SRES, and a resolution of 25 * 25 km were used for the projections. The PRECIS output was provided as an input to the hydrological model, QSWAT (version 1.2) and streamflow was simulated. After calibration of QSWAT model, a Nash Sutcliffe Efficiency (NSE) and R^2 of 0.7 were obtained indicating a good fit. Streamflow predictions were done till the year 2050. The streamflow is likely to decrease in the decades of 2040s and 2050s. To comprehend the temporal variation in water availability in the future, dependable flow and peak flow analysis was done. Based on the results, site-specific recommendations have been provide for better management of the water resource.

Keywords

Climate change; PRECIS model; QSWAT; stream-flow, Goa

Climate Change Sensitivity Assessment using SWAT for a Highly Agricultural Watershed, Shell Creek, Nebraska, USA.

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Abstract

Water resources around the globe come under increasing pressure due to climate change causing emerging trends in world food demand. The increase in temperature directly influences the evapotranspiration process of a particular watershed and consequent increase in the loss of water to be supplied to the crops. Further, the changes in the precipitation patterns will influence the crop water requirements in terms of the amount of water to be supplied following the crop demand. Quantifying the hydrological response and therefore Irrigation Water Requirement (IWR) over a command area to increased atmospheric CO_2 concentration is critical for the agricultural water management systems. This study modeled the agricultural water availability based on Intergovernmental Panel on climate Change projections. The Soil and Water Assessment Tool (SWAT) was used to simulate the hydrology and agricultural water availability in a agriculturally dominated landscape located in the Shell Creek watershed in east-central Nebraska, USA. This watershed has an area of 1200 km^2 with 78.2 % of cultivated land cover. The hydrological responses such as water yield, evapotranspiration, irrigation water use are simulated under current and future scenarios with calibrated and validated with 1991-2007 and 2008-2014 data sets respectively. Overall, the results indicate that the Shell Creek river basin hydrology and agriculture in terms of water yield, evapotranspiration and irrigation water demand etc. is very sensitive to potential future climate change.

Keywords

Irrigation Water Management, Evapotranspiration, Water Yield, Climate Change

Hydrological Assessment of Climate Change Impacts on Sustainable Agriculture - A Case Study in Krishna Basin

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Abstract

Krishna River Basin well known as closed basin has largest paddy growing area in India. A deviation in the rainfall pattern and temperature is being observed in the basin. The impact of these changes in climate over agriculture plays a predominant role on the economy of the country. The main aim of this case study is to assess the Hydrological parameters for changing climate and analyse its impact on crop production. The Basin on an average receives 800 mm rainfall in the monsoon period with a maximum of 2000 mm in the Western Ghats and the minimum of 300mm in the south. The SWAT model is run for the future climate simulations to assess PET, Soil Water, Water Yield, water availability and crop water demand. The intensity of rainfall is understood to increase with more rainfall in less number of rainy days thereby creating extreme climate events of both drought and flood. The mitigation plan of investigating crop models and developing crop varieties to cope with extreme climate condition is of urgent need.

Keywords

Crop Production, Water Availability, Crop Water Demand, Krishna Basin

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