Application of SWAT Model Driven by CMADS

Yutong Sun[1, 2, 3, 4, 5, *], Panpan Zhang[1, 2, 3, 4, 5] and Liheng Xia[1, 2, 3, 4, 5]

[1]Shaanxi Provincial Land Engineering Construction Group Co., Ltd., Xi'an 710075, China;

[2]Institute of Land Engineering and Technology, Shaanxi Provincial Land Engineering Construction Group Co., Ltd, Xi'an 710075, China;

[3]Key Laboratory of Degraded and Unused Land Consolidation Engineering, Ministry of Natural Resources, Xi'an 710075, China;

[4]Shaanxi Provincial Land Consolidation Engineering Technology Research Center, Xi'an 710075, China

[5]Land Engineering Technology Innovation Center, Ministry of Natural Resources, Xi'an 710075, China;

*Corresponding author: sunyt0924@126.com

Abstract. The SWAT (Soil and Water Assessmennt Tool) model is a hydrological model that has developed rapidly and has great influence in recent decades. It is mainly used to simulate and predict the impact of various management measures and climate change on the supply of water resources. The atmospheric input data used in the model is the SWAT Model China Atmospheric Assimilation Driven Dataset (CMADS). The data set introduces the Chinese land surface assimilation system, and uses various technical means such as data nesting, resampling, model estimation and bilinear interpolation to ensure the reliability of meteorological input data. The advantage of the CMADS series dataset over traditional meteorological data is that it provides a more complete dataset without missing values. In the process of hydrological modeling after the introduction of the physical model, the accuracy of the input data is constantly improving. Therefore, the CMADS series datasets will be very good hydrological model-driven data at this time.

Keywords: CMADS, SWAT, meteorological data, DEM.

1. Introduction to the SWAT model

SWAT (Soil and Water Assessmennt Tool) is a watershed distributed hydrological model developed on the basis of the SWRRB model. It has great functions and can be applied to a wide range of watersheds. So far, it has been used in watersheds ranging from 491,700 km^2 to 0.395 km^2. Moreover, the SWAT model can directly reflect physical process simulation, water movement, sediment transport, crop growth and nutrient cycling, etc.; the model can not only be applied to watersheds lacking observational data such as flow, but also can be used for climate, land use/coverage, etc. Quantitative evaluation of the impact of changes on watershed runoff and water quality. The model can also divide the watershed into several sub-watersheds for analysis and simulation. In the horizontal direction, it is mainly divided into sub-watersheds with different areas according to the different natural conditions of the underlying surface of the watershed; By layering and solving differential equations of hydraulics and physics at the same time, the accuracy of hydrological simulation can be greatly improved, and the influence of spatial differences on the simulation can be reduced.

Among them, the water balance equation used in the model is as follows [1]:

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$$

In the formula, SW_t is the soil water content on the ith day, (mm), SW_0 is the pre-soil moisture content on the first day (mm), t is the time step (day), R_{day} is the rainfall on the ith day (mm), Q_{surf}

is the surface runoff on the ith day (mm), E_a is the evaporation on the ith day (mm), W_{seep} is the infiltration and lateral infiltration at the bottom of the soil profile on the ith day Flow rate (mm), Q_{gw} is the groundwater content (mm) on the i-th day.

2. Research progress at home and abroad

It was carried out relatively early in foreign countries. Based on the topographic map, vegetation map, soil map and 20 years of meteorological data of the United States, Srinivasan[2] and others established the corresponding database required for the SWAT model with the assistance of GIS and other software. The runoff simulation work was carried out and the ideal simulation results were obtained. Bingner [3] took the Goodwin watershed, a tributary of the Mississippi River as the research object, and conducted a runoff study using the SWAT model. The results showed that the runoff simulation effect of most sub-basins was good, and the simulated value reached 90% of the measured runoff value. In addition, The SWAT model is more suitable for simulating the hydrological process of the watershed for a long period of time.

Ping Huang [4] summarized the distributed hydrological mathematical models in foreign countries and analyzed their shortcomings. Based on this, they proposed a three-dimensional dynamic hydrological numerical model of the basin composed of the basin slope flow equation and the three-dimensional saturated-unsaturated flow equation. The idea is that the model uses two-dimensional form to simulate slope flow, and three-dimensional form to simulate groundwater flow. It is believed that its spatial distribution can more truly reflect the actual situation of the watershed. On this basis, a two-dimensional distribution hydrological mathematical model of forest slope was established and related verification applications were carried out [5]. Liliang Ren [6-7] carried out DEM preprocessing, generation of river network and generation of topological relationship of river network based on digital elevation model (DEM), and then established a digital runoff model on each catchment unit (using Xin'an River). Model), according to the topological relationship of the river network structure to establish a digital river network confluence model (Muskingen method by river section), thus constructing a digital hydrological model. Lan Li [8-9] proposed a distributed hydrophysical model that combines mathematical physics and flood forecasting, which can be used to analyze the evolution of precipitation and runoff and real-time flood forecasting. Shenglian Guo[10-11] proposed a distributed watershed hydrophysical model based on a digital elevation model (DEM), which applied mathematical-physical equations to describe plant interception, evapotranspiration, snowmelt, infiltration, surface runoff, subsurface runoff, and flood routing in grid cells and other hydrophysical processes. Based on the idea that the system relationship between rainfall and runoff is nonlinear, Jun Xia [12-13] developed a distributed time-varying gain water cycle model (Time Variant Gain Model, TVGM). TVGM builds a nonlinear surface runoff model in the watershed unit grid divided by DEM, uses the water balance equation and storage and discharge equation to build a soil water runoff model, and uses the kinematic wave equation to build a hierarchical grid confluence model. Yangwen Jia [14-16] proposed the IWHR-WEP model based on the characteristics of China's inland river basins and the WEP model. Then, on the basis of the IWHR-WEP model, a large-scale distributed hydrological model WEP-L (Water and Energy Transfer) was developed with the "natural-artificial" binary water circulation system as the simulation object for the super-large watershed such as the Yellow River Basin. Process in Large river basins) model. Dawen Yang [17] based on the geomorphology-based hydrological model (GBHM) of hillside hydrology, which considers the influence of changes in the underlying surface of the watershed and the spatial distribution of rainfall on the hydrological response of the watershed, and uses the area equation and the width equation to approximate the runoff and runoff process in the watershed. It is transformed into a "hillside-channel" system, and the entire watershed is divided into several hillside unit watersheds step by step. In general, although the research on distributed hydrological models in my country has achieved certain results, it is still in its infancy, and the application of most models is limited to specific research areas and needs further development [18].

In my country, hydrologists apply the SWAT model to their own research areas. Liping Zhang [19] applied the SWAT model to the Bailian River Basin, and the results showed that the model could well simulate the flow process of the watershed, verifying the applicability of the SWAT model in small and medium-sized watersheds. Chen et al. [20] used the SWAT model to simulate the yellow duck The daily runoff process of the river basin has achieved good simulation results.

3. Introduction to CMDAS

Using atmospheric and hydrological models to quantitatively describe the variation law of land surface-related variables has always been a research hotspot in the field of atmospheric science and hydrology. However, due to the lack of stations in western my country, traditional meteorological observation stations can no longer meet the needs of high-precision simulation and analysis of large-scale surface components. Establish the SWAT model China Meteorological Assimilation Driving Datasets for the SWAT model (CMADS) to drive the SWAT (Soil and Water Assessment T001) model (referred to as CMADS+SWAT model).

Atmospheric assimilation datasets that incorporate more observational data can greatly improve the model output accuracy [21]. At present, there are many kinds of atmospheric reanalysis at home and abroad. Since traditional atmospheric observation stations are not all over the world, the reanalysis dataset provides important data support for the analysis and application of climate scenarios in areas with missing meteorological measurements [22]. However, for regional refinement simulations, the accuracy of the above reanalysis data needs to be improved. Pal et al. [23] used the regional climate model RegCM3 to simulate and evaluate the monthly variation of precipitation in winter and summer in the East Asian monsoon region on a seasonal scale and found that: the regional model RegCM3 has a large error in precipitation, This phenomenon is particularly prominent in winter. Zhao et al. evaluated the regional availability of ground pressure and temperature elements in NCEP, ERA, and JRA datasets and found that there were significant seasonal and regional differences between the three reanalysis datasets [24]. Shi et al. used various technical means to evaluate the applicability of NCAR-driven data (including: air temperature and wind speed) in China and found that the anomaly error of wind field data is negatively correlated with altitude. The above studies all show that although various reanalysis products can better reflect the spatial modes of large-scale meteorological elements, however, since most of the reanalysis datasets have not been corrected by automatic stations in all regions of my country, they cannot be used in a better way. It reflects the real weather conditions near the surface in my country. To sum up, the use of atmospheric data sets that are closer to my country's real meteorological fields to drive mature hydrological models can better analyze the spatiotemporal evolution laws of large-scale surface components in my country.

4. SWAT model based on CMADS data

4.1. SWAT model surface input data

The input data of SWAT model mainly includes digital elevation model (DEM), soil data, land use data and meteorological driving field. Soil physical properties determine the production and confluence characteristics of different hydrological response units in the SWAT model. It is also the reference for the SWAT model to define the Hydrological Response Unit (HRU).

4.1.1 Digital elevation model data

Digital Elevation Model (DEM) is a mathematical model that approximates the elevation information of the terrain surface. It contains a large number of hydrological elements and terrain information [25]. With the continuous development of computer technology and 3S technology, the introduction of DEM has promoted the rapid development of distributed hydrological models, and the technology of digitizing watersheds and extracting landform features based on DEM has been widely used [26]. The accuracy and spatial resolution of DEM have an important impact on the

extraction results of basin geomorphological features and the simulation accuracy of runoff and runoff. In theory, the higher the accuracy and resolution of DEM data, the better the simulation results [27]. However, it is difficult to obtain high-precision and high-resolution DEMs at this stage, and when performing large-scale hydrological simulations, the computing power of ordinary computers is difficult to meet the simulation operation of the model. The SWAT model can generate a digital river network based on DEM data. If the generated river network is not ideal, the actual river network can be input to calibrate the generated digital river network.

4.1.2 Soil data

Soil data is the key input data in the pre-processing of SWAT modeling, and the quality of the data will have an important impact on the simulation results. The soil data used in the model include soil type distribution data and soil physicochemical property data. Among them, the physical properties of soil determine the movement of water and air in the soil profile, and play an important role in the water cycle in the hydrological response unit.

4.1.3 Land use data

In 2000, the Institute of Space Technology of the European Union's Contact Research Center joined more than 30 countries and regions to jointly develop a global land cover dataset. Different land use types affect runoff formation and sediment generation and transport processes.

4.2. Atmospheric drive input data

The atmospheric input data used is the SWAT model China Atmospheric Assimilation Driven Dataset (CMADS), which introduces the China Land Surface Assimilation System and uses various technical means such as data nesting, resampling, model estimation and bilinear interpolation. , to ensure the reliability of meteorological input data.

4.3. Model Settings

Using the SWAT model as the simulation platform, the river network information of the basin is extracted based on DEM, and the DEM data is used to divide the basin into smaller sub-basins. The size of the sub-basins can be changed by the minimum catchment area. Finally, the SWAT model subdivides each sub-watershed into several hydrologically corresponding units (HRUs are areas within the same sub-watershed with the same land use type and soil type). In the SWAT model, the water balance within each HRU is based on surface runoff , soil midflow, base flow (regressive flow), infiltration, channel transport loss and evapotranspiration. (The above pre-processing settings need to be consistent before simulating the three different modes in the later stage). The combination of the driving field (CMADS) driven SWAT model is called the CMADS + SWAT model. In order to reflect the advantages of the CMADS dataset compared to traditional weather stations, the Penman-Monteith method is used to calculate potential evapotranspiration, which requires input of solar radiation, air temperature, relative humidity and wind speed (selecting this method can fully reflect that the CMADS dataset is better than traditional weather stations. does not provide the advantage of solar radiation input). Since the input data is daily data, the surface runoff calculation is calculated using the Soil Conservation Service’s curve (SCS) curve, which is a nonlinear function between precipitation and initial loss. Surface runoff will be calculated in each hydrologically corresponding unit and eventually converged to the main channel of the basin. Finally, the channel storage method based on the continuity equation is selected to calculate the water volume evolution of the main channel.

The SWAT model can spatially interpolate the meteorological data of a single point in the watershed to the entire watershed through the interpolation principle of the Centriod method. In order to reduce the error caused by spatial discrete interpolation and improve the precipitation accuracy of the hydrological corresponding unit (HRU) and natural sub-basin (Sub basin), combined with the information extracted from the basin elevation, multiple elevation zones were divided. The precipitation gradient can better simulate the precipitation distribution in different elevation zones in

the basin, because the precipitation of each sub-basin after the elevation adjustment will be generated through the model output.

5. Discussion

Due to the introduction of advanced assimilation technology, the CMADS data set has also been corrected by the national automatic observatory. In addition, the CMADS series of data sets also have multiple versions (1/3°, 1/4°, 1/8°, 1/16° and other resolutions) datasets. There is no doubt about the observation accuracy of traditional meteorological stations. However, due to the lack of test stations and the sparse number of stations in my country, especially in the western region, traditional meteorological stations cannot play their effective role in the basins where there are no meteorological stations at all. effect.

For a watershed or a large-scale region, quantitative analysis of its spatial-scale water balance and other element components is of great significance to clarify the ecological and hydrological components on the longitudinal section of my country. However, currently limited by a variety of objective and realistic factors, traditional meteorological stations have been unable to meet today's large-scale surface component analysis and modeling work. It is conceivable that when the basin hydrological station and the meteorological station are in the same area, and there are meteorological stations in the basin, the traditional meteorological station is undoubtedly the best choice for data input. However, if there are sparse meteorological stations in the watershed, or there are even no meteorological observation stations in the study area, the CMADS series datasets are undoubtedly the best atmospheric driving data for hydrological modeling. In addition, the advantage of the CMADS series dataset over traditional meteorological data is that it provides a more complete dataset without missing values. In short, in the process of hydrological modeling, especially after the introduction of physical models, the accuracy of input data is constantly improving. At this time, the CMADS series of data sets will be very good hydrological model-driven data.

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