J. Agr. Sci. Tech. (2010) Vol. 12: 121-131

Modeling of Sediment Yield and Bicarbonate Concentration in Kordan Watershed

F. Sarmadian[1]*, P. Rahimy[1], and A. Keshavarzi[1]

ABSTRACT

In the present study, the Soil and Water Assessment Tool (SWAT 2000) model was tested on both a monthly and yearly basis and applied to the Kordan Watershed, located in Iran. The main objective of the research was to assess the accuracy of the model in sediment-yield and surface water bicarbonate concentration estimation. The attributes of sub-watersheds, tributary channels and the main channel in each sub-watershed were generated using the Digital Elevation Model (DEM) and Geographical Information System (GIS) Arc View SWAT 2000 interface. The model was calibrated and validated for the period from 1990 until 2004. Calibration results revealed that the model predicted monthly and yearly sediment-yield, but not such good results were obtained for the bicarbonate concentration. Therefore, some efforts were made in order to find a solution for SWAT bicarbonate temporal modeling. Around 70 samples of the Kordan River water quality data were used and, upon doing statistical calculations, the best correlation between the average pH–EC of water and the bicarbonate concentration was obtained. The formula shall be tested at several watersheds, and it can also be defined to SWAT in order that the model is able to calculate bicarbonate concentration according to pH and EC of the river water, which are introduced to SWAT by the user as a stream water quality file (SWQ) .

Keywords: EC, pH, Sedimentation, SWAT.

[DOR: 20.1001.1.16807073.2010.12.1.11.7]

INTRODUCTION

One of the most important concerns in arid and semi-arid areas is erosion caused by water. Erosion brings about ablation, transmission and sedimentation of soil particles. Soil particle transmission from farm and orchards to other areas causes improvement of fertility in the land. But, if non-fertile soils, particularly those mixed with a high quantity of stones, are transferred to farm land and accumulate, the fertility of such lands decreases gradually. Moreover, sedimentation in water channels clogs the water ways, It may also transfer pollutants into farm lands and dams, which are used for irrigation and drinking purposes. Hence, a study of surface water potential as well as for sediment-yield seems extremely urgent, in order to plan suitable management actions for the reduction of erosion and sedimentation.

Another problem of arid and semi-arid areas is the danger of land alkalinization, which frequently causes soil to crust, swell and disperse and which greatly decreases the hydraulic conductivity. Clay particles disperse and plug soil-water flow channels. Swelling of clay particles also slows down the water flow. Decreased permeability does interfere with the drainage requirements for normal salinity control and with the normal water supply and aeration requirements for plant growth.

One of the most important solutions related to the sodium hazard of irrigation water is bicarbonate concentration.

[1] Department of Soil Science, College of Agriculture,Tehran University, Islamic Republic of Iran.
* Corresponding author, e-mail: fsarmad@ut.ac.ir,

Bicarbonate toxicity generally arises from deficiencies of iron or other micronutrients caused by high pH. The optimum level of bicarbonate is 1.5-8.5 mmol l^{-1}, if the concentration of bicarbonate reaches over 8.5 mmlo l^{-1}, bicarbonate hazard will be seen (FAO Report, 1988).

Precipitation of calcium carbonate lowers the concentration of dissolved calcium, increasing SAR, and the exchangeable-sodium level of the soil.

$Ca^{2+}+2HCO_3^{-}= CaCO_3+H_2O+CO_2$

The quantity of precipitating bicarbonate depends upon the proportion of water percolating through the soil, or the leaching fraction (Bohn, 1985).

MATERIALS AND METHODS

Description of the Model

A physically based continous time model, a Soil and Water Assessment Tool (SWAT 2000) (Arnold *et al.,* 1998, 2001; Neitsch *et al.,* 2001) was used to represent the hydrologic balance of the chosen watershed. The model is linked with the raster-based geographical information system (GIS) to facilitate input of the spatial data such as land use, soil maps and digital elevation models (DEM). The model itself is based on the water balance equation:

$$W_t = W_0 + \sum_{i=t-1}^{t} (R_{day,i} - Q_{surf,i} - E_{a,i} - W_{seep,i} - Q_{gw,i})$$

Where, W_t is the final soil water content in mm; W_0 is the initial soil water content in mm; t is the time in days; $R_{day,i}$ is the amount of precipitation on day i in mm; $Q_{surf,i}$ is the amount of surface runoff on day i in mm; $E_{a,i}$ is the amount of evapotranspiration on day i in mm; $W_{seep,i}$ is the amount of water entering the vadose zone from soil profile on day i in mm; and $Q_{gw,i}$ is the amount of return flow on day i in mm.

Surface runoff $Q_{surf,I}$ is calculated by applying an improved Soil Conservation Service (SCS) curve number approach. Peak runoff predictions are based on the Modified Rational Formula. The rainfall intensity during the watershed time of concentration is estimated for each storm as a function of total rainfall using a stochastic technique.

Watershed time of concentration is estimated using Manning's formula considering both overland and channel flow. The percolation component W_{seep} consists of a linear storage up to 10 layers. The flow rate is governed by hydraulic conductivity and the available water storage capacity of each layer. For subsurface flow a kinematic storage model is used. Percolation from the root zone recharges a shallow aquifier, which is also connected to stream flow. The model offers three options for estimating potential evapotranspiration (ET): the Hargreaves, Priestly-Taylor, and Penman-Monteith approaches. The model calculates the evaporation and transpiration terms separately. The actual evaporation is a function of the soil water content and soil depth. Transpiration is computed as a linear function of potential plant evapotranspiration and leaf area index. Canopy storage for each crop is also included.

The Soil and Water Assessment Tool (SWAT 2000) is one of the most recent models developed jointly by the United States Department of Agriculture (USDA), Agricultural Service and Agricultural Experiment Station in Temple, Texas. Application of Arc View SWAT (AVSWAT) in the present study provides the capability to streamline GIS processes tailored towards hydrologic modeling and to automate data entry communication and the editing environment between GIS and the hydrologic model.

Fohrer *et al.* (1999) have calibrated and validated the SWAT for a gauged '*Aar*' Watershed with a land use map derived from satellite images of 1987. Fohrer *et al.* (2001) and Santhi *et al.* (2001) validated the SWAT modeling concept for watersheds with widely differing land use. Saleh *et al.* (2000) validated the SWAT for the baseline condition within Upper North Bosque River Watershed and the model output was compared to flow, sediment and nutrient measurements for 11 stream sites within the watershed for the period of October 1993-July 1995. Weber *et al.* (2001) suggested on the basis of SWAT results, that land use has a significant influence on the water balance catchment's components.

In Iran, very few efforts have been made on the use of hydrologic and water quality models to develop a management plan for agricultural watersheds using a systematic modeling approach. The watershed under study receives an average annual rainfall of 250 mm. Due to undulated topography much of the naturally incoming water flows out quickly as run-off and results in poor recharge of underground water reserves and much soil loss. The light textured and very permeable soils are able to hold a limited quantity of water in the root zone.

Considering hydrological behavior of the watershed understudy and applicability of the existing models for the solution of the aforesaid problems, the current study was undertaken by application of SWAT 2000 in combination with GIS and Remote Sensing to estimate the sediment yield. Although there is no sodicity danger in the study area, an attempt was also made to estimate the bicarbonate concentration changes by using the bicarbonate concentration of each soil layer as nitrate input to SWAT. The reason for suggesting this hypothesis is that both nitrate and bicarbonate have similar chemical and, to some extent, biological characteristics in both soil and water.

Study Area

Kordan Watershed is located in Karaj district, Tehran Province, Iran, located between 35˚52´54˝ and 36˚06´56˝ N latitude and 50˚39´30˝ and 51˚05´24˝ E longitude. Elevation of the watershed is around 4,100 meters above the mean sea level. The main stream of the watershed joins Shoor River at Nazar Abad plain. The location map of the study watershed is shown in Figure 1. The total area of the watershed is 30,000 ha and it is dominated by Andesite, Tuff, Sandstone, Shale, Alluvial and Colluvial Structures. Topography of the watershed is undulating with the land slope varyies from 5 to 67%; the general slope of the area runs from North to North East. The region falls within a semi-arid climate zone with four defined seasons. Average annual rainfall in the area is 250 mm, most of which occurs during fall and winter. Daily mean temperature ranges from maximum of 25˚C (June) to a minimum of -10˚C (January). The daily mean relative humidity varies from a minimum of 26% (July) to a maximum of 74% (January).

Major crops grown in the area are vegetables, melons at lower parts of the river and fruit trees at the upper parts of the river. The indigenous plants are Astragalus, Gundelea, Fertua, Diplotansa, Psathyrostachis fragilis, Cirsium and some other species of grasses and graminea. 55% of the watershed area is poor range, 30 % is range with good plant coverage and the rest 15% is orchards.

The predominant soil classes of the watershed are Lithic Xerorthent loamy skeletal mixed (calcareous), mesic (1.22%), Typic Calcixereptss, Clayey over loamy, mixed (calcareous), mesic (3.16%), Lithic Xerorthents Loamy skeletal, mixed (calcareous), mesic (18.21%), Lithic Xerorthents, Loamy skeletal, mixed, mesic (19.79%), Lithic Xerorthent, Loamy skeletal, mixed, calcareous, mesic (8.58 %) , Typic Haploxerepts, Fine, mixed, mesic (14.50%), Typic Xerorthents, Loamy skeletal mixed, non calcareous, mesic (7.84%), Typic Xerorthents, Loamy skeletal, mixed calcareous, mesic (10.24%), and Typic Xerorthents, Fine loamy mixed, calcareous, mesic (16.28 %).

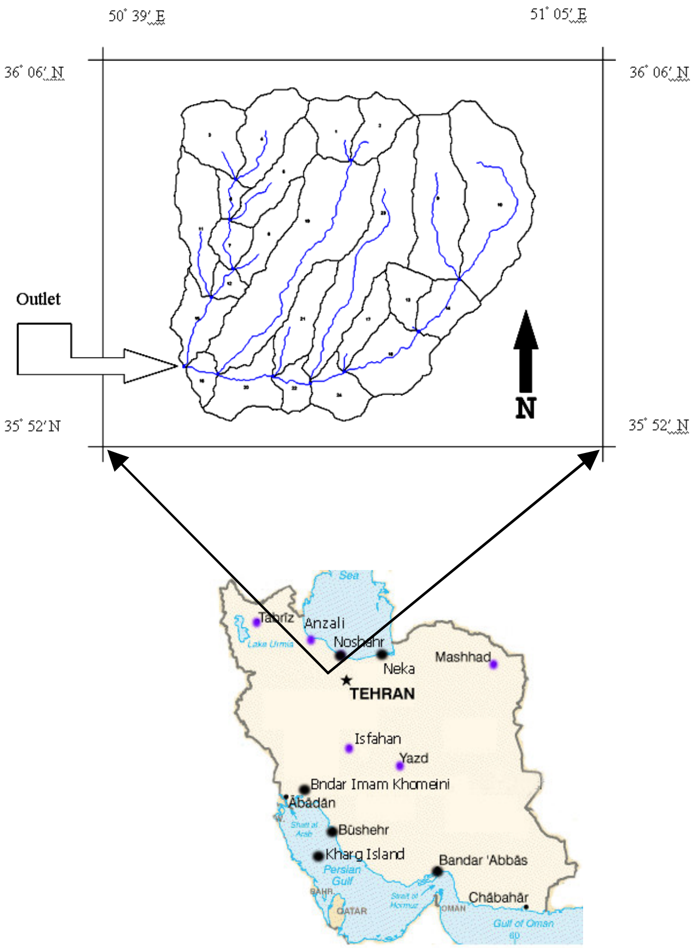

Figure 1. The location map of study watershed.

Data Acquisition

Twenty years (1980-2000) of daily rainfall, maximum and minimum temperature, relative humidity, wind speed, and solar radiation data of the watershed were collected and analyzed to determine various statistical parameters. The monthly and annual sediment yield of the watershed for the period from 1987 to 1999, were collected from the Energy Ministry of Iran. For the determination of bicarbonate concentration in the Kordan River, around 70 measurements of bicarbonate concentration were collected from the same source. Radar Based Digital Elevation Model (DEM) on a 1:50,000 scale as collateral data were acquired from the Soil Conservation Institute of Iran.

Land use /land cover map of the district, on a 1:50,000 scale, was obtained from the Soil Conservation Institute of Iran which was prepared by a supervised classification of ETM^{+} satellite image (30m×30m) pertaining to the year 2001. The land use/land cover for 1998 was also available but there is no significant difference between the two. A soil map of the watershed was acquired from the Watershed Management Department of the Agriculture Ministry of Iran. Each polygon on the map is a soil map unit. A sample profile was dug in each soil map unit, and then the profile description sheets for each profile were filled including the required information. Both disturbed and undisturbed soil samples of each profile soil horizon were taken to the soil laboratory of Tehran University, for further analysis.

Data Processing

Daily observed rainfall and temperature data for a 20 year periods (1980-2000) were used in the preparation of precipitation and temperature data files in the AVSWAT environment. These data were also analyzed to determine monthly values of probability of a wet day following a dry day, probability of a wet day following a wet day, average number of days of precipitation, maximum half hour intensity, average daily solar radiation, average daily dew point temperature and average daily wind velocity.

The observed sediment yield data was used to compare with the simulated values for model evaluation; around 77 available water quality data for the river tributaries were collected. The data included pH, EC, concentration of bicarbonate and chloride of the water.

The disturbed soil samples were sieved into 2 mm filters. Then the percentage by weight of the gravel fragments was calculated. The sieved soil was used for the following analysis: soil particles distribution by the Hydrometer Boycoss Method; calcium carbonate by the volumetric method; CEC by the Bower method, organic matter and carbon by the Walkely-Black method; and the soil Albedo by using the following formula, which has been obtained from the SWAT website.

Albedo= (0.7/(Exp (0.5596×[average of Organic matter in soil layer]))) ^{2}

The soil extracts were taken by using distilled water in order to measure the bicarbonate concentration in soil solution for each layer.

Undisturbed soils which were taken by a core sampler were used for measurement of the field capacity, permanent wilting point water percentage, available water holding capacity and moist bulk density at field capacity.

The saturated hydraulic conductivity was estimated by the RETC software using Van Genuchten method.

Digital Data Classification

Supervised classification was performed for classification of the satellite data. The overall accuracy of classification for 2001 was about 91% and the Kappa coefficient for the image was 90 %. The input parameters required in the model were generated from various map themes using the AVWAST interface. Various input files, i.e. sub-basin (.bsb), soil (.sol), routing (.rte); weather generator (.wgn), management (.mgt), ground water (.gw) and chemical (.chm) were also generated through the interface. The weighted average values of the curve number (CN) and slope were used in the analysis. Daily observed values of maximum and minimum temperature, rainfall and relative humidity were used as input to the model. The Penmann-Monteith method was selected for estimation of evapo-transpiration.

Observed annual data of sediment yield were available for the period of 1987-1999, and the observed monthly sediment-yield data were available for the years 1995-2000. No daily data were available, thus simulation of daily sediment yield was not played in the current research.

RESULTS AND DISCUSSION

Calibration of the Model

Sediment Yield

The annual and monthly values of sediment yields from 1987 till 1990, recorded at the outlet of the watershed were used for calibration of the model. The calibrated parameters are presented in Table 1.

[DOR: 20.1001.1.16807073.2010.12.1.11.7]

Table 1. Parameters used for the model calibration.

Serial number	Calibrated value	Values selected	Prescribed range
1	Manning's n for overland flow	0.065	0.01-0.12
2	Manning's n for the main channel	0.135	0.01-030
3	Manning's n for the tributary channel	0.11	0.01-30
4	Effective hydraulic conductivity, mm h^{-1}	10	0.01-150
5	Alpha factor for ground water	0.80	0.00-1.00
6	Base flow alpha factor	0.08	0.00-1.00

After calibration, the model was validated by all the available hydrologic data. The annual and monthly values of sediment yields from 1987 till 1999, recorded at the outlet of the watershed, were used for validation of the model. Statistical analysis of the observed and simulated data is presented in Table 2.

The annual values of both observed and simulated sediment-yields are compared graphically in Figure 2.

According to the graph, the peaks of simulated and observed sediment yield match well; although the model slightly overestimated or underestimated the sediment yields, the differences are not significant. The student *t*-test indicated that the observed and simulated mean sediment yields were not significantly different at the 97% confidence level. A high value for r^2 indicated a close relationship between the observed and simulated sediment yield although, for the use of the model in estimation of the actual sediment yield, the formula which is obtained and shown in the Figure 3 must be used.

Abbaspour *et al.* (2002) and Pandey *et al.* (2004) observed a regression coefficient of 86 and 80%, respectively, for the annual sediment yield.

The monthly sediment yield predictions of the model from year 1987 to 2000 were compared as well. Figure 4 shows a close relation between the observed and simulated values. The r^2 is 90%, which is close to the results of the earlier researches of Nasr *et al.* (2000), Pandey *et al.* (2004) and Sing *et al.* (2005) in which the regression coefficient were 87, 90 and 85 percent, respectively.

The regression coefficient and the regression equation obtained, indicates that the simulation of monthly data is more accurate than the simulation of annual data. The *t*-student also shows there is no significant difference between the observed and simulated values. (Table 1).

Discharge from the River

For calculating the discharge from the river, a calibrated relationship which is available at the Energy Ministry of Iran was used to estimate the discharge out of the surface height of the river.

The following formula is the relationship which was previously obtained for the Kordan Watershed:

Discharge (m3 s^{-1})= [0.2345* runoff height (mm)]+0.7679

Table 2. Statistical analysis of monthly and yearly sediment yield for both observed and simulated data.

	Annual sediment yield (tone)		Monthly sediment yield (tone)	
Statistical parameters	Observed	Simulated	Observed	Simulated
Mean	2785	2547	225	237
Standard deviation	2399.5	1405.3	644.88	647.5
Count	14	14	48	48
t-calculated	0.2088 ^{ns}		-0.45^{ns}	

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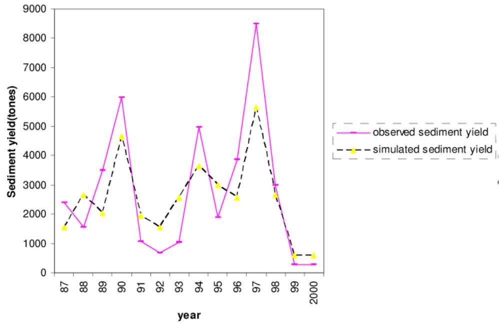

Figure 2. Observed and simulated annual sediment yield for model calibration (1987-2000).

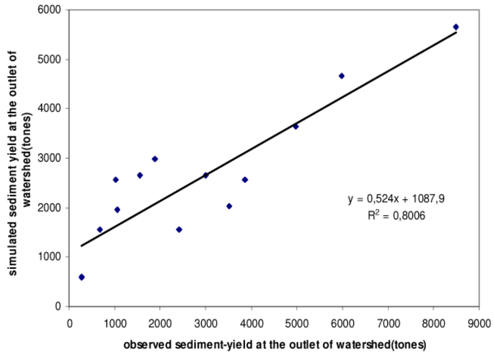

Figure 3. Regression comparison between observed and simulated annual sediment yield for model calibration (1978-2000).

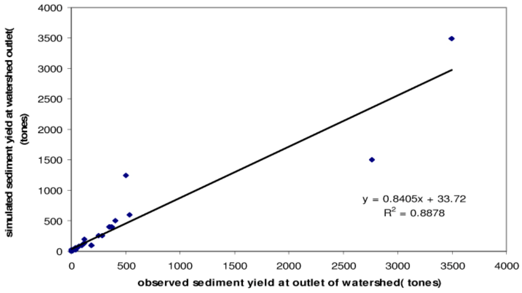

Figure 4. Regression comparison between observed and simulated monthly sediment yield for model calibration (1987-2000).

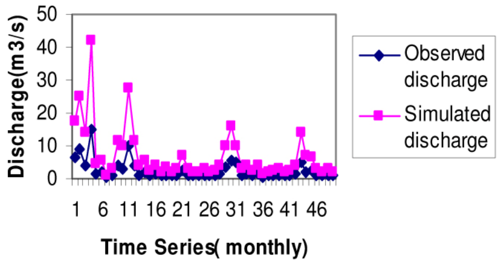

Figure 6. Observed and simulated river discharge for model calibration

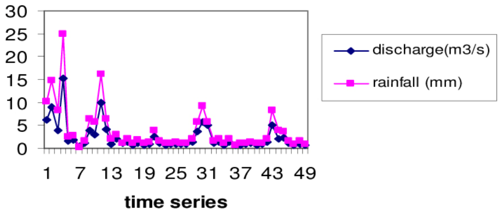

Figure 7. Simulated discharge of the river hydrograph.

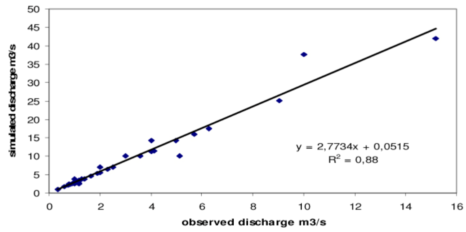

Figure 8. Comparison between observed and simulated monthly values for model calibration

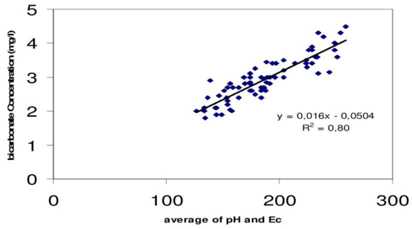

Figure 9. Relation between average pH-EC and bicarbonate concentration (mg l^{-1}) of the river water.

[DOR: 20.1001.1.16807073.2010.12.1.11.7]

Table 3. Statistical analysis of monthly river discharge for both observed and simulated data.

Statistical Parameters	Monthly discharge ($m^3 s^{-1}$)	
	Observed	Simulated
Mean	2.5	7.11
Standard Deviation	3.05	8.48
Count	48	48
t-Calculated	-0.4^{ns}	

The monthly values of the river discharge from 1987 till 1990, recorded at the outlet of the watershed, were used for calibration of the model; after calibration, the model was validated by the whole available hydrologic data.

The time series of the observed and simulated monthly river discharge for the validation period are compared graphically (Figure 6). It was observed that the time to the peaks of the simulated discharge graph fitted well with its observed values throughout the period.

The model generally over predicted the water depth which may be due to the retention of a major portion of rainfall in deep holes which are abundantly located in the watershed.

It was noticed that for high rainfall events the predicted discharge is also high (Figure 7).

A scatter gram of the observed and simulated monthly river discharge for the validation period (Figure 8) showed that the simulated discharge values are quite close to the observed values.

The student *t*-test showed that observed and simulated discharge of the river was not significantly different at 95% confidence level. The coefficient of determination r^2 of 0.88 indicated a close relationship between the observed and simulated discharge. Statistical analysis of the observed and simulated data is presented in Table 3.

The results are close to those of Arnold *et al.* (2000) and Nasr *et al.* (2000) who obtained an r^2 of 91 and 80 percent, respectively.

Note that the calibration of the model showed that the best Manning's roughness coefficient of the region to be introduced to SWAT is 0.03.

Bicarbonate Concentration

The bicarbonate concentration of each soil layer was entered into the nitrate database of the model in order to be used as nitrate data input to simulate the concentration of the bicarbonate as it does for nitrate.

But as the statistical tests, including the regression and t-student test show no good correlation between observed and simulated values was observed. The r^2 of 23%, and the t-test indicated that the regression coefficient is not significant at the level of 95% confidence. This means that SWAT is not able to simulate bicarbonate changes in the water. There fore, according to the importance of bicarbonate simulation in water, it was tried to find a relation between some water quality parameters of the model water quality file, by which the model could simulate the bicarbonate concentration.

Since some water quality parameters such as pH and EC are easily available at database of hydrometric stations, and these both parameters are effective on the bicarbonate concentration, we elaborate on these parameters in relation to bicarbonate concentration.

The data of around 70 samples of the different tributaries of the river were compared. The Regression test was done and outlier data were omitted. A very good relation between average of pH-EC and Bicarbonate concentration was found, as shown in the Figure 9.

As the Regression test indicates, there is good relationship between the average pH-EC and bicarbonate concentration. Hence, the following relation (Formula 1) can be a good estimation for measuring the bicarbonate using pH and EC values.

$$[HCO_3]= 0.016(\frac{pH+EC}{2})-0.0504$$

where: $[HCO_3]$ is the bicarbonate concentration in milligrams per liter; EC is the electrical conductivity in µmhos cm^{-1}.

CONCLUSIONS

Based on the analysis of the results obtained from hydrologic modeling studies of the Kordan watershed, it was concluded that the SWAT model is able to simulate both yearly and monthly sediment yield of the watershed. But the monthly simulation was much more accurate (with higher r^2) than the yearly one. This conclusion should be tested for other watersheds and for all daily, monthly and yearly values.

According to the results, the model is quite efficient and can be used in watersheds where are not gauged and there is no hydrometric station. It is also proposed to use the model for simulating all the missing data of this matter. The model program is defined for the quality factors of nitrate, phosphate, pesticides, BOD, excluding bicarbonates. This disadvantage of the model limits its utility in arid areas. The proposed formula (Formula 1), should be tested for several watersheds so that the relation be smoothed and more accurate. If such a relation could be written into the source code of SWAT, then user may define pH and EC of water into the stream water quality file of SWAT. In such a way, SWAT simulates average concentration of bicarbonate which will be used in making decision for irrigation and leaching management.

ACKNOWLEDGEMENTS

Herewith we appreciate the Soil Science Department of Tehran University, Soil and Water Conservation Institute, the Energy Ministry and Weather Administration of Iran for their great support to accomplish the project.

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مدلسازی تولید رسوب و غلظت بیکربنات آب رودخانه حوضه کردان

ف. سرمدیان، پ. رحیمی و ع. کشاورزی

چکیده

در تحقیق حاضر، مدل AVSWAT ، در حوضه رودخانه کردان که از زیر حوضه های رودخانه شور می باشد، به منظور شبیه سازی زمانی تولید رسوب سالیانه و ماهانه، دبی ماهیانه و مفدار غلظت بیکربنات آب رودخانه، مورد بررسی قرار گرفت. برای اجرای این پروژه، پارامترهایی شامل داده های بارش، حداقل و حداکثر دمای روزانه، مدل رقومی ارتفاع منطقه (DEM)، اطلاعات خاکشناسی افقهای خاک که شامل: وزن مخصوص ظاهری در نقطه ظرفیت زراعی، مقدار رطوبت در نقطه ظرفیت زراعی و پژمردگی، درصد کربن آلی، آلبیدو، بیکربنات، هدایت هیدرولیکی اشباع و بافت است به همراه نقشه خاک حوضه، نقشه کاربری و پوشش اراضی و مختصات خروجی حوضه، به عنوان داده های ورودی، به مدل معرفی شد. در مدل، ابتدا زیر حوضه ها جدا و سپس فرمان اجرای محاسبات هیدرولوژیکی در هر یک از آنها، داده شد. پس از اجرای مدل، خروجی ها مرتب، و مورد آنالیز آماری به منظور کالیبره کردن و مقایسه با داده

های مشاهده شده توسط وزارت نیرو، قرار گرفتند. نتایج حاصل از آنالیزها نشان داد که مدل به خوبی قادر است، پس از کالیبراسیون، مقادیر تولید رسوب ماهیانه و سالانه، همچنین دبی رودخانه را تخمین بزند. همچنین مشخص شد که مدل قادر به شبیه سازی تولید رسوب ماهانه با دقت بیشتری می باشد، ولی قادر به شبیه سازی مقدار بیکربنات آب نمی باشد. لذا حدود ۷۰ نمونه داده کیفیت آب وزارت نیرو جمع آوری شده و روابط بین مقدار بیکربنات و پارامتر های کیفیت آب که در SWAT تعریف می شوند، بررسی شد. محاسبات رابطه ای را بین میانگین pH و EC ، بدست آورد. این رابطه باید در مورد حوضه های دیگر تست شود و در صورت تایید، می توان آن را برای مدل تعریف کرده، بدین صورت مدل قادر خواهد بود با داده های فایل کیفیت آب (SWQ) ، مقدار بیکربنات را نیز شبیه سازی کند.

[DOR: 20.1001.1.16807073.2010.12.1.11.7]