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Comparative analysis of hydrological models for estimating sediment yield

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Abstract

The sediment that rivers carry into reservoirs can cause a reduction in the reservoir's capacity. Sedimentation from soil erosion is a major cause of water pollution. The length of the overland flow and the degree of soil loss are the two main factors that can be used to predict the amount of sediment carried. Physically based models and empirical models are the two major categories for estimating sediment yield. Important factors to take into account are the models' efficiency and complexity. The aim of this study is to choose the best model for estimating sediment yield. While estimating sediment yield, it is important to take into account variables like soil type, slope percentage, and land area. The study suggests several hydrological models for this purpose, including KINEROS, GLEAMS, SWAT, AGNPS, LISEM, and ANSWER (Areal Nonpoint Source Watershed Environmental Response Simulation model). These models are assessed based on their adaptability to input variables, suitability for use with different-sized watersheds, precision in estimating soil erosion, and overall effectiveness. This review paper offers an in- depth review of the benefits and drawbacks of various models for estimating sediment yields. It assists in selecting the most appropriate model for accurately estimating sediment yield. The study delves into great detail about how these models perform, which aids in guiding the selection procedure based on particular requirements.

Keywords: Sediment yield, soil erosion, KINEROS, GLEAMS, SWAT, AGNPS, LISEM, answer

Introduction

The sediment yield, which is typically expressed in tons per year or kilograms per year, can be described as the quantity of sediment that reaches or passes a place of interest in a particular amount of time. The various hydrological models that estimate sediment yield include:

Empirical models: These are observation-oriented models that solely use the information from the data that is already available without taking into account the characteristics and workings of the hydrological system.

Examples: Physically based SWAT models: In physically based hydrologic modeling, the hydrologic process of water movement is either modeled using an empirical equation or a finite difference approximation to a partial differential equation representing the balance of mass, momentum, and energy.

In the 1960s, the KINEROS (K2) model (Kinematic Runoff and Erosion model) was developed as a distributed event-based model that conceptualizes a watershed as a series of overland flow model elements flowing into trapezoidal channel model elements. This model's performance in predicting streamflow and sediment yield in response to changes in DNDP is known as the KINEROS MODEL performance. Peak flow, direct runoff, and sediment yield increased by 47.36%, 31.39%, and 26.96% for the DNDP event on April 12, 2014, according to KINEROS findings. For the 18 April 2013 and synthetic design storm events, similar results were achieved. A mathematical model called GLEAMS MODEL (Groundwater Loading Effects of Agricultural Management techniques) was created for field-sized regions to assess how agricultural management techniques affect the flow of agricultural chemicals inside and through plants. In order to allow for the estimate of pesticide translocations and leaching below the root zone depth as functions of pesticide properties and percolation, additions to the CREAMS model known as GLEAMS were described. In the Three Gorges Reservoir Areas (TGRA), AGNPS MODEL (Agricultural Non-Point Source Pollution) is becoming a serious hazard and seriously impeding the sustainable development of the agricultural industry and rural environment. Where 19% of the total area provides 35% of the total P and 34% of the total N entering the main stream, as reported by Young *et al*. (1989) [26], locations producing substantial contributions of total N and total P closely resemble those having the highest contributions of sediment. It has certain benefits and drawbacks. An event-oriented, disturbed parameter model called ANSWER MODEL (Areal non-point source watershed environment response simulation) was created for planning and assessing strategies for monitoring non-point source pollution from agricultural lands. Its goal is to encourage a watershed's distributaries in agriculture by tracking various rainfall events with the aid of a GIS (Geographical Information System), but it also focuses on environmental repercussions. It is completely dependent on changes to environmental factors since they affect how well the data is calibrated. The answer model benefits from sediment yield deposition and direct contamination of streams, which is one of the answer model's drawbacks

A continuous, semi-distributed, basin-scale model called SWAT MODEL (Soil and Water Assessment Tool) was created for the Agricultural Research Service (ARS).It enables users to take into account the long-term effects of rural and agricultural management techniques, as well as the conflux and sediment confluence processes, and when combined with GIS, it builds soil and water conservation modules. IT divides a watershed into smaller sections called hydrological responses units that have comparable soil types, land uses, and slopes. It can simulate large basins quickly and cheaply due to its great calculation efficiency, but it cannot effectively assess processes like exceptional daily flow occurrences, the complicated dynamics of soil nitrogen and carbon, or the stimulation of runoff production.

The USDA created the CREAMS MODEL (Chemical, Runoff and Erosion from Agricultural Managements Systems Model), a field-scale lumped approach model that calculates runoff volume, peak flow, infiltration, soil water content, percolation, and evapotranspiration daily but is unable to provide process information or be applied to large basin-scale processes for rural scale.

Hydrological Models

KINEROS Model

The distributed model K2 has been successfully calibrated and verified on experimental watersheds with high-resolution inputs and observations up to 150 km2. It is adaptable from plot to watershed scales. In overland flow (Hillslope), channel, detention pond, urban, injection, and non-pressurized culvert model elements, K2 is an event-based model that calculates runoff, erosion, and sediment transport. A selection of research using K2 at various scales and locations across the United States and the rest of the world for various applications. The model with biogeochemistry has a continuous simulation version that is being tested but is not included in this article. Rain gauge measurements in time and cumulative rainfall pairs or time-intensity pairs are the most common types of precipitation inputs. On time periods of tens of minutes or less, radar-rainfall intensity estimates are given. The output time steps are user-defined, while internal computational time steps are automatically changed to satisfy the Courant condition (Roberts 2003) [18].

K2 conceptualizes the watershed under modeling as a set of spatially dispersed model pieces. The model's components essentially reduce the watershed to a collection of forms that can be arranged to assume one-dimensional flow. Additionally, if needed (For example, for significant impervious areas, for abrupt changes in slope, soil type, or for large impervious regions), user- defined subdivision can be established to segregate hydrologically distinct segments of the watershed. The geometric features of watershed modeling components (Such as slope, flow length, and area) and the variables impacting infiltration and routing (Such as soil hydraulic properties, hydraulic roughness, land use, and land cover) must both be estimated through watershed characterisation. A real-time kinematic (RTK) GPS survey or a high-resolution topographic survey created using lidar would be ideal. If resources are not limited, it would be ideal to have a distributed collection of tension infiltrometer or rainfall simulator measurements along with soil textural and bulk density studies adequate to define the variability of the fields, consistent with the model's geometric complexity. The input, status, output, and basin characterization data should always be thoroughly checked for anomalies, mistakes, and temporal trends as well as for temporal record discontinuities, such as if land was disturbed throughout the process.

Advantages

- This model is event oriented, a physically based model describing interception, infiltration, surface runoff, sediment yield from small and urban watershed
- The model equation describing overland flow, channel flow, erosion, sediment yield and all parameters.
- This model is used to determine the effects of various artificial features such as urban development.
- Disadvantages:
- This model cannot compute in the places where heavy rainfall, and have uneven topography
- The routine estimation should be done
- It does not discretize the basin by cells but by sub basins that discharge into channels
- Enlarging flow velocity
- Increasing runoff and flow items

GLEAMS Model

The Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model was created as an expansion of the Chemicals, Runoff and Erosion from Agricultural

Management Systems (CREAMS) model. It is a continuous simulation, field scale model. GLEAMS makes the assumption that a field has uniform soils, land use, and precipitation. Hydrology, erosion/sediment yield, pesticide movement, and nutrients make up its four main parts. GLEAMS was created to assess how management strategies can affect possible nutrient and pesticide leaching within, through and below the root zone. Additionally, it calculates sediment losses from the field and surface runoff. The development of GLEAMS did not aim to create an exact predictor of pollutant loading. It is a technique for comparing and contrasting the chemistry of complex pesticides, soil characteristics, and weather. The impact of farm level management decisions on water quality can be evaluated using GLEAMS.

The possible effects of management strategies, such as planting dates, cropping systems, irrigation schedules, and tillage operations, on chemical mobility can be estimated using GLEAMS. To take into consideration these systems and lessen the likelihood of root zone leaching, application rates, procedures, and timing can be changed. The model takes different soil types and meteorological conditions into account when calculating leaching potential. GLEAMS can be helpful in long-term simulations for soil/management pesticide screening. The model monitors the movement of pesticides in sediment, runoff, and percolated water. Evaporation and transpiration replicate pesticide upward migration and plant uptake. For substances that contain potentially harmful byproducts, metabolite degradation is also modelled. A modified version of the Universal Soil

Loss Equation is used to estimate erosion in locations with overland flow. To calculate the sediment yield at the field's edge, chemical erosion and deposition in temporary impoundments like tile outlet terraces are taken into account.

Advantages

- Automatic irrigation, manual irrigation, and chemigation options.
- A comprehensive erosion \ sediment yield components allowing the user to describe in details the topographic features of the field.
- All channels in the field are assumed to be naturally eroded.

Disadvantages

- Input metric solar radiation.
- Reduce rainfall energy in northern and southern latitudes.
- Removal of all biomass in the top of 1cm of soil with sod harvest.

AGNPS Model

AGNPS model is a event based agricultural non-point source model. In a hilly agricultural watershed the model predicts the runoff, sediment and nutrients load. In order to evaluate runoff, soil erosion, and related nonpoint source pollution for occurrences observed in the Alpone watershed, located in Italy, the AGNPS (Agricultural Non-Point Source) model was utilized. This model, which is event-based and operates on a cell basis, allows the study of the entire watershed to take into account the geographic variation in parameters of each cell. Twenty observed incidents that took place in 1992 and 1993 were compared to runoff projections. The predictions for sediment output and nutrient loading to seven actual events were compared (Bingner *et al*. 1992) [5]. To effectively generate the numerous data inputs required, an integrated AGNPS/GIS system was designed. Additionally, graphic representations of the outcomes have demonstrated to be a very effective and efficient method of interpretation and decision-making during calibration of a model. In order to achieve this goal, important sub-watershed locations where excessive erosion and runoff has led to phosphorus delivery to surface water in agricultural watersheds were located using the AGNPS model. A watershed is divided into square grid cells with the aid of GIS, creating an accessible and affordable model that shows great promise for determining how much altering agricultural practices might lessen the amount of sediment and nutrients flowing from cropland portions to surface waters in agricultural watersheds. According to the authors, a useful tool for simulating sediment and nutrient loads in middle-to-large watersheds with predominately vineyard usage is the distributed AGNPS model connected with GIS. The Alpone watershed results have indicated specifically in the case of heavy storm rainfall events, which, as highlighted by (Bingner *et al*. 1992) [5], are the occurrences that produce the largest annual total load of sediment and nutrients in the watershed, the model's capacity to estimate sediment and nutrient production and their spatial distribution is called out. In order to determine the effects of short-term rainfall intensity and space fluctuations on the model outputs, in particular on sediment and nutrient loads, this early work clearly demonstrates the necessity for further analysis of more extensive data.

In order to get consistent and reliable predictions, the Minnesota Pollution Control Agency (MPCA) and the Soil Conservation Service collaborated with the US Department of Agriculture's Agriculture Research Service to develop the AGNPS model (Young *et al*. 1987) [26].

To examine the outcomes of different conservation options that could be implemented into the management of watersheds, of runoff quality with a primary focus on nutrients and sediments. This model divides watersheds into square working areas (Cells) using a distributed parameter technique. To analyze flow and water quality at every point in the watershed, runoff characteristics and transport processes of sediment and nutrients are simulated for each cell and routed to the outlet in a sequence of phases for a single storm event. Surface water runoff is predicted by the Soil Conservation Service (SCS) runoff curve number approach, while soil erosion and sediment yield are predicted by a modified version of the Universal Soil Loss Equation (USLE, Wischmeier and Smith 1978) [24]. Eroded sand, silt, clay, small aggregates, and big aggregates are the five particle size classes used to categorize soil and sediment output. The approach makes use of the relationships between sediment movement and deposition (Foster *et al*. 1980) [7], Lane 1982, and Bagnold 1966 described. Each cell in the AGNPS needs to have 22 input parameters, which correspond to 22 layers of input data (Table 1). Watershed data includes details on cell size, the total number of cells in the watershed, rainfall totals, and the USLE energy intensity factor (EI). It is possible to set output settings for a single cell or the full watershed. This evaluation includes each area's mean sediment concentration, runoff volume, peak flow rate, area-weighted erosion for upland and channel areas, sediment delivery ratio, sediment enrichment ratio, and total sediment yield where N, P, and COD mass per unit area for both soluble and sediment adsorbed nutrients, as well as N and P concentration, as well as electrical conductivity in the runoff, are included in the nutrient analyses of the five sediment size classes.

Advantages

- It provides perfect estimation of nutrients in runoff water and the sediment absorb phases
- It helps to predict runoff water, sediment yield values accurately
- It also helps us to predict the impact of water quality due to sediment yield
- It minimizes nutrient and yield loss.

Disadvantages

- It applies only on mid and small region
- Large area required
- Routine removal of sediment is done
- High water wasted

SWAT Model

The Soil and Water Assessment Tool (SWAT) model (Arnold *et al*. 1998) [2], a physically based spatially distributed hydrological model, is recognized as a practical tool that has been successfully used to simulate runoff (Kannan *et al*. 2007) [9], sediment yield (Xu *et al*. 2009, Prabhanjan *et al*. 2015) [25, 16], water quality and Various watershed issues, such as evapotranspiration, have been predicted using SWAT (Kannan *et al*. 2007, Licciardello *et al*. 2011) [9, 12], Crop yield (Srinivasan *et al*. 2010) [21], total maximum sediment load (Chaplot 2005, Jha *et al*. 2007) [6, 8], climate and LULC changes, effect of sediment control structures in small watersheds and modeling of ungauged catchments (Prabhanjan *et al*. 2015) [16]. Other models have been incorporated into various research employing SWAT (Babar and Ramesh 2015, Song *et al*. 2015) [3, 20]. In comparison to other models, researchers (Parajuli *et al*. 2009, Talebizadeh *et al*. 2010) [15, 22] have found that the SWAT model has a greater model efficiency and an acceptable level of uncertainty. SWAT has the following advantages over alternative tactics. The primary cause of soil erosion and sediment input into the reservoir is due to the features of the watershed. Thus, the SWAT model has been chosen as the modeling strategy for this investigation. To reduce uncertainty and improve the accuracy of the model's output, it is crucial and effective to have information on sensitivity analysis, calibration, and validation. The majority of research papers on the use of the SWAT model, however, exclude thorough details of the model calibration and validation processes. Additionally, the model is typically run on a monthly or annual time scale, which may not look at the precise information of the hydrological processes (Manaswi and Thawait 2014, Kumar *et al*. 2015) [13, 10]. Due to these deficiencies, the following goals of this study were set, taking into account the hydrological behavior of the watershed and the high temporal resolution of the sediment flow data: (1) thorough documentation of the SWAT model's daily calibration and validation; (2) locating erosion-prone sub-watersheds within the watershed; (3) calculating each sub watershed’s SDR; (4) analyzing the effects of various combinations of LULC and soil types on sediment erosion; and (5) establishing correlations between rainfall, runoff, soil erosion, and sediment yield for the entire watershed. The prerequisite input parameters for the SWAT model are geographical variables like topography, land use, and soil data. It contains a weather simulation component that can forecast the missing information in the weather data observed records. In order to simulate surface runoff through the channel networks within the sub-watershed, SWAT divides the total watershed into sub-watersheds based on Digital Elevation Models (DEMs). The sub-watersheds are then further divided into a number of homogeneous Hydrological Response Units (HRUs), each of which is distinguished by a particular combination of land use, soil type, and average slope. Rainfall, temperature (maximum and minimum), relative humidity, wind speed, and sunlight hours make up the climatic parameters. The surface runoff and sediment output are calculated using SWAT at the HRU level, aggregated to the sub-watershed level, and then transported to the watershed outlet via the stream network.

Advantages:

- It can also stimulate sediment yield for a watershed where erosion and water quality problem exist.
- Its prevention and control of silt transport in catchment area will reduce.
- This model will be adequately useful for a long-term planning of annual schemes.
- Disadvantages:
- The RBNN model perform better than SWAT model in stimulating sediment yield at a single outlet of watershed.
- RBNN model can give more accuracy than SWAT model.
- The present study report that MLP artificial neutral network model simulates sediment yield better than SWAT model during calibration and validation

CREAMS Model

The cream model forecast and manage field runoff and erosion. The cream model has been restrained and adapted for Finnish condition. The model modification and adaptation for new snow accumulation, simple soil frost and snow melt model. The implementation of a plant growth model for calculating leaf area index and soil loss ratio, and allowing for variation in the rainfall erosivity parameter. The model contains hydrology, erosion and chemical components in separate computer programs. The daily time-step water balance and runoff method (William and nicks 1982) [23]. A daily time step was decided upon when CREAMS was being developed. In order to work constantly with daily precipitation as input, SCS curve number approach was updated, which was first used to estimate design-storm runoff (USDA 1972a). As a result, it became the fundamental hydrology element. The hydrological component included a modified Green-Ampt infiltration option (Smith and Parlange 1978) [24], which made use of breakpoint or hourly rainfall data. With the exception of certain studies or study areas, these data were not always easily accessible, but they provided model users with an alternative. The daily peak discharge rates required to mimic the transport of sediment in the erosion component were computed for both solutions. To estimate soil water accounting, daily soil evaporation and plant transpiration calculations were made, and the sum was added between periods of rainfall for the pass files. Since precipitation varies greatly from year to year, the option to enter up to 20 years' worth of climatic data was provided. In order to interpolate mean daily values, mean monthly temperature and solar radiation data were fitted with a Fourier series. Using these data with the Priestly-Taylor approximation, it was possible to determine the daily potential soil evaporation and plant transpiration. The straightforward degree-day simulation of snowmelt also made use of this data. These estimates were adequate for all practical purposes at the research locations of the majority of the modelers, who were based in the southern U.S. When CREAMS was used to evaluate simulation outcomes of competing management systems, as was the original model intent; When CREAMS was used to evaluate simulation outcomes of competing management systems, as was the original model intent, these assumptions held true for all locations. The universal soil loss equation (USLE) (Wischmeier and Smith 1978) [24] was updated by Foster *et al*. (1980) [7] to mimic daily erosion rather than long-term average yearly erosion. Additionally, since organic carbon is the main carrier of pesticides, CREAMS was used to simulate sediment transport in daily runoff as a function of particle/aggregate size and transport capacity. This gave enrichment ratios for the small sediment particles that were required for the chemical component. For example, a culvert outlet or a field-scale detention pond with an uncontrolled outlet could be designated as a field representation using one of six flow sequences: overland, overland-pond, overland-channel, overland-channel-pond, overland-channel-channel, and overland-channel- channel-pond (Foster *et al*., 1980) [7]. Except for the erosion component, which used a distributed- parameter model to take sediment transport by particle classes into account and calculate the enrichment ratios required in the chemistry component, CREAMS was essentially a one- dimensional lumped model with uniform soil, uniform precipitation, and one management system per field. As a result, unit-area-based depths or masses were used to depict soil water flow, runoff, evaporation, transpiration, erosion and sediment output, as well as pesticide and plant nutrient runoff. For all intents and purposes, CREAMS was a surface-response model; nevertheless, percolation below the root zone was computed in order to achieve a water balance for the field. Utilizing percolation volumes, the mass leaching of pesticides below the root zone was determined. This allowed for the computation of a pesticide mass balance together with degradation.

Answer Model

ANSWER (Areal Nonpoint Source Watershed Environmental Response Simulation) model work is modeling soil erosion and surface runoff in a catchment area or watershed. It purpose is to stimulate the distributaries of a watershed in agriculture by following different rainfall occurrence with assist with GIS (Geographical Information System). GIS analyzes and visualizes different geospatial data of geographical location. Answer works on environmental effects, it totally depends on change in environmental aspects as the condition of nature it can calibrate the data. Answer is event based model. This study calibrate and compares Yalin equation with the original sediment transport equation of the Answer model. After concentrating Yalin equation with the original sediment transport equation of the answer model. The observed data stated that both these equation underestimate the sediment concentration. Non-point source pollution management model, ANSWER-2000, was developed to stimulate long term average annual runoff and sediment yield from agricultural watersheds. The model is based on the event-based ANSWERS model and is intended for use without calibration.

Advantages

- Answer model was stimulated to gain information about various watershed.
- Due to its flexibility, it has a huge range of condition

Disadvantages

- Answer needs a lot data storage and vital and large computer for stimulating large watershed. The description of data is more complex.
- Answer is stimulated in a predicted size limit about 10 acres or 4 ha.

Sediment yield deposition and direct contamination of waterways helps in the answer model which is one of the losses for answer.

Conclusion

After studying deeply the review paper indicates that SWAT model is the best hydrological model to estimate sediment yield because SWAT model can estimate the sediment yield up to 99.26% of the total year and it has a good correlation among rainfall, runoff and sediment in food period which no other model does and rest of the model is not so much accurate as SWAT in case of estimating sediment yield.

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