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Hydrological modeling for watershed management

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ABSTRACT

A watershed is a complex and dynamic bio-physical system which is identified as planning and management unit. A watershed is also a hydrological response unit and a holistic ecosystem in terms of the materials, energy and information present. Land and water are the two main resources of the watershed. Unplanned and uncontrolled use of resources results in deterioration of watershed which is further aggravated by human interventions. Watershed management is the balanced use of land and water resources to obtain optimum production and with minimum perils to natural resources. The objectives of the watershed management primarily focus on conservation of soil and water resources of the watershed by harvesting of runoff water through farm ponds, reservoirs and other water harvesting structures and preventing land degradation in the watershed by constructing soil erosion control structures like bunds, terraces, trenches, check dams, vegetative barriers, etc. thereby planning for soil and water conservation. Hydrological models are important tools to understand the hydrological behaviour of the watersheds and hence have been used for watershed management. The hydrological models are capable of simulating the impact of different soil and water conservation structures. This helps the policy makers to apply the suitable conservation measures in the erosion prone areas. This study gives a synoptic view of several hydrological models and their applications for watershed management.

Keywords: Best management practices, Erosion 3D, Hydrological modeling, Rain water harvesting, Remote sensing and GIS, WEPP, SWAT

INTRODUCTION

Watershed is the geographical area which is drained by the network of streams to the common outlet. A watershed is a complex and dynamic bio-physical system which is identified as planning and management unit. A watershed is also a hydrological rejoinder unit and a multifaceted ecological unit in terms of the resources (materials), energy and information present. The watershed not only is a useful unit for physical analyses, it can also be an appropriate socio-economic-political component for the execution of management strategies. In essence, a watershed is a basic organizing unit to manage resources (Sadeghi, 2020).

The terrestrial and aquatic environs are the two main resources of the watershed. Unplanned and uncontrolled use of resources results in deterioration of watershed which is further aggravated by human interventions. The population residing in the watershed is one of the most important assets of that watershed and the condition of a particular watershed depends heavily on its population. So, it is imperative to involve the people for conservational strategies actively involving proper management and execution of the watershed resources. The planning and management of watershed is done to accomplish the task related to overall development of watershed, which may be in respect of water quality and quantity improvement, management of ecosystem, enrichment of socio-economic status of the watershed inhabitants, enhancing the employment opportunity for the people and selection of most appropriate cropping pattern etc. (Anonymous, 2008). The classical managerial agenda pertaining to watershed conservation will not suffice its self sustaining processes, if the enhancement in efficiency and production of supplementary income does not proportionate with the investment. The positive upshot in biomass and fodder production is the resultant of an integrated management of watersheds that helps to transform the status of livestock to more inexpensive animals and abridged seasonal exodus of herds due to guaranteed fodder availability during the year. The harvested precipitation in petite storage reservoirs can be successfully exploited for auxiliary irrigation requirements during scarce water availability to improve crop production. Water harvesting configurations (structures/farm ponds/ storage tanks) has proven to be cost-effectively viable, environmentally feasible and socially suitable (Samra, 2002).

Watershed Management

Watershed management is the balanced exploitation of terrestrial and aquatic resources for acquisition of optimal production with petite vulnerability to the natural assets. It basically adopts the rehearsal of soil and water conservational strategies in the watershed, for example, appropriate exploitation of the land, defensive measures of land against anthropogenic pressures, enhancement and management of soil fertility, water conservation for irrigational practices, proper supervision of local water supplies for drainage, protection against flash floods and reduction in runoff and soil erosion, and also escalating the production from all the existing land use patterns. Adaptive watershed management strategy focuses on "*5 E's*, that is, Ecology, Economy, Equity, Education and Evaluation" which basically leads and encourages the progression of interdisciplinary adaptive, and integrally-informed perceptive of socio-ecological setups at the watershed level. The information is then transmitted to diverse departments to aid in alliance among the different stakeholders and stewards of the environment (Sadeghi, 2020). Novel approaches such as the Water-Energy-Food (WEF) nexus can also be adopted for watershed management. The WEF nexus focuses on the interdependency of water, energy, and food protection to be overtly recognized in the decision-making process (Mohtar *et al.,* 2015). Watershed management programmes should be self-sustainable which is possible with the increase/ enhancement in yield and production of supplementary revenue. Amplified biomass and fodder production ensuing from "*Integrated management of watershed*" helps to change the composition of livestock to more inexpensive and condensed seasonal wandering of animal herds due to secure fodder supply during the autumn and winter too (Arora, 2020).

The objectives of the watershed management primarily focus on conservation of soil and water resources of the watershed by harvesting of runoff water in farm ponds, reservoirs and other water harvesting structures and preventing land degradation in the watershed by constructing soil erosion control structures like bunds, terraces, trenches, check dams, vegetative barriers, etc. thereby planning for soil and water conservation. But it is important to properly design and construct soil and water conservation strategies to achieve the desired objectives of the watershed management. For this, quantification of various hydrological processes is one of the fundamentals for triumphant planning of the design and execution of conservation strategies and water resource improvement in a watershed. Hydrological models are essential to soil and water resources evaluation, improvement and management. At the field scale, hydrologic models are engaged for devising and designing of soil conservation practices (Wurbs, 1998), management of irrigation water, water quality evaluation and water supply availability etc. (Wurbs, 1998). Hydrological models are important tools to comprehend the hydrological behaviour of the watersheds. Hydrological models have been classified in different types, viz., "empirical models, conceptual models and physically-based models". Empirical models are those models which are based on cause and effect relationship and do not simulate the physical processes. These models are relatively simple and require less input data. Conceptual models are those models which simulate the physical processes but with major simplifications. Each process of the hydrological cycle is simulated using the simple equations. Physically-based are those models which simulate the processes through a speculative approach without using chief simplifications. Such models are very accurate but require large data and are difficult to operate. Examples include WEPP model, SWAT model, EROSION 3D model etc. Fig. 1 and 2 shows the basic concept for hydrological modelling used in WEPP and SWAT model, respectively.

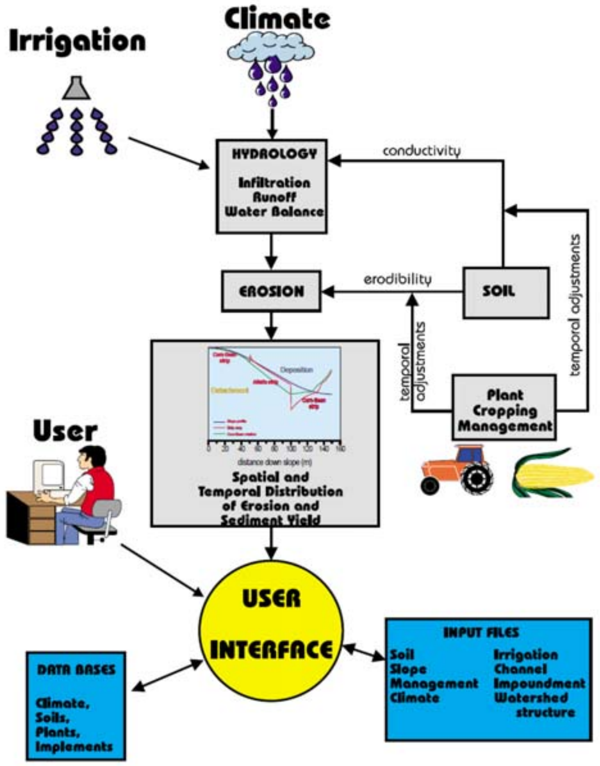

Figure 1. Flow chart for WEPP runoff and erosion prediction model (Source: Flanagan *et al.,* 1995)

Hydrological models for watershed management

Hydrological models have been successfully applied to estimate the runoff and soil erosion from the watersheds. Hydrological models in conjunction with remote sensing and GIS techniques not only estimate the quantum of runoff and erosion but also give the spatial and temporal description as well (Yousuf and Singh, 2016). Once the quantity of runoff generated from the particular area is known, suitable water harvesting structures can be designed accordingly. The hydrological models are also capable of simulating the impact of diverse soil and water conservation structures. This helps the end users or policy makers to apply the suitable conservation measures in the erosion prone areas. Similarly, hydrological models with the help of remote sensing and GIS techniques can be used to select the sites for different water harvesting structures. Some of the basic applications of hydrological modeling for watershed management are runoff (Yousuf *et al.,* 2017; Ruan *et al.,* 2016; Wang, 2019), soil erosion (Ganasri and Ramesh, 2016), sedimentation (Liu and Jiang, 2019; Tan *et al.,* 2018), prediction of precipitation events, stream flow, flood forecasting (Mosavi *et al.,* 2018), drought assessment (Sehgal and Sridhar, 2019) and water quantity and quality. Many advanced applications of such models like prediction of land use dynamics, climate change studies (Koch and Cherie, 2013; Nivedita *et al.,* 2018), impact of land use transformation on water resources development and management (Barlow *et al.,* 2014; Baker and Miller, 2013), movement of various chemicals and nutrients, non-point source pollution, designing of best management practices (Park *et al.,* 2015), evaluating current surface water resources and its impact on future development and consumption of water

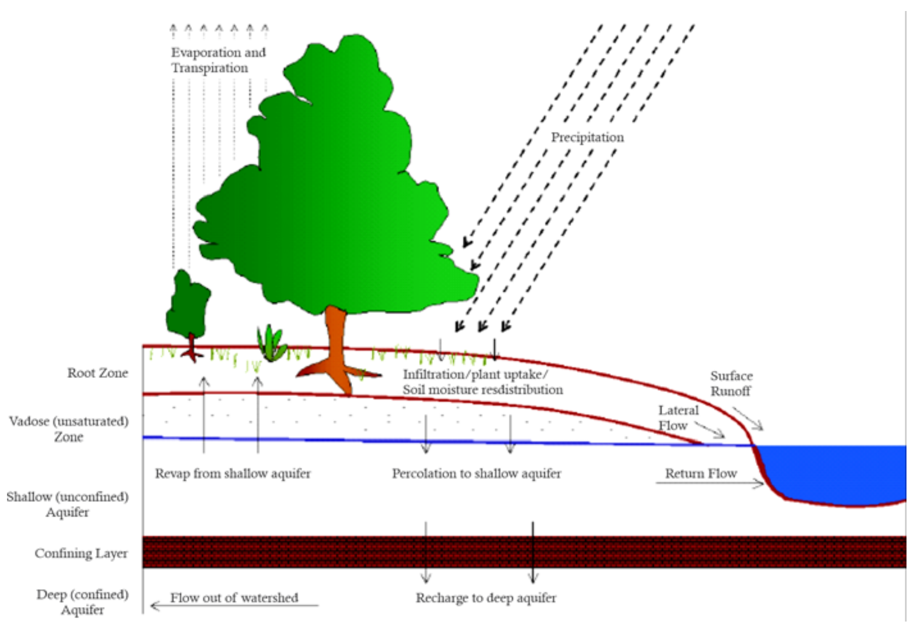

Figure 2. Representation of hydrologic cycle in SWAT model (*Source:* Neitsch *et al.,* 2011)

resources (Ayivi and Jha, 2018) etc.

Kumbhar *et al.* (2012) applied the SWAT model for watershed management on a Doddahalla watershed having an area of 61000 ha. The aim of the study was to prioritize the micro-watersheds based on their hydrological, demographic and socio-economic status. Parajuli and Ouyang (2013) applied SWAT and HSPF on two watersheds in Mississippi, USA. The models were calibrated and validated using USGS observed streamflow data and were applied to envisage impact of future climate change scenarios on hydrology. The study demonstrates how future climate change scenarios shall impact stream flow from the watersheds. Eduardo *et al.* (2016) applied SWAT model for water resource management of Mortesruver basin, MG, Brazil. The study reveals the successful application of SWAT model for water resource management in the study watershed. Tegegne *et al.* (2017) applied and compared three hydrological models, SWAT, IHACRES and GR4J, for assessment of water resources in data scarce region of Blue Nile river basin. It was concluded that all three models generally captured the magnitudes and variabilities of the observed stream flows for the four gauging stations. De Salis (2019) used the JAMS J2000 software for sustainable water resources management in built-up areas above Karst topography. It was concluded that hydrologic modeling allowed quantification of flow components, namely surface flow, percolation in soil and groundwater flow. Schindewolf *et al.* (2015) applied EROSION-3D model to simulate the sediment input and deposition in Baderitz reservoir in Germany. It was observed that annual soil losses of approximately 12 t/ha correspond to sediment inputs of nearly 8800 tonnes. The mean annual increment of 9 cm in the reservoir bottom results in depreciation of reservoir depth by 13% per decade. It was concluded that the model results could be used for planning and marginalization of mitigation measures. Ruan *et al.* (2016) applied SWAT model for simulation of runoff using high resolution data in the upper Heihe river basin in Tibetan Plateau. It was concluded from the study that high resolution data shows very good heterogeneity on spatial data. Similarly, Wang (2019) and many others applied different models for estimation of runoff for small watershed to basin level. Ganasri and Ramesh (2016) applied RUSLE model with GIS for estimation of soil erosion in Nethravathi basin of India. In this study, calculation of various factors of RUSLE was done using GIS. Results of the study was helpful in identification of critical erosion prone zones and also for applied best policy to overcome erosion. Similarly, Mahala (2018) also used RUSLE model with GIS for estimation of soil erosion. Liu and Jiang (2019) and Tan *et al.* (2018) studied sediment yield estimation using different models. Bandaragoda (2008) studied prediction of stream flow for an ungauged watershed using TOPMODEL. Mosavi *et al.* (2018) conducted a study for prediction of flood using machine learning models. Sehgal and Sridhar (2019) assessed drought using a SWAT hydrological model for drought analysis in USA. Koch and Cherie (2013) and Nivedita *et al.* (2018) studied prediction of land use dynamics and climate change in a watershed. Barlow *et al.,* 2014 and Baker and Miller (2013) conducted a study on impact of land use change on water resources development and management. Malago *et al.* (2017) reviewed the movement of nutrient fluxes in Danube river basin using SWAT model. Yuan *et al.* (2020) studied various non-point source pollution and water quality models at the watershed level. Ayivi and Jha (2018) conducted a study for estimation of water balance and water yield in a watershed of North Carolina using SWAT model. The Fig. 3 shows the application of EROSION-3D model to simulate the runoff and soil erosion.

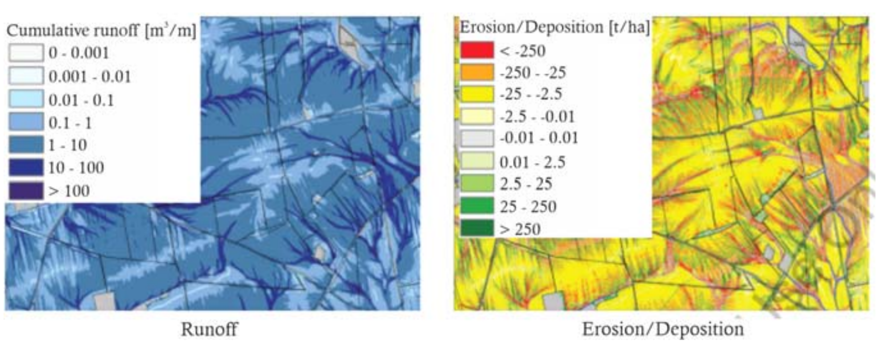

Figure 3. Runoff and soil erosion output maps of EROSION 3D model (*Source:* Schmidt and Werner, 2020)

CONCLUSION

From the present study, it can be concluded that the hydrological models can be successfully used to manage the resources of the watershed. The hydrological models are important tools for planning and design of conservation practices in the watershed. Hydrological models have diverse application in the watershed management. Some of the basic applications of hydrological modeling for watershed management are runoff, soil erosion, sedimentation, prediction of precipitation events, stream flow, flood forecasting, drought assessment and water quantity and quality, land use dynamics, impact of land use transformation on water resources development and management, movement of various chemicals and nutrients, non-point source pollution, designing of best management practices evaluating current surface water resources and its impact on future development and consumption of water resources.

Conflict of Interest

The authors declare that they have no competing interests.

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