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Runoff and sediment yield modeling from a small agricultural watershed in India using the WEPP model

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Summary The WEPP (Water Erosion Prediction Project) watershed model was calibrated and validated for a small hilly watershed (Karso) of India. Sensitivity analysis of the model was carried out for the input parameters. The analysis shows that the sediment yield is highly sensitive to interrill erodibility and effective hydraulic conductivity, whereas, runoff is sensitive to effective hydraulic conductivity only. Initially, the model was calibrated using data from the 1996 monsoon season and subsequently its performance was evaluated by estimating the daily runoff and sediment yield using the monsoon season data of different years. Coefficient of determination (R^2) (0.86–0.91), Nash–Sutcliffe simulation model efficiency (0.85–0.95), and percent deviation values (7.90–15.15) indicate accurate simulation of runoff from the watershed. Performance of the WEPP model for simulation of sediment yield was also evaluated. High value of coefficient of determination (R^2) (0.81–0.95), Nash–Sutcliffe simulation model efficiency (0.78–0.92) and percent deviation values (4.43–19.30) for sediment yield indicate that the WEPP model can be successfully used in the upper Damodar Valley, India.

Introduction

Reliable prediction of the quantity and rate of runoff and sediment from land surface into streams and rivers is difficult, expensive and time consuming. In India, an estimated 175 Mha of land constituting about 53% of the total geographical area suffers from deleterious effect of soil erosion and other forms of land degradation (Reddy, 1999). Active

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erosion caused by water and wind alone accounts for 150 Mha of land, whereas 25 Mha has been degraded due to ravine/gullies, shifting cultivation, salinity/alkalinity, and water logging (Reddy, 1999). At the same time, availability of accurate runoff and sediment yield data is scarcely available at few selected places. Hence, this necessitates the simulation of processes like runoff and transport of sediment as well as pollutants from watersheds through hydrological modeling. Estimation of runoff and sediment yield is necessary for developing watershed management plans involving soil and water conservation measures. Thus, research in hydrological modeling and related watershed planning issues form a strong component of the environmental activities. During the last three decades, researchers have developed hydrological models of empirical or conceptual nature for prediction of hydrological variables. Hydrological models like SWAT (soil and water assessment tool) (Arnold et al., 1993), AGNPS (agricultural non-point source pollution) (Young et al., 1989), ANSWERS (areal non-point source watershed environment response simulation) (Beasley et al., 1980) and WEPP (Water Erosion Prediction Project) (Laflen et al., 1991) are being extensively used for sustainable development of watersheds. Thus, hydrological and water quality models provide the basis for improved understanding of hydrological processes and also for assessing the impact of human activities on environment and agricultural production. A major limitation in hydrology is the lack of availability of adequate data to quantitatively describe a hydrologic process accurately. Rapid parameterization of hydrologic models can be derived using remote sensing (RS) and geographic information systems (GIS) as remotely sensed data provides valuable and up-to-date spatial information on natural resources and physical terrain parameters. Numerous studies described the use of RS and GIS in hydrologic modeling (Hession and Shanholtz, 1988; Tim et al., 1992; Maidment, 1993a; Srinivasan and Engel, 1994; Bhaskar et al., 1992; Sekhar and Rao, 2002; Chowdary et al., 2004; Pandey et al., 2005, 2007). In all these studies, the potential benefits of RS and GIS in hydrologic and water quality modeling have been clearly demonstrated.

The upper Damodar Valley is facing serious problems of land degradation due to soil erosion and about 66% of this region is affected by different types of erosion and 35% of the agricultural land is under moderate to severe sheet erosion (Misra, 1999). Hence, in order to preserve natural resources and the useful life of the reservoirs, there is a need to identify the critical areas in this region that contribute higher runoff and sediment. The WEPP (Water Erosion Prediction Project) (Laflen et al., 1991) model was used for prediction of runoff and sediment yield for the case study area. The WEPP model is capable of (a) identifying zones of sediment deposition and detachment within permanent channels or ephemeral gullies, (b) accounting the effects of backwater on sediment detachment, transport and deposition within channels, and (c) representing spatial and temporal variability in erosion and deposition processes as a result of agricultural management practices (Ascough II et al. 1995a). It is intended for use on small agricultural watersheds (less than 260 ha) in which the sediment yield at the outlet is significantly influenced by hillslope and channel processes (Ascough II et al. 1995b). Model application is constrained by the following limitations: (1) no partial area response; (2) no headcutting; (3) no bank sloughing; and (4) no perennial streams (Ascough II et al. 1995c). The WEPP model has been widely applied to predict runoff and sediment yield at field and watershed scales (Chaves and Nearing, 1991; Tiscareno-Lopez et al., 1994; Risse et al., 1994; Favis-Mortlock et al., 1996; Zhang et al., 1996; Ghidey and Alberts, 1996; Baffaut et al., 1997; Flanagan and Nearing, 2000 and Renschler and Harbor, 2002). Contrary to earlier studies, Gronsten and Lundekvam (2006) reported that the yearly and daily surface runoff and soil loss simulated by the WEPP Hillslope model v. 2002.7 from two different soil erosion plot sites in south-eastern Norway did not yield satisfactory results as equations used for predicting erodibility parameters in the WEPP model are not applicable to Norwegian soil types. Nearing et al. (1990) performed a sensitivity analysis of the WEPP hillslope model and identified precipitation, rill erodibility, rill residue cover, and rill hydraulic friction factors as dominant factors while saturated hydraulic conductivity and interrill erodibility were found to be moderately sensitive parameters.

Tiwari et al. (2000) evaluated the prediction of soil loss from natural runoff plots at 20 different locations in the United States using the WEPP model and compared the results with measured data and with the predictions made by USLE and RUSLE. They concluded that the model performance is close to the traditional empirical methods without calibration of any parameter. Laflen et al. (2004) reported that WEPP performs very well as compared to USLE and RUSLE based models in different conditions. Bhuyana et al. (2002) compared the soil loss predictions using WEPP, EPIC and ANSWERS model and concluded that all three models performed reasonably well and the predicted soil losses were within the range of measured values. For managing large quantities of data for WEPP applications at the watershed scale, integration of WEPP with GIS is desirable because it can facilitate and possibly improve the application of the model. An initial application of the WEPP model with a raster-based GIS was conducted by Savabi et al. (1995) in a small watershed in Indiana. Cochrane and Flanagan (1999) developed an interface between WEPP (Watershed version), and Arc View GIS for small basins (0.59—29 ha), comparing the results obtained from the manual application of WEPP with those obtained using the interface, and studying the effect of DEM resolution on the results from the GIS WEPP interface. There was no significant difference between the manual and the automated applications, and results obtained from different classes of resolution were also not statistically different. Further development in techniques to automate the application of the WEPP model has resulted in GeoWEPP (Renschler, 2003).

The WEPP model was extensively used worldwide by several researchers viz., Spain (Soto and Diaz-Fierros, 1998), UK (Brazier et al., 2000), Australia (Yu et al., 2000; Yu and Rosewell, 2001), Norway (Gronsten and Lundekvam (2006)) and Brazil (Bacchi et al., 2003). Though, several studies were carried out using the WEPP model, further refinement and additional testing of the model is still required for wide range of conditions and agricultural watersheds. From the literature, it is evident that very limited information on application of WEPP model using RS and