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Journal of Hydrology 318 (2006) 184–199
Journal of Hydrology
www.elsevier.com/locate/jhydrol

Hydrological studies for small watershed in India using the ANSWERS model

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Received 15 March 2004; revised 29 May 2005; accepted 3 June 2005

Abstract

A study was undertaken with the objective of investigating the performance of the physically based distributed parameter Areal Non point Source Watershed Environment Response Simulation (ANSWERS) model for a 16.13 km^2 small watershed in eastern India by using digital elevation model (DEM), GIS and remote sensing techniques for automatic extraction of the model input parameters. The model was calibrated by using sixteen storms of 1993 and 1994 and validated with fifteen storms of 1995 and 1996. For calibration storms, the model simulates surface runoff, peak flow and sediment yield with average per cent deviation (Dv) equal to −9.32, 1.24 and −3.04 and coefficient of efficiency (E) equal to 0.964, 0.881 and 0.884 respectively. For validation storms, the model simulates surface runoff, peak flow and sediment yield with average per cent Dv as −8.13, −2.25 and −1.63 and E as 0.991, 0.741 and 0.965 respectively. During model calibration and validation the peaks of the simulated hydrographs for majority of the storms were found to occur after the peaks of the observed hydrographs. The statistical comparisons indicate that the model simulates runoff, peak flow and sediment yield well for most of the storms with Dv less than 15% from the observed values and average value of E greater than 0.80. The model calibration and validation results indicate that the ANSWERS can be successfully used for simulating the watershed response under varying soil moisture and watershed conditions. The study reveals the suitability of the ANSWERS model application for the other Indian watersheds of similar hydro-geological characteristics.

Keywords: ANSWERS; DEM; Hydrograph; Runoff; Sediment yield; Simulation

1. Introduction

Degradation of water and land resources is an issue of significant societal and environmental concern. In India it has been estimated that out of the total geographical area 329 million hectare (mha), nearly 188 mha of land suffers from various form of land degradation problem (Sehgal and Abrol, 1994).

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doi:10.1016/j.jhydrol.2005.06.011

The Upper Damodar Valley (17,513 km^2) comprising 39 sub catchments is infested with serious problems of land degradation by soil erosion affecting the agricultural, forests and waste lands of the region. Survey carried out by Damodar Valley Corporation (DVC) revealed that about 66% of total land of Upper Damodar Valley (UDV) is affected by different types of erosion. Also 35% of agricultural land is moderately to severely eroded under sheet erosion (Misra, 1999). Sedimentation studies of major reservoirs in India revealed that the annual rate of siltation from unit catchment has been 2–3 times more than the designed values (Murthy, 1980). The actual sedimentation survey of Panchet and Maithon reservoirs of Damodar valley revealed that siltation rate was as high as seven times of the designed rate (Misra and Satyanarayana, 1991; Misra, 1999). In order to preserve natural resources and the useful life of these reservoirs, soil and water conservation measures are essential and now included as major component in all river valley projects (RVP) of the country.

The Soil Conservation Department of DVC, one of the prime RVP in the country, has an established network of stream gauging stations and sediment observation posts for monitoring hydrological parameters of the catchments. The purpose is to develop the region for erosion control and to enhance production on sustained basis with an eye on reducing the sediment inflow to multipurpose reservoirs. Out of 1130 small watersheds (1300–2000 ha) of UDV, the gauged watersheds are 69 only. The accurate information on watershed runoff and sediment yield are necessary for the design of conservation structures to offset the ill effects of sedimentation. These information for ungauged watersheds are to be generated through watershed simulation studies, to identify the priority watersheds for implementing watershed management programmes with the limited available funds and also for assessment of their impacts. Hydrologic models provide cost-effective means for determining the best management practices (BMPs) that minimizes water and land degradation due to soil erosion.

The runoff and sediment from agricultural lands have major impact on water quality of the river. Diffuse pollution sources, such as agricultural lands are more difficult to assess and treat than point sources. Methods of identifying the sources of sedimentation and quantities of runoff and sediment are therefore required. Distributed parameter watershed models are applicable for this type of assessment. The AGNPS (Young et al., 1989) and the ANSWERS (Beasley et al., 1980, 1982), are the commonly used distributed parameter models, for simulating the small watersheds (Bingner et al., 1992). These models take spatial variability of watershed characteristics into account through concept of hydrologic response units. The model used to assess the impact of diffuse pollution must simulate both runoff and sediment transport using equations that are applicable to the study region. The ANSWERS simulates both runoff and sediment transport and uses mainly physically based relationships. It is therefore an appropriate model for assessing BMPs and identifying the sources of runoff and erosion.

The ANSWERS model has been used for simulating the hydrologic response of small agricultural watersheds (Montas and Madramootoo, 1991; Razavian, 1990). The integration of Geographical Information System (GIS) with distributed parameter models reduces the time needed for generating large number of input data associated with these models as compared to conventional methods. GIS provides an alternative way of manipulating the input data and preparing model input files. Raster-based GIS worked well with the ANSWERS for generating model input information (De Roo et al., 1989; Rewerts and Engle, 1991). Remote Sensing data provide real time accurate information on spatial and temporal variations in land use and land cover (LULC) of the study area, which are required for watershed simulation studies (Chakravorty, 1993; Tiwari et al., 1997). The GIS and grid digital elevation models (DEM) have been successfully used for automatic extraction of the watershed parameters (e.g. watershed delineation, drainage networks, slopes, aspects etc.) requied for hydrologic and non point source (NPS) pollution studies (Garbrecht and Martz, 1993; Tiwari et al., 1997). The planning and implementation of BMPs for effective conrol of soil erosion and development of water resources, can be improved by the integrated use of physically based distributed parameter models, GIS and remote sensing techniques. Although, physically based distributed parameter models have been successfully used in developed countries for