Agriculture, Ecosystems and Environment 139 (2010) 675–688

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Application of SWAT model to investigate nitrate leaching in Hamadan–Bahar Watershed, Iran

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ARTICLE INFO

Article history:
Received 26 February 2010
Received in revised form 24 October 2010
Accepted 26 October 2010
Available online 20 November 2010

Keywords:
Nitrate leaching
SWAT model
SUFI-2
Uncertainty
Calibration

ABSTRACT

Application of large amounts of mineral and organic fertilizers in intensive agricultural regions of Hamadan–Bahar watershed in western Iran contributes to excessive nutrient loads in soils and groundwater bodies. Groundwater supplies approximately 88% of the water consumed in Hamadan. The objective of this study was to investigate the temporal and spatial variability of nitrate leaching in Hamadan–Bahar watershed. We employed the Soil and Water Assessment Tool (SWAT) to model the amount and dynamics of nitrate leaching from a typical crop rotation in this watershed. The SWAT model was calibrated and validated with uncertainty analysis using SUFI-2 (Sequential Uncertainty Fitting, ver. 2) based on measured daily discharge data from 7 hydrometric stations, wheat and potato yield, and measured daily nitrate at the outlet of the watershed. The calibration using crop yield increases the confidence on soil moisture and evapotranspiration. The calibration (R^2 = 0.83, NS = 0.77) and validation (R^2 = 0.70, NS = 0.70) results were quite satisfactory for the outlet of watershed. Spatial variations in nitrate leaching were also found to agree reasonably well with measured nitrate concentrations in groundwater (73% overlap based on a defined criterion). Also, nitrate leaching was found to be more significant under potato (*Solanum tuberosum* L.) rotation (254–361 kg N ha^{-1} year^{-1}), representing 30–42% of nitrogen applied to the soil. About 36% of Hamadan–Bahar aquifer has a nitrate leaching rate higher than 100 kg N ha^{-1} year^{-1}. The presented model and its results have the potential to provide a strong base for considering different scenarios to reduce nitrate leaching and suggest a BMP (best management practice) in Hamadan–Bahar watershed.

1. Introduction

In Hamadan–Bahar watershed, water scarcity has become an increasingly serious problem. Groundwater is the major source of water supply for drinking, domestic, industrial, and agricultural sectors in this region. One of the problems affecting the quality of groundwater is leaching nutrients from the soil, which is especially evident in agricultural dominated watersheds (Jalali, 2005). Application of large amounts of nitrogen fertilizers, at higher than crop uptake requirement rate, in intensive agricultural regions of Hamadan–Bahar plain contributes to excessive nitrate accumulation in soils and leaching into groundwater bodies (Jalali, 2005; Nadafian, 2007; Rahmani, 2003).

Nitrogen leaching from agricultural lands is a widespread global problem. In areas where nonpoint source pollution is dominant, regional models are often the only practical way to examine the impacts of changing landuse on the concentration of nitrate pollution. Hydrological models that are able to calculate the nitrogen fate and transport are useful tools to determine the probable effects

Abbreviations: 95PPU, 95% prediction uncertainty; Φ, efficiency criterion based on modified R^2; σ^2, variance; *b*, slope of the regression line; CN, curve number; *g*, objective function; HI, Harvest Index; HRU, hydrologic response unit; HRWA, Hamadan Regional Water Authority; LAI, leaf area index; MCMC, Monte Carlo Markov Chain; MOJAH, Ministry of Jahade-Agriculture of Hamadan; MSE, mean square error (range of values $-\infty$ to $+\infty$); *n*, number of observations; N_{Load}, monthly nitrate loads carried by surface runoff (kg N month^{-1}); NO_3^-, nitrate concentration (mg l^{-1}); NS, Nasch–Sutcliffe factor (range of value ≤ 1); *P*-factor, %data bracketed by the 95PPU (range of value 0–1); *p*-value, *p*-value shows the significance of the sensitivity (range of value ≥ 0); ParaSol, Parameter Solution; PET, potential evapotranspiration; *q*, discharge in the river reach (m^3 s^{-1}); R^2, coefficient of determination; RMSE, root mean square error; *R*-factor, the average thickness of the 95PPU band divided by the standard deviation of the measured data (range of value 0–1); SDNCO, denitrification threshold water content; SUFI-2, Sequential Uncertainty Fitting, ver. 2; SWAT, Soil and Water Assessment Tool; SWAT-CUP, SWAT Calibration Uncertainty Procedures; Y_{obs}, observed crop yield (ton ha^{-1}); Y_{sim}, simulated crop yield (ton ha).

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doi:10.1016/j.agee.2010.10.015

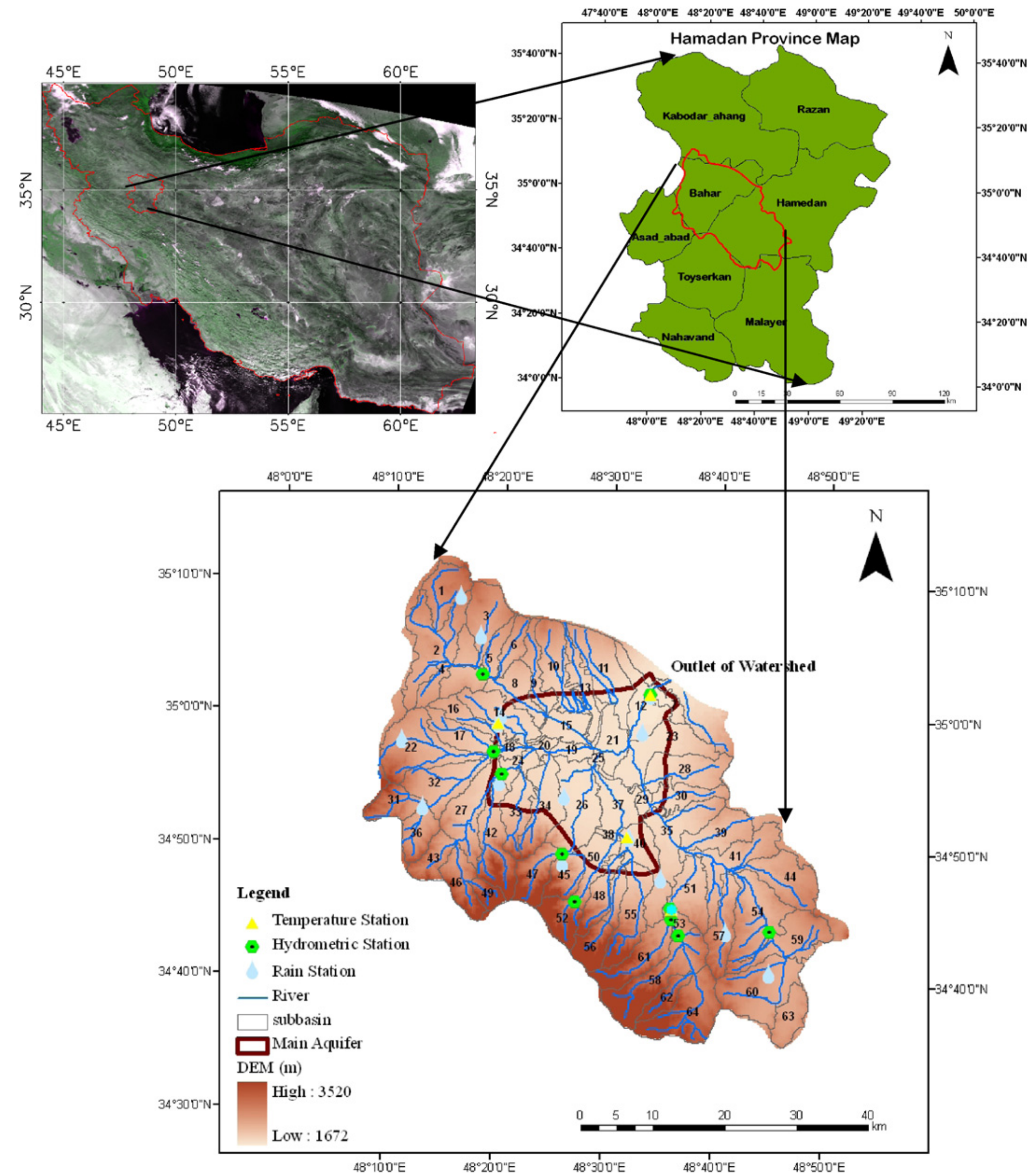

Fig. 1. Study area of Hamadan–Bahar watershed in Hamadan province, Iran. In this figure, river network, main aquifer, meteorological stations and SWAT-delineated sub-basins are shown.

of agricultural activities on local hydrology and aqueous geochemistry. Direct measurement of the impact of agricultural practices on groundwater quality is tedious and usually too expensive. For example, soil sampling is time consuming and sampling water quality at field level, using suction cups or lysimeters is expensive and impractical (Lord and Shepherd, 1993). Such approaches cannot directly help in making a general decision in large scales. These issues demand integrated management of water resources in watersheds (Pohlert et al., 2007), which rely mostly now on modeling.

Nonpoint source nitrate loading has substantially impacted groundwater nitrate concentrations in Hamadan–Bahar aquifer (Jalali, 2005; Nadafian, 2007; Rahmani, 2003). These water resources are located in the vicinity of drinking water wells. Therefore, it is essential to determine how management practices will impact groundwater nitrate concentrations.

With this background in mind, the objectives of this study included: (1) using the SWAT program to model the temporal and spatial variability of nitrate leaching dynamics for the present agricultural activities at hydrologic response unit (HRU) level with monthly time steps, (2) to calibrate, validate and perform uncertainty analysis for the SWAT hydrologic model for Hamadan–Bahar watershed based on river discharge and nitrate data, and then (3) to calibrate, validate and perform uncertainty analysis for the SWAT crop yield model using the main regional crops, which are potato (*Solanum tuberosum* L.) and irrigated and rainfed wheat (*Triticum asestivum* L.).

2. Materials and methods

2.1. Description of the study area

The Hamadan–Bahar watershed with an area of 2460 km^2 is situated between longitudes of 48°7′E and 48°52′E and latitudes of 34°35′N and 35°12′N, in western Iran (Fig. 1). In this watershed, most of the rivers originate from southern heights (Alvand Mountains). All of the rivers merge in the central plain and form the Siminehrud (Fig. 1). The outlet of watershed is Koshkabad in the