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Seasonal Climate Variations and Watershed Hydrology and Water Quality Response

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ABSTRACT: Water is the most valuable natural resource to maintain ecological balance and sustain life on earth. In recent years, especially in the post technological revolution era, climate is being alleged to have changed, with particular reference to the increase in temperature and variations in the occurrence and distribution of rainfall. The situation is more egregious in tropical and subtropical regions where high intensity monsoon rains and changing land cover conditions have more pronounced effects on hydrologic processes. In the present study, we assessed the watershed response and variations in nutrient losses (N and P loads) from a watershed due to the changes in intra-seasonal rainfall pattern with the help of a hydrologic-water quality model: Soil and Water Assessment Tool (SWAT). We analyzed the intra-seasonal variations in the rainfall occurrence and modeled its affect on water soluble NO_3–N, NH_4–N, P, organic N and organic P loads moving with runoff and percolated water as pollutants of water downstream.

The results of the study reveal that the NPS pollutant load in runoff varies with seasonal rainfall patterns and account for a maximum of 4.52 kg/ha as NO_3–N in surface runoff from the watershed. The total loss of N from the watershed accounts for as high as 8.84 kg/ha, whereas P load is 0.02 kg/ha. These losses can be as high as 14984.14 kg of total N and 50.85 kg of total P when estimated as NPS pollutants from the watershed. The study can be useful to estimate the extent of these pollutants varying with seasonal rainfall patterns and help in managing the resources as well reducing pollution of water resources.

Keywords: Modelling, Watershed, SWAT, Seasonal Climate, Nutrient Load, Water Pollution.

INTRODUCTION

Water quality has grown as a major problem in recent years. In response to technological revolution, climate is being alleged to have changed, with particular reference to the increase in temperature and variations in the occurrence and distribution of rainfall. Because of these changes coupled with intensive human interaction to harness greater benefit from land resources, water quantity and quality are approaching an alarming situation. In humid and sub-humid subtropical regions, changed climatic condition has affected the society in many ways, such as a rise in regional and seasonal temperature (Kothawale and Rup Kumar, 2005) resulting in increased requirement of water for human beings as well as crops. There seems to be global consensus that climate is changing due to global warming (Boer *et al.,* 1992; Hulme *et al.,* 1998) and it is affecting the rainfall occurrence and distribution (Dore, 2005; Yu and Neil, 1991) with seasonal and decadal variability. The increased rainfall variability is resulting in intensive runoff and concomitant transport of sediment along with agro-chemicals (fertilizers, insecticides and pesticides) which, in turn, are fast degrading land resources, polluting water resources, and strongly influencing the hydrologic behavior of watersheds. The widespread nature of these losses of NPS pollutants in response to watershed hydrology, land use pattern and changed climate conditions makes their measurement difficult by any deterministic procedure and thus poses complex technical problems to its assessment and management. Hence, knowledge of the mechanism of pollutant runoff under seasonal rainfall variation is useful to understand the nature and extent of pollution and to develop environmental management of watersheds.

Many investigations have been conducted on the surface and sub-surface losses of N and other agrochemicals (pesticides and insecticides) from watersheds under unique land use (LU)/Land Cover (LC) conditions (Li and Zhang, 1999; Vlaming *et al.,* 2004; Kull *et al.,* 2005) to integrate catchment and water management policy goals. However, there is hardly any discussion on the effects of seasonal climate variation on NPS pollution. The present study tries to explore the effect of season rainfall variation on the NPS pollution, namely sediment yield, nitrate nitrogen (NO_3–N), ammonium nitrogen (NH_4–N), and water soluble phosphorous (P). We employ the SWAT model to simulate the watershed response under variable weather conditions for losses of NO_3–N, NH_4–N, water soluble P, organic N and organic P from a watershed as NPS pollutants to downstream water resources. The idea may be helpful to quantify the total losses of major nutrients from a watershed and can be further utilized in the management strategy formulation to avoid losses under changing climate conditions.

MATERIALS AND METHODS

Study Area

The study was carried out in a small watershed named Banha (1695 hectares, Figure 1) of Damodar Valley Corporation (DVC) Command, Hazaribagh, Jharkhand, situated in the sub-humid sub-tropical region of northern India. The slope of the area ranges from 1 to 18% with an average slope of 1.9%.

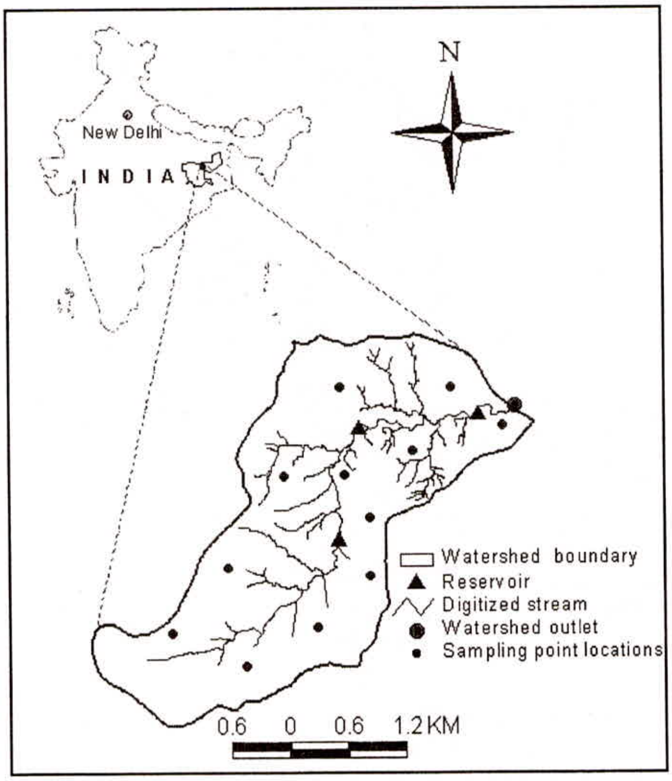


Fig. 1: Banha Watershed of DVC Command, Hazaribagh, Jharkhand, India showing the sampiing point locations, digitized stream and watershed outlet

The average annual rainfall of the area is about 1200 mm. The overall climate of the area is classified as sub-humid sub-tropical. The soils of the watershed vary texturally from loamy sand to loam with sandy loam as the common texture. Texturally soils are uniform with depth, neutral to slightly acidic with medium organic matter and low salt content. The bulk density of soils varies around 1.5 g/cc with moderately low saturated hydraulic conductivity varying from 9.7 to 16.8 cm/day.

The land use/land cover of the area during monsoon season comprises mainly the rice crop. Chemical fertilizers and Farm Yard Manure (FYM) are generally used in crop cultivation practices. Therefore, the possible causes of NPS pollution from the area are fertilizers, individual housing effluent and forest residues.

Model Description

The physically based, continuous time step Soil and Water Assessment Tool (SWAT) model, developed by USDA-ARS, was used to estimate the hydrological behavior and N and P yields from the watershed experiencing varying weather, land use and management conditions. The model simulates the hydrologic cycle based on the water balance equation. Surface runoff volume is estimated from daily rainfall by using the SCS curve number technique (USDA-SCS, 1972) and sediment yield is computed by using the Modified Universal Soil Loss Equation (MUSLE).

Nutrients

SWAT uses the modified EPIC model to compute nutrient yield and cycling from the sub-watersheds (Arnold *et al.,* 1996) and is briefly discussed as below.

Nitrate

The amount of NO_3–N contained in runoff, lateral flow and percolation losses are estimated as the product of the volume of water and concentration. The amount of NO_3–N in run-off is estimated for each sub-watershed by considering the top 10 mm soil layer only and given as,

$$VNO_3 = (QT)\,(C_{NO_3})$$

where VNO_3 is the amount NO_3–N lost from the first layer, QT is the total water lost from the first layer in mm, and C_{NO_3} is the concentration of NO_3–N in the first layer.

Leaching and lateral subsurface flows in lower layers are estimated with the same approach as used in the upper layer except that surface runoff is not considered.

The organic nitrogen loss along with the sediment transported is estimated by a loading function developed by McElroy *et al.* (1976) and modified by Williams and Hann (1978) applicable to individual runoff events. A loading function estimates the daily organic N runoff loss based on the concentration of organic N in the top soil layer, the sediment yield and enrichment ratio as,

$$YNO = 0.001(Y)(CON)(ER)$$

where *YON* is the organic *N* runoff loss at the outlet (kg/ha), *CON* is the concentration of organic *N* in the top soil layer (g/t), *Y* is the sediment yield (t/ha), and *ER* is the enrichment ratio as described by Menzel (1980) and given as:

$$ER = X_1 C_a^{X_2}$$

where C_a is the sediment concentration (g/m^3), X_1 and X_2 are parameters set by the upper and lower limits. The enrichment ratio approaches 1.0, the sediment concentration would be extremely high and vice versa.

Phosphorous

P is mostly associated with sediment and the soluble P with runoff in the SWAT model, and is expressed as,

$$YSP = \frac{0.01(C_{LPP})(Q)}{k_d}$$

where *YSP* is the soluble P (kg/ha) lost in runoff volume *Q* (mm), C_{LPP} is the concentration of soluble P in soil layer (g/t), and k_d is the P concentration in the sediment divided by that of the water (m^3/t). C_{LPP} is constant for the whole simulation and initially inputted to the model.

The sediment associated P is simulated with a loading function as,

$$YP = 0.01(Y)(C_p)(ER)$$

where *YP* is the sediment associated P loss in runoff (kg/ha), C_p is the concentration of P in the topsoil layer (g/t), and *ER* is the enrichment ratio.

The model performs the simultaneous computations on sub-watersheds and routes the water, sediment and nutrients through reaches and finally sums as loadings from the watershed.

Data Collection

Daily measured data on rainfall, temperature (maximum and minimum), runoff and sediment transport from 1991 to 2001 were collected, processed and used to run the model for this study. The NO_3–N, NH_4–N and water soluble P concentrations as NPS pollution data were monitored and measured at the watershed outlet during monsoon months of 2000 and 2001.

The topography, soil type, texture, existing land use/land cover, water resources, drainage pattern features of the watershed obtained from field measurements, topographic maps and remotely sensed imagery, were stored in the ArcInfo GIS tool and used to generate the model input. The physical and chemical properties of the surface and sub-surface soil layers (up to 100 cm depth) were measured at 12 locations, well distributed over the watershed (Figure 1). The watershed was delineated from the Survey of India topographic sheets and after establishing a digitized contour coverage, 30 m × 30 m DEM was generated to estimate the slope, drainage pattern and aspect of the watershed. The Satellite imagery (IRS-1D, 15th December, 2000) was classified to get the information on the land use/land cover extent of the watershed. The land use/land cover of the watershed was classified in 9 categories: low land paddy (rice), upland crops, shallow water body, deep water body, growing forest (new plantation), degraded forest, dense forest, fallow land and eroded land as shown in Figure 2.

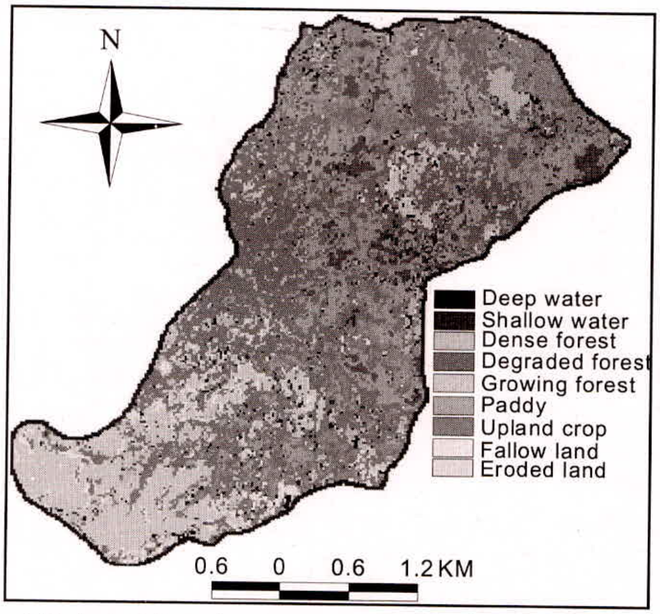


Fig. 2: Land use/land cover map of Banha Watershed for the Year 2000

The SWAT model was calibrated against the daily stream flow and sediment yield measured at the watershed outlet during the monsoon months from June to September, 2000 as our concern was to study the intra-seasonal rainfall variability effect on hydrology and NPS pollution loads during monsoon season. The calibrated model was tested to simulate the NO_3–N, NH_4–N and water soluble P concentrations in stream flow and the simulated values were compared with the measured values. The properly validated model was then used to estimate the loads of NPS pollutant runoff from the watershed.

RESULTS AND DISCUSSION

We simulated the watershed conditions employing the SWAT model using observed and measured meteorological and hydrologic information for the year 2000 and 2001. The results are discussed as the effects of seasonal changes in rainfall pattern on run-off, sediment yield and transport of N and P as pollutants run-off from the watershed as below.

Seasonal Rainfall Variation and its Effect on Runoff and Sediment Yield

We compared the daily rainfall occurrence and distribution during the monsoon season (June, July, August and September) of the years 2000 and 2001 and its effect on runoff and sediment yield generation from the watershed (Figure 3). This figure shows a close correspondence between rainfall and observed as well as SWAT estimated runoff. Due to the smallness of the watershed area, runoff and sediment yield closely synchronized with the rainfall distribution.

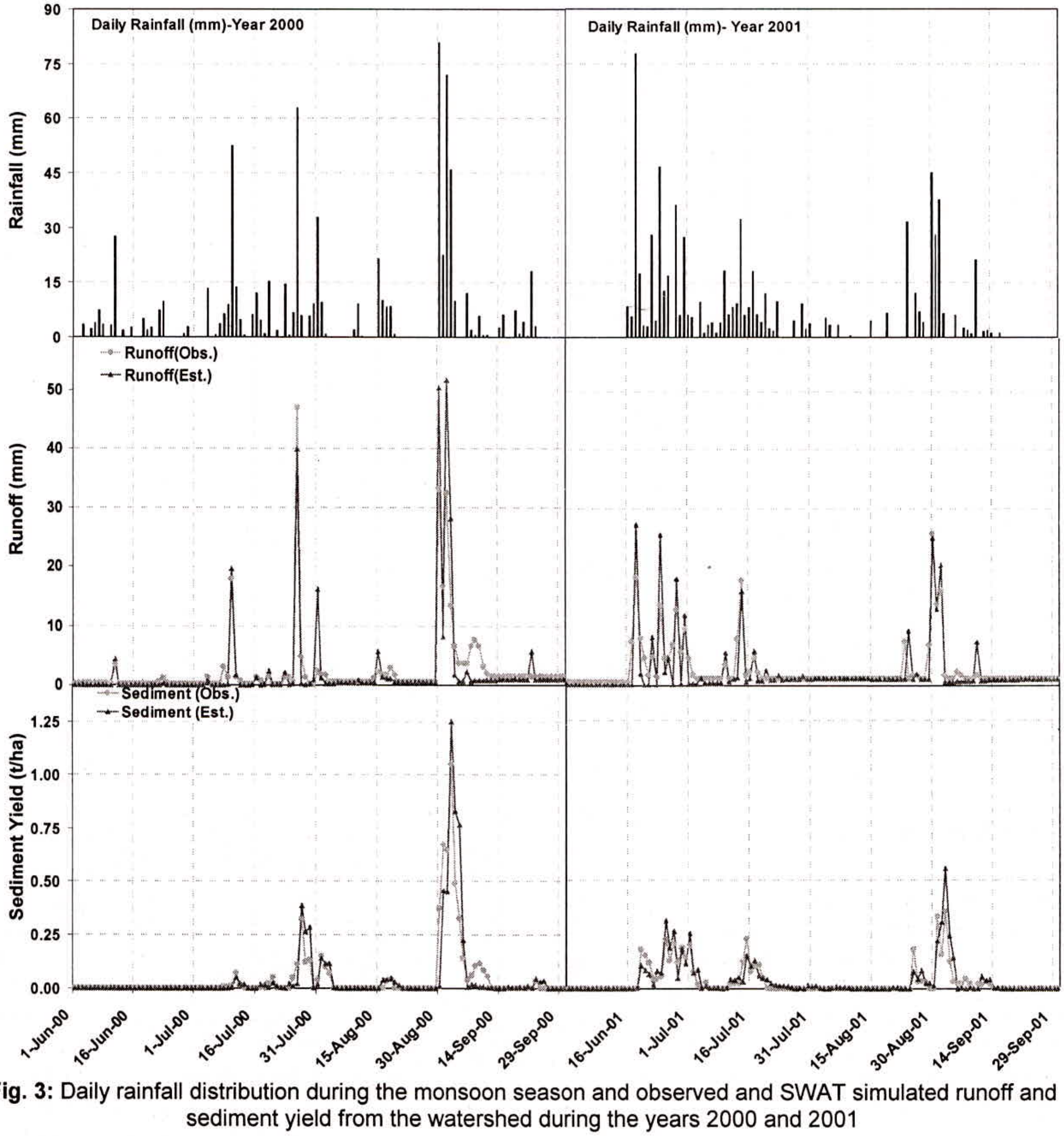


Fig. 3: Daily rainfall distribution during the monsoon season and observed and SWAT simulated runoff and sediment yield from the watershed during the years 2000 and 2001

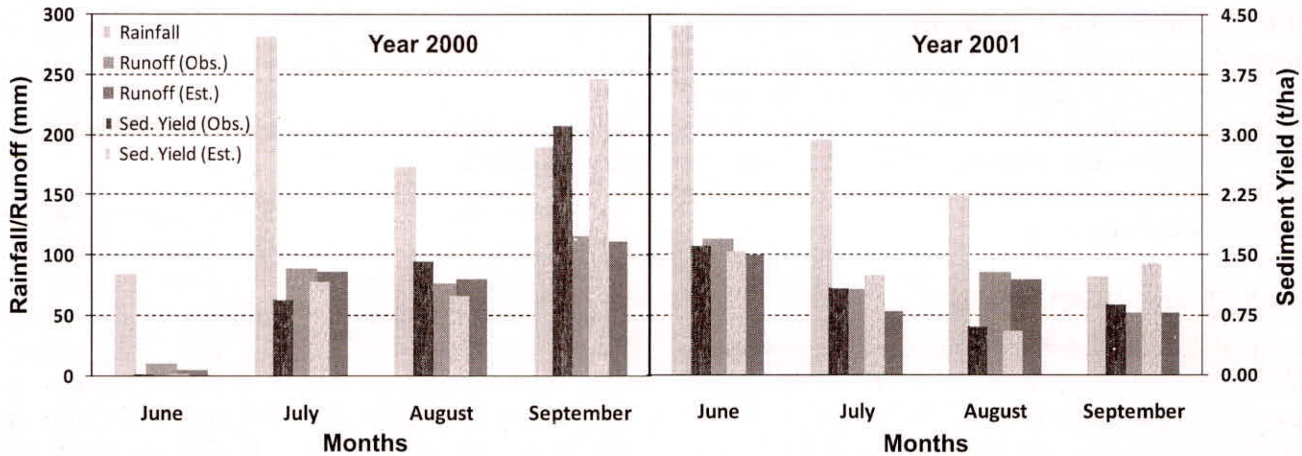


Fig. 4: Monthly rainfall distribution during the monsoon season and observed and SWAT simulated runoff and sediment yield from the watershed during the years 2000 and 2001

In June 2000, there were less intensive rains compared to June, 2001 which generated less amounts of runoff as well as sediment yield in 2000. At the same time, at the end of August and beginning of September in year 2000, watershed received intensive rains compared to year 2001 and thus generated high runoff as well as sediment yield in year 2000.

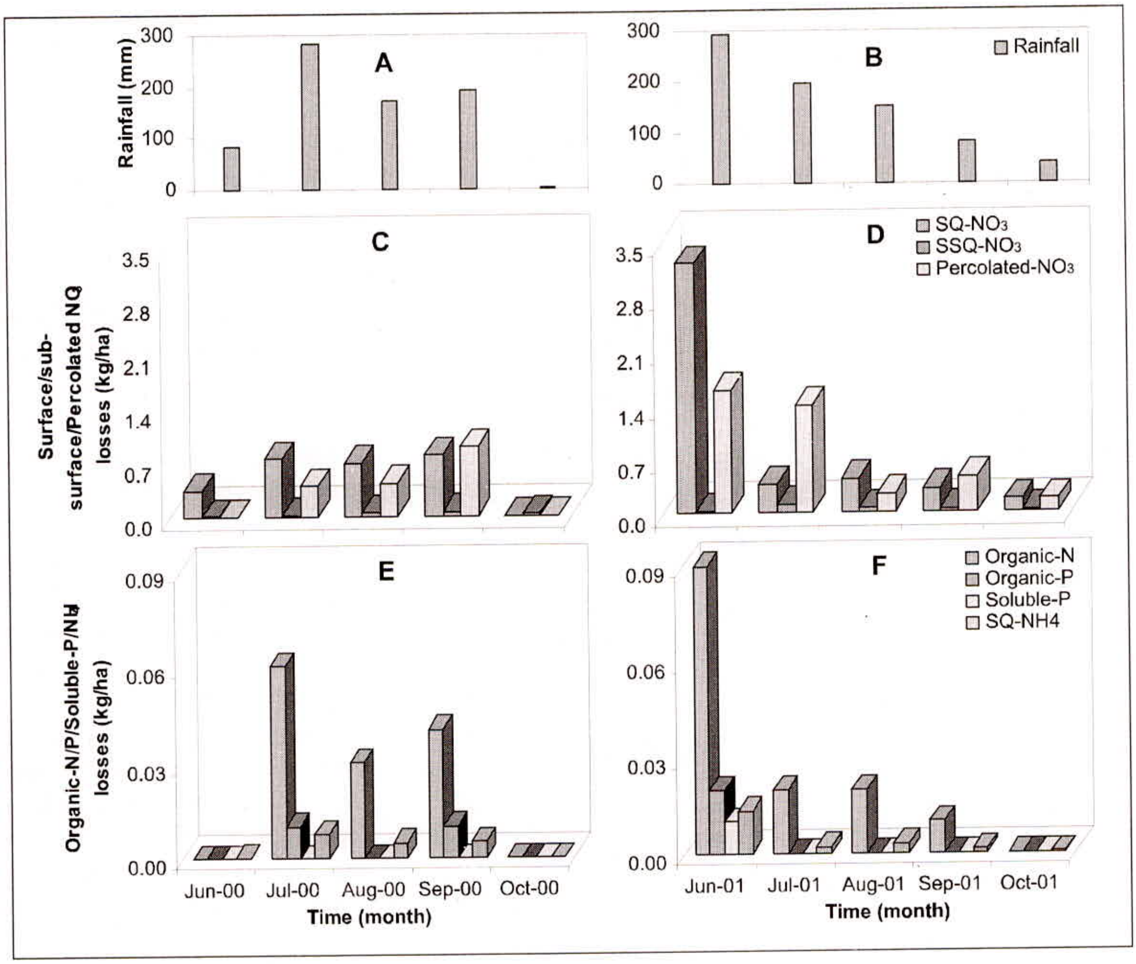
We also analyzed the effect of monthly rainfall variation on observed and SWAT estimated runoff and sediment yield, as presented in Figure 4. From the figure it becomes more clear that in the year 2000, monthly rainfall had a high variation than in the year 2001. The initial dryness in June followed by high rainfall in July and average rainfall in August and September in year 2000 generated more runoff as well as sediment yield from the watershed in comparison to initial high rainfall in June and consistently reduced rainfall in the following months over the watershed in year 2001. In the year 2001, the problem of sediment generation during the monsoon season was overall less than in the year 2000. These analyses clearly showed that the seasonal variation in the occurrence and distribution of daily as well as monthly rainfall generated a high variation in the watershed hydrologic response.

Variation in NPS Pollutants with Seasonal Rainfall Variability

We employed the calibrated SWAT model to simulate the NPS pollution of water due to the losses of nutrient from the watershed during June to September, 2000 and 2001. Monthly surface and sub-surface losses of NO_3–N, NH_4–N, Soluble P, organic N and organic P on a per hectare basis as NPS pollutants loads from the watershed to the downstream water were investigated for varied rainfall conditions in the 2 year period. The results obtained are presented in Figure 5 (C&D). It is apparent from this figure that the appreciable amount of NO_3–N was lost by surface runoff and the percolated water. However, nutrients loss due to sub-surface flow was relatively low. The loss of organic N was quite high as compared to organic P and NH_4–N (Figure 5 E&F). The quantified nutrient loads from the watershed varied from 2.57 to 4.52 kg/ha as NO_3–N lost through surface runoff, 0.17 to 0.29 kg/ha as NO_3–N lost in sub-surface runoff, 1.73 to 3.87 kg/ha as NO_3–N lost with percolated water, 0.13 to 0.14 kg/ha as organic N, 0.02 kg/ha as NH_4–N, 0.02 kg/ha as organic P and 0.01 kg/ha as soluble P from the watershed as NPS pollutants during the monsoon months of 2000 and 2001.

Figure 5 shows a clear variation in the simulated losses of N and P among 2000 and 2001 which was due to the variation in rainfall intensity and distribution in both the years and had a high effect on the transport characteristics of NPS pollutants. Because of small initial rainfall in 2000, the surface runoff loss of NO_3–N was less than that in 2001 (Figure 5 C&D). Owing to a higher generation of sediment yield due to dry soil condition in 2000, the organic N loss was more in the monsoon months of 2000 than in 2001.

These per hectare losses were very much varying with the variation in rainfall occurrence and distribution over the watershed. A comparative assessment is shown in Table 1, showing the total load of these agro-chemicals as NPS pollutants from the watershed for the years 2000 and 2001. It is clear from the table that stream water going out from the watershed contained a maximum load of NO_3–N when rainfall was well distributed, soil was moist and thus more agro-chemicals were mixed with the runoff water as in 2001.



SQ—Surface runoff, SSQ- Sub-surface runoff

Fig. 5: SWAT-simulated surface and sub-surface losses of NO_3–N, NH_4–N, Soluble P, organic N and organic P from the watershed in 2000 and 2001

In the present study, the load of NO_3–N ranged from 4356.15 kg in 2000 to as high as 7661.40 kg in 2001. Along with surface runoff, losses of agro-chemicals remained high for the year 2001 for percolated NO_3–N, surface runoff losses of NH_4–N, losses as organic N and soluble organic P.

Table 1: SWAT Estimated Losses of N and P Species as NPS Pollutants from the Watershed

Losses of N and P Species in-	*Runoff Loads as Losses (kg) from Watershed in year*	
	2000	*2001*
Surface runoff NO_3–N	4356.15	7661.40
Subsurface runoff NO_3–N	288.15	491.55
Percolation NO_3–N	2932.35	6559.65
Surface runoff NH_4–N	30.07	34.24
Organic N	220.35	237.30
Organic P	33.90	33.90
Soluble P	0.00	16.95

CONCLUSIONS

The effect of seasonal climate, especially variation in rainfall occurrence and distribution during the monsoon season has been studied for a small watershed in sub-humid, sub-tropical region and the following conclusions can be drawn from this study:

1. The study shows that physically based modelling can be employed to estimate the watershed diffuse losses and the quantity of nutrients naturally removed with watershed hydrologic cycle components.
2. Variations in seasonal rainfall pattern show a profound impact on the losses of nutrient N and P from the watershed during 2000 and 2001.
3. Protection and control management strategies can be formulated utilizing the modelling tool prior to the occurrence of losses.
4. To reduce non-point source pollutant loading, the best management practice on land use, improved tillage, applications of fertilizer and soil and water conservation practices can be adopted suitably.

5. The results of the present study suggest for an intensive study of climate change/variability impacts on the NPS pollutant behaviour on a watershed scale for better utilization of limiting resources and NPS pollution control of water resources.

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