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Impact of land cover and land use change on runoff characteristics

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A R T I C L E I N F O

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A B S T R A C T

Change in Land Cover and Land Use (LCLU) influences the runoff characteristics of a drainage basin to a large extent, which in turn, affects the surface and groundwater availability of the area, and hence leads to further change in LCLU. This forms a vicious circle. Hence it becomes essential to assess the effect of change in LCLU on the runoff characteristics of a region in general and of small watershed levels (sub-basin levels) in particular. Such an analysis can effectively be carried out by using watershed simulation models with integrated GIS frame work. SWAT (Soil and Water Analysis Tool) model, being one of the versatile watershed simulation models, is found to be suitable for this purpose as many GIS integration modules are available for this model (e.g. ArcSWAT, MWSWAT). Watershed simulation using SWAT requires the land use and land cover data, soil data and many other features. With the availability of repository of satellite imageries, both from Indian and foreign sources, it becomes possible to use the concurrent local land use and land cover data, thereby enabling more accurate modelling of small watersheds. Such availability will also enable us to assess the effect of LCLU on runoff characteristics and their reverse impact. The current study assesses the effect of land use and land cover on the runoff characteristics of two watersheds in Kerala, India. It also assesses how the change in land use and land cover in the last few decades affected the runoff characteristics of these watersheds. It is seen that the reduction in the forest area amounts to 60% and 32% in the analysed watersheds. However, the changes in the surface runoff for these watersheds are not comparable with the changes in the forest area but are within 20%. Similarly the maximum (peak) value of runoff has increased by an amount of 15% only. The lesser (aforementioned) effect than expected might be due to the fact that forest has been converted to agricultural purpose with major portion as plantations which have comparatively similar characteristics of the forest except for evapo-transpiration. The double sided action (increase in evapo-transpiration owing to species like rubber and increase percolation due to its plantation method by using terracing) might be the reason for relatively smaller effect of the land use change, not commensurate with the changes in the forest area amounting to 60% and 32% for Manali and Kurumali watersheds respectively. Water harvesting methods like rain harvesting ditches can be made mandatory where species with high evapo-transpiration are grown. This action shall enhance the groundwater percolation and shall counter act the effect due to high evapo-transpiration.

1. Introduction

Water availability in an area depends very much on how rainfall over the area is divided into various components such as surface runoff, interflow, groundwater recharge etc. Proportions of these components in the area are principally affected by the land cover and land use (LCLU) of that area. Hence, a change in LCLU of an area can alter the proportions of the aforementioned components, which in turn, results in phenomenal change in the ecological system of the area. It is understood that there has been sizeable change in LCLU for the last few decades over many parts of the globe. This change alters the proportions of the aforementioned components and hence can affect water availability in the respective area. Change in the availability of water in general, and change in surface runoff in particular, of an area can affect the LCLU. This circular dependence -water availability on LCLU and vice versa -can lead to many adverse changes in the local ecosystem. Change in LCLU is normally induced by human activities rather than natural

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events. Currently, agricultural expansion, burning activities or fuel wood consumption, deforestation, expansion of grazing land, some construction works and urbanization are some of the man made activities which cause LCLU changes. Such changes can have great impact on the environment of watersheds as they alter the hydrological processes such as infiltration, groundwater recharge, base flow and runoff (Niehoff et al., 2002). Study of change in runoff characteristics due to human activities has an important role in understanding the effects of LCLU change on hydrological processes over the earth surface (Shi et al., 2007). To understand the future effects of land use change on runoff characteristics, it is important to have an understanding of the effects that historic changes in land use have had on runoff (Crooks et al., 2000). Hence it is imperative that the effect of change in land use on the runoff characteristics of a region be assessed (Shi et al., 2007). Watershed models are very much suited for this purpose.

Watershed models are powerful tools for simulating the effect of watershed processes on soil and water resources. An integral part of any watershed model is the rainfall-runoff process which tries to estimate the various components of runoff from available meteorological characteristics. It is also very much important how the watershed simulation models represent the rainfall-runoff processes; based on which these models can be classified into three categories viz., physically based model, conceptual models and black box models. This classification is based on the degree of representation of physics of rainfall-runoff processes; physically based model has a rigorous representation of the process while the other two have lesser and least representations. Numerous watershed models with varying capabilities, strengths, and weaknesses are available in each of these categories (Randall et al., 1998).

Among watershed models, the Soil and Water Assessment Tool (SWAT) is a versatile watershed model as it has the capability of simulating many processes right from rainfall-runoff process up to plant growth (Neitsch et al., 2002; Gassman et al., 2007). The SWAT is a computationally efficient agro-hydrological watershed scale model and is well-suited for studying the large-scale impacts of land use changes (Breuer et al., 2009). Components of the model include weather, hydrology, soil characteristics, plant growth, nutrients, pesticides and land management (Gassman et al., 2007).

Many attempts have been made for modelling runoff in an ungauged watershed with little or no calibration efforts (Arnold et al., 1998). Here, ungauged watersheds refer to the watersheds for which topographic and climatic properties are available, but discharge data are not available. The SWAT model could simulate runoff from a watershed in Kerala with reasonable accuracy even without any calibration data (Jayasree and Sajikumar, 2012). Wang et al. (2012) compared the effect of change in land use by utilising the SWAT and partial least square method. Githui et al. (2009) used SWAT model for assessing the impact of land use change on runoff characteristics and found that varying degree of dependence of land use change on the runoff characteristics. Several such studies have been conducted by many investigators for assessing the effect of land use change on runoff characteristics (Li et al., 2009; Wang et al., 2012; Alibuyog et al. 2009). These studies indicate that impact of land use changes on runoff characteristics varies from place to place. Therefore it becomes imperative to assess the effect of LCLU change on runoff characteristics in the area of interest, especially where unique features exist in such area. Hence the objectives of the current study are set as:

- To assess the effect of local LCLU on the runoff characteristics of some of the typical watersheds in Kerala, India where slope of the terrain changes drastically within a relatively smaller length of the river.
- To appraise how the change in LCLU in the last few decades affected the runoff characteristics of these watersheds.

2. Materials and methods

2.1. Study area

The current study focuses on the effect of LCLU change on runoff characteristics of two watersheds, viz., watersheds of Manali and Kurumali rivers. Both the rivers originate from the Western Ghats. The Manali River originates from Vaniampara hills and has a catchment area of 145.0 km^2 with reference to the outlet located at latitude of 10°35′30.76″N and longitude of 76°20′2.30″E (Fig. 1). The above mentioned area excludes the catchment area of Peechi reservoir because that part of the watershed has been modelled as a reservoir contributing the discharge to the river. The Kurumali River originates at Chimmony from Poomalai in the Western Ghats and flows through the Thrissur District. The Mupli and the Chimmony rivers join to form Kurumali River in Elikode near Karikulam. This watershed has a catchment area of 322.5 km^2, with reference to the outlet located at latitude of 10^{0}26′30.76″N and longitude of 76^{0}16′2.30″E.

Major forest area in these watersheds are located in the upstream portion of the watersheds, viz., western ghat engulfing Peechi-Vazhani Wildlife Sanctuary. Evergreen, semi evergreen, moist deciduous and scrub sorts of forest are the main vegetation types present in the area, of which the first three account for more than 60% percent. Owing to inadequate protection/conservation efforts, this forest area is characterized by high degradation levels and low density of wildlife (Deepa, 2000). Inhabitants in the area are mostly agriculturists who cultivate a variety of crops such as vegetables, banana, rice, tapioca, cashew, rubber, etc. Inhabitants, both tribal and other local communities, living immediately around the natural forests depend very much on the forests for their lively needs such as firewood, cattle grazing and small construction needs; resulting in degradation of the forest area. A survey indicated that there has been significant changes in the land use, which have had adverse effects on the forest ecology, water yield, dry season flow, soil erosion, stream sediment load, etc. (Muraleedharan et al., 2007). Though that study generally touches upon the water yield, an elaborate study on the effect of land use change on behaviour of the runoff on this region has not been carried out.

2.2. Data sources

The Arc SWAT, an interface for SWAT in Arc GIS, requires basic spatial data such as Digital Elevation Model (DEM), soil type and land use. The other essential data for simulating rainfall-runoff process include weather data, parameters describing watershed characteristics, and data pertaining to reservoir. The DEM was obtained from the NASA 90-m Shuttle Radar Topographic Mission (SRTM) dataset. It is freely downloadable at http://srtm.csi.cigar.org. This DEM was used to delineate the watershed and analyse the drainage pattern of the land surface terrain. The study uses three land use sets for each watershed, viz., landuse data from global source, land use of sixties and recent land use of the area from local source. The word 'global' and 'local' are used to indicate whether the data are obtained from a publicly available land use covering entire globe or they are prepared for the local area using satellite imagery. The Global land use map of the study area was obtained from Water base website http://www.waterbase.org/home.html. This land use data were constructed from the USGS Global Land Cover Characterization (GLCC) database and has a

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