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Research article

Past, present and future land use changes and their impact on water balance

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ABSTRACT

Landuse change influences the water balance of a region affecting the available water along with the change in the evapotranspiration (ET). The major objectives of this study are to assess the landuse change and its impact on the water balance of the study area, which is a part of the Narmada river basin in Madhya Pradesh, India. Landuse changes of 1990, 2000 and 2011 have been analyzed and the Markov Chain model has been used to predict decadal change of 2020, 2030, 2040 and 2050 landuse. The influence of the past, present and future landuse change on water balance has been analyzed with the SWAT (Soil and Water Analysis Tool) model in the study area. The effect of changes are shown in 12 different sub-watersheds of the area, reflecting an increased water yield (runoff, including ground-water outflow) and surface runoff but decreased ET, which is due to change in the curve number (CN) values (79.85 in 1990 to 84.63 in 2050). Increased CN value in different sub-watersheds of the region has been observed due to a reduction in the vegetation areas, and increase in the agricultural land and settlements. This has caused an increased runoff and decreased ET. The water yield has increased by 6.98% from 1990 to 2011 (1.92 CN increase) and by 17.5% as projected in the 2050 (4.78 CN increase). The actual ET decreases by 3.37% from 1990 to 2011 and by 8.40% in 2050. Simulation with the SWAT using landuse change showed reduction in ET and increased runoff in different sub-watersheds, which needs to be considered in terms of management.

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1. Introduction

Water is an extremely essential element to sustain life and increasing population is raising the demand of water. The long dry season may also affect the water resource of a region. Availability of water is largely dependent on the rainfall distribution over an area, which again get distributed into various components of interflow, surface runoff, evapotranspiration etc. Landuse and land cover changes considerably affect and modify the proportion of these components, which again causes significant changes in the ecological systems (Sajikumar and Remya, 2015). According to Memarian et al. (2014), implications of the landuse change form a base for the sustainable planning and development. The land cover indicates the physical type of land, such as the water or forest areas, while landuse refers to the way of use of land by humans. The transformation of the landuse and land cover due to human interference or action, influencing the integrity of the natural resource and also the goods and services of the ecosystem. Cautious planning and development, however, can result in new landuse and land cover pattern that may improve the well being of human beings (Millennium Ecosystem Assessment, 2005). Future landuse change and its effect on the hydrology of the Hulu Langat basin of Malaysia showed increased runoff, groundwater recharge and monthly sediment load (Memarian et al., 2014). Landuse and land cover changes are considered as the main focus of the research in this century since they modify the hydrological processes such as runoff, evapotranspiration, groundwater recharge, infiltration and the quality of water (DeFries and Eshleman, 2004). Therefore, the effects of landuse changes are considered as notable for many ecosystems (Bateman et al., 2013). Landuse change or evaluation of pavement effects on runoff of urban area has been studied by many researchers (Kamali et al., 2017; Chen et al., 2017). Long term change analysis of landuse and hydro-climatology is observed in the work of Souza-Filho et al. (2016). It

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also affects the global climate (Hartmann et al., 2013), but, the influence of the human induced landuse changes prevails over the climate change in response to human habitation for the next decades (Skole et al., 1997). The importance of landuse change effects on hydrology is immense, but despite of that it is related to uncertainties (Stonestrom et al., 2009). Wagner et al. (2016) has worked on the rapid landuse change and its effect on water resources in India showing its effect in near future (2009–2028). In countries with limited water resources and rapid landuse changes have the problems of aggravated water scarcity as in India. In different parts of India, rapid urbanization and development in socioeconomic aspects have resulted in the landuse changes to a large degree and in the future also further impacts are anticipated (DeFries and Pandey, 2010; Lambin et al., 2003). In India, depleting water resources are observed in different parts by various researchers (Garg et al., 2012, 2013; Wagner et al., 2013; Mishra et al., 2007).

Diverse modelling tools have resulted in a new scientific framework for landuse analysis from the descriptive to the more quantitative in addressing the spatial and temporal variations. The most common aim of most of the landuse models is a simulation of the future dynamics of landscape in various coherent scenarios at multiple scales (Kok and Verburg, 2007) and also enhanced understanding of the sensitivity of the main processes within the landuse (Lambin et al., 2000). It is also necessary to understand the historical changes of landuse on runoff for the proper assessment of future landuse change effects (Crooks et al., 2000). Various watershed models are important and necessary for this purpose. Different hydrological models are applied for estimating runoff ranging from physical to empirical in the past few decades. Urban runoff model for stormwater management has been studied by Beck et al. (2017). The Soil Water Assessment Tool (SWAT) has been very famous and is used widely in many countries. The SWAT is used for simulating quality and quantity of water and to analyze the effect of landuse change for water resource management (Shi et al., 2011). The SWAT is considered as a comprehensive conceptual model that uses many parameters while calculating. Because of difficulties faced in measuring and access of various parameters, these inputs sometimes lead to bad outputs (Lenhart et al., 2002). Therefore, sensitivity analysis is very important to reduce the uncertainties within the model (Kushwaha and Jain, 2013). Sensitivity analysis also manages the over-parameterization (Van Griensven et al., 2006) that usually occurs in the hydrological modelling (Box and Jenkins, 1976). The SWAT is considered as a physical and continuous time based model of watershed that operates on the basis of daily time steps and also gives a prediction of the impact of water and sediment management, chemical yields of agriculture in an ungauged watershed (Arnold et al., 1993, 2000). Streamflow simulation has been done by Yu et al. (2011), who reported satisfactory results of SWAT in the areas with scarce data. The SWAT model has also been used in India for runoff simulation and sediment yield in a watershed of the Sutlej river in the Himalaya that gives an agreeable result with the scarce dataset (Jain et al., 2010), which shows the suitability of the SWAT model. However, it has been observed from all these studies that analysis of landuse change impacts of the past, present and future in water balance is lacking, particularly change in surface runoff and evapotranspiration in different sub-watersheds of an agricultural based economy. This type of studies are essential for the future allocation of available water resource and management. Therefore, the main objectives of the paper are (i) sub-watershed wise landsue change analysis and future prediction (ii) assessment of sub-watershed wise water balance condition and critical analysis of landuse change impacts on water balance of the past, present and future.

2. Study area

The study area is a part of the Narmada river basin situated in the Madhya Pradesh (MP), India, which extends from 21°47′24″ to 23°26′06N latitude and 77°34′44″ to 78°42′21″E longitude. The total study area is 12,290 km^2 constituting major districts of Betul, Hoshangabad and Raisen and some parts of Chhindwara in the southeast and Sehore in the northwest. The region experiences similar climate features of sub-tropical climate of MP with hot and dry summer from April to June, and cool, dry winter from December to February. The average rainfall varies from 900 to 1150 mm annually as observed in the last 41 years of rainfall data. Highest rainfall (more than 80%) is experienced during the monsoon season (April to September). Annual minimum and maximum temperature ranges from 19.5 to 32.5 °C (last 41 years temperature data). The basin study area is subdivided into 12 watersheds, outlet and reach. The study area is illustrated in Fig. 1.

3. Data used for the study

Landsat images of 1990 (Landsat Thematic Mapper 5 or TM5), 2000 (Enhanced Thematic Mapper Plus or ETM+) from USGS [http://glovis.usgs.gov] and LISS-III (Linear Imaging Self Scanning Sensor) image of 2011 from IRS (Indian Remote Sensing Satellite) are used for the assessment of landuse change and future prediction by Markov model. For the SWAT model, the climate data of rainfall, temperature, humidity, sunshine hour and solar radiation, daily discharge data have been used (Table 1).

4. Methodology

Landsat and LISS-III data sets have been used to classify the landuse. Three images of 1990, 2000 and 2011 are projected in the Universal Transverse Mercator (UTM) projection zone 44 and WGS 84 (World Geodetic System 84) datum. Geometric and radiometric corrections of the images are carried out, where the first order polynomial model is used with the Root Mean Square Error (RMSE) of 0.5 pixels in geometric correction. Images are classified with the Maximum Likelihood Classification (MLC) and images have been checked for accuracy assessment. This method has been recently used in many studies (Verma et al., 2017; Karan and Samadder, 2016; Zheng et al., 2016; Wingate et al., 2016). Ground truth points are collected from the field for the accuracy assessment. To predict future landuse change, the Markov Chain model is used on the classified outputs of 1990, 2000 and 2011. Calibration and validation of Markov model is carried out by comparing the 2011 classified image with the 2011 model generated image. Then future decadal predicted maps are generated by the Markov model for 2020, 2030, 2040 and 2050. The area and probability statistics of different years are used to analyze the change in the future. The ArcSWAT interface has been used for watershed delineation by using Digital Elevation Model (DEM). Then, sub-watersheds are generated that develops the topographic report of the area. Two types of data are used in the process, spatial data (slope, landuse and soil) and non spatial data (weather data). The landuse maps generated by the Markov model have been used as inputs in the SWAT. The spatial data are used for generating Hydrological Response Unit (HRU) and the combination of both spatial data and weather data develops the model setup. The model is then ready to run and calibration of the model is performed. Validation is done with the observed data. If the results are not satisfying, then the model parameters are edited again with respect to the PET calculation, simulation period and the management. Finally, the water balance results or reports are generated (Fig. 2). The CN for AMC (Antecedent Moisture Condition) II condition are selected and the

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