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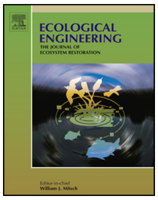

Individual and combined impacts of future climate and land use changes on the water balance

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ABSTRACT

Both the climate and land use changes have considerable impact on the water balance of a basin and sub-watersheds influencing various parameters such as water yield, surface runoff, evapotranspiration (ET), etc. Therefore, to predict the trend in the future water balance, individual and combined impact of both should be considered. The major objective of the study is to assess changes in the future water balance by investigating the independent and integrated impacts of climate and land use changes using SWAT (Soil and Water Assessment Tool) model in a part of the Narmada river basin in Madhya Pradesh, India. This includes the sub-objectives of future projection of rainfall and minimum and maximum temperatures by LS-SVM (Least Square Support Vector Machine) and SDSM (Statistical Downscaling Model) models to estimate climate change impact, and prediction of land use change of the basin area by the Markov Chain model. The present and future climate of the 2020s, 2050s and 2080s have been projected along with the past, present and future land use projection (1990, 2000, 2011, 2020 and 2050). The individual and combined effects on water balance have been shown in 12 sub-watersheds (SW) of the basin projecting increased water yield and decreased ET in the future. Individual impact of climate change shows high water yield, surface runoff and ET, while the individual impact of land use change shows increased water yield and surface runoff but decreased ET in the future. The SW 1–7 indicate comparatively higher surface runoff and water yield due to the presence of bare lands, agricultural lands and settlements and lower ET, while southern SW of 8–12 show low water yield and surface runoff but higher ET due to the presence of more vegetation and forest areas. The impact of climate change is found to have a more prominent effect on the water yield while impact of land use change is more on ET.

1. Introduction

Water resources are controlled by different factors including weather, geology topography and environment. Several difficulties arise during the analyses and evaluation of water resources. This also occurs due to a deficiency in the proper scientific understanding and analysis of various atmospheric, land, and oceanic processes along with the impacts of increased growth of population pressure on the adequate water availability to be used to develop environment, health, and economic wellbeing (Sivakumar, 2011). Despite the fact that evaluation and prediction of future water resources are essential for the planning of water resources, there is a limitation in the accuracy of the outputs because of the high uncertainty. The factor of climate change due to warming is considered as a critical factor in the prediction and evaluation of the future water resources (Kim et al., 2014). Continuous evaluation of the change in the climate and its effect on the water balance and runoff characteristics are observed (Cuo et al., 2011; Obeysekera et al., 2011). The impact of both the climate and land cover change on the river hydrology has been assessed by Cuo et al. (2011) for the mid-twenty first century. Availability of water in an area is largely dependent on the distribution pattern of rainfall and its division into various components such as groundwater recharge, surface runoff, evapotranspiration, etc. A major proportion of these components are affected by the land use and land cover of an area, which can further cause unprecedented changes in the ecology of the area. Such changes affect the availability of water, thus influencing the runoff change which in turn affects the land cover (Sajikumar and Remya, 2015).

The climate and land use are both considered as the drivers of various hydrological processes in a river basin (Oki and Kanae,

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2006; Li et al., 2009; Wada et al., 2011). The effects of these processes are reflected in the changes of the catchment (Ceola et al., 2014). This has been agreed widely that variability of climate and land use are the two essential factors affecting water resources (Li et al., 2009). Change in climate can influence precipitation, frequency of floods and runoff (Zhang et al., 2012; Ye and Grimm, 2013). Demand for water has increased to meet the human needs, associated with the socioeconomic development resulting in an imbalance of demand and supply of water (Zhao et al., 2016). Many studies have indicated that the human activities can change the land use, soil water, evapotranspiration or ET and flood (Hosseini et al., 2012; Wu et al., 2013; Zhou et al., 2013). Climate trend of rainfall, temperature and evapotranspiration of central India has been assessed by Kundu et al. (2016a). Higher rate of deforestations and alterations in the agricultural landscape have been found to have occurred in Brazil in the Upper Xingu River Basin, where much of the original forest area has been converted to the croplands (Leite et al., 2011; Macedo et al., 2012; Dias et al., 2015). It has been observed that the decrease in the vegetations resulted in an increased annual mean discharge (Bosch and Hewlett, 1982), and is also confirmed by many studies (Andréassian, 2004; Brown et al., 2005). Integrated study of climate and land use change has been carried out by El-Khoury et al. (2015), to analyze the effect on water quality using SWAT (Soil and Water Assessment Tool) model in a Canadian river basin. There are several studies analyzing the individual or the combined impacts of climate or land use alterations on the hydrology of the catchment (Li et al., 2009; Setegn et al., 2011; Santos et al., 2014; Guse et al., 2015). Chawla and Mujumdar (2015) applied the isolated and combined impact of climate and land use changes on streamflow in the upper Ganga basin of India. However, future land use change has not been applied and 2011 was taken as constant. Hence, it is important to analyze and evaluate the variability of climate and land use independently and combinedly on the water resources for improving the management processes.

All the existing studies discussed above involve combined or individual impacts of climate and land use changes on different factors. However, studies of independent and combined effects of both future climate and land use changes on water yield are lacking, particularly in the central India, with critical analyses according to different sub-watersheds. The study area is a part of the Narmada river basin which is considered as the lifeline of this region and agriculture is the major economic base. Future change in both climate and land use might affect the water balance as well as the agricultural production of the area. Therefore, the main objective of the present study is the estimation of future water balance by SWAT in different sub-watersheds considering climate and land use changes. The sub-objectives are (i) investigating future climate change by downscaling methods (by Least Square Support Vector Machine or LS-SVM and Statistical Downscaling Model or SDSM); (ii) analysis of land use change pattern of the past, present and future by the Markov Chain Model; and (iii) water balance estimation in view of (a) only climate change impact on water balance, (b) only land use change impact on water balance, (c) combined impact of both on water balance.

2. Study area

The study area is a basin in the Madhya Pradesh, which is a part of the Narmada river basin, India. The area extends from 21°47′ to 23°26′ N latitude and 77°34′ to 78°42′ E longitude occupying about 12,290 km^2. It constitutes major districts of Betul, Hoshangabad and Raisen and also includes parts of Chhindwara in the southeast and Sehore in the northwest. The region experiences sub-tropical climatic characteristics of Madhya Pradesh with dry and hot summer and cool and dry winter. Highest rainfall of more than 80% is observed during the monsoon season (April to September) and the average annual rainfall ranges from 900 to 1150 mm as observed in the rainfall data of last 41 years. Annual minimum and maximum temperature vary from 19.5 to 32.5 °C, which is also obtained for the last 41 years observed temperature data. The study area is subdivided into 12 watersheds, outlet and reach in between gauge stations of Hoshangabad and Sandia (Fig. 1).

3. Data

Climate data of 3 stations (Betul, Hoshangabad and Raisen) are taken from 1961 to 2001 to downscale. GCM (HADCM3) and NCEP (National Center for Environmental Prediction) data of the A2 scenario has been used obtained from the given link (http://www.cccsn.ec.gc.ca/?page=pred-hadcm3). The climate data of rainfall, temperature, humidity, sunshine hour and solar radiation are obtained from the Indian Meteorological Department (IMD) to be used in the SWAT. Daily discharge data are obtained from the Central Water Commission of Bhopal, Madhya Pradesh. The satellite data of Landsat (1990, 2000) and ASTER Global Digital Elevation Model (GDEM) are obtained from the United States Geological Survey (USGS) and LISS-III (Linear Imaging Self Scanning Sensor) of 2011 is obtained from the Indian Remote Sensing Satellite (Table 1).

4. Methodology

The complete methodology used for this study is given in Fig. 2. The climatic GCM data along with the NCEP data has been used to downscale rainfall and temperature variables with the LS-SVM and SDSM methods. Calibration and validation are carried out and future downscaled scenario has been projected for the 2020s, 2050s and 2080s. To assess the land use change and prediction, satellite images of 1990, 2000 and 2011 have been classified with the supervised classification technique and Markov Chain model is used to predict future land use changes of 2020 and 2050 and all 1990, 2000, 2011, 2020 and 2050 are compared and analyzed. The ArcSWAT has been used to study the water balance of the area. Spatial data (DEM, land use and soil) and weather data have been used for the model setup and to run, which is then calibrated and validated for the estimation of water balance. Then, the outputs of future climate and land use have been applied to estimate the impact of climate and land use change on future water balance (Fig. 2). Details of the processes have been discussed below.

4.1. Future climate change with LS-SVM and SDSM

The predictor data obtained from the NCEP is for 41 years from 1961 to 2001 (Kalnay et al., 1996) of scale 2.5° (latitude) × 2.5° (longitude). Projection of future climate is carried out with the monthly variables of rainfall, minimum and maximum temperature with the downscaling methods of LS-SVM and SDSM. The HADCM3 (Hadley GCM 3) or GCM data has been used under the A2 scenario with the model output from 1961 to 2099. HADCM3 has a grid dimension of 2.5° latitude × 3.75° longitude (417 km × 278 km area). The grid point location of the NCEP and HADCM3 do not match, hence inverse distance weighted method (IDW) of interpolation has been used prior using the GCM outputs. Observed data of stations (Betul, Hoshangabad, Raisen) have been taken as the predictands with the NCEP data from 1961 to 2001. Selected predictors are standardized and model calibration and validation have been carried out. Calibration is performed with 70% of data (1961–1989) and validation with 30% of data (1990–2001). Trained LS-SVM and SDSM models have been assessed to obtain downscaled future rainfall and temperature. Bias correction is applied to the predicted data. Projection of rainfall and temperature at 30 years' interval is presented in the