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IMPACT ANALYSIS OF LANDUSE/LANDCOVER CHANGE ON HYDROLOGIC REGIME OF UPPER CAUVERY BASIN

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Abstract

The developmental activities of any region are governed by the availability of the water resources. Alteration in the land use and landcover (LULC) could be due to both natural and anthropogenic activities, which considerably effects both soil and water resource. Understanding the effects of change in land use on hydrology of a watershed is vital for its conservation and development planning. This study intends to simulate the impacts of land use change on hydrological components of different systems of the watershed using Soil and Water assessment tool (SWAT) model. For different land use layers, streamflow was calibrated and validated from 2002 to 2014. Significant changes were noted with respect to decreased forest area and increased agricultural and urban areas increasing the surface runoff and water yield while diminishing the evapotranspiration and ground water recharge rate. Modification in land use and hydrological variation due to it was more prominent at sub watershed scale compared to watershed scale. In the study area, western part of it exhibited much change in LULC which showed significant impact on the regional hydrological components. This study could help to provide quantitative information on change in hydrological components in response to land use change in watersheds especially enduring the rapid loss of forest and undergoing cultivation and urbanization. This shall guide the watershed managers and decision makers to develop required strategies for water resource management.

Index Terms: Hydrologic components, Impact, Land use/landcover, Simulation, Sub watershed, SWAT, Watershed.

1. INTRODUCTION

The change in global environment is of utmost concern due to its disparate environmental impacts impelled by the change in land use. Land use change may occur due to human induced activities or natural, influencing either positively or negatively on the watershed hydrology [1]. Development of urban areas, change in cultivation practices and conversion of forest land to agricultural, residential or industrial area can impact the hydrological cycle of a basin [2], [3]. It significantly changes the hydrological components like rainfall and temperature, water yield, surface runoff, sediment yield, total aquifer storage, evapo-transpiration, etc. [3], [4], [5], [6], [7], [8], [9], [10]. Therefore, it is indispensable to identify the consequence of LULC change on hydrology to conserve and manage the watershed effectively. From the past 2 to 3 decades, hydrologists are committed to quantify the impacts of landuse change on streamflow dynamics associated mainly with deforestation and socio-economic development [11], [12]. The trend of increased streamflow is observed with decline in forest, shrub, grass and water areas and substantial growth of agriculture and settlement areas [13], [14],[15]. Zhu and Li (2014) [16], in their study on Little River Watershed of Tennessee found that urban development was the reason for increased streamflow in lower watershed. Mawasha and Britz (2020) [10], observed increased surface runoff from 70.5mm to199.3mm during the period from 1987 to 2015 due to significant expansion in the built-up area over Jukskei River Catchment, South Africa. Alteration in the land use not only impacts the river flow, but also drastically shrinks the volume of infiltration affecting soil moisture content and ground water storage [17], [14]. Urbanization increases the imperviousness leading to reduced rate of infiltration of water into the soil. On Gilgel watershed of Ethiopia, Andualem and Gebremariam (2015) [18], noted that reduction of forest, grass and shrub land and expansion of agricultural land led to the increased streamflow and sediment yield while there was a dip in lateral and ground water flow. Decline in forest and spike up of farmland reduces the ET due to the fact that forest has more potential compared to farmland [19], [7]. The changeover of forest area to urban and cropland led to the increased runoff and baseflow and conversely decreased ET due to decreased canopy cover for interception and transpiration [20], [21]. Saddique et al. (2020) [3], found increase in forest area and water area with change in LULC on the Jhelum River Basin of Pakistan, which gave rise to increased ET, decreased water yield and surface runoff. Increased runoff in a basin contributes to increased sediment yield [22], [14]. Sediment yield increased by 17.39% within a span of 22 years in Tekeze Dam Watershed, Ethiopia [23]. Setyorini et al. (2017) [24], through their study on Upper Brantas River Basin, Indonesia revealed that both LULC change and climate variability affects the hydrological regime of the watershed. Periodic variation in streamflow was largely observed in Poyan Lake basin, China due to change in LULC and climate [25]. The associations between different land use and runoff generation dynamics are still clearly unidentified [26] and therefore, researchers across the globe are still thriving to understand the complexity involved within it. It is vital to comprehend the hydrological processes inter-connected with the potential impact of LULC change for the future land use planning and development of sustainable watershed management strategies. Several methods have been used to identify the effect of LULC on hydrologic components viz., paired catchment method - used only for a watershed with smaller area of about 100km^2 flow regime of catchments having similar topographical (physical) characteristics are compared to analyze the cause of change in flow regime; Statistical analysis method – where variation in the hydro-climatic trends is analyzed at the observation stations in the study area; Hydrological modelling method- considers inter-relationship between both spatial and temporal aspects [27]. Hydrological models are most widely used to confront water resource management issues. Furthermore, hydrologic models are extensively used to measure the influence of LULC on hydrologic processes [28], [3]. Hydrological models require spatial, temporal and meteorological data input to model and simulate the hydrologic components [28], [29]. Many hydrological models are being used to examine the effects of change in land use but SWAT hydrological model is the most used one. From Table 1, it is evident that SWAT can efficiently simulate streamflow, effects of changes in land use and can predict future land use scenarios and its impact on hydrologic regime and water availability. The aim of the current study was to investigate the pattern of change in LULC and derived effects of it on hydrologic components at watershed and sub-watershed scale using SWAT hydrologic model.

TABLE 1: APPLICATIONS OF SWAT IN DIFFERENT REGIONS TO STUDY IMPACTS OF LULC CHANGE

Key Reference	Study area	SWAT application
Mekuriaw 2019 [30]	Sore and Geba Waterhsed, Ethiopia	Quantified surface runoff
Schilling et al. 2008 [31]	Raccoon River watershed, United States	Quantified annual water balance
Saini et al. 2018 [32]	Kanva watershed, India	Predicted water balance components
Kumar et al. 2017 [28]	Tons River Basin, India	Quantified and predicted the historical and future impacts of LULC on hydrologic processes
Baker and Miller 2013 [33]	Njoro watershed, Kenya	Land use change foot print on Water resources
Palamuleni et al. 2011 [34]	Shire River, Africa	Evaluated the influence of LULC change on Hydrological processes regime
Santos et al. 2018 [35]	Iriri River basin, Brazil	Predicted the impact of future conversion of forest to pasture and its result on flow and water balance regime
Machado et al. 2018 [36]	Pinhal watershed, Brazil	Predicted the effect of converting agricultural land by forest on hydrological processes
Ahsan et al. 2015 [37]	Upper Betwa Basin, India	Analyzed the impacts of LULC within the basin
Qihui et al. 2020 [38]	Jinsha River basin, china	Quantified the consequence of climate and LULC change on runoff

2. MATERIALS AND METHODOLOGY

2.1 Study Area

The Upper Cauvery, upstream of KRS reservoir, rises at Bramhagiri range of Western Ghats, Kodagu District, and Karnataka, India. River Harangi and River Hemavathi are the tributaries in this stretch. The basin lies between 75°27' to 79°54' east longitudes and 10°9' to 13°30' north latitude with a total area of 10709.78 sq km (Fig. 1). Harangi River rises at Pushpagiri hill of Madikeri district, Karnataka located between 75°55'E longitude and 12°49'N latitude, at an elevation range of 818 to 1635m above mean sea level (MSL). It covers a stretch of 50km and ultimately joins Cauvery River at Kudige near Somawarpet. The area of the watershed is about 409.84 sq km. Hemavathi River rises at Ballarayana Durga hill range, Chikkamagaluru district of Karnataka located between and 76°03'E longitude and 12°45'N latitude at an elevation range of 843 to 1795m above MSL. It travels 245km before joining Cauvery River. The area of Hemavathi watershed is around 2839.19 sq km. The study area is dominated by agricultural land and silt, silty clay loam and silty loam types of soil.

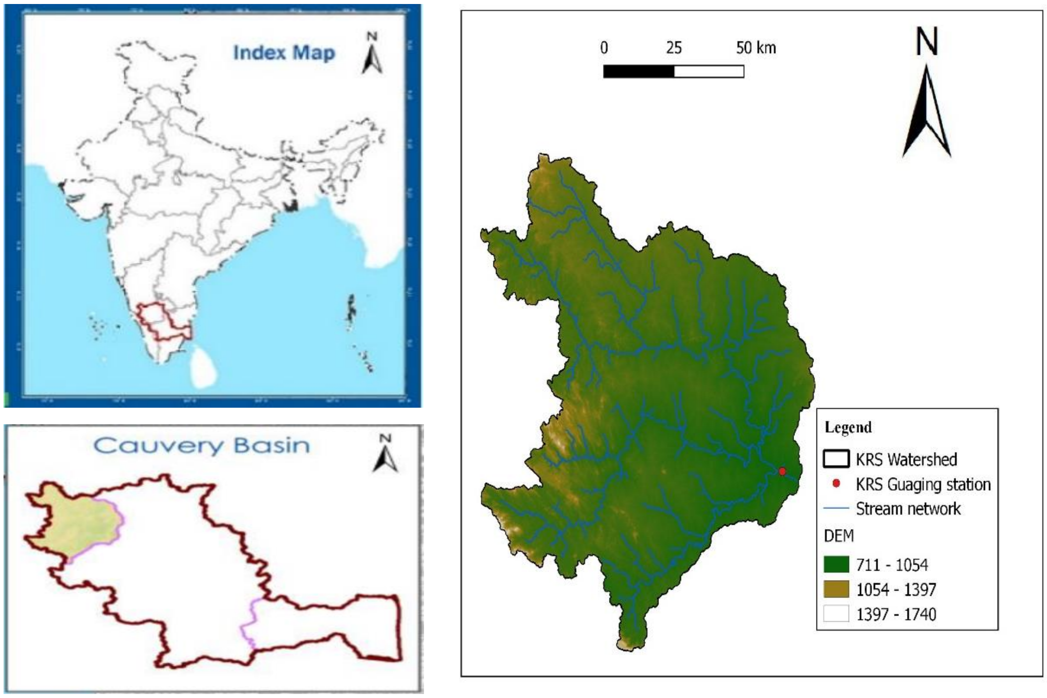

Fig. 1. Location of Upper Cauvery Basin, Upstream of KRS watershed

2.2 Model input data

Precipitation data from gauging stations and 0.25°X0.25° gridded data were also collected from IMD, Pune for the period 1982-2014. Observed daily streamflow data was sourced from Central Water Commission (CWC), India. Reservoir flow details were acquired from reservoir divisional office. It is required to input digital elevation model (DEM) and soil distribution map to simulate the hydrological processes in the study area (Table 2). Land use maps of the year 2005 and 2013 were used as the input for the SWAT model. In this study, a total of 11 LULC classes are considered: Agricultural Land-Generic, Barren or Sparsely Vegetated, Irrigated Cropland and Pasture, Forest Evergreen, Grassland, Shrubland, Industrial, Urban High Density, Urban Medium Density, Water Bodies and Herbaceous Wetland.

TABLE 2: INPUT DATA AND ITS SOURCES

Input data	Spatial resolution	Source
Digital Elevation Model (DEM)	90m X 90m	Shuttle Radar Topography Mission (SRTM)
Landuse and Soil	1:50,000	Karnataka State Remote Sensing Application Centre (KSRSAC), Mysuru

2.3 SWAT model description

SWAT is semi-distributed, physically based model developed by United States Department of Agriculture (USDA) to assess the impacts of climate and land management practices on hydrologic components. It also helps to evaluated the sediment yield and pollution transport in a watershed [39], [40]. Using SCS curve number or Green & Ampt infiltration equation, SWAT model simulates surface runoff occurring in a basin. Model provides user with an option to choose method for calculating ET, such as Pristley-Taylor, Hargreaves and Penman-Monteith method. The other hydrologic components such as ground water flow, lateral flow and infiltration are calculated based on the principle of water balance as shown in equation (1) [39].

$$SWt = SW0 + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right) \qquad (1)$$

Where SWt is final soil water contents (mm), SWo initial soil water content on day i (mm), Rday is amount of precipitation on day i (mm), Qsurf is amount of surface runoff on day I, Ea is amount of Evapotranspiration on day i (mm), Wseep is amount of water entering the vadose zone from soil profile on day i (mm), Qgw is amount of return flow on day i (mm).

2.4 Simulation Methodology, Model Calibration and Validation

All the necessary data like DEM, hydro-meteorological, land use maps were input to the SWAT model and executed the run for 33 years from 1982 to 2014 to simulate the streamflow, of which 1982-1987 was warmup period, 2002-2011 calibration period and 2012-2014 validation period. To analyze the change in hydrological components, delta approach method was adopted where two independent simulations were performed with land use layers of 2005 and 2013 while maintaining all other input data the same. The sequential steps adopted in the methodology is shown in Fig. 2.

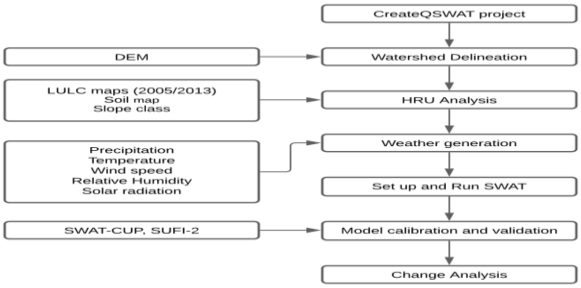

Fig. 2. Frame work of the LULC change analysis methodology

SWAT model simulation with default parameters was unable to estimate the streamflow at KRS station (Fig. 1) properly as some baseflows and peaks were either overestimated or underestimated. Therefore, the model needed to be calibrated in order to reproduce the simulate the streamflow as close as possible with the observed flow. SUFI 2 program of SWAT was used to conduct sensitivity and uncertainty analysis in two stages. Using Latin hypercube one-factor-at-time (LH-OAT) technique of SWAT- CUP, sensitive parameters and their range were found out manually in the first stage. Second stage was a semi-automatic process where identified sensitive parameters were input to the model manually and routine SUFI-2 program was performed for uncertainty analysis [41]. Table 3 lists the sensitive parameters identified for calibration. The SWAT model was run for baseline scenario from 1982-2014 including warm up period of 5 years using 2005 land use layer. The model was used for calibration of flow on monthly time scale at KRS gauging point from 2002-2011. Calibrated model was validated for 2012-2014 using SUFI-2 algorithm of SWAT-CUP [42].

TABLE 3: PARAMETERS USED FOR CALIBRATION

Parameter Name	**Definition**	**Process**
Sol_AWC	Available water capacity (mm/mm)	Soil
CN2	SCS runoff curve number for moisture condition II	Runoff
ESCO	Soil evaporation compensation factor	Evaporation
EPCO	Plant evaporation compensation factor	Evaporation
GW_delay	Groundwater delay (days)	Ground water
RCHRG_DP	Deep aquifer percolation factor	Ground water
Sol_K	Soil conductivity (mm/h)	Soil
Shallst	Initial depth of water in shallow aquifer (mm)	Ground water
Alpha_BF	Base flow alpha factor (day)	Ground water
CH_K2	Effective hydraulic conductivity in main channel alluvium (mm/h)	Channel

3. RESULTS AND DISCUSSIONS

3.1 LULC change analysis

To investigate the impacts of LULC change on hydrological components both at watershed and sub-watershed systems, changes in each land use class in the study area were analyzed using calibrated and validated model. The performance of observed and simulated streamflow both during calibration and validation period indicated good performance of the model [43]. Calibration and validation results of the model are presented in Table 4. The spatial and area distribution of land use classes of the Upper Cauvery basin for the year 2005 and 2013 are presented in Fig. 3. By comparing the land-use classes of both the LULC maps, percentage change in land use was found out (Fig. 4). It was found that the Upper Cauvery basin is greatly influenced by human activities in the form of development of agriculture, settlements, urbanization and industrialization with significant decline in forest area. During the period of 2005-2013 forest was converted to agricultural land mainly at the upstream of Harangi and downstream of Hemavathi while, rapid urbanization and industrialization is observed throughout the watershed transforming huge forest area and small area of irrigated cropland into impervious area. During the study period, forest area declined significantly by 8.53%, irrigated cropland decreased by 1.64% where agricultural land augmented by 7.18%. There was also transformation of grassland and barren land to agricultural and shrub land especially in the downstream areas of the sub-watersheds. Expansion in the urban and industrial area are 3.61 and 1.37% respectively in the watershed, though these changes are not significant in comparison to the total geographical area of the watershed. Along with these changes, decrease in waterbodies by 2.27% was also found during the investigation period. In general, at some regions of the watershed, agricultural land was increased by reducing the forest area; at the same time, decline in cropland was also noticed due to increase in the urban areas in the other regions of the watershed.

TABLE 4: STATISTICAL PERFORMANCE OF SWAT MODEL AT KRS WATERSHED

Year	Calibration			Validation		
	NSE	R2	Pbias	NSE	R2	Pbias
2005	0.62	0.67	-15.0	0.60	0.60	3.5
2013	0.63	0.63	-5.2	0.59	0.61	-6.3

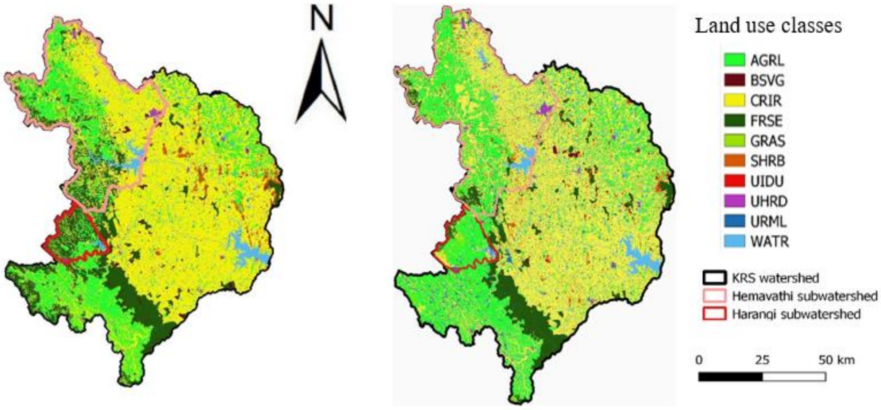

Fig. 3. LULC maps for 2005 and 2013 (Sq km)

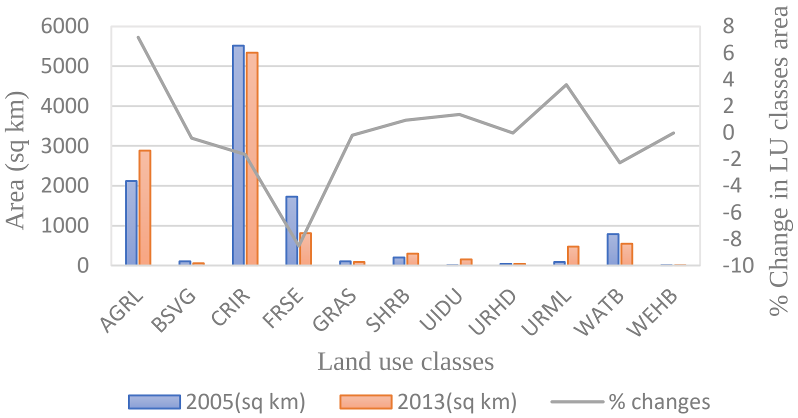

Fig. 4. Comparison of land use maps for the year 2005 and 2013

3.2 Impact of LULC on hydrological components

Impact of land use change over KRS watershed on various hydrological components were analyzed on an annual time scale particularly for ET and WYLD. Incessant model simulation for 33 years (1982-2014) was performed to estimate the changes in annual average of hydrological components. The simulated results indicated the changes in hydrological balance in the upper Cauvery basin over the period of 8 years both at watershed and sub-watershed level. The average annual evapo-transpiration (ET), Surface runoff (SURQ), ground waterflow (GW_Q) and total water yield (WYLD) for different LULCs are shown in Fig 5. From the simulation result, it was found that evapotranspiration and ground water recharge has dropped at both watershed and sub watershed system while the reverse impact was observed with water yield and surface runoff. ET decreased by 11.45%, 9.24%, 13.47%; GW storage decreased by 9.48%, 6.62%, 2.88% whereas WYLD increased by 15.94%, 16.68%, 12.98%; and SURQ increased by 12.11%, 16.80% and 12.11% at Harangi, Hemavathi and KRS watershed respectively. This is due to the fact that decline in forest areas and expansion of cultivation and urban areas leads to increased surface runoff and water yield [44],[45]. The transformation of forest land to other uses leads to considerable reduction in trees, ground vegetation and leaf litter resulting in declined ET through canopy interception and plant transpiration. The water permeability and storage capacity of soil is greatly affected by the loss of vegetation [11] and reduces the organic matter contents due to loss of top soil resulting in the reduced infiltration capacity. The reduction in soil infiltration capacity results in the accumulation of surface runoff as greater proportion of rainfall is converted to surface runoff [46], [6]. Results indicated that modified land use have considerable impact on hydrological components and streamflow of the study area. The analysis of annual average streamflow shows that the annual surface runoff has amplified by 18.7% between 2005 (1843.55 m3/s) and 2013 (2266.02 m3/s) (Fig. 6). Spatial changes in ET (Fig. 7) and WYLD (Fig 8) were detected in many of the subbasins within the watershed in response to change in land use. However, hydrological components have changed significantly in the western part of the study area, where Western Ghats (evergreen forest) have undergone significant deforestation and transformation of forest land to agricultural land especially in the Harangi sub watershed. At the same time, a portion of land in few subbasins were transformed from shrub and barren land to forest area thereby increasing the ET and decreasing WYLD in that area. This might be due to increased leaf area index and transpiration from the vegetative surface [3]. The result of altered land use was much more distinct at sub-watershed scale rather than at watershed scale.

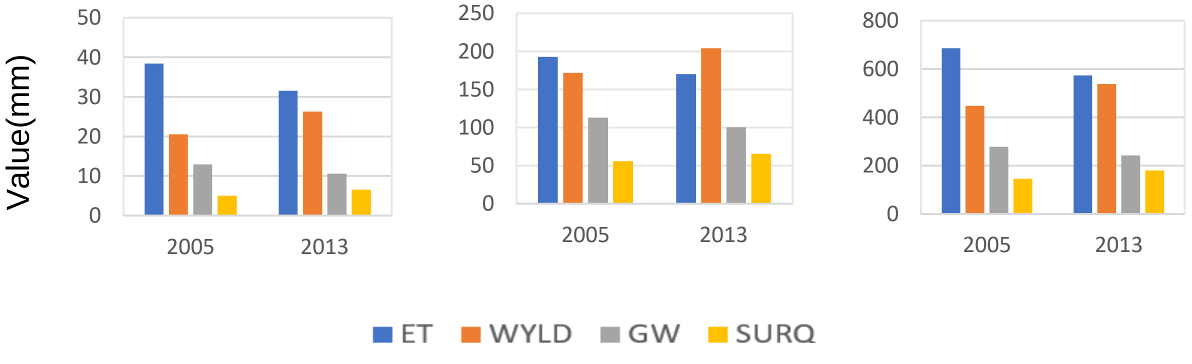

Fig. 5. Annual water balance components of Harangi and Hemavathi sub-watershed and KRS watershed system

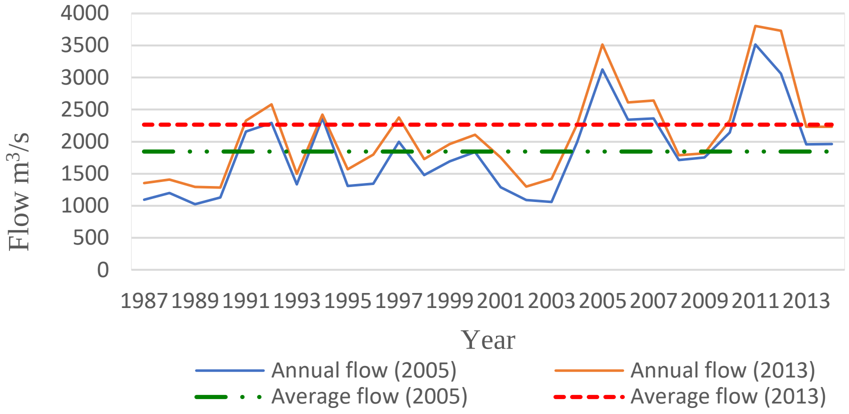

Fig. 6. Annual stream flow of Upper Cauvery Basin for 2005 and 2013 LULC maps at KRS gauge station

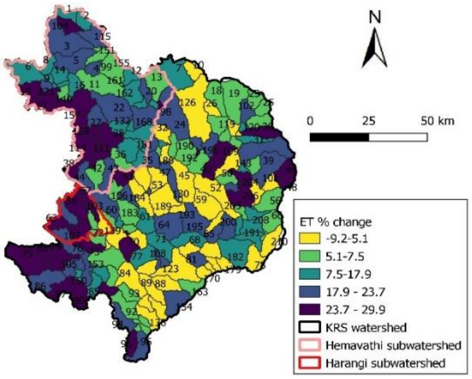

Fig. 7. Percentage changes in ET

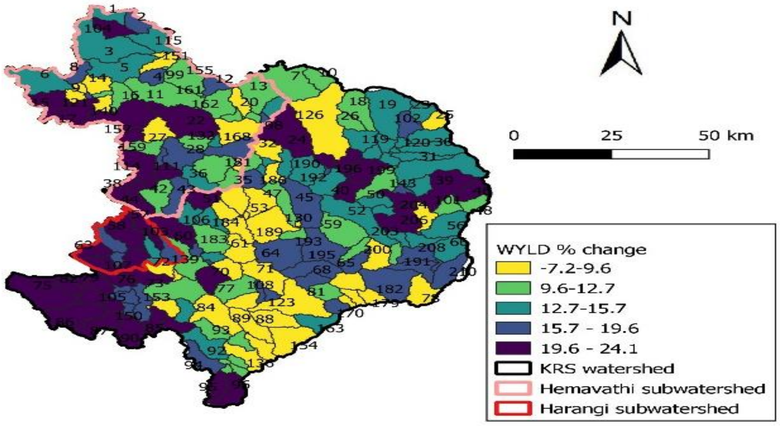

Fig. 8. Percentage changes in WYLD

4. CONCLUSIONS

It has been attempted in the present study to evaluate the hydrological impacts of transformed land use on the Upper Cauvery basin at watershed and sub watershed scale between 2005 and 2013. Upper Cauvery basin has greatly influenced by the transformation of forest area to agricultural and built-up area. From this study, it is evident that modifications in land use and vegetative distribution have profound effect on basin's hydrology and water balance components. Based on the study results, the effect of land use change has greater impact at sub watershed scale as compared to watershed scale (Fig 5). It was also found that the annual streamflow distribution in the watershed is significantly affected by the vegetation and soil which can modify the local hydrological cycle. Increased impermeable areas (urbanization) intensifies the surface runoff and stream flow (Fig 6). With the conversion of forest to agricultural and built-up, a trend of increased surface runoff and decreased evapotranspiration is observed. In the basin, urbanization has a profound impact on the hydrology controlling streamflow and water yield. It is indispensable to evaluate contributions of LULC change to ET and water yield as provides vital data to planners and decision makers for better resource conservation and management strategies. This study aids in understanding the potential influence of land use change on the watersheds by adopting hydrological modelling. Furthermore, in the process of resource conservation and management, decision makers and managers could consider the identified implications of LULC modification.

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