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EVALUATING THE HYDROLOGICAL RESPONSE TO LAND COVER CHANGE - DASANAKATTE CATCHMENT OF VARAHI RIVER, WESTERN GHATS, KARNATAKA

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Abstract: Both climate and vegetation are changing in most part of India and it is widely perceived that such changes will reduce the water resources available for human use. The knowledge on the interaction between climate and vegetation is essential for evaluating the future water availability of a region. In this regard, this paper attempts to determine the extent to which the climate and land use influences the river flow regime of a predominantly forested catchment namely Dasanakatte catchment of Varahi River located in Western Ghats of Karnataka. In order to verify these linkages, the daily rainfall and runoff data of 28 (1976-2004) years were analysed along with the land cover/land use data of 1973, 1983 and 2000.

The land use/land cover changes during 1973 and 2000 showed small changes in forest cover to agriculture and plantations especially after mid-90s. Similarly, results of rainfall trends does not show any significant changes in the rainfall pattern during the study period, whereas streamflow showed a decreasing trend after 1995 which coincide with the observed changes in land cover/land use changes in the catchment. Streamflow analyses indicate a change in seasonal flow pattern induced by water abstraction from river to supplement the irrigation for increased area under agriculture. Further it is noticed that, there is a sharp incline in the number of dry stream days and decline in the numbers of days of flow after cessation of rain. The observed changes in streamflow have partly resulted from changes in land cover degradation in watershed that involved destruction of native vegetal cover, expansion of agriculture and forest plantations in addition to population increase

Finally, all these analyses lead to an understanding that the impact of climate change and land cover changes are responsible for influencing the hydrological regime of the Dasanakatte catchment.

***Keywords**: Land use/cover change, hydrology, Varahi River, Base flow, Streamflow*

1. INTRODUCTION

Land cover and climate change and their impact on hydrological processes are a widespread concern and great challenge to researchers and policy makers. The current understanding of the link between land cover change and watershed functions at larger scales and their possible variations with vegetation, geology and rainfall pattern are limited. To address this concern and related issues, it is important to know how the climate, land use and land cover changes affect the annual and seasonal variations in basin hydrology especially the streamflow. This understanding is very essential for optimization of the available water resources and can enhance the ability of planners, practitioners, researchers and farmers to formulate and implement sound policies to minimize undesirable future impacts and devise management alternatives.

Hydrological response is an integrated indicator of watershed function, and significant changes in land cover may affect overall health and function of watershed (Hernandez et al, 2000). There is a significant

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change in climate and land cover during the last few decades causing a degradation of watershed functions which affect the hydrological conditions and greatly influence living conditions of local inhabitants.

This is very true in the context of India in general and Western ghats in Particular. The Western Ghats region is the origin and primary catchment of many west and east flowing rivers of peninsular India. The lives of the majority of the rural population in the four southern states (Kerala, Tamil Nadu, Andhra Pradesh and Karnataka) plus parts of Maharashtra are thus critically dependent upon the watershed services provided by the these forests. The portion of the Western Ghats that lies in Karnataka State contains the major portion of the forests. It is reported that, there has been increased anthropogenic activities in the Western Ghats region (Bhat, et al. 2001) and a rapid change in variety of land-use and land cover are taking place, which could have very significant impact on the water regime of the region including baseflow, groundwater recharge (Reddy, 2000, Biggs *et al* 2007).

A number of studies have been carried out to assess the deterioration of land cover and their change over a period of time in the Western Ghats region. Recently, Jha *et al* (2000) reported a massive changes in the nature and extent of forest cover with extensive development of monoculture plantations replacing natural grasslands, dense forests changing into open and degraded forests, forests getting converted to tea, coffee and as well as deteriorated due to the implementation of infrastructural projects (Priya *et al*., 2007). The likely effects of these changes on watershed services such as streamflow and sediment transport are complex but likely to be very significant.

Similarly, many studies have been carried out to understand hydrological impacts due to changes in land cover. Samraj et al. (1988), Sharada *et al*. (1998) and Sikka *et al*. (2003) looked at the change of natural grassland to bluegum on runoff from experimental catchments in Nilgiris. In an identical study, Pradeep and James (2004) looked at the impact of forest degradation on runoff in Kerala Western Ghats which showed prolonged lower runoff volume from catchments dominated by dense forest as compared to degraded catchments. Few other isolated studies (Unni *et al*. 2004, Sahoo *et al*. 2004) show a lesser runoff from forested catchment and more from other degraded/converted catchments which depended on level of degradation as well as on what the type of present land cover. All these studies have looked at short term response of runoff from different land use/land cover types.

Studies by Venkatesh *et al*. (2006) have analysed the long term rainfall and runoff of selected watersheds within the part of Western Ghats covering Kerala and Karnataka. These studies were aimed at assessing the impact of land use changes on hydrological responses across an array of climatic regime and ranging in catchment size of the selected basins in impact of land cover changes on watershed functions. These studies showed that few catchments have undergone drastic land cover changes during 1970's and 2000's which has affected the hydrological functions of these watersheds specially the stream flow.

The many of the empirical studies carried out in the Western Ghats prove limited ability to generalise the results. In order to extrapolate the results of other land use settings, process-based models provide a means in areas lacking sufficient field study. These observations have further enhanced the effective use of process based mathematical models in evaluating the land use changes on streamflow regime. The studies carried out elsewhere support the use of process based model for assessing the impact of land use changes on hydrological responses (Vanshaar, *et al*., 2002; Bowling *et al*., 2000). However, these models can also be used to asses the different scenarios of land use and their impact on hydrological responses in a catchment.

In view of the fact that many major rivers of peninsular India are originating from the Western Ghats and are vital for the sustenance of the region, it is pertinent to investigate any possible impact of climate change in conjunction with the land use changes on the water availability of the region. The response of hydrological systems in this region may get altered significantly due to any possible climate changes. Therefore it is proposed to take up a typical study in the Dasanakatte catchment of Varahi basin to investigate possible changes in the flow pattern due to variations in the climatic regime and due to the changes in land use over a period. Therefore, the objective of the present study is of two fold, firstly to investigate the trends in both rainfall and runoff in the catchment between two time periods; and secondly to assess the influence of changes in land use on hydrologic response of the catchment after controlling natural variability of rainfall. The results of this study would be useful in assessing the direction of land use changes and their impact on the water resources of the basin in particular and of the region in general. It is also expected to help to define and assess the risk of flooding and droughts, agricultural planning and other developments associating with the mitigation and adaptation strategies for climatic and land cover changes in the region.

2. STUDY AREA

The present study has been carried out in the Dasanakatte catchment of Varahi River in Shimoga District, Karnataka. The river originates from Hebbagilu in Shimoga district, and flows westward and finally joins Varahi River. The Dasanakattehole has a catchment area of 141km^2 & joins the main river Varahi at Haladi.

The catchment is located in the up-ghats region of the Western Ghats. The average annual rainfall for the catchment is about 5670mm and average annual streamflow is about 6559 cumecs. The main part of the basin experiences humid equatorial climate, dry season is mainly from December to May while heavy rains are common during SW monsoon and NE monsoon (October-November). Approximately 70% of the rainfall is getting converted to runoff in the catchment. Geologically, the catchment has pre-Cambrian formations and soils are mainly red-soils and black soils. The catchment is dominated with evergreen to semi-ever green forests in the upstream area.

3. DATA AND METHODOLOGY

Daily rainfall data available for eight stations in and around the catchment for the period 1970-2007 in conjunction with streamflow data for the same period has been made use of in the present study. Figure 1 shows the Dasanakatte Catchment with locations of rain gauges and streamflow gauge. List of stations together with data availability and average annual rainfall are presented in Table 1.

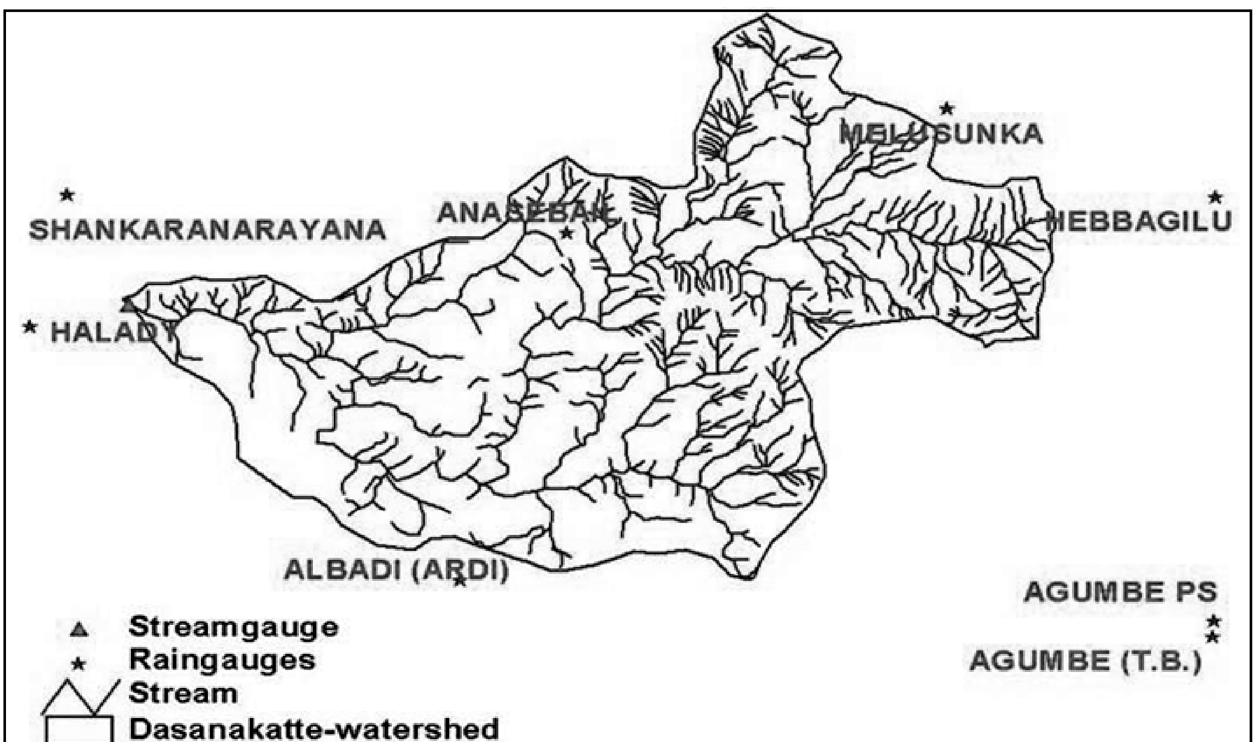

Figure 1: The Dasanakatte Catchment-Varahi River with Locations of Raingauges and Stream Gauge

Table 1
Raingauges in Dasanakatte Catchment with Data Availability and Mean Annual Rainfall

Sl.no	*Station name*	*District*	*Data period*	*Mean Annual RF (mm)*
1	Melusunka	Shimoga	1981-2004	6690
2	Hebbagilu	Shimoga	1976-2004	7482
3	Agumbe PS	Shimoga	1976-1999	7316
4	Agumbe TB	Shimoga	1976-2004	7412
5	Halady	Uduppi	1976-2004	4493
6	Sankaranarayana	Uduppi	1994-2004	4460
7	Albadi	Uduppi	1976-2004	4783
8	Anasebail	Uduppi	1976-2004	5601

Rain gauges falling in or near the catchment were identified and checked for consistency. Missing/ erroreneous values were interpolated using standard techniques. Point to areal rainfall generation has been carried out using Thiessen polygon method. The average annual and seasonal rainfall together with their standard deviation and variability were also computed.

Daily streamflow data collected from Water Resources Development Organization (WRDO) are checked for erroreneous values. As streamflow interpolation are not feasible they are processed as such because the data provided are without explanations on measuring techniques and individual responsible were often difficult to contact and therefore uncertainties in the data are difficult to resolve. Average annual as well as average seasonal streamflow were computed together with standard deviation and variability.

3.1 Baseflow Estimation

The baseflow, the most important part of streamflow comes from ground water and/ or shallow subsurface storages. There are various techniques to separate baseflow from streamflow of which we have used the continuous baseflow separation (HYDATA) procedure suggested by Institute of Hydrology, Wallingford in its report on low flow estimation (Report No: 108, 1992) to separate the baseflow from mean daily hydrograph of the catchments.

3.2 Rainfall-streamflow Relationship and Trend Analysis

The runoff coefficient, the ratio of runoff/rainfall both in same units gives a broader influence of climatic zone and also controls effect of rainfall variations on runoff pattern. In order to understand the trends in rainfall and runoff, we have used the Sen's slope and Kendall statistics which are computed for different time steps. The details of the methodology for trend analysis are described elsewhere (Venkatesh et al, 2006).

3.2.1 Estimation of Sen Slope

Sen's method for the estimation of slope requires a time series of equally spaced data. Sen's method proceeds by calculating the slope as a change in measurement per change in time, as shown here in Equation (1) for the simple case of one data measurement per time spacing.

$$Q = \frac{X_{i'} - X_i}{i' - i} \tag{1}$$

where: Q = slope between data points $x_{i'}$ and $x_i, x_{i'} =$ data measurement at time $i', x_i =$ data measurement at time I, and $i' =$ time after time I,

3.3 Land Cover Mapping

In this study, we have used the land cover maps of CISED, 2006 for comparing land cover of 1973 and 2000. Land cover maps were generated from satellite imageries LANDSAT-MSS for 1970's LANDSAT ETM of 2000 (public domain: Global Land Cover Facility of ESDI-Earth Science Data Interface was used. Unsupervised (ISODATA algorithm, supervised (maximum likelihood algorithm) classifications, visual interpretation and post-classification smoothening were carried out for land cover classification of the catchment. Detailed methodology has been described in the report (CISED, 2006).

3.4 Linking Climate/land Cover Changes on Runoff Processes

Various parameters of the times series data on rainfall and runoff were analysed to detect the effect of change in land cover after controlling the effect of variation of rainfall. Hydrologic response of the catchment was quantified and characterised using indices such as rainfall-streamflow trends, runoff coefficient, peak flow variations and base flow index (calculated using HYDATA algorithm) and flow coefficients.

4. RESULTS AND DISCUSSION

Rainfall-runoff relationship within a watershed is the result of interplay of many factors but is driven primarily by the interaction of climate, land cover and soils. In this study, long term land use and rainfall variations are considered to evaluate their influence on runoff generated in the catchment. Other determinants of streamflow are assumed constant as their influence on watershed functions are limited. To understand the watershed response, various approaches like trend analysis, variation in runoff coefficient and baseflow contribution are analysed. In addition an analysis was carried out to understand variation in observed peak flow; dry river period and extension of flow after cessation of rains were carried out. The runoff and peak discharges and the low flows are the main indicators of conditions and therefore are the predictors for ramifications associated with the land cover changes.

The Dasanakatte river catchment is originating in the upghat of Western Ghats from the Ballimane reserve forests and flows mainly through forested and agriculture lands before joining the main river Varahi at Haladi. Since the catchment is mainly dominated by forest area, particular attention was given to identify forest area losses whether they are indigenous or plantations through conversion. The study looks at the changes in forest degradation and/or conversion and evaluates the effect on streamflow characteristics of the Dasanakatte catchment.

The land cover changes during 1973 and 2000 show that the river catchment is dominated by forest area (Figure 2). From the map as well as in Table 2 we can see a decrease (9%) in forest area and increase in areas under agriculture (4%) and plantation (2%) forest. Though the changes seem minor, these shifts in the land cover can alter water use pattern in the catchment which is mainly a function of degree of change as well as on type of land conversions.

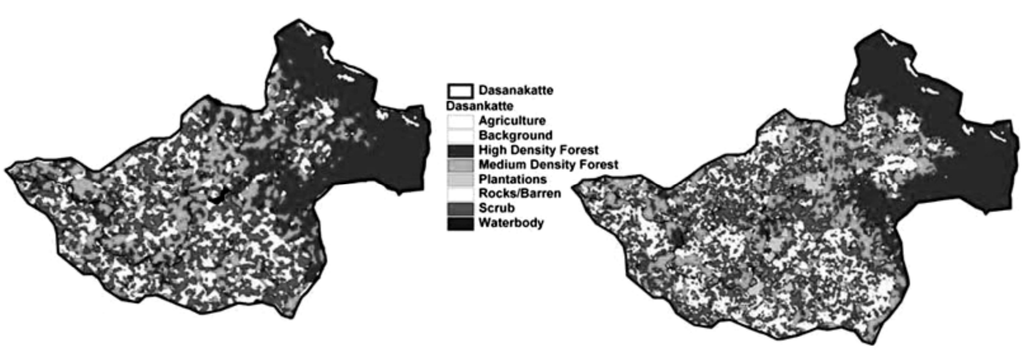

Figure 2: Land Cover Classification of 1973 and 2000 for Dasanakatte Catchment

Table 2
Percentage Change in Land Cover During 1973-2000

Land cover class	*1973*	*2000*	*% change*
Water body	1.10	0.70	–0.30
HD forest	52.6	39.7	–9.10
MD forest	32.1	34.2	1.60
LD forest	0.00	0.00	0.0
Agriculture	22.5	27.5	3.70
Dense scrub	31.7	36.00	3.0
Acacia/Teak	0.30	2.60	1.60
Barren Rock	0.90	0.50	–0.10

Results of the trend analysis of areal average precipitation are presented in Table 3 which shows that rainfall trend is more or less arbitrary. The trend in streamflow for monthly, seasonal and annual time steps show a decreasing trend (Table 4). Since we have considered only rainfall and land cover changes to flow responses and that rainfall has not changed significantly implies that land cover changes are affecting the flow regime in the catchment.

Table 3
Sen's Slope Estimate of Rainfall in Dasanakatte Catchment

Station name	*Annual*			*Monsoon*		
	Auto Corr	*M.K. Test*	*Sen's slope*	*Auto Corr*	*M.K. Test*	*Sen's slope*
Melsunka	S	1.24	**	S	12.4	**
Hebbagilu				S	0.63	42.98
Agumbe PS						
Agumbe TB	NS	0.35	22.67	NS	0.16	6.29
Halady	NS	0.29	5.7	NS	0.23	4.65
Sankaranarayana						
Albadi	NS	–0.59	–0.69	NS	–1.19	**
Anasebail	NS	1.66	40.01	NS	1.74	36.34

'S" Significant at 95% confidence level

Table 4
Sen's Estimates of Observed Runoff Dasanakatte Catchment

Month	*Sen's slope*
Jan	–2.79
Feb	–1.55
Mar	–1.62
Apr	0
May	0
Jun	–15.38
Jul	–39.83
Aug	–57.22
Sep	–4.97
Oct	–3.61
Nov	–2.01
Dec	–108.10
SW-monsoon	–4.62
NE-monsoon	–10.31
Annual	–127.10

Further, to identify the impact of rainfall variations on runoff regime, time series plot of rainfall and runoff were used. Figure 3, show that runoff follows the pattern of rainfall and inter-annual variability in the streamflow response exhibits substantial non-linearity in the partitioning of precipitation to runoff. These observations are evident during the wet years 1978-1979, 1994-1995 & 2000-2001, streamflow response to rainfall exhibits a proportionately greater change in comparison to the normal or dry years. A plot of runoff coefficient (Figure 4) show that runoff is declining especially after mid 90's which can be linked to forest conversion during this period confirming the influence of land cover on the flow regime.

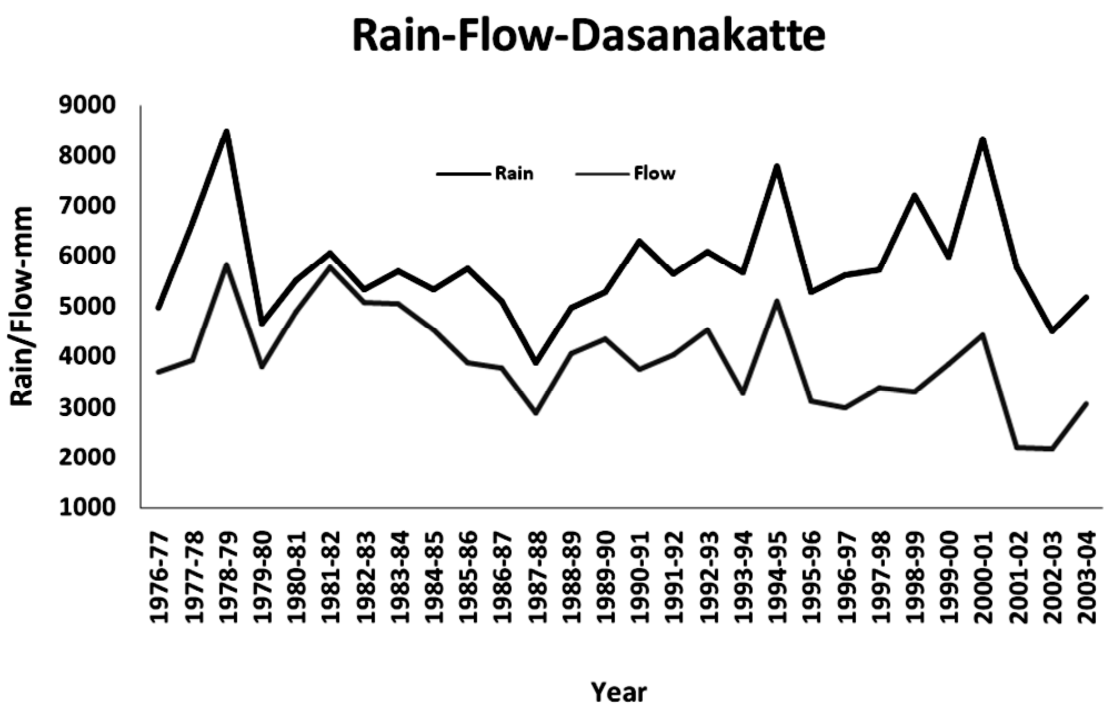

Figure 3: Yearly Variation of Rain and Flow-Dasanakatte

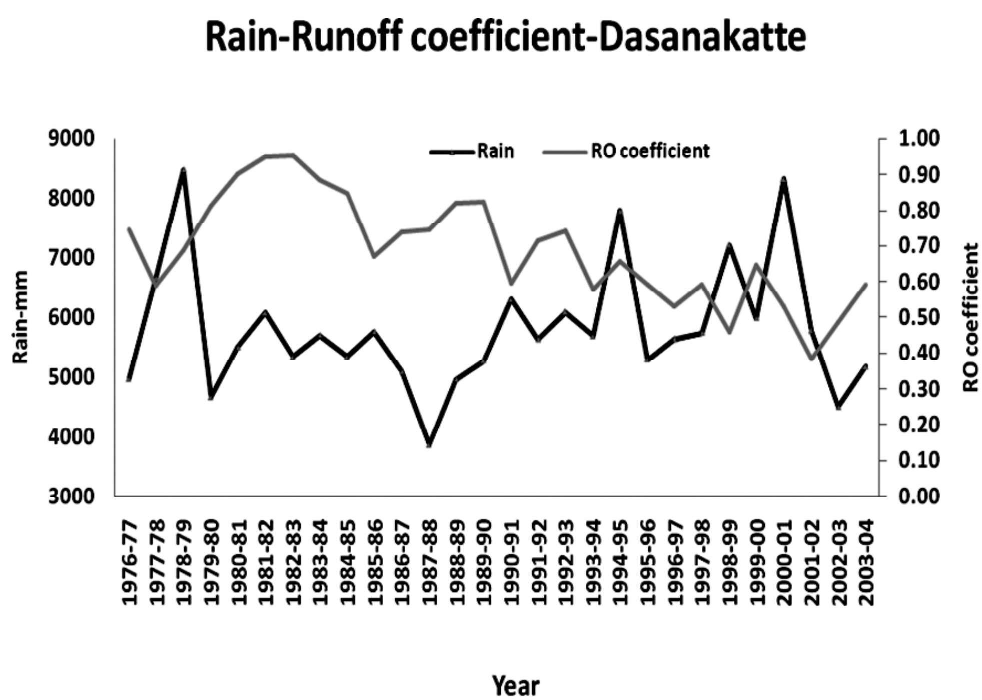

Figure 4: Yearly Variation of Rain and Runoff Coefficient-Dasanakatte

From the trend analysis as well as plots of runoff and rainfall time series, it can be noted that the major determinant of inter-annual variation of runoff is still rainfall. Dasanakatte, being a high rainfall catchment, most of the flow comes out as saturation excess during monsoon. The flows are generally consistent with the rainfall variations and showing little influence of land cover changes, which are very hard to discern. Therefore we tried to study the impact of land cover changes on buffering capacity (peak flow to peak rainfall) of flow and baseflow, which are indicators of geomorphologic property of the watershed. The time series of buffering capacity as well as the peak runoff residue (Figure 6) show a negative trend showing that peak flows are moderated by land cover changes. It is obvious that 9% reduction in forest cover is not sufficient enough to cause drastic changes in flow volumes, but these minor changes definitely alter the runoff pattern especially the low flows. Since catchment has more agriculture and plantation which increases water uptake leading to reduction in flow especially during summer. A study on the baseflow index response to rainfall shows a more or less arbitrary trend showing little effect of land cover induced changes on the lean season flow volumes (Figure 7). Further it is observed a sharp incline in the number of dry stream days and decline in the numbers of days of flow after cessation of rain. Figure 7 shows a decline during last decade implying a change in flow pattern. The observed changes in streamflow have partly resulted from changes in land cover degradation such as destruction of native vegetal cover, expansion of agriculture and forest plantations in addition to population increase (this is not considered as a part of this study).

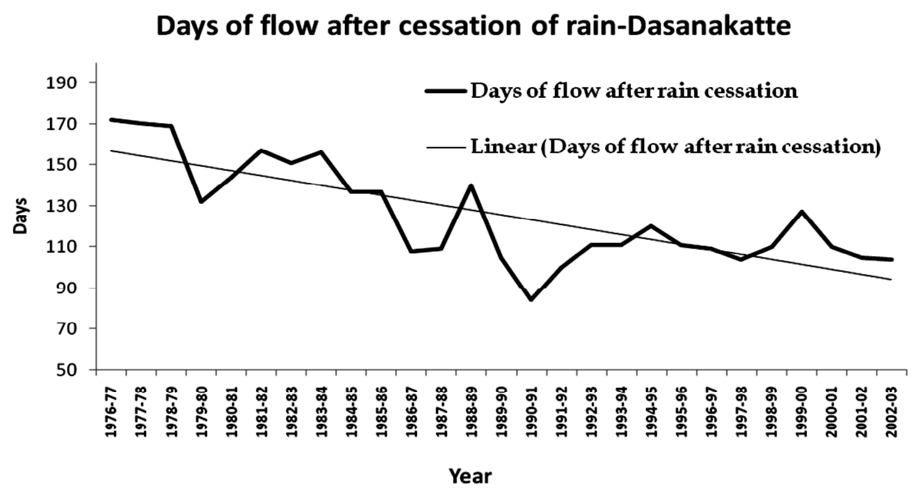

Figure 5: Number of Days of Flow After Cessation of Rain-Dasanakatte

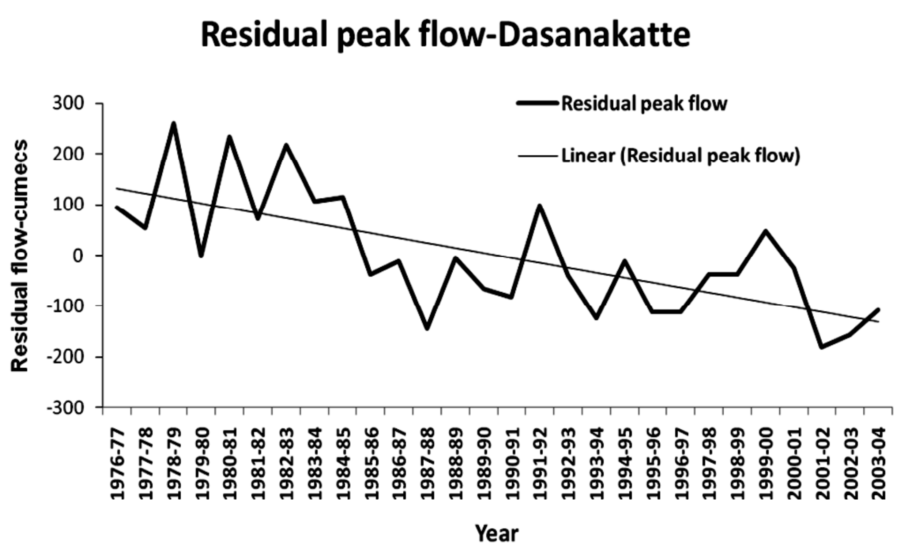

Figure 6: Yearly Variation of Residual Peak flow-Dasanakatte

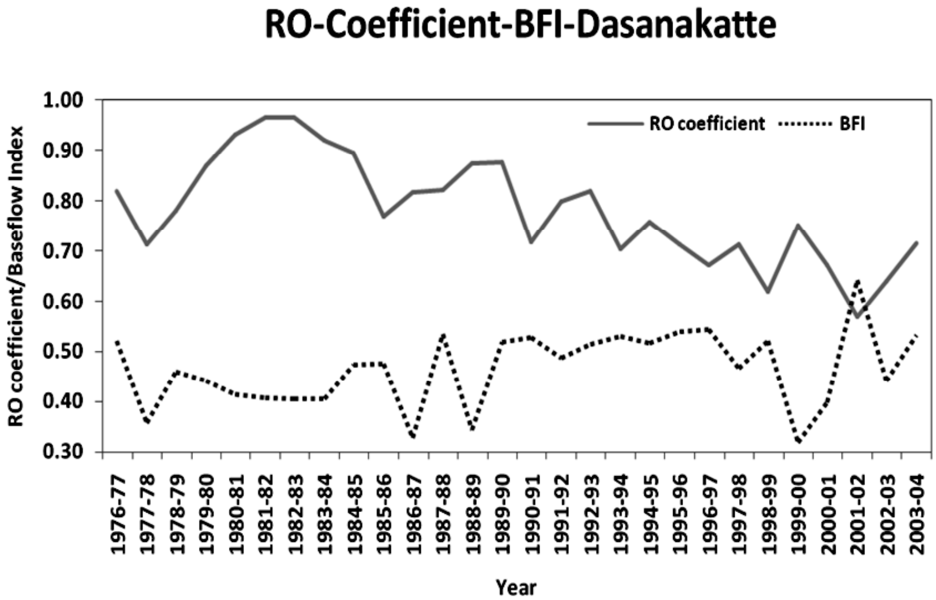

Figure 7: Yearly Variation of Runoff Coefficient and Baseflow Index-Dasanakatte

All these analyses leads to understand the impact of climate change and land cover changes influencing the hydrological regime of the Dasanakatte catchment. There are no obvious impacts of changes in tree density or any other land cover on river flow during rainy season as flows are mainly generated by saturation excess mechanism. In the dry season, the runoff is composed mainly of baseflow which comes from groundwater & shallow subsurface storages. There are not many changes in flow volumes either during monsoon or in non-monsoon season. However, obvious deviations are identified in the dry weather flow during last decade due to changes in water use pattern induced by agriculture and plantation rise which are indicative of interaction of landuse and rainfall in determining the runoff processes.

5. SUMMARY

This study was designed to investigate the variability in observed annual river yield due to changes in land cover in a small mountainous catchment of Western Ghats, Karnataka. The river response to land cover changes are not exactly on flow volumes and are more pronounced in dry season flow pattern which are attributed to increased regional water demand induced by agriculture/plantation increase. Demand for water is also exacerbated by long term variations in climate and rainfall distribution. The observed declines in streamflow are reflected by runoff coefficients. These variations are mainly due to change in land covers and are getting hidden in general variations of rainfall and streamflow. In order to develop a relationship between river yield and changes in the catchment vegetation cover, a detailed mapping of land cover for different time periods are necessary.

The analyses also indicate that though rainfall regime dominates the river flow volumes, land cover changes do modify the flow patterns in the catchment. It is therefore important that more detailed studies should be conducted to gain further insight into these relations and their impact on socio-economics of the people in the catchment.

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