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Evaluating the Changes in Water Resources due to the Impact of Man-Made Modifications for the Varahi River Basin, Karnataka

V. JAYASREE[1] and B. VENKATESH[2]

[1]*National Institute of Advanced Studies, IISc Campus, Bangalore 560012*

[2]*Hard Rock Regional Centre, National Institute of Hydrology, Hanuman Nagar, 2nd Stage, Belgaum - 590 019, Karnataka*

***Email:** jayasree_nias@yahoo.in, bvenki30@yahoo.com*

Abstract: Western Ghats, which runs parallel to the west coast of India are extremely important from the viewpoint of water resources in peninsular India because almost all the major rivers originate in them. However, this region is undergoing tremendous change in land-use/cover due to deforestation on one hand and forestation of degraded and grass lands by plantation forest on the other. The effect of such changes on the hydrologic regime of this hydro-ecologically sensitive region has not been studied comprehensively to understand influence of various hydrological parameters and how they acted together in defining the hydrology in this sensitive region. The Varahi is one such river in Karnataka which has undergone drastic changes in land cover due to human interventions. Therefore, the present study was taken up to evaluate the influence of land use changes and changed water use pattern on the hydrologic function of the river. These changes were studied by dividing the basin into two portions such as controlled and uncontrolled catchment by using remote sensing and geographic information techniques together with hydro-meteorological data. Analyses revealed a drastic change in flow patterns in the catchment especially after mid-90's when the major changes in land cover due to human interference have taken place. Changes in flow pattern are most profound during non-monsoon season compared to monsoon season indicating a cumulative impact of changes in catchment viz., deforestation, urbanization and other land use activities. The individual contribution of each of these changes on total flow is difficult to discern due to lack of hydrological and meteorological records for acceptable time span. The study had provided empirical evidence on how land covers changes and commercial agriculture activities in the river catchment has brought drastic economic disparity between the upstream and downstream regions. This evidence can provide vital information for future planners to adopt measures which can ensure equal growth for both the regions.

Keywords: *Geographic Information System, Hydrometeorology, Land Cover Change, Remote Sensing, Varahi River*

Introduction:

Human activities have had significant impacts on hydrological cycle, both in quantity and quality of water flowing within it. Many river flow regimes are heavily affected by human activities ranging from direct abstraction of water to changes in catchment land use. These changes in land use 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 catchment hydrology especially the stream flow. 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.

Changes in water resource especially the stream flow 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 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 resources 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, Jhaet 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 (Priyaet 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.

There are many studies conducted in India on land cover change impact on hydrology. Many of the empirical studies carried out in the Western Ghats, ex. Land cover change and its impact on flow (Samrajet al.1988;Sharadaet al.1998; and Sikkaet al. 2003) prove limited ability to generalize 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 assess 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 sub catchments of Varahi basin to investigate possible changes in the flow pattern due to variations in the climatic regime andthe changes in land use induced by anthropogenic factors 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 catchments during various time periods; and secondly to assess the influence of changes in land use occurred in the catchment due to various commercial and development activities on hydrologic response of the catchment after controlling natural variability of rainfall. The study was carried out in two major portions of the catchment such as (i) catchment (Dasanakatte draining an area of 141 sq.km) with no major water diversions (assuming it as the virgin catchment with no human interference considered as uncontrolled and (ii) catchment (Haladi with drainage area 535 sq.km) with human interference, wherein the flow is controlled by operating the dam in the sub-basin.Methodology involves detecting the changes in land cover due to various developmental and occupational activities, catchment response characterization by assessing runoff variations and impact assessment by relating these changes to various flow indices to identify shifts in water regime.

Study Area:

The present study has been carried out in the Varahi River in Karnataka (Figure 1) The River originating from Kavaledurga in Shimoga district at an elevation of 600m above .sea level and covers an area of 759 km flowing a distance of 66km and joining Arabian sea near Kundapura town in Dakshina Kannada district.

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 stream flow 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 South West monsoon and North East 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.

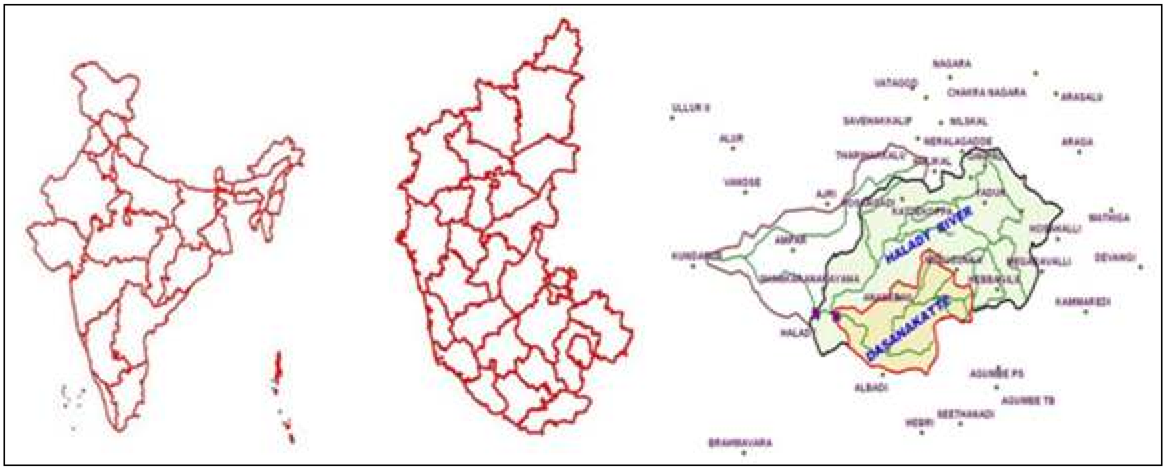

Figure 1: *varahi River with Sub Catchments, Rain Gauge and Stream Gauge Locations*

Data and Methodology:

A. Land Cover Data and Classification:

Land cover classification has been carried out for various time periods --early 1970's, early 1990's and 2000's and late 2000s'. A LANDSAT multispectral scanner system (MSS) image of 1-3-1973 was used for the initial period. Two scenes of LANDSAT Thematic Mapper (TM) were used for 19-11-1989 and 1-3-1992 for classification of early 90's. Landsat ETM of 14-3-2000 and IRS-LISS III image acquired on 25-4-2007 were used for 2000's. The MSS, TM and ETM images were downloaded from USGS Global Visualization Viewer (http://glovis.usgs.gov/) and IRS image was procured from National Remote sensing Centre, Hyderabad.

A hybrid approach consisting supervised classification, visual interpretation techniques and post-classification smoothening was followed for the land cover classification. Area under various land cover has been estimated and the changes are found out. Detailed methodology has been described elsewhere (DST report: Jayasree, 2011).

B. Rainfall and Streamflow Data Processing:

The Varahi river is gauged at Dasanakatte (145 sq.km) and Haladi (535 sq.km). The streamflow data are maintained by Water resource development organization (WRDO) and the Central Water Commission (CWC). The daily time series data available for the time periods 1976-2008 for Dasanakatte and 1970-2008 for Haladi were collected. Daily rainfall data for 43 stations in and around the catchment for the time period 1970-2008 were obtained from Directorate of Economics and Statistics.

Rain gauges falling in or near the catchment were identified and checked for consistency. Missing/erroneous 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 erroneous 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 & therefore uncertainties in the data are difficult to resolve. Average annual as well as average seasonal stream flows were computed together with standard deviation and variability.

a) Spatio-Temporal Variations in Rainfall and Runoff:

In order to understand the spatial distribution in rainfall and runoff different statistics like average, standard deviation, coefficient of variation etc. were estimated for annual, seasonal and monthly time steps. Temporal variations were identified using trend analysis carried out using non parametric Kendall test and Sen's slope (Detailed methodology is described by Venkateshet al. 2006) and at 95% significance. The areal average rainfall for the catchments viz; Dasanakatte and Haladi were estimated using Thiessen polygon method.

b) Rainfall Runoff Relationship:

A simple and effective way to understand the rainfall-runoff relationship is the runoff coefficient (which is the ratio of runoff to rainfall both expressed as equivalent depth over the catchment area) and the baseflow (contribution from ground water) estimated using the continuous baseflow separation (HYDATA) procedure in the "Low flow report for the United Kingdom" of the Institute of Hydrology, Wallingford (Report no. 108, 1992).

c) Derivation of Flow Coefficients

While runoff coefficient gives an indication of partitioning of precipitation to runoff, various flow indices like the buffering capacity (ratio of peak flow to peak rainfall), residual peak flow, number of days of flow in the river after rain stops and number of dry stream days provide information on inter-annual and inter-seasonal variations in the flow pattern.

C. Linking Climate/Land Cover Changes on Runoff Processes

Various parameters of the times series data on rainfall and runoff were analyzed 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 characterized using indices such as rainfall-streamflow trends, runoff coefficient, baseflow variations, peak flow alteration, dry river period and extension of flow after cessation of rain. These changes are evaluated separately for the uncontrolled upstream catchment gauged at Dasanakatte and controlled downstream catchment gauged at Haladi.

Results and Discussion:

A. Uncontrolled Dasanakatte Catchment:

The land cover maps for the Dasanakatte catchment for various time periods are presented in the Figure 2 below.

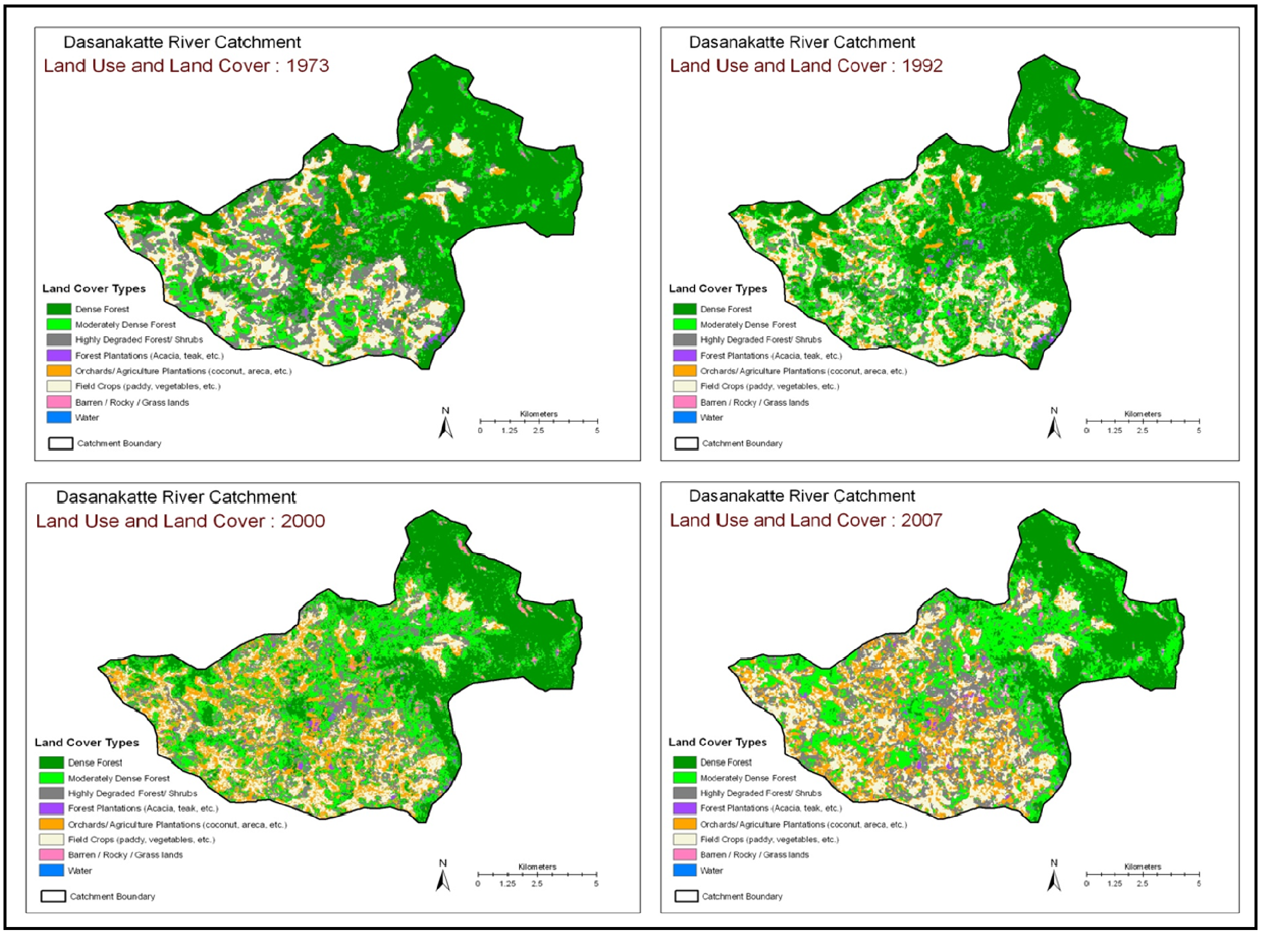

Figure 2: Land Cover during Different Time Periods-Dasanakatte

We can see from Table 1 that there is substantial reduction in forest area between 1973 and 2007 with subsequent increase in plantations. Most of the changes have taken place after mid-90's with increasing coffee cultivation in the catchment.

The study relates these changes in land cover to hydrology after controlling the natural variability in rainfall. The annual as well as seasonal runoff volumes were consistent with rainfall pattern, rainfall being the major determinant in runoff generation. The trends showed that rainfall is more or less arbitrary while the annual, monsoonal and non-monsoonal runoff decreased. The changes in runoff volumes were only marginal. Though these changes are minor, rainfall following an arbitrary trend and runoff decreasing especially after mid-90, these changes could be attributed to land cover and subsequent water usages.

Table 1: *Area (sq.km) Under Various Land Cover Classes-Dasanakatte*

Land Cover-Dasanakatte	1973	1992	2000	2007
Dense Forest	66.58	70.36	42.41	30.3
Moderately Dense Forest	18.16	24.87	32.96	33.42
Highly Degraded Forest/ Shrubs	24.97	11.3	20.55	26.38
Forest Plantations (Acacia, teak, etc.)	0.41	1.3	1.61	1.87
Orchards/ Agriculture Plantations (coconut, areca,coffee etc.)	8.1	9.25	23.34	21.89
Field Crops (paddy, vegetables, etc.)	22.13	23.11	18.52	25.53
Barren / Rocky / Grass lands	0.15	0.31	1.11	1.11
Water	0.03	0.03	0.03	0.03

As flow volumes are little affected, we tried to look at other indicators which would alter the flow regime as a result of the land modifications. Table 2 gives the trend of the different flow variables in the catchment. We can see that the runoff coefficient decreased and base flow, the contribution from ground water showed a northward trend (Figure 3). Decreasing runoff volumes and increasing base flow are indicative of more water usage in upstream to meet irrigation requirements of commercial plantations and water not reaching downstream.

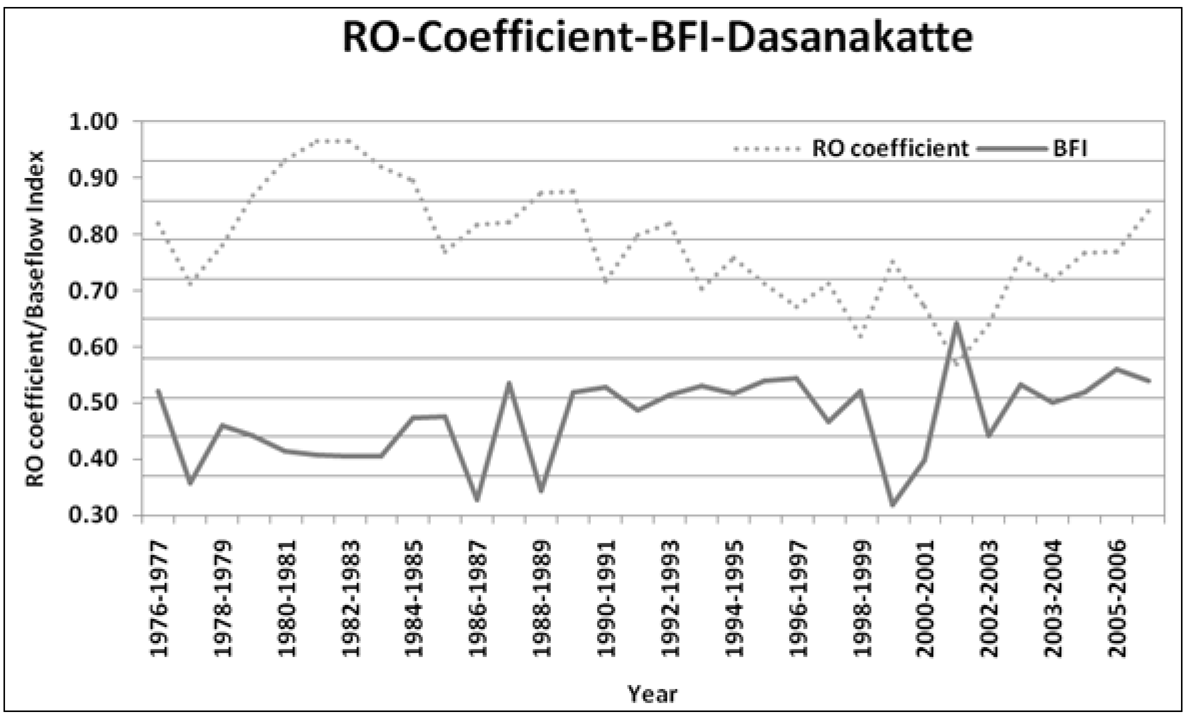

Figure 3: *Runoff Coefficient and Base Flow Index-Dasanakatte*

Parameters like the buffering capacity and residual peakflow (Table 2), which are indicators of geo-morphological property of the watershed decreased in the catchment showing flow moderation due to modification of land scape. Nature of flow marked by number of days of flow in the river after cessation of rain indicated an increasing consumption of water upstream.

The seasonal pattern of flow showed that most of the changes are pronounced during non-monsoon months. Monsoon flow mainly because of saturation excess mechanism were not affected much due to changes in land cover where as dry season flows reduced during the last decade in conjunction with the changes in land cover. Varying land scape involving destruction of native vegetal cover and expansion of agriculture and plantation together with population increase have resulted in more water extraction resulting in water shortages and even scarcity in the catchment. These deviations in dry weather flows are indicative of interaction of land use and rainfall in determining the runoff processes.

Table 2: *Trend of Flow Variables-Dasanakatte*

Flow variable	Trend	Change rate
Runoff coefficient	Decrease	0.01
Base flow index	Increase	0.03
Buffering capacity	Decrease	0.023
Residual peak flow	Decrease	9.4
Days of flow after cessation of rain	Decrease	2.1

B. Controlled Catchment – Haladi:

The catchment of Haladi River (535 sq.km) includes the Dasanakatte Hole. This catchment has undergone drastic changes in last three decades which are mainly forest reduction for development projects, urbanization and other activities (Figure 4). The dams and diversions have come up in the upstream of the catchment. Mid reaches dominate with agriculture and horticulture plantations and there are few projects coming up in downstream.

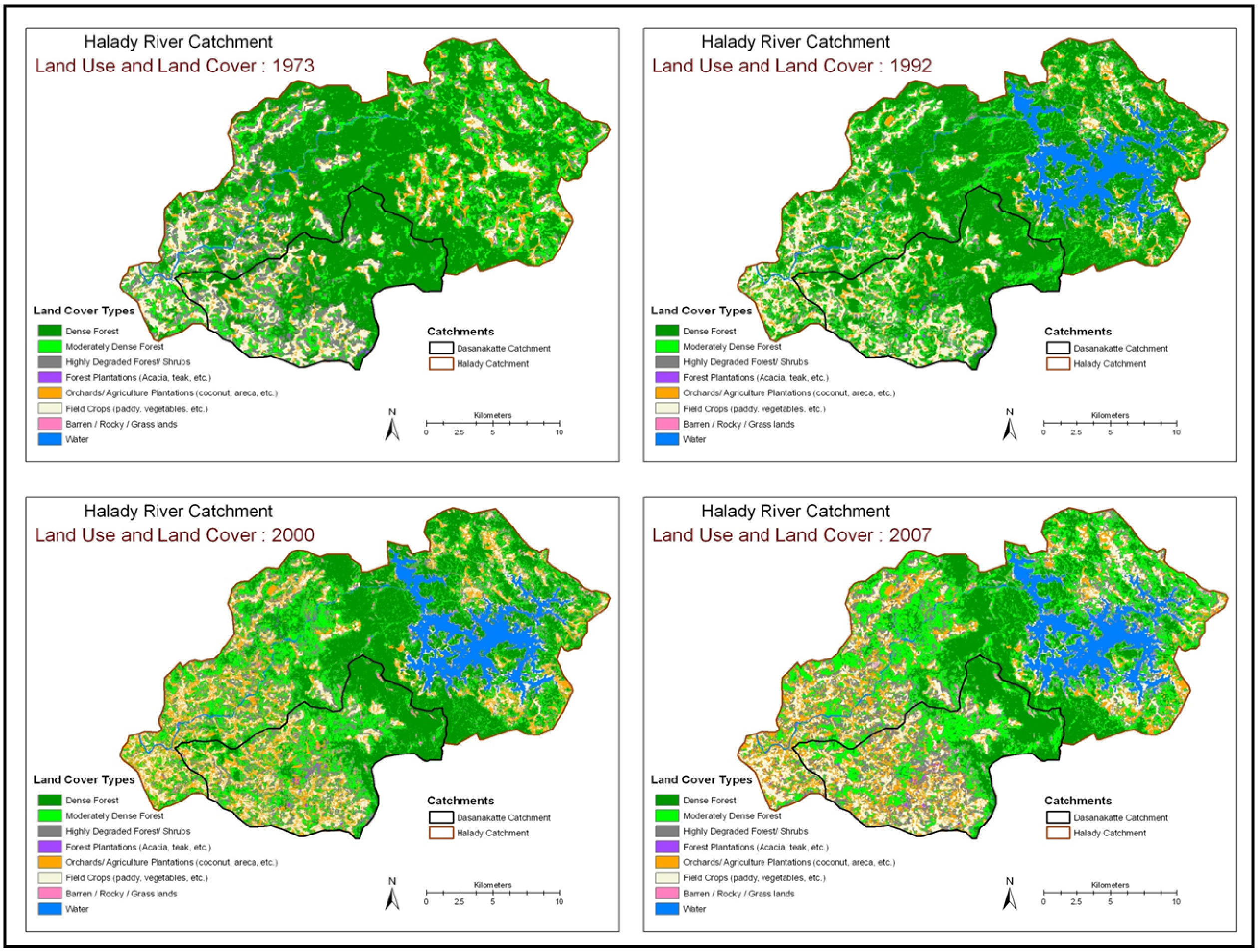

Figure 4: *Land Cover during different Time Periods-Haladi*

It can be observed from the Table 3 that there is substantial expansion to agriculture and commercial plantations like rubber, areca, cashew, coconut etc. A significant area of land has been utilized for reservoir construction during the 1980's.

Table 3: *Area (sq.km) Under Various Land Cover-Haladi*

Land Cover –Haladi	1973	1992	2000	2007
Dense Forest	252.76	255.41	174.77	116.59
Moderately Dense Forest	99.5	95.34	118.15	140.01
Highly Degraded Forest/ Shrubs	76.36	41.57	63.29	82.01
Forest Plantations (Acacia, teak, etc.)	0.62	2.12	4.36	6.4
Orchards/ Agriculture Plantations (coconut, areca, etc.)	36.29	33.79	72.8	69.41
Field Crops (paddy, vegetables, etc.)	67	65.56	57.49	76.44
Barren / Rocky / Grass lands	0.49	1.46	4.38	4.38
Water	2.44	40.22	40.22	40.22

The rainfall-runoff analyses for Haladi catchment showed that the flow pattern is consistent to the rainfall. Similar to the Dasanakatte catchment, Haladi rainfall is also more or less arbitratrywhereas the annual and monsoonal flows showed decreasing trends. But non-monsoonal flows increased especially after 1980's in conjunction with the reservoir operations.

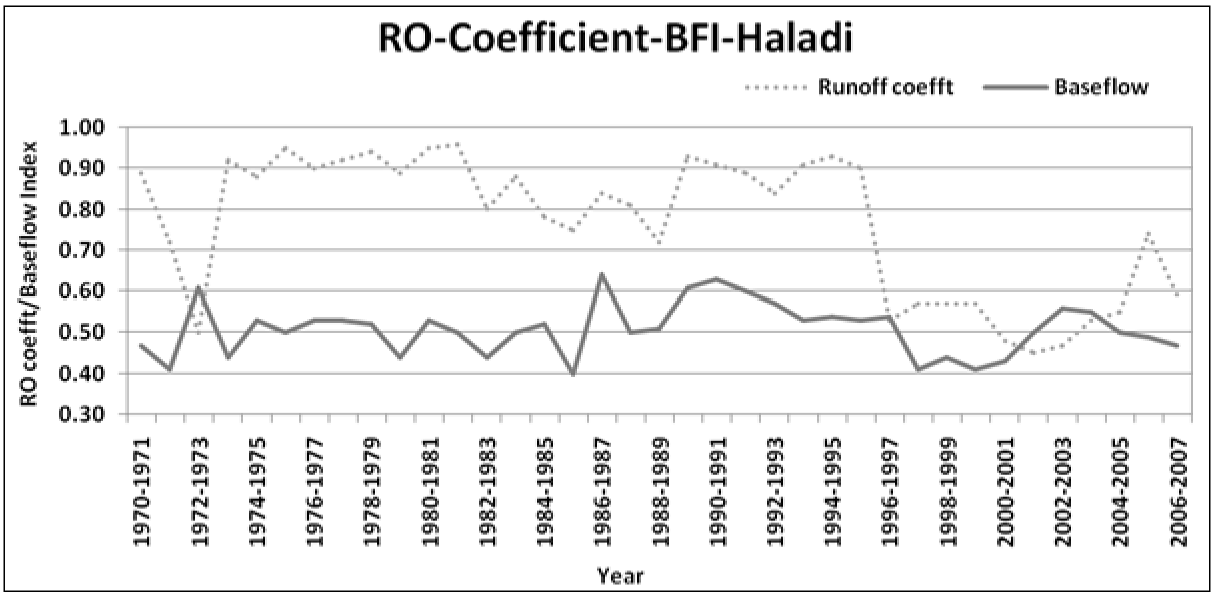

Figure 5: *Runoff Coefficient and Base Flow Index-Haladi*

The flow characteristics described by runoff coefficient and base flow (Figure 5) showed different trends. Runoff decreased in the catchment whereas the base flows were more or less arbitrary. These changes could be related to more water usage in the upstream and supplementary irrigation from the dam during the lean period.

Table 4: *Trend in the Flow Variables-Haladi*

Flow variable	Trend	Change rate
Runoff coefficient	Decrease	0.014
Base flow index	Decrease	0.028
Buffering capacity	Decrease	0.042
Residual peak flow	Decrease	15.30
Days of flow after cessation of rain	Increase	1.23

Table 4 presented above gives the trends of flow variables. The buffering capacity and peak runoff residue have decreased whereas the number of days of streamflows after stopping of rain increased again indicating the flow in the streams and canals for irrigation from the dam.

In mid-Haladi catchment has many development projects alongside upcoming projects which consume lot of water thereby altering the hydrologic regime. The disturbance wrought by intensive human activities especially through construction of reservoirs in the main stream and subsequent land conversion has resulted in streamflow reduction in the catchment. The individual contribution of each of these changes on total flow is difficult to discern due to lack of hydrological and meteorological records for acceptable time span.

5.0 Summary:

This study was designed to investigate the variability in observed river yield due to changes in land cover due to human interference in a small mountainous catchment of Western Ghats, Karnataka. The catchment has undergone drastic changes in land cover which are attributed to development projects and urbanization. The land cover in the catchment has changed significantly between 1970's and late 2000's with marked forest degradation. Forests have given way to development projects and commercial crops. Mid reaches dominate with agriculture and horticulture plantations.

The hydro-meteorological analyses clearly indicated domination of rainfall regimes over river flow volumes. Rainfall remained arbitrary during this period with decline in runoff in the catchment which could be attributed to land cover changes. There is a decline in stream flows as reflected from runoff coefficients especially from mid-90 are when the changes in land cover have taken place. Distinct variations between upstream and downstream are noticed with regard to ground water contributions – former region with land scape alterations and latter with more irrigation from dams.

The study indicated that the river response to land cover changes are not exactly on flow volumes but are on the flow patterns which are getting hidden in general variations of rainfall and stream flow. The monsoon flows are little affected as it is generated due to saturation excess mechanism whereas obvious deviations in summer flows are identified in dry weather flow due to changes in water use pattern induced by changing land cover indicating the interaction of anthropogenic activities.

On one hand the development projects have promoted summer cultivation in the catchment where as there is water scarcity in the downstream. Flow moderation is visible in the catchment which is pronounced in seasonal flows especially during summer. Demand for water is also exacerbated by long term variations in climate and rainfall distribution.

The results lead to the conclusion that the modifications in land cover have impacted the hydrological responses and thus the available water resources the degree of which depend on intensity as well as the locations of land cover changes within the catchment.The study highlights the importance of considering the effects of land use and land cover on eco-systems and water resources for an informed decision on proper catchment planning and management.

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