Factors Influencing the Runoff Trend in a Medium Sized River Basin in the Western Ghats, India

P.P. Nikhil Raj and P.A. Azeez

Abstract The present study examines the trends in the annual runoff of a tropical river basin Bharathapuzha, a medium sized river in southern India under the influences of anthropogenic pressures and climate change. The examination of the temporal trends in the rainfall, temperature and river runoff was done using historical datasets. It was supplemented with the data on the land use/land cover (LU/LC) change in the basin based on the LANDSAT TM data. By using a multiple regression model, the influential factors determining the river discharge were identified. The results show that while the rainfall influences the runoff positively, new water bodies, dams and other diversions in the fluvial setup in the basin influence the river runoff negatively.

Keywords Tropical river system · Bharathapuzha · River runoff · Climate change · Land use · Regression model

1 Introduction

Rivers and other water bodies hold enormous ecological values (Schuyt 2005), provide very vital ecological services, and have been the cradles for most of the world's civilizations. Nevertheless, the pressures from human activities and global change in the climatic system are jeopardizing these ecosystems (Turner 1991; Naiman et al. 2002). Human pressures and their manifestations on the river systems are wide and varied and are well known not only to the scientific community, but

P.P.N. Raj · P.A. Azeez
Environmental Impact Assessment Division, Sálim Ali Centre for Ornithology and Natural History (SACON), Coimbatore 641108, India

P.P.N. Raj (✉)
Centre for Sustainable Future, Amrita Vishwa Vidyapeetham, Amritanagar (PO), Coimbatore 641112, India
e-mail: ppnraj@gmail.com

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also to the general public. Local alterations (construction of dams and dykes, diversion of the bulk of water flow for agriculture, industrial or human consumption, and waste disposal, and embankment and encroachments across the flow regime) are carried out largely with narrow myopic objectives without giving considerations towards the sustainability of the natural fluvial ecosystems. According to recent statistics 41 % of the global human population resides along river courses of extreme water stress (Bates et al. 2008; CBD 2005). Degradation and alternation of riverine ecosystems have resulted in the extinction or near extinction of about 20 % of the world's fresh water species (CBD 2005). According to the Millennium Assessment report (2005) the world's fresh water ecosystems are reported to be the areas of highest species extinction and several species in this zone fall among the list of threatened species.

Most of the world river basins have been undergoing major change since 19th century. Overexploitation as a result of agriculture and industrial revolutions had modified many of the global rivers. To cater the growing needs of the population, the agriculture required more irrigation facilities and diversion of water. Dams for irrigation and energy production and the extensive inorganic agriculture practices not only altered the natural flow regimes but also polluted the water resources (Varghese 2009). It is noted that 40 % of the world agriculture output purely depends on irrigation (Fischer et al. 2006), and as a result, the water impounded in the reservoirs has quadrupled since 1960 (Millennium Assessment 2005). Industrial revolution had further aggravated the situation by polluting the rivers with industrial, municipal and other forms of wastes. There are many case studies that have unequivocally demonstrated how over-exploitation coupled with other human pressures and climatic changes affect the sustainability of rivers (Dai et al. 2010; Changming and Xiaoyan 2009; Tijiu and Xiaojing 2007; Wilk and Hughes 2002).

Measures to assess the health of the rivers are debatable. According to Changming and Xiaoyan (2009), the continuous and consistent runoff, favourable riverbed and complete drainage system verifies the health of any river. Apparently, the river runoff being directly related to the hydrologic cycle of a basin is an integrated measure of the influence of climate, land cover, and human activities on the hydrologic cycle over a drainage basin (Sharma et al. 2000). Taking the stream flow as a parameter, several river basins located across the globe are examined with reference to the impact of the contemporary environmental changes on the river runoff. Fang et al. (2009) studied the Yellow River, China and appraised the direct influence of rainfall (50 %) and anthropogenic activities (<50 %) on the stream flow in the basin. Sharma et al. (2000) revealed that the anthropogenic pressure coupled with the global warming adversely affected the discharge in the Kosi River basin in the Himalayas. Several authors studied the hydrology of various river basins by focusing on the water quality and runoff (for example, Riedel et al. 2000; Gupta and Chakrapani 2005; Sileika et al. 2006; Quadir et al. 2007; Raj and Azeez 2009a).

During the last few of decades the world has been witnessing drastic changes in land use and land cover (Zhu et al. 2008). Land use change along the catchment of rivers affects the entire river system by altering the river runoff and ground water flow (Zade 2005; Tijiu and Xiaojing 2007; Xu et al. 2007) in general and more precisely by changing the inputs of water, light, and allochthonous materials into the system (Nilsson et al. 2003; Strayer et al. 2003). Studies have been conducted investigating the effect of changes in land use on river basins around the globe (for example, Xiaoming et al. 2007; Galster et al. 2007; Yang et al. 2004; Bhaduri et al. 2000). Expansion of agriculture in river basins is closely associated with diversion of water from the rivers. Nilsson et al. (2003) reported the effect of encroachment in the basin as well as in the riverbeds on the hydrology. Similarly studies on several river basins have documented how the dams altered the natural water flow (Burke et al. 2009; Tukur and Mubi 2002; Cowell and Stoudt 2002) and the natural profile of the river beds (Altaiee 1990).

Untoward variation in climate is one of the determining factors of the health and status of the world's fresh water resources. There are notable studies on meteorology and its relation with the hydrology of the river basins (Yin et al. 2000; DeWit et al. 2007). Drastic and adverse fluctuations in the climatic conditions are likely to have a direct influence on the fresh water resources. The global surface temperature is reported to have risen by 0.74 °C since 1906 and the warming was more rapid during the last 50 years (Bates et al. 2008). The India Meteorological Department (IMD) also reports a 0.913 °C hike in temperature in 2009 than the 1961–1990 average (IMD 2010). However, due to the lack of climate stations and availability of historical climate datasets there is a huge lacuna in documenting the global river flow in relation to the climate change. Seawater intrusion is yet another major crisis observed in most of the river basins particularly those with low physiography. It affects the water quality and the ecosystems in a larger perspective. Sea level rise was observed at a rate of 1.7 ± 0.5 mm/yr for the 20th century (Bates et al. 2008).

The rivers of India are broadly grouped into four classes according to their location and topography: Himalayans, Deccan, Coastal, and rivers of inland drainage basins. The three big rivers, Indus, Ganges, Brahmaputra and their network of tributaries in the Indo-Gangetic plains constitute the Himalayan river systems. The Deccan rivers include the west flowing Narmada and Tapti and east flowing Mahanadi, Krishna, Godavari and Cauvery. The coastal rivers include the small river basins along the eastern and western sides of the peninsula. The small rivers of Rajasthan are known as the inland drainage rivers. The rivers of India could be also classified as major, medium and minor rivers on the basis of catchment size (Jain et al. 2007); the class 'major rivers' includes those with catchment area >20,000 km^2, 'medium rivers' includes those with catchment area between 2,000 and 20,000 km^2, while 'minor rivers' are those with Catchment area <2,000 km^2.

The state of Kerala, located at the southwest corner (8.5°–11°N and 76°–77°E) of the Indian peninsula is unique in its physiography with an undulating terrain bounded by the Western Ghats on its east and the Arabian Sea on the west. The State has 44 rivers with an average length of 64 km. The network of their tributaries and distributaries cover almost 74 % of the total area of the state. The average rainfall of the state is 3,000 mm and the total annual yield from the 44 rivers to the state is 70,323 MCM (http://www.kerenvis.nic.in). However, Nair (2008) states that Kerala's per capita water availability lies far below the more arid states of India such as Rajasthan and Maharashtra. Studies reveal that there is a general declining trend in the annual rainfall in the state (Soman et al. 1998; Kumar et al. 2004; Krishnakumar et al. 2009), and some of the studies reported local aberrations and decline in the annual rainfall in different parts of the state (Soman et al. 1998; Raj and Azeez 2010a).

Although Kerala is covered by a rich river network, studies documenting the environmental status of these rivers are very rare. The present study was carried out on the Bharathapuzha river basin. The Bharathapuzha river system, a major one in the western side of the Western Ghats, is critical as a support system for over 4.5 million people and more than four hundred thousand hectares of agriculture (Raj 2011). In the recent decades, the river in the downstream areas is turning barren with no notable and consistent flow and is experiencing serious water scarcity sometimes even immediately after the monsoons. Apparently unsustainable consumptive water demands, unsustainable exploitation of natural resources such as river-sand and untenable encroachment of the river course are some of the major threats to the river system. Extensive mining of sand and clay have interfered with the flow regime of the main course of the river and most of its tributaries. In addition, imprudent and unhygienic disposal of urban wastes add to the grievous degeneration of the river course (Raj 2011). In this context, the present study attempts to examine the annual runoff in the river in relation to various anthropogenic and climatic parameters.

2 Study Area

The Bharathapuzha River (Fig. 1) is one among the forty-one west flowing rivers of the Kerala State and is bounded by 10°25′–11°15′ north and 75°50′–76°55′ east. Four major tributaries namely, Kalpathy, Chittur, Gayathri and Thootha that originate from the Western Ghats (one of the biodiversity hotspots in India) and join the stem channel of the river which is classified as a seventh order river and is grouped under the median rivers of the country (Jain et al. 2007). It debouches into the Arabian Sea at Ponnani located at the western coast of India. The river flows through high land (>76 m), mid land (76–8 m) and coastal plains (<8 m). The river basin covers almost one-ninth of the total geographical area of the state.

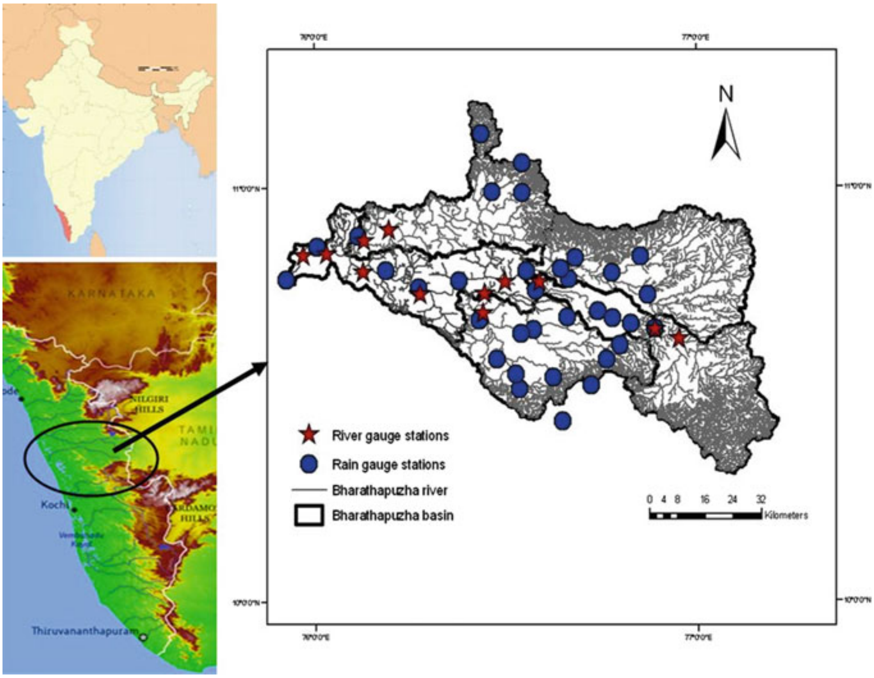

Fig. 1 Map showing the location of the Bharathapuzha river basin and the river and rain gauge stations within the basin

3 Materials and Methods

To study the hydrologic trend of the basin, runoff data for 34 years (1968–2005) from 12 river gauge stations maintained by the Central Water Commission (CWC, Government of India) and Irrigation department (Government of Kerala) were collected. This was followed by examination of the climate trend of the river basin using available meteorological data (annual, monthly temperature and rainfall data) collected from the Indian Meteorological Department (IMD, Pune) for the same period (1968–2005). The basin has a network of 37 rain gauge stations operated by the Irrigation department, Government of Kerala. However, data from only 29 selected stations, that have continuous monthly and yearly data, were used for the study.

The annual runoff, temperature and rainfall trend of the basin were analyzed using the Mann-Kendall rank correlation analysis, since it is a suitable statistical test for a long period of data (Basistha et al. 2007; Krishnakumar et al. 2009; Raj and Azeez 2010a, 2012). The values of t were used as the basis of significance test by comparing it with $Tt = 0 \pm tg\sqrt{[4N + 10/9N(N - 1)]}$, where, tg is the desired probability point of the Gaussian normal distribution. In the present study, tg at 0.01 and 0.05 were considered as the levels of significance.

To understand the land use/land cover changes (LU/LC) in the river basin LANDSAT TM data, with a pixel resolution of 30 m, for 1973, 1990 and 2005 for the whole basin obtained from the Global Land Cover Facility (www.glcf.umd.edu) were utilized. LU/LC analysis was made with the help of Arc GIS 9.3 and ERDAS IMAGINE 8.5 software. Since continuous data on LU/LC for the basin were not available, a method of gross approximation was adopted such that the LU/LC data of the three periods were used to extrapolate and estimate the data for the whole period of the study.

Multiple regressions coupled with partial regression analyses were carried out to identify the parameters that influence the river runoff and to find out the respective weight of each parameter on the annual river runoff. The multiple regression analysis could be regarded as a convenient and robust tool to find the respective weights among two or more factors. It is also applicable in testing hypothesis and in predicting or interpolating the relationships (Zar 1999; Nawaz and Adeloye 1999). It is assumed that both the climatic and anthropogenic factors influenced the trends in the runoff in Bharathapuzha Basin. The factors such as rainfall, number of rainy days, maximum, minimum and mean temperatures were considered as the climatic factors while the land use/land cover changes were considered as the anthropogenic factors. The land use/land cover was categorized into five major classes (agriculture, natural vegetation, roads, urban centers and water bodies) and accordingly the land use changes in the river basin for the time span of 1973–2005 were examined. For generating unbiased results, the area under plantation and agriculture were merged together since the means of utilization of river water is same by both these types of land uses. Altogether, the factors were classified into two; those likely to influence the river runoff positively and those having a negative influence on it. It was assumed that the number of rainy days, rainfall, natural vegetation, roads and water bodies to be positively related with the river runoff and the temperature, urban area and agriculture area to be inversely related with it (Fig. 2).

4 Results

4.1 Trends in the River Runoff, Rainfall and Temperature

It is interesting and useful to examine the annual trend of runoff of a river and the factors influencing it. The data extending to almost four decades show the average runoff in the Bharathapuzha Basin to be 5.39 km^3 (STDEV ± 1.58). Mann-Kendall rank correlation analysis shows a significant ($p < 0.01$) decreasing trend in the runoff as the years proceeds (Table 1, Fig. 3). On examining the temporal trends of the rainfall (Raj and Azeez 2012), it is found that the rainfall shows a statistically significant ($p < 0.01$) decreasing trend (Table 1, Fig. 4). Analysis of the temperature in the basin for the same period shows a significant ($p < 0.01$) increasing trend.

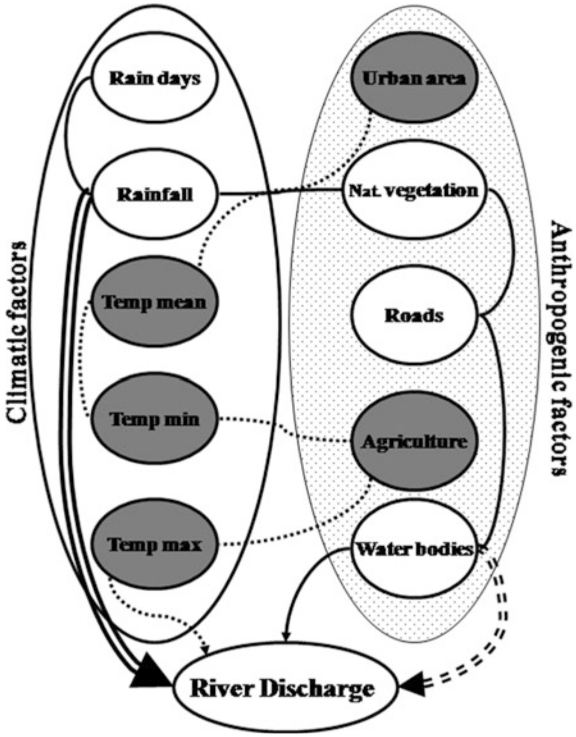

Fig. 2 Factors influencing the river runoff in the Bharathapuzha River Basin (*black single lines* represent the hypothetical scenario, while *black double lines* mark the results after the analysis. *Thick lines* indicate the positive relationship while the *dotted ones* represent the inverse relationships among the factors)

Table 1 Mann-Kendall's rank correlation statistics showing the temporal trend of runoff and other climatic factors in Bharathapuzha river basin

Factors	Coefficient
Annual river runoff	−0. 504[a]
Annual rainfall	−0.496[a]
Annual T max	0.317[a]
Annual T mean	0.404[a]
Annual T min	0.428[a]

[a] Significant at 0.01

Similar trend (Raj and Azeez 2011) is observed for annual maximum (T max), minimum (T min) and mean temperature of the basin (Table 1, Fig. 5).

4.2 *Temporal LU/LC in the Basin*

During the early period (1973–1990) of the study, land under natural vegetation cover in the basin was 44 % of the total basin area followed by the area under agriculture. During the second half of the study period, the area under agriculture was the highest in extent (41.7 %) followed by the area under urban centre. In 2005, the

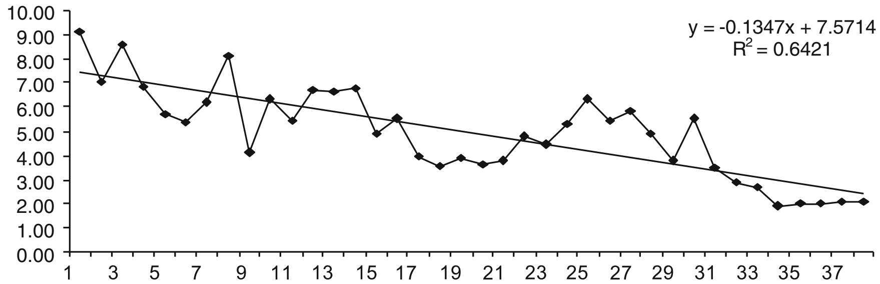

Fig. 3 The temporal trend in annual runoff in the Bharathapuzha river basin

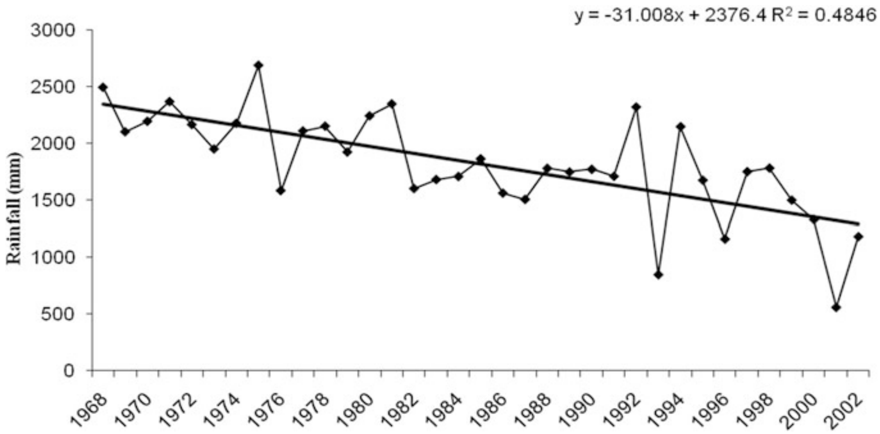

Fig. 4 Temporal trend of rainfall in the Bharathapuzha river basin

area under urban centers was the major land use type in the basin, followed by agriculture at the second position. Thus, the area under the natural vegetation cover consistently showed a declining trend of decline. A positive growth trend of urban centers in the basin was observed during the whole period (Table 2; after Raj and Azeez 2010b).

4.3 Factors Influencing the River Runoff

The trend in runoff of the river was examined to identify other determining factors. The correlation analysis of various parameters on runoff shows significant positive correlations ($p < 0.01$) only with rainfall and natural vegetation ($p < 0.05$). Similarly, the area under water bodies ($p < 0.01$), and the agriculture area ($p < 0.01$ levels) shows negative correlations with the runoff (Table 3).

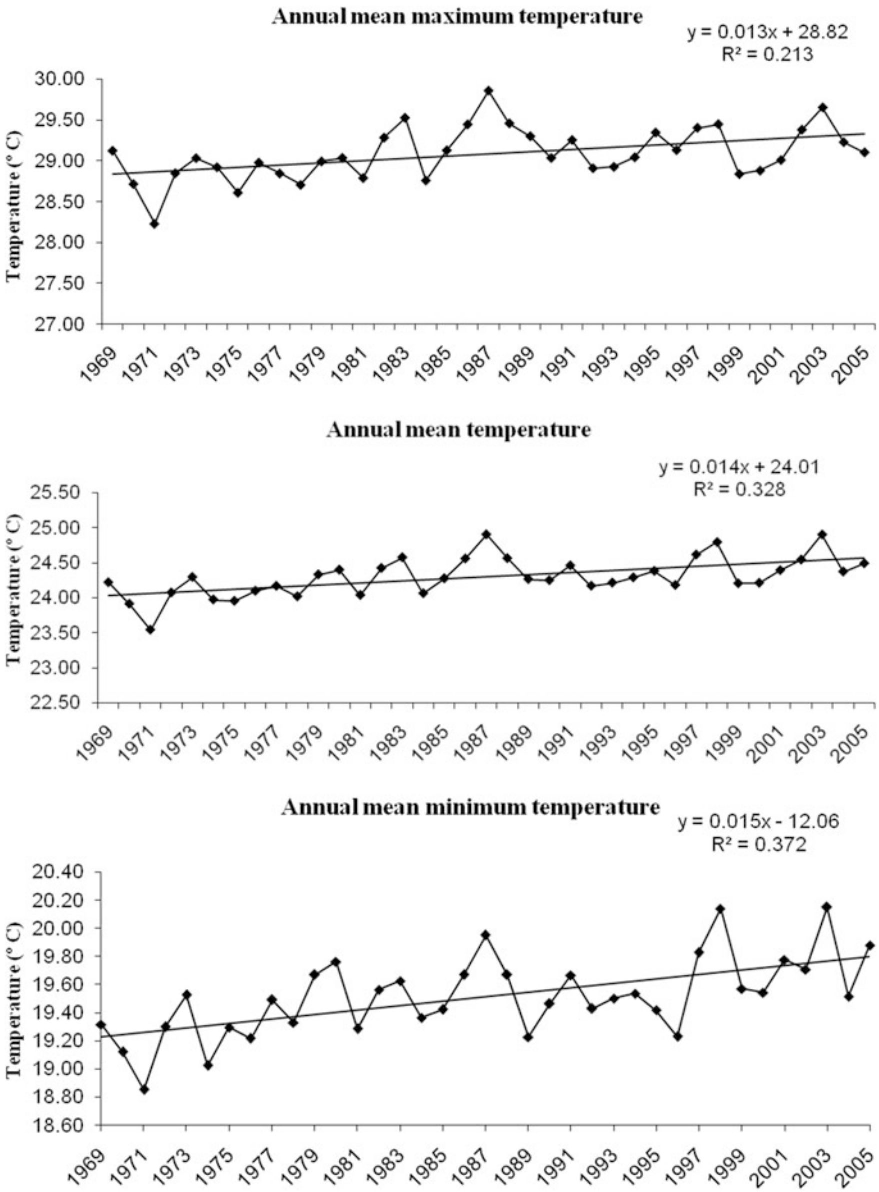

Fig. 5 Temporal trend of T max, T mean and T min in Bharathapuzha river basin

Table 2 Total land cover (in %) as a proportion to the total area, and the net change during the study period

Land use	1973	1990	2005	Change (%) during 1973–1990	Change (%) during 1990–2005	Change (%) during 1973–1005
Agriculture	35.31	41.74	27.80	6.43	−13.94	−7.51
Natural vegetation	43.43	12.07	12.28	−31.36	0.21	−31.15
Road	7.61	8.40	16.24	0.79	7.83	8.62
Urban centers	9.83	32.63	41.76	22.80	9.13	31.93
Water bodies	3.82	5.16	1.93	1.34	−3.23	−1.89

Table 3 Mann-Kendall's rank correlation analysis showing the relationship between runoff and other parameters

Variables	Coefficient
Rainfall	0.442[a]
Rain days	0.17
T max	−0.15
T min	−0.063
T mean	−0.103
Natural vegetation	0.277[b]
Water bodies	−0.459[a]
Roads	0.166
Agricultural area	−0.451[a]
Urban centers	−0.166

[a] Significant at 0.01 [b] 0.05 levels

5 Discussion

Except for the physical structures in the catchment, the rainfall exerts direct control over the river runoff (Pfister et al. 2000) which is true for all river systems dependent on monsoon precipitation (Raj and Azeez 2009). The general rainfall in the basin shows a statistically significant decreasing trend as the year proceeds (Fig. 3, Table 1). At the same time, the temporal trend shows a decrease in the number of rainy days in the basin, which is in conformity with the nation-wide trend reported earlier by Ramesh and Goswami (2007). The past few decades have seen extensive expansion of road transport infrastructure and allied structures. Notwithstanding the flow regimes, the positive relationship (albeit at statistically low levels—Table 3) shown by the areal extent of roads with the river runoff, which is a cause of concern and need to be studied specifically.

The area under water bodies in the basin includes natural water bodies and man-made structures such as dams and ponds. Dams and other embankments reduce or alter the natural flow in the river especially in the lower reaches. There are

Table 4 Summary of the multiple regression model

Model	R	R2	Adjusted R^2	Std. error of the estimate	Change statistics				
					R2 change	F change	df1	df2	Sig. F change
1	0.740	0.547	0.521	3091.44	0.130	10.085	1	35	0.00

Predictors (Constant) Area under water bodies, Rainfall
Dependent Variable Runoff

11 such dams and irrigation projects in the Bharathapuzha Basin. Of these, the Aliyar dam located in the Chittur Basin is the largest and is a part of the Parambikulam Aliyar Project (PAP) and stores water from three river basins, namely, the Bharathapuzha, Periyar and Chalakkudipuzha (Ravi et al. 2004) and may have contributed towards significant negative impact on the total water discharge in the Bharathapuzha River Basin (Sadasivan 2003). The runoff and the agriculture area in the Bharathapuzha river basin show a statistically significant ($p < 0.01$) inverse relationship (Table 3). Change in the vegetation type, conversion of natural forested area into agriculture alters the river runoff due to the change in the vegetation type (Hudson et al. 1997). The over-exploitation of water and diversion for agriculture is a common practice in the Bharathapuzha Basin (Kumar 2001).

Taking these observations as cues, a multiple regression model was attempted, anticipating that the runoff of the basin could be predicted using the above variables. All the factors were utilized through a step-wise and multiple regression that resulted in the model equation $Qw = 13879.29 + (-0.36*Aw) + (4.752*Rf)$, where Qw denotes the runoff, Aw the area under water bodies and Rf the annual rainfall in the basin. The variables namely, maximum, minimum, and mean temperature, natural vegetation, areas under roads, urban centers and agriculture, and total rain days were excluded from this analysis due to their respective lower weights on the river runoff (Table 4). The regression model thus generated is highly significant ($R^2 = 0.521$, Table 4). The multiple regression analysis refined the result such that only two out of the ten factors that were initially considered were found influential. The results have shown that the area under water bodies ($p = 0.000$, $R2 = 0.400$) and rainfall ($p = 0.003$, $R2 = 0.293$) were found to be the influencing factors (Table 5).

Concurrent decreasing trend of rainfall in the basin (Fig. 3, and Table 3) in this context will have a crucial role in determining the health of the river in the

Table 5 Regression Model for predicting runoff in Bharathapuzha river basin

Model	Un-standardized coefficient		t	Significance	Partial correlation coefficient
	B	Std error			
Constant	13,879.29	4,218.85	11.62	0.002	
Area under water bodies (W)	−0.36	0.08	−4.35	0.000	−0.592
Rainfall (RF)	4.752	1.49	3.18	0.003	0.473

coming years. The presence of dams and the other man-made water storage structures have a negative effect on the river runoff. In fact, it is observed that among the four sub-basins of the river, the river Thootha, the only lesser-disturbed sub-basin in the river contributes highly to the annual runoff of the river (Raj and Azeez 2009). Many of the streams in the river basin, except the river Kunthi flowing through the Silent Valley National Park and the Thuppanadupuzha river flowing through the Chenath Nair Reserve Forest have been facing pressures from various corners for harnessing for irrigation as well as power generation, during the last couple of decades. That would have seriously affected the runoff in the main Bharathapuzha River, constraining its other ecological and socio-economic services downstream.

6 Conclusions

- The historical data shows a decreasing trend in the annual runoff in the basin.
- As could be expected in a monsoon dependent fluvial system, the river runoff is predominated by the intensity of rainfall and the number of rainy days, notwithstanding the physical structures in the catchment and resultant changes in the flow and percolation regimes
- Conversion of forestland into agriculture land use has significantly contributed towards enhancing the river runoff while the maximum, minimum and mean temperature, area under plantation contribute negatively to the river runoff.
- Out of ten factors that were initially considered for the study, only two namely, rainfall and areal extent of waterbodies have been found to be significantly influencing the runoff.
- A temporal trend of decrease in rainfall, number of rainy days and increase in maximum, minimum and mean annual temperatures is a cause of concern and this basin warrants urgent adoptive strategies to the changing climatic scenario.

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