IMPACTS OF ANTHROPOGENIC REGULATION ON STREAMFLOW IN THE HUMID TROPICS OF WESTERN GHAT REGIONS OF KERALA STATE

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ABSTRACT

The paper discuss about the downstream impacts of flow regulations by Hydro Electric Projects (HEPs) in the Periyar and Muvattupuzha river basins, central Kerala, Southern India. During the last four decades, three HEPs were commissioned in the Periyar basin. The Idukki HEP (1976) is an inter-basin water transfer project to the adjoining Muvattupuzha river basin whereas the Idamalayar (1987) and the Lower Periyar (1997) HEPs are within basin regulations. Reliability and trend analysis of streamflow show that inter-basin water transfer under the Idukki HEP has worsened the situation in the Periyar river basin and completely altered the flow regime in the Muvattupuzha river especially during the non-monsoon period. The analysis show that with the commissioning of another two HEPs in the Periyar river basin, flood moderation and lean-flow augmentation improved considerably. Indicators of Hydrologic Alteration (IHA) model results and Dundee Hydrological Regime Assessment Method (DHRAM) scoring show considerable flow regime changes after the commissioning of HEPs in both the rivers. Hydrologic alterations due to inter-basin water transfer were considerably higher than within the basin regulations.

KEYWORDS: *Hydro-electric projects, inter-basin water transfer, intra-basin regulations, flood moderation, lean flow augmentation*

I. INTRODUCTION

The humid tropical climate is characterized by season-long precipitation. The rainy season lasts at least six months in a year and creates a humid climate, in which more water falls than can evaporate. The annual precipitation usually ranges between 2000 to 4000 mm. Temperature in humid tropics usually varies in a very narrow range annually. The humid tropics have the greatest biodiversity, while the biodiversity decreases towards the north and south poles as the temperatures decrease. As these regions are characterized by a wide range of species diversity of aquatic biota and riparian vegetation including several endemic species, they are considered as bio-diversity hot spots**.** The loss of biodiversity in such bio-diversity rich regions could be attributed to the expanding anthropogenic activities by way of habitat destruction through fragmentation and degradation and overexploitation of species for human use and many other complex unexplored factors.

Hydro-electric projects play a very important role in the power sector of Kerala State, since about 60% of the requirement of electric power is met from HEPs. The reservoirs under HEPs help in meeting water demands in various sectors like agriculture, industry, water supply, inland water transport and tourism sectors. Out of the 3000 mm of rainfall received annually in the State, 60% is received during S-W monsoon (June-August), 25% during N-E monsoon (September-November) and the remaining 15% during summer months spread over six months (December-May). Highly varying temporal distribution of rainfall in this region makes the role of reservoirs all more important as they play a very important role in meeting water demands in power, agriculture, industry, water supply, inland water transport and tourism sectors.

During past four decades, the statistical domain of hydrology has broadened to encompass the problems of both surface water and groundwater systems. With such a broad domain, statistics has emerged as a powerful tool for analyzing hydrologic time series. The main aim of time series analysis is to detect and describe quantitatively each of the generating processes underlying a given sequence of observations [1]. In hydrology, time series analysis is used for building mathematical models to generate synthetic hydrologic records, to forecast hydrologic events, to detect trends and shifts in hydrologic records, and to fill in missing data and extend records [2, 3].

Streamflow regime describes the magnitude and timing of river discharge at a point. It is one of the key driving forces in river eco-systems [4]. Any alterations from the natural streamflow conditions, cause disturbance in the habitat conditions and subsequently impact negatively on the sustainability of aquatic/ riparian biota. Man-made structures considerably alter the flow regime and through analysis of historical records, these alterations to hydrologic regimes can be evaluated [5, 6]. Comparison of flow records at a downstream flow gauging site during pre and post project period would be helpful in such evaluation of changes to flow regime [7].

The hydrologic changes due to inter-basin (from one river basin to another) and intra-basin (within a river basin) regulations of stream flow are reflected in the shape and characteristics of hydrographs and or flow duration curves. Along with moderated flood, other components of the hydrograph such as the timing and duration of low/high flows, the rate of change and the frequency of hydrograph rise/fall also contribute to the alterations in the aquatic life cycle [8] [9]. The magnitude, frequency, duration, timing and rate of change of flow conditions are the five major components which control the ecological processes in a river [10, 11].

Richter *et al*. (1996) [4] developed a method referred to as the 'Indicators of Hydrologic Alteration' (IHA) to assess the degree to which human disturbance impacts the hydrologic regime within an ecosystem. They proposed the Range of Variability Approach (RVA) [7] as a tool for evaluating alterations caused by human interventions in a naturally flowing river. The objective of the RVA is to guide efforts to restore or maintain the natural streamflow regime of a river, using the range of natural variability in thirty three different ecologically relevant flow parameters, as a basis for setting management targets. RVA is meant to enable river managers to define and adopt readily interim management targets before conclusive long-term eco-system research results are available [11]. The values of these parameters for undisturbed flow can be a guiding factor, to maintain the flow regime within a threshold limit of natural flow variability. These parameters were used to assess hydrologic alterations. Hydrologic Alteration (HA) can be defined as any anthropogenic disruption in the magnitude or timing of natural river flow and is the measure of the degree to which the RVA target is not met. The mean and coefficient of variation for 32 parameters considered under IHA model study is used for Dundee Hydrological Regime Assessment Method (DHRAM) scoring.

The paper is organized to discuss both the positive and negative impacts of inter-basin water transfer (from one river basin to another) and intra-basin (within the basin) regulations. Section II gives the details of study area, the Periyar and Muvattupuzha river system, in the Central Kerala, Southern India. Statistical methods and models used to quantify the impacts of regulations and hydrologic alterations are detailed in section III. Results of time series analysis, non-parametric trend analysis and hydrologic alteration studies are detailed in section IV. Conclusions are detailed in Section V and scope for future research is given in Section VI.

II. PERIYAR AND MUVATTTUPUZHA RIVER BASINS

Periyar river basin is located in the Central part of Kerala State, India (Figure-1). There are twelve reservoirs in Periyar river basin; all of them fall under seven hydroelectric projects. With a catchment of area of 5398 sq km, the Periyar river basin is one of the largest river basins in the Kerala State, India [12]. The Periyar river basin is flanked by the Chalakudy river basin on the north and the Muvattupuzha and Pamba river basins on the south (figure 1). From its source at 1850 m above the mean sea level (amsl), the Mullayar flows down traversing 48 km, and joins the Periyar from its right at an elevation of 850 m amsl. The Periyar river continues to flow towards the west for another 16 km and passes through a narrow gorge, where the Mullaperiyar dam was constructed in 1896, which gave birth to Periyar lake, famous for its wildlife. The Idukki HE project with an effective storage of 1459 million cubic meters located further downstream at an elevation of 540 m amsl. The tail race from the

Idukki project, after harnessing power, is diverted to the Muvattupuzha river basin located on the southern side of the Periyar river basin. Several small HE projects were developed in Periyar river basin before commissioning of Idukki H E P. Idamalayar HE project in (Idamalayar River), with an effective storage of 1017.8 million cubic meters and Lower Periyar H E Project (Periyar Main Stream) with an effective storage of 4.55 million cubic meters were subsequently commissioned in the Periyar river basin, which contribute to intra- basin regulations [13].

Vembanad wetlands *(a Ramsar site rich in bio-diversity)*, Corporation of Cochin, and fast growing industrial belt of Kerala are located in the lower reaches of Periyar river. Two major irrigation projects [(Periyar Valley Irrigation Project (PVIP) and Idamalayar Irrigation Project (IIP)] receive water from the Periyar river. About 48 water supply intakes [rural and urban schemes coming under Kerala Water Authority (KWA)] receive water from Periyar river. Tourism and Inland water transport are other two sectors which depend on Periyar river [13].

Commissioning of Idukki dam resulted in inter-basin water transfer and the other two dams (Idamalayar and Lower Periyar) resulted in within basin (intra-basin) regulation. After commissioning of Idukki dam, on an average 45 cubic meters/ sec of water is transferred to adjoining Muvattupuzha river. The positive and negative impacts due to changes in streamflow regime in the Periyar and Muvattupuzha rivers for different degree of regulations is analyzed in this paper.

III. METHODS

In the present study, an attempt is made to analyze the changes in the streamflow pattern in the Periyar and Muvattupuzha rivers due to regulated release from H E Schemes in the basin using historical streamflow records. The impacts of reservoirs on streamflow before and after commissioning of Idukki (1976), Idamalayar (1987) and Lower Periyar (1999) were analyzed based on data available before and after commissioning of these projects.

3.1. Time Series Analysis

Streamflow data at three gauging stations Neeleshwaram (1964-2011) [Central Water Commission, Government of India] and Kalady (1964-2009) [Water Resources Department, Government of Kerala] in the Periyar river and Muvattupuzha (1964-2009) [Water Resources Department, Government of Kerala] in the Muvattupuzha river (Figure 1) were used to analyze flow regime changes before and after commissioning H E projects. Temporal variations of gauged streamflow for different magnitudes of regulation were analyzed. Six monthly, four monthly, three monthly and monthly time series for different conditions were analyzed. Impact of flow regulation on flood and fair-weather flow were analyzed. Streamflow for different reliability levels were also quantified for different magnitudes of regulation, based on the analysis.

3.2. Mann-Kendall Trend Analysis

Mann-Kendall trend analysis was also performed to bring out the significance of streamflow trends after commissioning of these large storage structures [14,15]. This test compares the relative magnitudes of sample data rather than the data values themselves. A Z value can be obtained from the test and can then be used to determine the significance of any trend in the data set. One benefit of this test is that the data need not conform to any particular distribution.

Moreover, data reported as non-detects can be included by assigning them a common value that is smaller than the smallest measured value in the data set. When multiple data points exist for a single time period, the median value is used.

$$VAR(S) = 1\ [n(n-1)(2n+5) - \Sigma\ t_p(t_p-1)(2t_p+5)] \quad \ldots(1)$$

Where n is the number of data points, g is the number of tied groups (a tied group is a set of sample data having the same value), and *p t* is the number of data points in the p_{th} group.

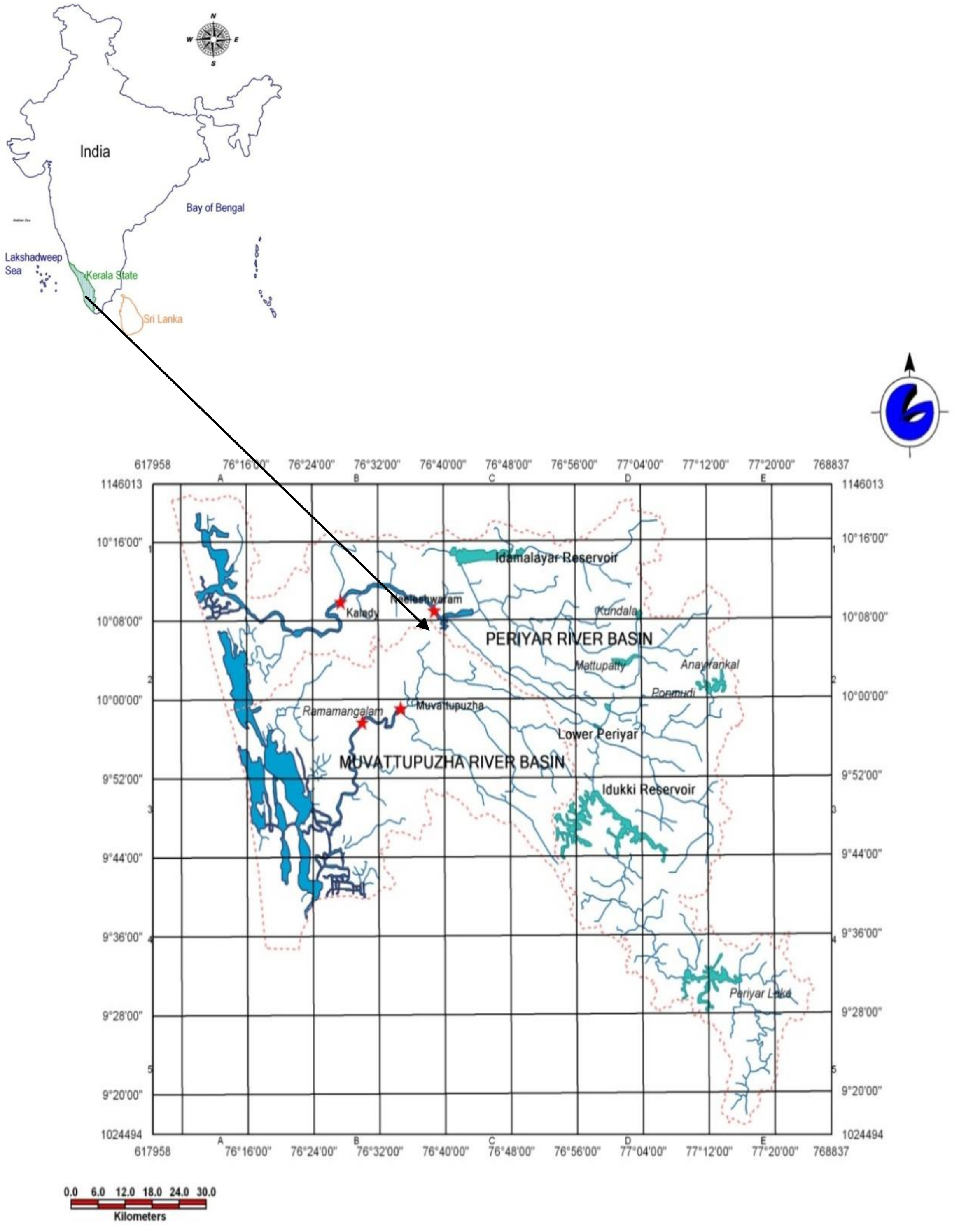

Figure-1 Periyar and Muvattupuzha river basins in Central Kerala

Compute a normalized test statistic Z as follows:

$$Z = (S-1) / [\mathrm{Var}(S)]^{1/2} \quad \text{if } S > 0 \quad \dots (2)$$

$$Z = 0 \quad \text{if } S = 0 \quad \dots (3)$$

$$Z = (S+1) / [\mathrm{Var}(S)]^{1/2} \quad \text{if } S < 0 \quad \dots (4)$$

The trend is said to be ***decreasing*** if Z is negative and the computed probability is greater than the significance level. The trend is said to be ***increasing*** if the Z is positive and the computed probability is greater than the level of significance. If the computed probability is less than the level of significance, there is ***no trend***. Different significance levels (99.9%, 99%, 95% and 90%) were chosen as the criteria for determining if a trend was present. 95% significance in a case means that if a trend is identified as significant (either positive or negative) that there is only a 5% (1 in 20) chance that the trend is actually not present. Conversely, it could also be said with 95% certainty that the trend is statistically significant.[16,17]

3.3. Indicators of Hydrologic Alteration (IHA) study

Thirty-three parameters considered in the IHA software can be lumped into five groups: (1) magnitude of monthly flow conditions; (2) magnitude and duration of extreme flow events (e.g. high and low flows); (3) the timing of extreme flow events; (4) frequency and duration of high low flow pulses; and (5) the rate and frequency of changes in flows. For these parameters, the IHA can perform a Range of Variability Analysis. Hydrologic Alteration (HA) can be defined as any anthropogenic disruption in the magnitude or timing of natural river flow. HA is the measure of the degree to which the RVA target is not met. Summary of parameters used in the IHA Model is given in table-1.

Table 1 Summary of hydrologic parameters used in Range Variability Approach

General group	**Regime features**	**Hydrologic Parameters**
Group 1: Magnitude of monthly water conditions	Magnitude, timing	Mean value for each calendar month
Group 2: Magnitude and duration of annual extreme conditions	Magnitude, duration	Annual minimum 1-day means Annual maximum 1-day means Annual minimum 3-day means Annual maximum 3-day means Annual minimum 7-day means Annual maximum 7-day means Annual minimum 30-day means Annual maximum 30-day means Annual minimum 90-day means Annual maximum 90-day means
Group 3: Timing of annual extreme water conditions	Timing	Julian date of each annual 1day maximum & 1 day minimum
Group 4: Frequency and duration of low and high pulses	Magnitude, frequency, duration	Number of high pulses each year Number of low pulses each year Mean Duration of high pulses and low pulses within each year
Group 5: Rate and frequency of water condition change	Frequency, rate of change	Means of all positive differences between consecutive daily values Means of all negative differences between consecutive daily values Number of rises Number of falls

3.4 Dundee Hydrologic Regime Assessment Method (DHRAM)

The DHRAM Water Flow Analysis Tool is used to compare the un-impacted and impacted flow regimes and to assess the significance of the alterations in flow circumstances. DHRAM assess changes in hydrological regime and is based on IHA. Comparison of pre-project daily time series with post project flow series will help in characterization of changes [18]. It uses daily flow time series data at the site before and after intervention. For each of the 32 IHA parameters, an absolute percentage change in mean and coefficient of variation (%) values are generated. For each of the five IHA groups, averages of mean and coefficient of variation (%) are found out. Then a system of allocating points to indicate the relative degree of severity in each group is applied.
DHRAM scoring for different degree of regulations in the Periyar and Muvattupuzha rivers at different gauging sites was arrived at using daily streamflow records.

IV. Results and Discussions

Six monthly, four monthly and three monthly time series analysis was carried out for different streamflow regulation conditions. Before commissioning of Idukki dam in 1976, the existing seven dams were regulating the flow in Periyar. The total catchment area under these reservoirs is 630.33 sq kms, which was 12 % of the total catchment area of Periyar river basin. Idukki reservoir receives water from 649.31 sq km catchment and it is transferred to adjacent Muvattupuzha river basin after power generation at Moolamattom. A considerable reduction in streamflow for different time series can be noticed in table-2 after this diversion.

Idamalayar project was commissioned in 1987 and this H E project with a free catchment of 380.73 sq km an effective storage of 1017.80 million cubic meters considerably improved the flood moderation and lean flow augmentation conditions in the basin. The Lower-Periyar HEP was commissioned in 1997. Reliable streamflows for south west monsoon period (June to August) and second half of summer period (March to May) for different regulation intensities in the Periyar river are shown in figures 2 and 3. The negative impacts of inter-basin transfer after implementation of Idukki H E Project can be clearly noticed (Table-2, Figures 2-3). The conditions downstream, especially during fair weather flow period (November to May) worsened considerably after water transfer to Muvattupuzha river basin, causing more intense water quality deterioration and salinity intrusion conditions during summer months. Several water supply schemes and industries were also affected by the reduction in fresh water flow.

The water transfer after power generation from Idukki HEP to adjacent Muvattupuzha river basin created a completely different flow regime compared to the natural flow condition. Figure 4 shows the eco surplus condition created in the Muvattupuzha river after commissioning of Idukki reservoir. The reliable flows in the river during summer period were much higher than the natural condition, after the inter-basin diversion.

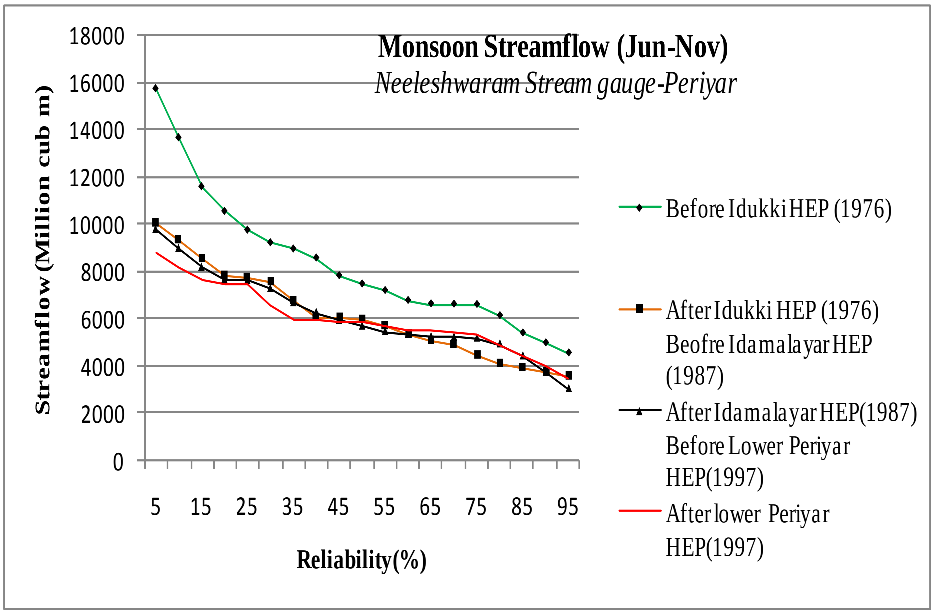

Figure-2 Reliable monsoon streamflow for different degree of regulations-Periyar river

Table-2 Mean streamflow for different time series -Kalady streamgauge station-Periyar river basin

TIME SERIES	Before Idukki HEP 1964-1976	After Idukki HEP 1979-86	After Idamalayar HEP 1987-1996	After Lower Periyar HEP 1997-2009
	Flow for the period as % of annual flow *(Change from before Idukki Dam Condition in %)*			
Monsoon Flow (Jun-Nov)	90.88	91.37 *(+0.49)*	84.5 *(-6.38)*	79.08*(-11.80)*
Non-Monsoon Flow (Dec-May)	9.12	8.63 *(-0.49)*	15.5 *(+6.38)*	20.92*(+11.8)*
Karif (Virippu -June-Sept)	74.92	76.44 *(+1.52)*	67.86 *(-7.06)*	64.9*(-10.02)*
Rabi (Mundakan Oct-Jan)	21.13	19.06 *(-2.07)*	21.67 *(+0.54)*	20.15*(-0.98)*
Summer (Puncha Feb-May)	3.95	4.5 *(+0.55)*	10.47 *(+6.79)*	14.95*(+11)*
South –West Monsoon (Jun-Aug)	63.42	66.23 *(+2.81)*	55.18 *(-8.24)*	52.57*(-10.85)*
North-East Monsoon (Sept-Nov)	27.46	25.14 *(-2.32)*	29.32 *(+1.86)*	26.51*(-0.95)*
First Half of summer (Dec-Feb)	5.79	4.87 *(-0.92)*	6.8 *(+1.01)*	8.21*(+2.42)*
Second Half of summer (Mar-May)	3.33	3.76 *(+0.43)*	8.7 *(+5.37)*	12.71*(+9.38)*

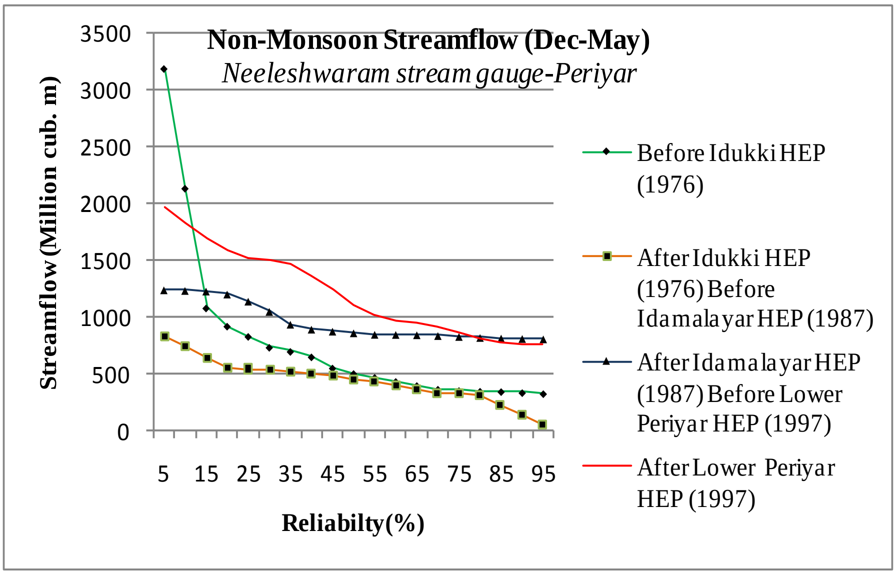

Figure-3 Reliable non-monsoon streamflow for different degree of regulations-Periyar river

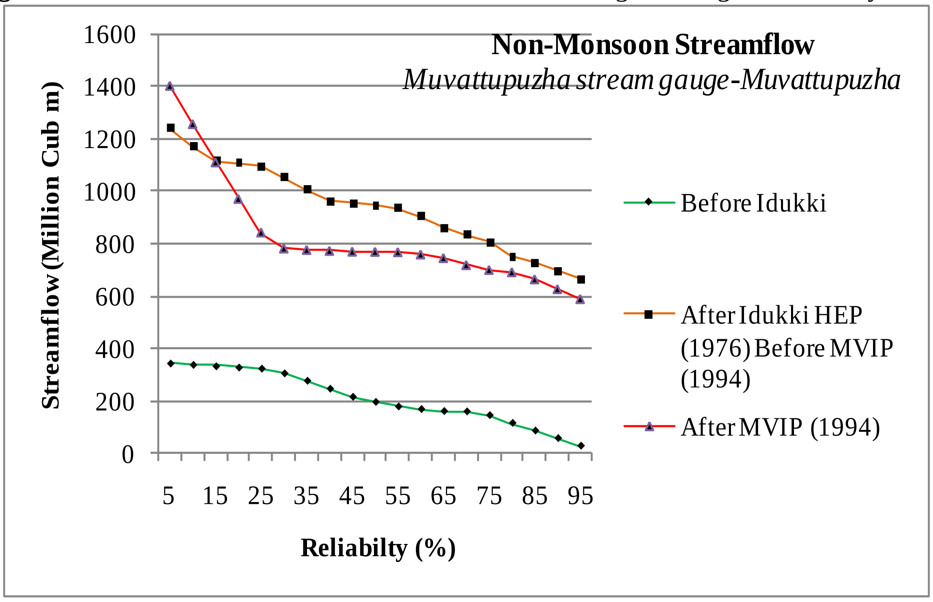

Figure-4 Non-monsoon streamflow- Muvattupuzha river

Table-3 Mann-Kendall Trend Statistics-Streamflow-1971-2011, Neeleshwaram

Time series	1964-85 (19 Years) Idukki Dam (1976)		1964-1997 (31 Years) Idukki Dam (1976), Idamalayar Dam (1987)		1964-2011 (44 Years) Idukki Dam (1976), Idamalayar Dam (1987), Lower Periyar dam (1999)	
	Test Z	Significance	Test Z	Significance	Test Z	Significance
Monsoon (Jun-Nov)	-1.42		-1.23		-1.44	
Non-Monsoon (Dec-May)	-0.77		3.48	***	3.93	***
Virippu (Jun-Sept)	-1.31		-1.36		-1.72	+
Mundakan (Oct-Jan)	-1.97	*	0.24		1.10	
Puncha (Feb-May)	-0.44		2.73	**	3.62	***
S-W Monsoon (Jun-Aug)	-1.31		-1.77	+	-2.23	*
N-E Monsoon (Sep-Nov)	-2.19	*	0.15		-0.19	
Summer 1 (Dec-Feb)	-0.88		3.15	**	2.97	**
Summer-2 (Mar-May)	-0.44		2.36	*	3.35	***
Annual	**-1.64**		**-0.48**		**-0.59**	

******* if trend at α = 0.001 level of significance, ****** if trend at α = 0.01 level of significance
***** if trend at α = 0.05 level of significance, **+** if trend at α = 0.1 level of significance

Non-parametric Mann-Kendall trend analysis results for different degree of regulations in the Periyar river is detailed in table-3. The trend turned to significantly positive for non- monsoon, Puncha cultivation Period (February to May (4-monthly time series)) and second half of summer (March – May, (3 monthly time series)) after commissioning of Idamalayar and Lower Periyar reservoirs (table-3).

The hydrologic alteration magnitudes were assessed for thirty two flow related parameter using IHA model study (Table-1). The mean hydrologic alteration in Periyar and Muvattupuzha rivers for different degree of regulations are detailed in the table-4. Hydrologic alterations showed a decreasing trend after the Lower Periyar HEP (1997) in the Periyar river and after Muvattupuzha Valley Irrigation Project (1994) in the Muvattupuzha river. Table-5 shows results of DHRAM study. The analysis show that due to flow regime changes the Periyar river flow is classified under moderate risk category and the Muvattupuzha under High risk catergory.

Table-4 Mean Hydrologic alteration calculated for different degree of regulations (IHA Model results)

Periyar river			**Muvattupuzha river**	
Before Idukki HEP & After Idukki HEP	Before Idukki HEP & After Idamalayar HEP	Before Idukki HEP & After Lower Periyar HEP	Before Idukki HEP & After Idukki HEP up to MVIP	Before Idukki HEP & After MVIP
55.93	61.69	61.25	69.91	65.49

Table -5 Impact points under DHRAM study (DHRAM scoring)

Groups	**Periyar river**						**Muvattupuzha river**			
	Before Idukki HEP & After Idukki HEP		Before Idukki HEP & After Idamalayar HEP		Before Idukki HEP & After Lower Periyar HEP		Before Idukki HEP & After Idukki HEP up to MVIP		Before Idukki HEP & After MVIP	
	Mean (m^3/s)	CV (%)	Mean (m^3/s)	CV (%)	Mean (m^3/s)	CV (%)	Mean (m^3/s)	CV (%)	Mean (m^3/s)	CV (%)

Group 1: Magnitude of monthly water conditions	2	1	2	1	2	1	3	1	3	1
Group 2: Magnitude and duration of annual extremes	1	0	1	0	0	0	3	0	3	0
Group 3: Timing of annual extremes	2	1	2	1	1	3	1	3	3	3
Group 4: Frequency and duration of high and low pulses	0	1	2	1	1	0	1	0	1	1
Group 5: Rate and frequency of change in conditions	0	2	0	0	0	0	0	1	1	2
Total Points	**10**		**10**		**8**		**13**		**18**	
Classification	**Moderate risk of impact**						**High risk of impact**			

V. CONCLUSIONS

Impacts of inter-basin water transfer: The reliability and trend analyses clearly show that the inter-basin water transfer from Idukki H E Project to Muvattupuzha river basin has worsened the situations in the Periyar river basin, especially during summer period. There are several reports which support this conclusion that the inter-basin transfer from the Periyar to Muvattupuzha river basin created more salinity intrusion and water quality deterioration downstream due to reduced fresh water flow in summer months. [13.19]. As the summer flow increased substantially in Muvattupuzha river, salinity intrusion magnitude from Vembanad lake during summer also reduced considerably. Increased fresh water flow in Muvattupuzha river after power generation from Idukki HEP helped in commissioning several domestic water supply schemes from this river.

Impacts of intra-basin regulations: The analyses show that within the basin (intra-basin) regulations with the commissioning of Idamalayar HEP (1987) and Lower-Periyar HEP (1997), considerably improved flood moderation and lean flow augmentation in the Periyar river and reduced negative impacts of inter-basin water transfer under Idukki HEP.

Hydrologic alterations due to regulations: IHA model study shows that the hydrologic alterations in both the Periyar and Muvattupuzha rivers are above 50% and the values are showing a decrease as the water utilization from the rivers increased in the recent years. The eco-surplus condition created in the Muvattupuzha river due to water transfer from Periyar to Muvattupuzha river altered the flow regime considerably. A fish survey result [20] indicates considerable reduction in food & ornamental fish species in the river. DHRAM study classifies the impacts of regulations by HEPs in the Periyar river under the “Moderate risk” class. The inter-basin regulations created more impacts in the Muvattupuzha river and is classified under “High risk of impact” class.

The study shows that before inter-basin transfer/ intra-basin regulation, the water demands in all dependent sectors downstream are to be critically analyzed. The minimum downstream environmental flows requirements are also to be critically analyzed. Reservoir operation policies for a sustainable river basin management should take into consideration impacts associated with flow regulations along with power requirements and water demands in various sectors.

VI. SCOPE FOR FUTURE WORK

Future studies on reservoir operation policies should take into consideration the alterations in flow regime from natural / unaltered condition that exists before the projects. Multi-disciplinary groups may attempt impact studies of flow regimes changes on aquatic and riparian biota, in bio-diversity rich humid tropical river basins such as the Periyar-Muvattupuzha system, which are yet to be attempted.

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