RIVER– GROUNDWATER INTERACTION OF A TROPICAL SUB BASIN OF BHARATHAPUZHA, KERALA, INDIA

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ABSTRACT

Stable isotopes of oxygen and electrical conductivity of groundwater, river water and rain water were used to elucidate the river -ground water interaction in the Thuthapuzha Sub-Basin of Bharathapuzha, the second largest river basin in Kerala, India. River and groundwater samples representing the upstream, midstream and the downstream of the study area were collected during the pre monsoon, monsoon and post monsoon season and were analyzed for $\delta^{18}O$ and electrical conductivity. The river-groundwater interaction was estimated by applying the isotope mass balance and conductivity mass balance methods. The base flow of groundwater was maximum in the downstream and minimum in the upstream during pre monsoon and post monsoon seasons. The percentage contribution of base flow determined by the isotope mass balance method was 43%, 25 % and 17% during the pre monsoon and 38%, 27% and 15% during the post monsoon season for the downstream, midstream and the upstream respectively. The base flow contribution to the river computed by the conductivity mass balance method was slightly higher than the results obtained by isotope mass balance method and were 48%, 26% and 12% in pre monsoon and 43%, 20% and 10% in the post monsoon for the downstream, midstream and upstream. The recharge of groundwater by the river peaked during the monsoon season.

***Keywords:* Conductivity Mass Balance Method, Environmental Stable Isotopes, Isotope Mass Balance Method, River-Groundwater Interaction, Thuthapuzha Sub Basin, Kerala**

I. INTRODUCTION

Groundwater and surface water have been historically considered as isolated components of the hydrologic cycle and have been managed individually [1]. In recent years it has been recognized that the management of one component of the hydrologic system, such as a stream or an aquifer is only partly effective because each hydrologic component is in continued interaction with other components [2, 3]. Groundwater interacts with surface water in a variety of ways, principally by gaining water from and providing water to river systems [4]. The process of surface water- groundwater interaction is complex and is influenced by the geological and climatic setting of the environment and a variety of physiographic processes. They have significant implications on both water quantity and quality [5,6,7]

Various methods are employed to determine the process of surface water-groundwater interaction. Conventionally, groundwater level measurements are used to define the hydraulic gradient and the direction of groundwater flow. Flow measurements at various points along the stream are used to estimate the magnitude of gain to or loss from the underlying aquifer. Other tools used to investigate surface water - groundwater interaction include seepage meters [8], river bed piezometers [9], time-series temperature measurements [10] and hydraulic models [11]. Although each of these methods have their own merits, the need for extensive periodic measurements make these methods more laborious and error prone.

Hydrogeochemistry has also proved to be an effective tool for studying surface water groundwater interaction and deciphering the sources of water [12]. Different hydrochemical parameters such as conductivity, sodium, nitrate, silica etc. are widely used to determine the surface water- groundwater interaction under different climatic and geologic settings [13]. Isotopic tracers such as stable isotopes of oxygen and hydrogen are also employed successfully in surface water- groundwater interaction studies [14]. Compared to the other techniques, isotope techniques are less laborious and precise [15]. It is generally accepted that a multiple approach, in which isotope methods combined with other methods provides the most accurate picture of interaction with the greatest levels of certainty [16].

The quantification of surface water -groundwater interactions using isotope and geochemical tracers is achieved by applying the isotopic or geochemical mass balance methods [17]. Interaction of river and the groundwater components in the Huaisha River basin of China [18], the Huasco and Limari river basins in the North Central Chile [19], the Hillsborough River watershed of West-Central Florida [20] etc. was estimated by applying the isotope mass balance and the conductivity mass balance method with other conventional methods like groundwater level monitoring and stream flow measurements.

The isotope mass balance methods have also been successfully employed in India in estimating the regeneration of river Ganga [21] and Yamuna [22], interaction of Nainital lake with groundwater [15] etc. All these studies focused mainly on the water resources of Himalayan region. In southern India, estimation of the hydraulic connection of Sasthamkotta lake of Kerala with the groundwater has been attended [23] by using isotope techniques. However, extensive studies using isotope techniques in water resources are limited in southern India.

The present study area lies in the state of Kerala located in the southwestern corner of Indian Peninsula as a long and narrow strip of land bordered by the Western Ghats in the east and the Lakshadweep Sea in the west. The state is popularly known as 'Gods own country' for its greenery, copious rainfall (3000mm/year) and water resources (44 rivers and their tributaries) giving the impression that the state has enough water resources for all its needs. However, due to the spatio-temporal variations in the distribution of rainfall and undulating topography with steep seaward slopes most of the water in the rivers quickly drains to the Arabian Sea. To cope with limited water resources available in various rivers, particularly during the non monsoon months, the groundwater is also intensively extracted to cater for the water demands of the State. Unsustainable exploitation of both river water and groundwater often lead to the lowering of groundwater table [24] saline intrusion [25] and reduction of base flow of groundwater to the rivers during periods of low flows [26]. Since flow of rivers during summer months are sustained mainly by the contribution of groundwater base flow [27], overexploitation of groundwater may even lead to the shifting of rivers from a perennial flow regime to an ephemeral flow regime. In this scenario, it is extremely important to understand and quantify the river-groundwater interaction for determining safe levels of groundwater allocation. It also helps to maintain river flows and also to identify transportation of contaminants across the river and groundwater.

The present study attempts to investigate river water – groundwater interactions in a tropical Sub-Basin (Thuthapuzha Sub-Basin) of Bharathapuzha, the second longest and second largest river basin of Kerala. The interaction between groundwater and river water is estimated by applying the two component oxygen isotope mass balance method. The results obtained by the isotope mass balance method are also compared with the conductivity mass balance method.

II. STUDY AREA

Thuthapuzha Sub- Basin is a sixth order basin covering an area of 1018 km^2 and located within the Palakkad and Malappuram districts of Kerala. Flowing between latitude 10°50’ to 11°15’ North and longitude 76° 05’to76°40’, Thuthapuzha is about 63 km in length with an average annual discharge of 1750 MCM [28]. There are four tributaries draining to Thuthapuzha namely Kuntipuzha, Nellipuzha, Kanhirapuzha and Thuppanadpuzha (Fig.1). Apart from the reservoir which is built across Kanhirapuzha that serves as a source of water for irrigation, there are no other major structures built in the river course.

The study area falls within three physiographic zones of Kerala state namely the high lands (600-2500m elevation above mean sea level), the midlands (300 – 600 m elevation above mean sea level) and the low lands (10-300m elevation above mean sea level). The Silent Valley Reserve Forest, the core of the Nilgiri Biosphere Reserve, is located at the northeastern corner of the Sub- Basin. The study area experiences a humid tropical climate and wide variation in rainfall ranging from 2800 mm to more than 5000mm/year, the rainfall is higher towards the north eastern part. Like the other part of Kerala State, the region also experiences two distinct monsoons, namely the south-west monsoon (June- September) and north-east monsoon (October-December). The south west monsoon accounts for about 65% of the annual rainfall, the north east monsoon and the summer showers contribute the rest total annual rainfall in the Sub Basin.

The study area comprises of a variety of Precambrian crystalline rocks like charnockite, charnockitic gneiss, hornblende biotite gneiss, garnet biotite gneiss, khondalites and migmatites etc. [29]. Charnockite occupies the greatest area and is characterized by well developed foliation, at many places, striking WNW-ESE with a southward dip of 30^0-50^0 [30]. A gabbro dyke traverses extensive lengths of the study area. The dyke trends in the NW- SE direction and the width of the dyke varies from 30 to 50m [31]. Laterite is observed as a capping over the major part of the study area. The thickness of the laterite exhibits considerable spatial variations with a maximum thickness of 20m along the western part. Towards the eastern part, laterite is either absent or observed as thin capping over the country rock.

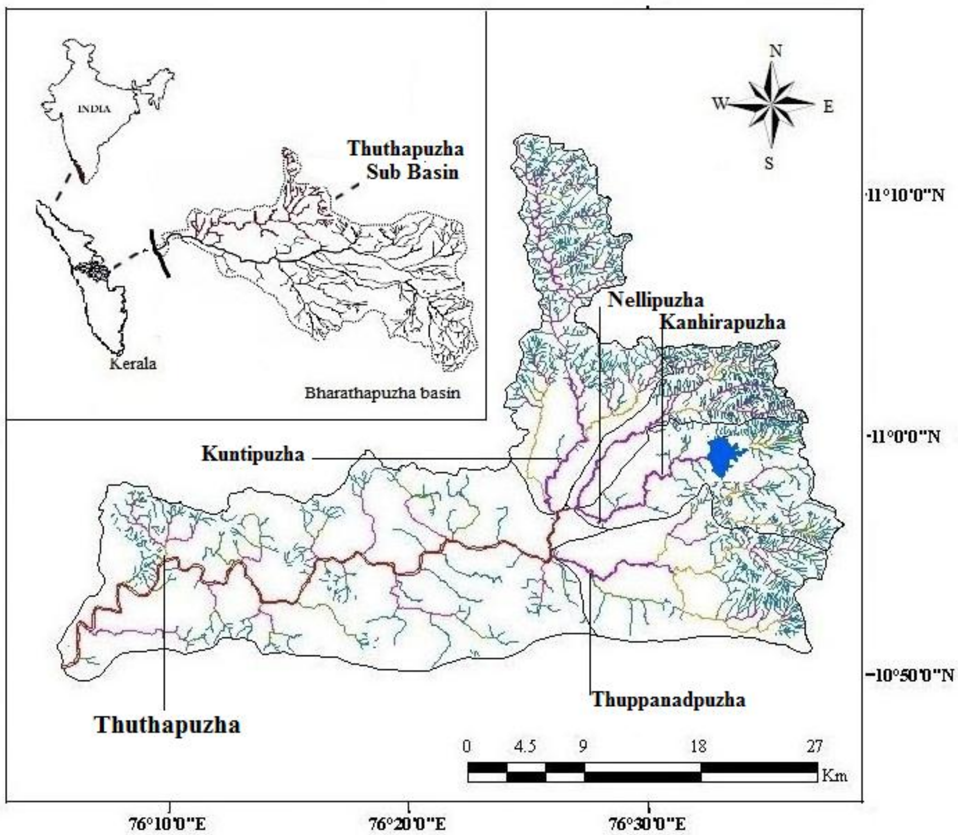

Fig.1.Location Map of the study area

III. METHODOLOGY

River water samples (n-5) were collected from the upstream (elevation greater than 80m above msl), midstream (50-80m above msl) and downstream (20-50 above msl) of the Sub-Basin (n-7 each). Groundwater samples were also collected from the upstream (n-5), mid stream (n-15) and downstream (n-15) of the study area. Rain water was collected from Pattambi, a station located in the downstream of the study area. These samples were collected during the pre monsoon, monsoon and post monsoon seasons.

Electrical conductivity of the samples was measured from the field itself using water analyser kit (Horiba U-10). For $\delta^{18}O$ measurement, the samples were taken in clean polythene (Tarson) 60 ml bottles by filling to the maximum level leaving only a little space (for thermal expansion) and closing the bottle tightly to avoid isotope exchange with air moisture. The samples were analyzed using continuous flow Isotope Ratio Mass Spectrometer (FINNIGAN DELTA^{PLUS} XP) housed at the Isotope Hydrology Division of Centre for Water Resources Development and Management. The oxygen isotope ($\delta^{18}O$) was analyzed using the CO_2-H_2O equilibration method (Epstein and Mayeda, 1953). The measurements were carried out against secondary laboratory standards that are periodically calibrated against the international isotope water standards recommended by IAEA (Vienna Standard Mean Ocean Water (V-SMOW), Greenland Ice Sheet Precipitation (GISP) and Standard Light Antartic Precipitation (SLAP). The analytical reproducibility of the oxygen isotope result is 0.08‰.

IV. RESULTS

The groundwater and river water levels were monitored at all the sampling stations during the pre monsoon, monsoon and the post monsoon seasons. In the study area, the water table elevation above mean sea level varied between 18m-157m during the pre monsoon, 21m-158m during the post monsoon season and 25- 159 m during the monsoon season. Except at a few locations, the groundwater table was above the river level during the pre monsoon and post- monsoon seasons. The contours of the water-table elevation above the mean sea level pointed in the upstream direction where they crosses the river during the pre monsoon and post monsoon seasons (Fig.2a and b) giving an indication that the river is effluent during these seasons. During the monsoon season, the river water level was above the groundwater level. The contours of the water table elevation pointed in the downstream direction of the river (Fig.2.c) which reflects the recharge of groundwater by the river

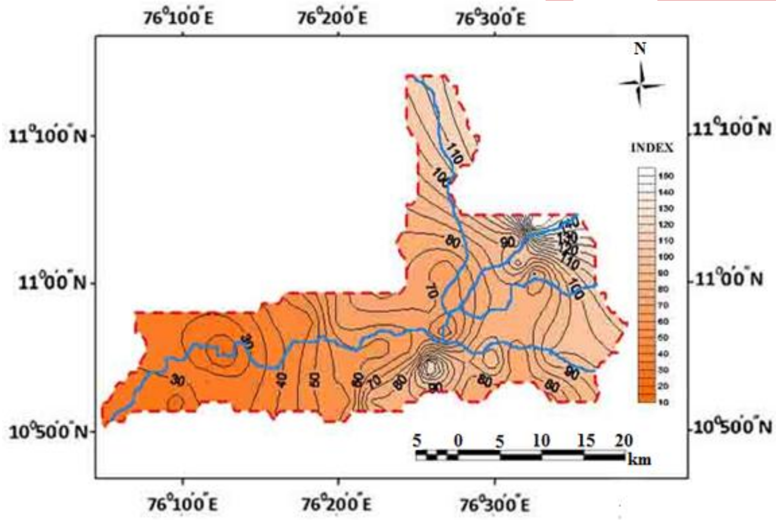

Fig.2.a. Water level contour map of Pre monsoon season

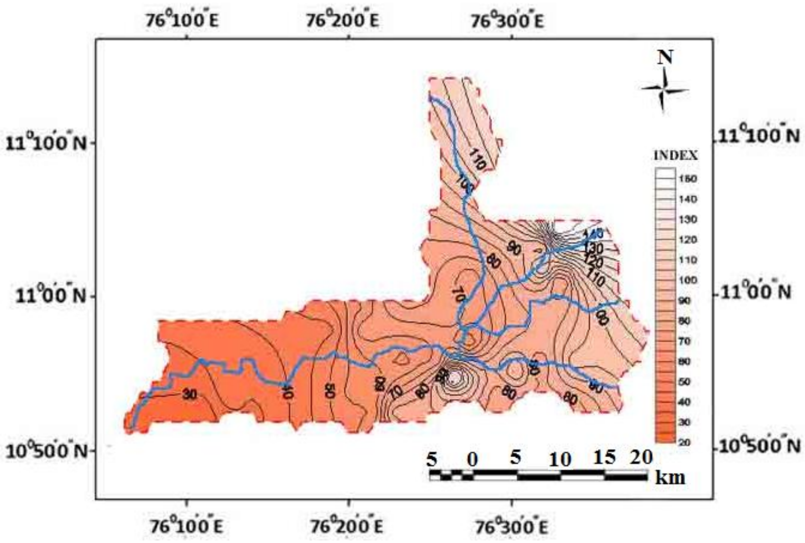

Fig.2.b. Water level contour map of Post monsoon season

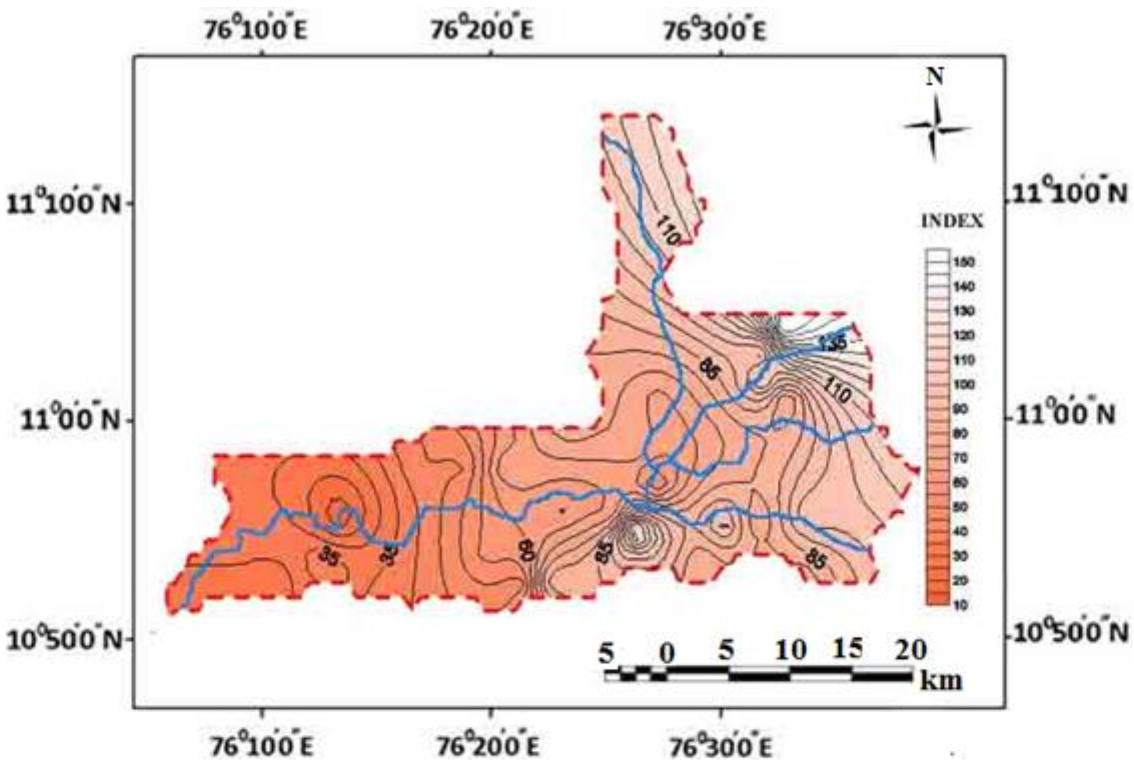

Fig.2.c. Water level contour map of Monsoon season

4.1 Stable isotope variations

The average $\delta^{18}O$ concentration of the river, groundwater and admixture representing the three sections (upper, middle and lower reaches) of the Sub- Basin during the pre monsoon, monsoon and post monsoon period are given in Table 1. The average $\delta^{18}O$ concentration of groundwater samples were -3.55‰, -3.73‰ and -3.82‰ during the pre monsoon and -3.80‰, -3.85‰ and -3.85‰ during the post monsoon season for the lower, middle and upper reaches of the river basin respectively. During the monsoon season the average $\delta^{18}O$ concentration of the groundwater were -3.78‰ for the lower reaches, -3.95‰ for the middle reaches and -4.21‰ for the upper reaches of the river basin. The river water also exhibited both spatial and temporal variations in $\delta^{18}O$ concentration. Compared to the groundwater, the river water was depleted in ^{18}O concentration during the monsoon season in all the three sections of the river basin. However, during the pre monsoon season and in post monsoon season, the river in the lower reaches was observed to be enriched than the groundwater which may be due to the effect of evaporation.

TABLE. 1. $\delta^{18}O$ (‰) of water samples of Thuthapuzha Sub- Basin

Location	**Source of Sample**	**Premonsoon $\delta^{18}O$ (‰)**	**Monsoon $\delta^{18}O$ (‰)**	**Post Monsoon $\delta^{18}O$ (‰)**
Upstream	River	-4.46	-4.59	-4.80
	Groundwater	-3.82	-4.21	-3.85
	Admixture	-4.35	-4.33	-4.66
Midstream	River	-3.25	-4.36	-4.49
	Groundwater	-3.73	-3.95	-3.85
	Admixture	-3.13	-4.04	-4.32
Downstream	River	-2.90	-4.03	-3.40
	Groundwater	-3.55	-3.78	-3.80
	Admixture	-2.62	-3.81	-3.25

4.2 Electrical Conductivity

The electrical conductivity provides a proxy for the hydrochemistry of the study area (Table.2). The electrical conductivity of Thuthapuzha river water ranged from 46 to 90µS/cm during the pre monsoon and 35-47µS/cm during the post monsoon season. In the monsoon season the electrical conductivity was slightly less and varied from 40-81 µS/cm. The river water displayed uniform pattern in the distribution of electrical conductivity by its increase towards the downstream direction irrespective of seasons. The electrical conductivity of the groundwater was observed to be higher than the river water in all the three seasons, reflecting the higher amount of dissolved solids.

4.3 Estimation of river- groundwater interaction

The river- groundwater interaction was estimated based on the mass balance approach, which assumes that the isotopic ($\delta^{18}O$) or chemical signature of water (electrical conductivity) of various water sources are unique and that conservation of mass applies to the water quantities and water quality including conservative mixing of different water components [32,33].

TABLE. 2. Electric conductivity (EC) of water samples of Thuthapuzha Sub- Basin

Sampling Location	**Source of Sample**	**Pre monsoon EC (µS/cm)**	**Monsoon EC (µS/cm)**	**Post Monsoon EC (µS/cm)**
Upstream	River	46	35	40
	Groundwater	144	141	138
Midstream	River	65	45	53
	Groundwater	154	145	150
Downstream	River	90	47	81
	Groundwater	153	160	150
	Rainwater	33	32	29

Using the Isotope Mass Balance method, the groundwater contribution to the river was evaluated using the equation (3) given below. According to mass balance equation

$$m1R1 + m2R2 = RAM \quad (1)$$

and $m1 + m2 = 1$ (2)

According to this equation, the groundwater contribution to the river

$$m1 = \frac{R2 - RAM}{R2 - R1} \quad (3)$$

The recharge of groundwater by the river is expressed as

$$m2 = \frac{R1 - RAM}{R2 - R1} \quad (4)$$

Where m_1 and m_2 are the fractions of groundwater and river water in the admixture, R_1 the isotopic composition of the groundwater body, R_2 the isotopic composition of the river and R_{AM} the isotopic composition of the admixture.

Both $\delta^{18}O$ and $\delta^{2}H$ can be applied in eqn.3 and eqn.4 to determine the groundwater interaction. In the present study, $\delta^{18}O$ values have been used to determine the river-groundwater interaction.

Using electrical conductivity mass balance method, the ratio of the subsurface/ groundwater flow to the total flow is expressed as

$$QG/QT = (EC\ River - ECRain) / (EC\ Groundwater - ECRain) \quad (5)$$

Where $EC_{River,,}$ $EC_{Groundwater}$, EC_{Rain} stands for the electrical conductivity of the river, groundwater and rain respectively.

The surface water- groundwater interaction computed using the oxygen isotope mass balance and conductivity mass balance method is presented in Table.3 and graphically presented in Fig.3 and 4. The percentage contribution of base flow determined by the oxygen isotope mass balance method showed a minimum contribution of 17% in the upstream to a maximum contribution of 43% in the downstream during the pre monsoon season. During the post monsoon season, the base flow was 38%, 27% and 15% for the downstream, midstream and upstream respectively. The results show that the base flow of groundwater contributes significantly in the maintenance of the river flow during both pre monsoon and post monsoon seasons. The ground water contribution to the river was also observed to be pronounced in the lower reaches and was relatively higher in the pre monsoon season.

TABLE.3. Percentage of base flow /recharge estimated using oxygen isotope mass balance and conductivity mass balance methods

Sampling season	Sampling Location	% of base flow using $\delta^{18}O$ (‰)	% of base flow using EC (µS/cm)
Pre monsoon	Upstream	17	12
	Midstream	25	26
	Downstream	43	48
Monsoon	Upstream	-32	-36
	Midstream	-22	-20
	Downstream	-11	-13
Post monsoon	Upstream	15	10
	Midstream	27	20
	Downstream	38	43

The base flow estimated by the conductivity mass balance method during the pre- monsoon season were 48%, 26% and 12% for the downstream, midstream and upstream of the sub-basin. Compared to the pre monsoon season, the groundwater contribution to the river in the post monsoon season was observed to be less in the downsream, midstream and upstream (43%, 20% and 10% respectively). The results estimated by the conductivity mass balance method was in agreement with the results obtained by isotope mass balance method with base flow contribution increasing towards downstream during both pre monsoon and post monsoon seasons. The water table elevation contours pointing in the upstream direction of the river where it crosses it (Fig. 2a & b), also supports the base flow of groundwater during the pre monsoon and post monsoon seasons.

Groundwater recharge in the monsoon season estimated by the isotope mass balance method was minimum (11%) in the lower reaches and maximum in the upper reaches (32%). The contribution of groundwater in the midstream was estimated as 22%. The recharge estimated by the conductivity mass balance method also showed a similar trend with maximum recharge of 36% in the upper reaches and minimum recharge of 13% in the lower reaches. This is also supported by the groundwater elevation contours pointing in the downstream direction where it crosses the river. Thus, during the monsoon period the entire stretch of Thuthapuzha sub- basin is recharged by the river water with groundwater recharge by the river decreasing towards the downstream direction.

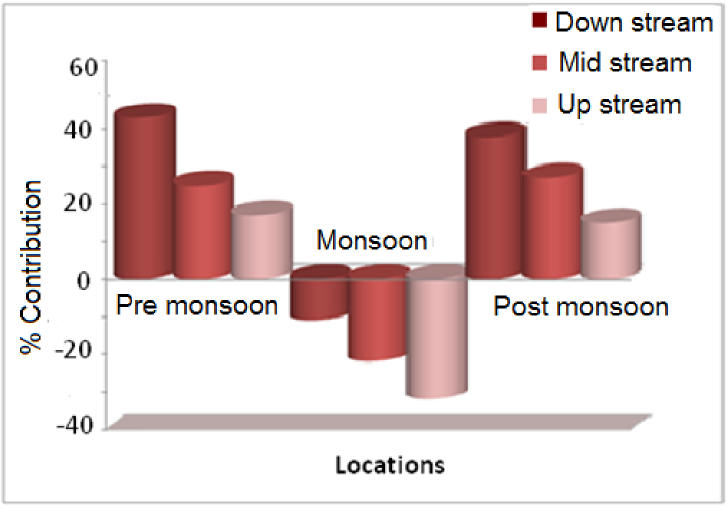

Fig.3. Percentage contribution of base flow/ recharge estimated using isotope mass balance method

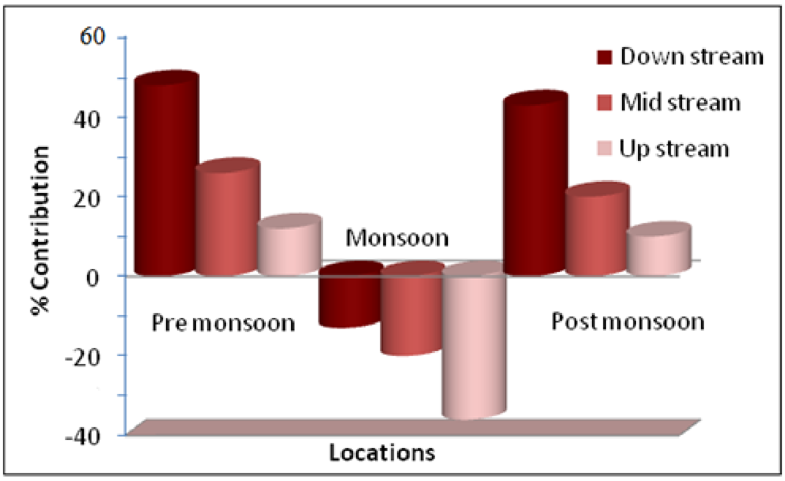

Fig.4. Percentage contribution of base flow/ recharge estimated using conductivity mass balance method

VI. CONCLUSIONS

The oxygen isotope mass balance and conductivity mass balance methods were employed to estimate the river water – groundwater interaction in Thuthapuzha Sub-Basin of Bharathapuzha. The following are the major inferences.

- The results obtained through the isotope mass balance method broadly agree with the results obtained by the conductivity mass balance method.
- Both the isotope mass balance and conductivity mass balance method demonstrated that the base flow of groundwater contributed significantly for sustaining the river flow during the pre monsoon and post monsoon seasons.
- The base flow of groundwater to the river exhibited both spatial and temporal variations. The base flow was observed to be maximum in the downstream and minimum in the upstream of the Sub-Basin during both pre monsoon and post monsoon seasons. The contribution of base flow during the pre monsoon was observed to higher than during the post monsoon season.
- The groundwater recharge by the river was significant only during the monsoon season in the upstream and midstream of the river.

VII. ACKNOWLEDGEMENTS

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