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OXYGEN AND HYDROGEN ISOTOPIC CHARACTERISTICS 
OF THE KAVERI RIVER SURFACE WATERS, SOUTHERN PENINSULAR INDIA 

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Abstract 

We present in this paper the spatial distribution of stable isotopic composition ($\delta^{18}O$ and $\delta D$) of Kaveri River surface waters to understand how the evaporation and precipitation affect the isotopic signature and dynamics of surface river waters. In the southern peninsular India, Kaveri River is one of the longest tropical river. Our stable isotope data indicate that the upper Kaveri region is influenced strongly by the SW monsoon. There is a narrow range between the $\delta^{18}O$ values found from the origin of the Kaveri River to its delta, and there is no significant orographic impact of the Western Ghats. A decreasing trend of $d$ values is found along the course of the river. This is attributed to evaporation effects, which nevertheless are not very strong. This difference in deuterium excess due to evaporation is also an indication of the moisture recycling in the lower Kaveri area, which is primarily controlled by evaporation from the wetlands in the delta plain but also from the surface waters and as such from the rivers. 

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Introduction

A river is the life line of any region and a proper understanding of the hydrodynamics of the river system and the hydrological processes of the drainage basin helps in the proper management of the river water resources for irrigation, agriculture, industry and other socio – economic projects. In the tropics, especially in India, onset of monsoon, its dissemination over the Indian sub continent and its occasional failure is closely connected to the agroeconomy and industry of the region (Sengupta and Sarkar 2006). Spatial distribution of stable isotopic composition (δ18O and δD) of precipitation and surface waters of rivers are powerful tracers for identifying the sources of vapour generated during the monsoon and its continental mixing. Few studies have been carried out on the variables that influence stable isotopes values in the tropics (Slati et al., 1979; Longinelli and Edmond, 1983; Gat and Matsui 1991; Araguas-Araguas et al 1998; Njitchoua et al., 1997 ; Lachinet and Patterson 2002) and due to this our understanding of stable isotope values of tropical waters is often inadequate to interpret isotopic records that are preserved by paleoclimate archives such as sediment, carbonate and ice cores (Lachinet and Patterson, 2002). Compared to Europe (Ogrinc et al., 2008; Kanduč et al., 2008; Cortecci et al., 2009; Lambs et al., 2009), North America (Lachinet and Patterson, 2009), China (Hong –jun et al., 2007) and Mongolia (Tsujimura et al., 2007) work on stable isotopes data on Indian surface river waters and precipitation is scanty (Sengupta and Sarkar, 2006). Barring few studies carried out on Indian rivers - Ganga river and the Himalayan river waters (Ramesh and Sarin, 1992; Lambs et al., 2005; Gajurel et al., 2006), Gaula river catchment in the Kumaun Himalaya (Bartarya et al., 1995), no stable isotope analyses have been carried out till date on the peninsular river surface waters such as the Krishna, Godavari, Mahanadi and Kaveri. Ramesh and Sarin (1992) suggested that the high-altitude streams (Ganga headwaters) show a δD-δ18O relationship close to that of the global meteoric water line. Samples from the lowland regions show a significant effect of evaporation, indicated by a reduced slope (of approximately six) in a δ18O-δD plot. The easterly flowing peninsular rivers receive the monsoonal rains and debouche the sediments into the Bay of Bengal. There are very few stable isotopic data collected on river, rain and lake waters of southern India that reflect the characteristic of the hydrological cycle and the water of this region (Lambs et al 2005).

Here we present a stable isotope study of the Kaveri river from its origin to the delta with the aim to understand how evaporation and precipitation affects its isotopic signature. This study is the first data generated on the Kaveri river to understand the water cycle of its basin since this river is one of the longest draining the tropical southern peninsular India. The data obtained here may have important implications for understanding the dynamics of surface river waters in the tropics.
The Kaveri River

Application of the Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) analysis indicates that the average elevation of the basin is 564 m a.s.l. (Figure 1 and 2). About 42 percent of the basin area lies between 650 and 1000 m. This upland area in the headwaters constitutes the Mysore Plateau. Almost an equal percentage of the catchment area occurs below 400 m. Approximately one-tenth of the basin area is above 2000 m.

The Kaveri River basin lies between latitude 10° 07’ N to 13° 28’ N and longitude 75° 28’ E and 79°52, E and drains a catchment area of nearly 87,900 km². The river originates on the Brahmagiri Hills in the Western Ghats (elevation of 1345 m a.s.l.) (Singh and Rajamani 2001), in Coorg district of Karnataka state, flowing in a south-easterly direction for about 800 km through Karnataka and Tamil Nadu states, and descending the Eastern Ghats in a series of great falls. Before reaching the Bay of Bengal south of Cuddalore (Tamil Nadu), it breaks into a large number of distributaries forming a fan shaped Kaveri delta. Its uppermost course is trellis, tortuous with bed rock and high banks. The river bifurcates twice, forming the sacred islands of Srirangapatnam and Sivasamudram, 80.47 km apart. Upon entering Tamil Nadu, the Kaveri continues through a series of twisted gorges until it reaches Hogenakal Falls and flows through a straight, narrow gorge near Salem. The Mettur Dam, nearly 1606 m long and 53.3 m high, impounds the Kaveri River water forming a lake (Stanley Reservoir). Further down the Kaveri River bifurcates forming the Srirangam Island and the distributaries of the river are the Kolliam, Velar, Vettar and the Coleroon that form the delta system and the drainage pattern is largely braided.

The important tributaries joining the upper Kaveri are the Kakkabe, the Kadanur and the Kummahole while the important tributaries joining the middle reaches of the river from the left are the Harangi, the Hemavathi, the Shimsha and the Arkavathi. The tributaries joining it from the right are the Lakshmanathirtha, the Kabbani, and the Survanavathi. Further down, the lower Kaveri is joined by the Bhavani, the Noyil, and the Amravathi.

The Kaveri River drains over several bed rock types of different geological ages. In its upper and middle reaches the river flows over the peninsular gneiss, charnockites and granitic rocks of Archaean age (Fig. 1). Intrusions of Closepet granite and the schist belts of the Dharwar craton are also observed in the upper and middle reaches of the river. Subsequently, the river flows eroding the exposed Cretaceous deposits comprising conglomeratic sandstone, fossiliferous limestone and shale north of Tiruchirapalli, where the Kaveri starts forming a delta and incising the Quaternary alluvium (Pattanaik et al., 2007).
The sharp rise of the Sahyadris followed after the narrow western coastal belt (40-140 m) with step like escarpments are a consequence of the rejuvenated vertical movements along the North strike slip displacement along the Precambrian basement NNW-SSE faults (Valdiya 2001, Rajamani et al., 2009) and also the result of the Late Cretaceous plume activity that poured out to form the Deccan Basalts (Naqvi 2005).

Between the Mysore plateau and the plains, a series of structural blocks formed due to the collision of the Indian continent and the Asian continent (Radhakrishna 1993; Valdiya 1998) strongly guiding the river course. The catchment area is also crisscrossed by several N-S and E-W striking shear zones and fault systems. The uplifted blocks are due to the reactivation of the shear and fault systems due to the Himalayan orogeny of which the timing and duration of the uplift is still to be ascertained. Although rocks of the drainage basin are older than 2500 Ma, they must have been first exposed during the Cenozoic and at places may have been during the late Quaternary (Singh and Rajamani, 2001; Rajamani 2009).

Thus hypsographically (Fig.2), three geomorphic domains are recognized in the Kaveri Basin: (i) the high elevation, high relief streams with narrow valleys (ii) middle elevation low relief Mysore Plateau with broad valleys and low-gradient streams in the west, and (iii) fluvio-deltaic plains to the east (known as the Tamil Nadu Plains). Between upper and middle domains there are a series of block mountains, such as the Nilgiris, the Sheveroy, the Biligirirangan, and the Mahadeswaramalai Hill Ranges.

The Western Ghats act as a climate barrier since at least the Pliocene period (Gunnell 1998) making the plateau eastwards arid (Rajamani et al 2009). The Kaveri river basin receives both the SW and the NE monsoon rains (the upland Kaveri river receives the SW monsoon rains between June to September (5000 mm) and the southern delta receives the NE rains from October to December) (Fig.1).

The highest rainfall in the basin is received along the western border of the basin during the southwest monsoon. The precipitation decreases from west to east (3800 mm to <1000 mm) because of orographic effects of the monsoon rains along the Western Ghats. The main plateau remains in the rain shadowed leeward side of the mountains (Fig. 1 and 2) and receives less than 1000 mm of annual rainfall (June to September) by the SW monsoon. The eastern side of the basin gets most of the rain during the northeast monsoon. Depressions in the Bay of Bengal affect the basin in the monsoon, causing cyclones and widespread heavy rains. Over 75% of the annual rainfall and runoff occurs during the southwest monsoon season and about 85% of the annual sediment load is carried during the wet season (Vaidyanathan et al., 1992). The average annual runoff for the Kaveri is about 21.4 km$^3$, which is significantly lower than other large rivers of the
Indian Peninsula, such as the Godavari (111 km$^3$), the Krishna (78 km$^3$), the Mahanadi (67 km$^3$) and the Narmada (46 km$^3$), implying very low rates of denudation. The mean annual temperature is 25°C although in summer (March to May) the maximum temperature reaches up to 43°C. And the minimum is 18°C. One observes a marked variation in vegetational canopy along the river course: evergreen to semi-evergreen forests in the Western Ghats, deciduous forests in the sub-humid zone on the leeward side of the Western Ghats, dry deciduous vegetation in the semi-arid plateau of Mysore, and the delta region-highly irrigated and cultivated (Rajamani et al 2009). The delta region is also called the rice bowl of India.

**Materials and methods**

The Kaveri River waters were collected in 100 ml poly vinyl bottles during the beginning of SW and NE monsoon seasons in two spells June 2008 and Nov-Dec 2009 avoiding the hot summer period. The sampling transect ran from the origin of the river Kaveri at Talakaveri (75° 49’ E; 12° 39’N) to the delta region near Vettar (79° 07.155”E; 10° 50.525”N) including the major tributaries. The water samples were collected from elevation between approximately 1250 m a.s.l. on the Western Ghat slope towards the delta 19 m a.s.l. (at or near sea level) with a rainfall gradient about 5000 to less than 1000 mm. Coastal river waters were avoided to prevent saline incursions. The sample elevation, stream length, and elevation of the stream head were estimated from 1:25,000 and 1: 50,000 topographic maps supported by spot heights using GPS survey instrument (Table 1).

$\delta^{18}$O and $\delta$D values were determined using a Wavelength-Scanned Cavity Ring-Down Spectroscopy (WS-CRDS) isotopic water analyzer (L1102-i) from Picarro, at the Stable Isotope Laboratory of the Department of Geosciences, University of Trieste (Italy). This new spectroscopy technology is explained in Brand et al. (2009). The results are expressed in $\delta$ notation relative to the V-SMOW standard (where $\delta^{18}$O or $\delta$D = {
\frac{\left(\text{18O}/\text{16O}\right)_{\text{sample}}}{\left(\text{18O}/\text{16O}\right)_{\text{V-SMOW}}} -1\} \times 1000). Calibrations were carried out using laboratory standards (TS 2010: $\delta^{18}$O -8.19‰ and $\delta$D -52.17‰; BBW $\delta^{18}$O -0.07‰ and $\delta$D -11.14‰; NS $\delta^{18}$O -15.52‰ and $\delta$D -114.76‰), periodically calibrated against the IAEA international standards VSMOW2, GISP and SLAP2. Analytical precision for $\delta^{18}$O and $\delta$D is ± 0.08‰ and ±0.5‰, respectively.

A correlation matrix, using several parameters such as, distance from the source, elevation, distance from Bay of Bengal, distance from Arabian Sea, $\delta$D, $\delta^{18}$O and d was carried out and presented in Table 2. The correlation factors highlighted in bold are considered significant.
Results and Discussion

Data on isotopes in precipitation are available from the Global Network of Isotopes in Precipitation (GNIP) only for two stations in southern India close to Kaveri basin area (Kozhikode and Hyderabad stations) (GNIP/ ISOHIS 2001). While the summer monsoon system (June to September) in the upland part of the Kaveri river is mainly controlled by the vapour derived from the Arabian Sea, the monsoonal precipitation in the southern Kaveri delta region is linked with the vapour originated from the Bay of Bengal and the Northeast rains during October to December (Bhattacharya et al., 1985, Deshpande et al., 2003, Gupta et al., 2005). The NE monsoon enters the Kaveri delta region and covers a distance of more than 2000 km. Along the Kaveri course no IAEA station exists and the first entry point of the SW monsoon is Kozhikode and the other Hyderabad. Both these stations receive the southwest monsoon. The Kozhikode station data show two distinct isotopic signatures for the SW and NE monsoons (Unnikrishnan et al., 2009) mainly due to different moisture sources and air mass trajectories.

Having isotopic data only for two stations does not allow us to define a Local Meteoric Water Line (LMWL). However, LMWL slopes of 7.6 and 7.89 were derived by Unnikrishnan et al. (2009), using Kozhikode station data, and by Chidabaram et al. (2009) using SW monsoon rain samples collected in 2006, respectively. Both these values are quite similar to the one reported by Rozanski et al. (1993) for the Global Meteoric Water Line (GMWL) and hence we are referring to it in this paper.

Oxygen isotope data

The $\delta^{18}O$ values of the Kaveri river range from -3.6 to -1.84‰, with a value of -2.77 at the source (in the Upper part at TalKaveri - the origin of the Kaveri river) and -2.28‰ (in the Lower Kaveri at Thiruvaiyar) in the delta plain (Table 1 and Figure 3a). There is a minor difference in the $\delta^{18}O$ data from the upland Kaveri waters towards the delta (a distance of nearly 900 km), and the $\delta^{18}O$ values of the river can be considered quite homogeneous. This minor difference may be due to the marginal latitudinal difference between the origin and the delta of the Kaveri river. No correlation between d18O and elevation is discerned nor with distance from the Arabian Sea and the Bay of Bengal (Table 2).

The isotopic values do not show significant changes before and after the dam (Mettur dam), although the only $\delta^{18}O$ value available for the water reservoir shows a very negative value of -7.70‰. The tributaries exhibit the same range of $\delta^{18}O$ values as the main river, with the exception of Amravati and Malingi with values of -5.55‰ and -3.61‰, respectively. More depleted $\delta^{18}O$
values are observed at the confluence of the main channel of the Kaveri river with Maingi due to the contribution of more negative values of this tributary. However, no influence is observed at the confluence of the Amravati with the Kaveri. This different response could be possibly due to a lower capacity of the Amravati compared to Malingi.

The $\delta^{18}$O values of the Kaveri river are close to the precipitation values of the nearby site (Kozhikode station) influenced by the SW monsoon (Unnikrishnan et al. 2010), suggesting that also the river is under the influence of the SW monsoon system.

The negative values found in the dam water and in the Amravati river may suggest that these could be influenced by NE rains. In fact, highly negative values in precipitation are found during the NE monsoon as shown by Unnikrishnan et al. (2010) at the nearby Kozhikode station, although the rainfall amount during NE monsoon is lower than during the SW monsoon. This hypothesis seems difficult and does not explain the values of the lower Kaveri that are not highly depleted as observed at Amravati and in the reservoir water. On the hand, these more negative values suggests that deep groundwater may contribute to these highly negative values. In fact the Kaveri basin is structurally configured by tectonics.

Deuterium excess data

Both isotopic ratios, $^{18}$O/$^{16}$O and D/H, were determined in the Kaveri river water samples allowing us to calculate the deuterium excess. This second order isotopic parameter, first defined by Dansgaard (1964) as $d = \delta D - 8 \times \delta^{18}$O, mainly depends on the climatic conditions (sea surface temperature, relative humidity and wind velocity) in the precipitation source regions (Merlivat and Jouzel, 1979). The position of a sample with respect to the GMWL (by plotting it in a $\delta^{18}$O/dD diagram) permits to infer if evaporation effects have affected its initial isotopic value.

The deuterium excess values, hereafter d, are reported in Table 1 and its variability along the course of the river is shown in figure 3b. d values range from 1.4 to 11.6‰ in the whole data set with higher values noted in the upland region of the Kaveri river from TalKaveri to Appangala (Fig. 3b), while low d values are found in lower Kaveri area. A slight correlation between d and elevation is observed as a consequence of its decreasing trend from the source towards the delta (Table 2). An exception is represented by the high value (11.2‰) exhibited by the dam water sample, similarly to what was observed in the $\delta^{18}$O value of the dam water.

In order to determine the effect of evaporation we plotted all $\delta^{18}$O values against $\delta D$ ones (Figure 4) distinguishing among different water types (Upper, Middle and Lower Kaveri, tributaries and dam). The upper Kaveri data fall on the GMWL suggesting that these values are not modified by evaporation and reflect the influence of the SW monsoon. On the contrary, the Middle and
Lower Kaveri values, as well as the tributaries, lie below the GMWL indicating that these samples have suffered some evaporation effects. Again, an exception is observed in the case of the dam water, which falls very close to the GMWL. We calculated the regression lines for middle and lower Kaveri data, as well as for the tributaries, in order to assess the magnitude of the evaporation slopes. The tributaries are lying on a line with a slope of 7.34, not so far from the values of LMWL found by other authors in nearby areas (7.6 and 7.89, Unnikrishnan et al. 2009 and Chidabaram et al. 2009, respectively) while slightly lower values are found along the course of the Kaveri river. This fact suggests that evaporation effects are increasing along the river, in agreement with the vegetation change observed. However, the slope values of Middle (6.69) and Lower (6.23) Kaveri do not indicate intense evaporation effects.

Conclusions

We analysed the surface river water of the Kaveri river from its origin to the delta using stable isotopes of oxygen and hydrogen. The stable isotope data shows that the upper Kaveri region is influenced strongly by the SW monsoon, being its isotopic values similar to that of the precipitation during SW monsoon as derived from nearby Kozhikode site. There is a narrow range between the $\delta^{18}O$ values found at the origin of the river to its delta, and significant orographic impact of the Western Ghats is not discerned. However, a decreasing trend of d values is found along the course of the river. This has been attributed to evaporation effects, which is not very strong. This difference in deuterium excess due to evaporation is also an indication of the moisture recycling in the lower Kaveri area, which is primarily controlled by evaporation from the wetlands in the delta plain but also from the surface waters and as such from the rivers.

The data reported in this study are preliminary but the only ones available presently for the entire length of the Kaveri River. No enough data is available at present to understand the impact of NE monsoon and its complexities involved with the evapotranspiration. Therefore more data need to be collected not only from the river surface waters but also, a network of rain gauge and pluviometer needs to be installed along the river course spatially and the data needs to be collected continuously for at least two-three years.

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References


T. Kanduč, D. Kocman and N. Ogrinc, *Hydrogeochemical and stable isotope characteristics of the river Idrijca (Slovenia), the Boundary watershed between Adriatic and Black Seas*. Aquat Geochem, 14 (2008), 239-262.


M.S. Lachinet and W.P. Patterson, *Oxygen isotope values of precipitation and surface waters in northern Central America (Belize and Guatemala) are dominated by temperature and amount effects*. Earth and Planet. Sci. Lett. 284 (2009), 435-446.


K.S. Valdiya, *Late Quaternary movements and landscape rejuvenation in southeastern Karnataka and adjoining Tamil Nadu in southern Indian shield*, J. Geol. Soc. India, **51** (1998), 139-166.


Figure 1. The panel A is showing the location of the Kaveri Basin with respect to the Peninsular India. The panel B is the Digital Elevation Map of the Kaveri Basin showing the main course of the river.
Figure 2. Elevation versus distance of the sites along the Kaveri River basin and sampled sites.
Figure 3a. $\delta^{18}O$ values versus the distance from the source showing no significant variations of the upper Kaveri and the lower streams. Distinct values are observed for the Mettur dam water and the Amravati river.

Figure 3b. Deuterium excess values versus the distance from the source showing a decreasing trend along the river course and distincty values for the Mettur dam water.
Figure 4. $\delta^{18}$O/$\delta$D plot for all water samples discussed in this study. The black line refers to the Global Meteoric Water Line (GMWL); the orange, green and blue lines refer to the regression lines calculated for the tributaries, the middle and lower Kaveri river samples, respectively. The regression line equations are also shown: the slopes are 7.3, 6.7 and 6.2, respectively. The graph suggests that the Middle and Lower Kaveri water samples have undergone evaporation. On the contrary, the Upper Kaveri samples are generally falling close to the GMWL. This may indicate absence of significant evaporative modification in the Upper Kaveri.
Table 1 Geographical coordinates of the sites along the Kaveri River and isotopic data.

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<th>Latitude</th>
<th>Distance from the source (km)</th>
<th>Elevation (m)</th>
<th>Distance from BOB (km)</th>
<th>Distance from AS (km)</th>
<th>δD (‰) (V-SMOW)</th>
<th>δ18O (‰) (V-SMOW)</th>
<th>d (‰) (V-SMOW)</th>
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BOB= Bay of Bengal, AS= Arabian Sea, d=δD-8δ18O
Table 2. Correlation matrix of the various parameters.

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<th>Distance from AS (km)</th>
<th>δD</th>
<th>δ18O</th>
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