Summary and Conclusions

Geochemical and Sr isotope study was carried out on water samples of Kaveri, Palar and Ponnaiyar rivers draining diverse Precambrian terrains of south India. The objectives of this study are (1) to take part in establishing an AMS facility at IUAC, New Delhi and carry out $^{10}$Be measurement on sediment core samples of Kaluveli lake, and (2) to determine the sources of solutes, chemical weathering rates and associated CO$_2$ consumption using abundances of major ions and $^{87}$Sr/$^{86}$Sr ratio of these rivers.

AMS facility was developed at Inter University Accelerator Center (IUAC), New Delhi, based on a 15UD Pelletron accelerator, during the course of this study. Chemical procedure for separation of $^{10}$Be from geological sample has been established at the Department of Earth Sciences, Pondicherry University.

Based on the $^{10}$Be measurement on different layers of the Mn-nodule from the north Indian Ocean, a growth rate of 3.01 mm/Ma has been determined and it is consistent with the growth rate reported by the other workers. Using $^{10}$Be abundance of the Kaluveli lake sediments, the sedimentation rate and age of the sediments were calculated. Using clay mineral assemblage and age of sedimentation paleo-climate fluctuation was inferred for this region.

The $^{10}$Be concentration in the core sample varies between 1.87 and $4.63 \times 10^8$ atom/g. Highest concentration is observed from the layer 1KL (40 – 50 cm). The age obtained for the depth up to 4.3 m is $5.25 \pm 0.37$ kyr with an average sedimentation rate of $0.82 \pm 0.06$ mm/y. The $^{87}$Sr/$^{86}$Sr ratios of the shells collected from 240 to 430 cm depth are similar to the present day seawater value which validates $^{10}$Be age of the sediments. The clay mineralogy of the core samples is dominated by kaolinite and smectites.

Based on the smectite/kaolinite ratio it is found that the climate changed from semi-arid to humid at about 3.4 kyrs and humid to present day semi-arid at around 2.24 kyrs ago. Lower $^{10}$Be concentration is observed in the sediment during the humid period ($2.24 \pm 0.32$ to $3.39 \pm 0.22$ kyrs) may be due to higher sedimentation rate caused by intense weathering and rainfall in the catchment area, which has diluted the $^{10}$Be concentration.

The pH values measured on Kaveri, Palar and Ponnaiyar rivers range between 6.3 to 8.76. The temporal variations in the ionic abundance of these water samples indicate that during pre-monsoon period water–rock interaction time and evaporation are higher than the monsoon period which has resulted in increased concentration of ions in the pre-
monsoon water samples. Bicarbonate is the most dominant ion (27 – 79% of anion budget) in all the river samples collected during monsoon period and it is followed by Ca$^{2+}$, whereas, in case of pre-monsoon water samples Na$^+$ is the most dominant ion (in meq/l). Ca concentrations in samples of both the periods are nearly equal and other ions such as Si, Mg, Na, Cl and SO$_4$ are higher in the pre-monsoon samples.

Most of the water samples are near to saturation with respect to calcite and dolomite, whereas, they are under-saturated with respect to gypsum and barite. River water samples plotted in different mineral stability diagrams for silicate system indicate that they are in equilibrium with kaolinite, Mg-montmorillonite and Ca-smectite. Based on the molar ratios between dissolved silica and cations resulting from silicate rock weathering in these river basins, it is inferred that formation of smectite is favored.

In case of Na, K and Mg, the mean percentages of atmospheric contributions are nearly equal with respect to monsoon and pre-monsoon water samples. Whereas, the atmospheric contribution of Ca and SO$_4$ are lower in the monsoon water samples compared to the pre-monsoon samples. Due to anthropogenic input from mining, industrial effluent, agricultural wastes and sewage, water of the tributaries like Noyil and Paykara were polluted and show unusually high concentrations of ions and TDS. The uptake of major ions as nutrient by biomass will be returned back to the system on their decay. Hence, it was assumed that on a long time scale the biomass storage of different ions will reach equilibrium balancing their uptake and release.

The corrected Ca* and Mg* abundances show a positive correlation indicating that both the elements might have derived from a common source. In the molar ratio plots most of these water samples clusters in and around the silicate field, from which a dominant role of silicate weathering is inferred. In most of the water samples Ca and Mg abundances are higher compared to other major cations. Presence of granulites, calc-gneisses with Ca–Mg bearing minerals and thick calcrites in the river banks form major sources of Ca and Mg to the Kaveri river ionic budget.

To find out the relative contribution of ions from silicate and carbonate end members, forward and inverse modelings were carried out. It has been observed that the calculated fractional contribution of cations by silicate weathering using inverse mixing model is higher than the forward mixing model. Inverse model is more reliable as the assumptions involved are fewer than the forward model. The inverse modeling suggest that during monsoon and pre-monsoon period 70% of dissolved ions were derived from weathering of silicate and remaining 30% from the carbonate rocks. Whereas, for Palar
and Ponnaiyar river 61% and 89% of solute load respectively, is derived from silicate weathering.

The average annual flow at Musiri is 8685.8 MCM and sediment load 6.098 ton/km²/y. The reported suspended load during monsoon period is 4.5 ton/km²/y (75% of the annual load) and observed load in this study is 4.7 ton/km²/y. In Kaveri river the physical weathering rate (Wph) at Musiri is 6.1 tons/km²/y or 3 m/Ma whereas at Billigundla it is 3 times higher i.e 18.6 tons/km²/y or 9.3 m/Ma. At Musiri weathering rate is 3 fold higher during monsoon period than the pre-monsoon period and at Billigundla it is 9 times than the pre-monsoon period.

Wherever dams were constructed the sediment load of Kaveri river reduces drastically. The Wch_a for Kaveri river at Musiri is 13 tons/km²/y or 5 m/Ma, which is much higher than the Wph at this site, whereas, at Billigundla located upstream of Mettur Dam, they are nearly equal (Wch_a =21.2 tons/km²/y and Wph = 18.6 tons/km²/y). Thus, the Mettur Dam is considerably reducing, about 50 % of the suspended sediment load of the Kaveri river. River Palar shows lowest annual major ion and TDS flux to the Bay of Bengal than Kaveri, Ponniyar and Vellar.

At Musuri the silicate weathering rate (SWR) is 7.9 tons/km²/y or 2.9 m/Ma and carbonate weathering rate (CWR) is 5.1 tons/km²/y or 2.1 m/Ma, out of which monsoon period stands for 80% and 81% respectively. In Kaveri river, silicate weathering flux at Musiri is 0.52 ×10⁶ tons a⁻¹, which accounts for 0.1 % of the global river silicate weathering flux of 550×10⁶ tons a⁻¹. The drainage basin coming under the site Musiri (0.066×10⁶ km²) is only 0.044% of global continental area (150×10⁶ km²). Thus the silicate weathering flux per unit area for Kaveri drainage basin is 2.1 times higher than the global average.

The final specific chemical denudation rate (Wch_a) estimated for Kaveri, Palar and Ponnaiyar basins (1.3 – 13 tons/km²/y) are much lower than the published global mean values (24 tons/km²/y). The chemical weathering is more intense in the Bhavani and upper reaches of the Kaveri basin, where physical removal of sediments from weathering profile is less which leads to development of thick soil profile.

In the Kaveri drainage basin at Musiri, the rate of CO₂ consumption during silicate weathering (F_{CO₂}^{sil}) varies between 2.95 × 10⁵ and 2.55 × 10⁵ mol km⁻² y⁻¹ and for carbonate weathering (F_{CO₂}^{carb}) it varies between 0.53 × 10⁵ and 0.46 × 10⁵ mol km⁻² y⁻¹. The estimated CO₂ consumption rate at different sites of the Kaveri river shows that
it increases towards upper reaches and varies between $3.49 - 8.48 \times 10^5$ mol km$^{-2}$ a$^{-1}$ in the main stream. The upper limit of CO$_2$ consumption rate of Kaveri basin is close to the area-weighted CO$_2$ consumption rate for the Deccan Traps $0.36 \times 10^6$ moles km$^{-2}$ y$^{-1}$ (Das et al. 2005).

Total CO$_2$ consumption rate for rock weathering in the Indus basin ($1.46 \times 10^5$ mole km$^{-2}$ y$^{-1}$) is lower, whereas, for the Ganga ($6.92 \times 10^5$ mole km$^{-2}$ y$^{-1}$) and the Brahmaputra ($4.93 \times 10^5$ mole km$^{-2}$ y$^{-1}$) the CO$_2$ consumption rates are higher than the Kaveri. Comparison with the percentage of CO$_2$ drawdown (20.00 to 23.13 $\times 10^9$ mole y$^{-1}$) during silicate weathering accounts for 0.22 – 0.26% of global CO$_2$ consumption for silicate weathering ($8700 \times 10^9$ mole y$^{-1}$) of 0.044 % global drainage area. Thus a 5.5 times higher CO$_2$ drawdown was estimated in this basin than the average global consumption rate per unit area.

The concentrations of Ba and Sr ions increase towards the mouth. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in monsoon water sample of Kaveri range from 0.714967 to 0.717931 in the main course ($\bar{X} = 0.716071$) whereas, tributaries Bhavani and Amaravati have lower $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of 0.710002 and 0.712770 respectively. The pre-monsoon water samples of Kaveri river main course varies between 0.713181 and 0.720296 ($\bar{X} = 0.716196$). The tributaries of Kaveri show a much wider range of $^{87}\text{Sr}/^{86}\text{Sr}$ ratios between 0.705285 (Nagavari) and 0.728212 (Arkavati). Pre-monsoon samples collected from Kaveri and its tributaries show low $^{87}\text{Sr}/^{86}\text{Sr}$ ratio than the monsoon sample with the exception of the sample collected from Hogainakal. The calcretes found on the banks of tributaries of Kaveri consist of calcite, dolomite and silicate minerals. $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in carbonate fraction of calcretes are positively correlated with the pre-monsoon water samples from the same locations.

The co-variation of Sr with Ca*, Mg*, Ba*, SO$_4$* and HCO$_3$, indicate that the Sr might have been derived from different sources. These river samples show distinct collinear arrays when $^{87}\text{Sr}/^{86}\text{Sr}$ ratio plotted against Ca/Sr and Mg/Sr ratios, which could be a result of two component mixing. Using the Ca/Sr, Na/Sr and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios fractional contribution of solute from granitoid gneisses, granulites, meta-volcanic rocks and mafic granulites are modeled.

From the result of the Sr isotope mixing model it is observed that the contribution from meta-volcanic rocks, mafic granulites and carbonate (MVC) end member is higher than the other end members at around 60%. However, the exposed area of these rocks as estimated from the geological map is around 10% and it may argued that the rate of
weathering is 3 times higher than the granitic gneisses and granulites. Even on
considering this aspect the proportion of contribution from MVC is two times higher.
This could be explained if preferential weathering of mafic minerals such as calc-
amphibole, clino- and ortho- pyroxene present in the tonalite, granitic gneisses and
granulites over the feldspars weathering takes place in these drainage basins. Based on
detailed study of weathering, in semi-humid catchment area of Kaveri at Mule Hole,
Braun et. al. (2009) have suggested that mafic minerals such as biotite and chlorite are
undergoing preferential weathering over other minerals in the gneisses.

Finally the various rock types present in the Kaveri drainage basin could be
clubbed into two major end member (a) granulites and (b) meta volcanics rocks +
carbonates + granitic gneisses. In the Kaveri river basin end member ‘a’ predominates in
lower and middle reaches and ‘b’ in the upper reaches. During SW monsoon upper
reaches receive high rainfalls which result in high $^{87}\text{Sr} / ^{86}\text{Sr}$ ratio in tributaries and in the
main course. During strong NE monsoon lower and middle reach of Kaveri receives
heavy rainfall and weathering of granulites and gneisses of Southern Granulitic Terrain
give rise to lower $^{87}\text{Sr} / ^{86}\text{Sr}$ ratio in the main course. Thus based on the $^{87}\text{Sr} / ^{86}\text{Sr}$ study of
authigenic phases combined with other proxies (such as pollen, $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$) deposited
in the Kaveri basin can give quantitative information on intensity of NE and SW monsoon
in the past.