Chapter 6

Summary and scope for future work

This thesis deals with reconstructing the variability of Indian Summer Monsoon (ISM) during the Holocene and the late Pleistocene from speleothems of Indian peninsula and Sediment core from the Andaman Sea. Such studies are important to understand the role of insolation and North-Atlantic oscillation on ISM and as yet such studies are limited over the Core Monsoon Zone (CMZ) of India. The present work has improved our understanding regarding the evolution of the monsoon during the late Pleistocene and the Holocene. The major findings of this study are summarized below :-

6.1 Reconstruction of ISM variability from stalagmites of the Kanger Valley cave complex, Chattisgarh

1. The Variability of ISM during the Holocene has been studied using three stalagmites from the Dandak (DAN-I and DAN-II) and the Kotumsar caves, central India. High resolution ISM reconstruction based on $\delta^{18}O$ (n = 5040)

measurements covers most of the Holocene. The record extends from 10.4 ka to the present, with brief hiatuses from 9 to 8.5 and 2.4 to 2.2 ka.BP.

2. The beginning of the Holocene between 10.4 - 9 ka is marked by amelioration of ISM . Increased monsoon was related to the Northward shift of the Intertropical Convergence Zone (ITCZ) in response to increased insolation.

3. Holocene North Atlantic oscillations known as **Bond events** are evident as abrupt decline in monsoon between 10.4 -9 ka, establishing a strong teleconnection between low and high latitudes.

4. In the past, the variability and trends in the ISM during the mid-Holocene has remained a debatable issue. While some proxy records showed changes to be gradual in response to decreasing insolation, there are observations of abrupt decline at 6 ka as well.Contrary to the consensus of gradual decrease in monsoon during the mid-Holocene, an abruptly declining monsoon between 6 and 5 ka was observed.

5. This abrupt decline in monsoon can be attributed to the external forcings or natural or internal fluctuations of the monsoon system. The external forcings include insolation and volcanic eruptions, whereas the internal fluctuations include North-Atlantic thermohaline circulation and El-Nino. The gradual decline in insolation is not sufficient to explain such a abrupt decrease. However, when superimposed with North-Atlantic climate changes, the millennial scale monsoon variability can be explained. The sensitivity of the monsoon to North Atlantic climate is also observed as Bond events leading to the weakening of monsoon in the mid-Holocene.

6. The second plausible cause behind the abrupt decrease of ISM at $\sim$ 6 ka could be sudden failure of internal feedback mechanisms governing the monsoon, leading to a sudden decline in the monsoon intensity.

7. The Dandak -I $\delta^{18}O$ timeseries shows a decrease in the monsoon from 4.8 - 3.8 ka. Anomalously depleted $\delta^{18}O$ values are present between 3.8 - 2.8 ka, implying amelioration of monsoon during this period. Such an increase was not reported so far from any other proxy and could be related to the local intensification of the monsoon or change in the moisture source(from the Arabian sea to the Bay of Bengal).

8. Post $\sim$ 2 ka BP, ISM strengthening is observed, consistent with previous observations. The ISM reconstruction shows abrupt decline in monsoon between 1550-1450 AD and 1350-1250 AD. Since the end of LIA, monsoon intensity has increased in 19^{th} and 20^{th} century, and entered an "active" phase.

9. A phase of prolonged weak monsoon, between 600 and 150 yr BP, with severe drought-like conditions at 300 yr BP (1700 AD) is seen in the reconstruction during the Little Ice Age.

6.2 Impact of ISM variability on human civilization

1. When sampling, evidences of controlled fire preserved as burnt earth and patches of charcoal mixed with soil and grasses in the form of three distinct layers in Kotumsar and one layer in Dandak cave were found, indicating sporadic human inhabitance. Based on radiocarbon dating of the charcoal deposits, human activity was observed during 6.9 - 4 ka.

2. ISM reconstruction during this time shows a decrease in monsoon from 6.5 - 4 ka. Use of caves during poorer monsoon episodes suggests that they were used as shelters during severe droughts. Also, decrease in monsoon intensity for prolonged periods must have led to stressed conditions for

agriculture. This could have forced people to store food grains for drought-like conditions.

6.3 ISM variability during late Pleistocene based on Speleothem studies

1. High resolution sampling of the **Kailash cave** stalagmite holds potential to address decadal and centennial monsoon variability during the **Bolling-Allerod event** from 13.9 - 13.4 ka.

2. Most of the sample deposited during the **Older Dryas** event separated by Bolling (peak at 14.5 ka) and Allerod oscillations (peak at 13 ka). The $\delta^{18}O$ timeseries shows multi-decadal low rainfall events throughout this period. The frequency of occurrence of these mega-droughts can be determined after establishing stronger chronological control over the sample.

3. The strength of ISM increased with the start of Allerod oscillation, resulting in plausible flooding at the sampling site and the cessation of the sample growth there after.

4. ISM variability during the inception of the **Last Glacial Period** is reconstructed using a stalagmite sample from the **Belum cave**, India. The stalagmite is used to reconstruct ISM from 181 ka to 173 ka and 104 ka to 81ka. Both the periods have $\delta^{18}O$ values in the same range, implying the factors controlling ISM during glaciations were likely the same.

5. With the onset of glaciation, stepwise decrease in monsoon was observed from 106 – 98 ka, with sharp increase in $\delta^{18}O$ values at $\sim$ 97 ka. This was followed by second step of 3‰ enrichment.

6. Analysis of Mg/Ca, and Sr/Ca indicate the role of prior calcite precipitation during the drier glacial period and point to extended drier period

between 90-85 ka. Interestingly, this time period is recorded as layers with high detrital content, and hence high Mn/Ca ratios. Unlike the previous hypotheses of Mn precipitation associated with high rainfall episodes, we observed that, enrichment of Mn is related to decreased ISM. Thereby we postulate that higher rainfall events accelerate the drip rate, washing off accumulating detrital particles from precipitating stalagmite.

7. The sample with two distinct hiatuses has a missing monsoon record during the last interglacial at $\sim$ 125 to 110 ka. This gap in deposition is explained as flooding of sampling site during the last interglacial period or shifting of feeding channel temporarily which resumed back in 104 ka.

8. The declining phase of monsoon during last glacial inception can not be solely attributed to changes in insolation. On comparing $\delta^{18}O$ profile with 30^0N insolation and the insolation gradient between Mascerene high and Tropical low over India, ISM seems closely related to the insolation gradient than insolation itself. Similar results were also reported from Xiaobialong cave,China, where the $\delta^{18}O$ profile follows the variability in the insolation gradient.

6.4 ISM variability during late Pleistocene based on the Andaman Sea sediment Core

1. The present work has correctly interpreted the Andaman Sea sediment core $\delta^{18}O$ data of *Awasthi et al.* [2014]. Evaluating the $\delta^{18}O$ values of *G.ruber*, we question the inference of the strengthening of ISM during the last Glacial Maximum based on geochemical evidences alone.The geochemical proxies are useful to determine the provenance of the sediments but can not be used to address the ISM variability.

2. Monsoon was weaker during the LGM between 20-18 ka, a finding which is supported by numerous studies carried out by several workers on different sediment cores from the Indian Ocean. Also based on the $\delta^{18}O$ record it can be inferred that strength of ISM was weakest during LGM in the past 70 ka. High influx of sediments from western Myanmar during LGM could be due to strengthening of winter monsoon.

3. The ISM variability reconstructed from the core SK-234-60 shows significant correlation with change in insolation during the past 70 ka.It can hence be said that the ISM is modulated by change in insolation to some extent.

6.5 Scope for future work

1. Although we have attempted to reconstruct ISM covering entire the Holocene, one such data set representing ISM is only indicative not complete in itself.

2. Contrary to the previous beliefs, we have shown that strength of the monsoon decreased abruptly at 6 ka. To strengthen this hypotheses, analyses of more samples from CMZ covering the Holocene need to be attempted.

3. Spectral analysis of the compiled Dandak and Kotumsar $\delta^{18}O$ timeseries is essential to address decadal and centennial variability in the monsoon.

4. Kanger valley cave complex, hosts many caves which still require detailed explorations. More speleothem studies from different caves in the same complex, will help for cross-correlation of the reconstructions.

5. There is a urgent need to set up a U-Th mass spectrometric dating facility in India so that speleothem science can be accelerated and more samples with better age models be analyzed.

6. Previous workers postulated the enrichment of trace elements in stalagmite during high rainfall events. These studies were not carried in an ISM

regime, which is in seasonal nature. Drip rates are higher during the monsoon season. We found that enrichment of trace elements in stalagmites is possible only when the rainfall is low, as high rainfall accelerates drip rate washing off the colloidal particles. However, trace element accumulation in Indian speleothems where ISM plays a key role is poorly understood and requires future investigation.

7. As previously stated, insolation is not the only governing factor for monsoon variability. Comparisons with El-Nino events, and different forcings factors are required to understand the millennial and centennial scale variability in monsoon.