# CHAPTER-7

# Summary

The thesis deals with reconstruction of the variability of Somali upwelling, aeolian influx, carbon export flux, nitrogen biogeochemistry and Indus fan sedimentation during the last 18.5 ka and 34.6 ka B.P. from two marine sediment cores (4018 and 4016) collected from the Western and North-eastern Arabian Sea. Such studies are essential to understand the internal feed-back mechanism of SWM. An attempt is therefore made to improve the current understanding regarding the influence of Somali upwelling on SWM precipitation, aeolian flux, carbon export flux, lateral advection of upwelled water on nitrogen biogeochemistry and sea level, climate and tectonic changes. The major findings of present study are summarized below:-

## 7.1 Somali upwelling and Southwest monsoon rainfall during the last 18.5 ka B.P.

1. Somali upwelling intensity during the last 18.5 ka B.P. has been reconstructed using biogenic silica concentration in marine sediment cores from the western Arabian Sea.
2. The comparison of reconstructed Somali upwelling history with southwest monsoon precipitation record during the last 18.5 ka B.P. is quite revealing.
3. The Somali upwelling was weak/absent due to the absence of southwest monsoonal winds during Last Glacial Period (LGP). While the precipitation in the south-western India was restricted due to the absence of southwest monsoonal winds and Indian Ocean Warm Pool (IOWP). These processes collectively address the positive relation between Somali upwelling and SWM precipitation during LGP.
4. The post-glacial onset of the southwest monsoon was marked by an increase in the strength of the Somali upwelling at 15 ka B.P., with the eastern Arabian Sea records showing increased southwest monsoon rainfall. The observed positive relation between Somali upwelling and SWM precipitation during 15 to 12.9 ka B.P. is attributed to change in the moisture source area. It has been proposed that the moisture source area for the SWM precipitation during 15-12.9 ka B.P. was restricted to central Indian Ocean, while the changes in the Somali upwelling might have had feeble influence on SWM precipitation.
5. The Somali upwelling was weak between 12.9 and 11.7 ka B.P., indicating another phase of weak southwest monsoon similar to that of the LGP. Weak SWM was probably caused by the southward shift of the ITCZ during 12.9 to 11.7 ka B.P. Overall, records of the Somali upwelling and southwest monsoon rainfall exhibit positive correlation between 18.5 and 11.7 ka B.P.
6. Shift from the positive to negative relation between the strength of the Somali upwelling and southwest monsoon rainfall occurred at 11.7 ka B.P. at the beginning of the Holocene, which marks the establishment of modern day climate system. Enhanced Somali upwelling during the last 11.7 ka B.P., except for the decline at 8 ka B.P., had a negative impact on the southwest monsoon rainfall. Both, latitudinal shifts in the Inter Tropical Convergence Zone (ITCZ) and changes in the moisture source region act as causative factor for the reversal in the relationship between upwelling and southwest monsoon rainfall.

7. It is observed that the change in moisture source for SWM precipitation can alter the relation between the western Arabian sea upwelling and SWM precipitation. This will require further studies on the causative factors that can change moisture source region.

| Time Period (ka B.P.) | Strength of Somali upwelling | Intensity of SWM rainfall | Somali upwelling vs SWM rainfall | Probable position of ITCZ during boreal summer | Proposed Moisture source region for SWM rainfall |
|---|---|---|---|---|---|
| 18.5-15 | Absent | Absent | Positive | South of core location | Not applicable |
| 15-12.9 | Strong | High | Positive | North of core location | Central Indian Ocean |
| 12.9-11.7 | Weak | Weak | Positive | South of core location | Not applicable |
| 11.7-0 | Intensified | Low | Negative | North of core location | Western Arabian sea and Central Indian Ocean |

**Table 7.1:** Summary of findings from Somali upwelling reconstruction and its comparison with southwest monsoon precipitation record.

## 7.2 Carbon export and Aeolian flux in the western Arabian Sea

1. The Aeolian flux and Carbon Export Flux (CEF) during the last 18.5 ka B.P. has been reconstructed using terrigenous fraction and biogenic barium concentration in marine sediment core from the western Arabian Sea.
2. Aeolian flux versus CEF shows negative relation for the time gap between 18.5 to 11.7 ka B.P., which suggests that the increase in aeolian flux had suppressed surface productivity. It is inferred that the availability of macro-nutrients was limited in the western Arabian Sea during 18.5 to 11.7 ka B.P.
3. Although the biogenic silica productivity reconstruction suggests the southwest monsoon induced upwelling was high during 15 to 12.9 ka B.P., the CEF to aeolian flux relation remained negative, which indicates the upwelling was not enough to keep the surface waters rich in macro-nutrients. It is also inferred that the north-western Arabian Sea is not a part of the last glacial biological pump that reduced atmospheric $CO_2$ to LGM levels.

4. Aeolian flux and CEF shows positive correlation during the last 11.7 ka B.P. Based on biogenic silica productivity it is inferred that the southwest monsoon induced upwelling increased throughout Holocene and caused high productivity. The increased upwelling might have created High Nutrient Low Chlorophyll (HNLC) like conditions in the study area during Holocene. The increased aeolian flux could have supplied more micro-nutrients and led to increased CEF throughout Holocene.
5. The present study suggests that the modern observation of HNLC like condition during southwest monsoon in the Arabian Sea started at the beginning of Holocene.

## 7.3 Productivity and nitrogen biogeochemistry in the northern Arabian Sea during the last 34.6 ka

1. The concentration and isotopic composition of nitrogen and organic carbon determined in the sediment core from the northern Arabian Sea provide a unique record of productivity and nitrogen biogeochemistry for the last 34.6 ka B.P.
2. Productivity maxima occurred during LGM and Holocene. The nitrogen isotopic composition demonstrates that denitrification was the primary controller of the nitrogen cycle in the northern Arabian Sea throughout the last 34.6 ka B.P.
3. Dominant role of convective mixing of water column is envisaged as a secondary process that influenced the nitrogen biogeochemistry during 34.6 to 16 ka B.P., whereas upwelling and lateral advection processes dominated during the last 16 ka B.P.
4. The increase in the $\delta^{15}N$ gradient observed between the coastal and open ocean records during the Holocene clearly indicates lower intensity of lateral advection of upwelled waters from Oman margin.
5. Based on the evidence for the presence of lateral advection of upwelled water, it can be further surmised that the southward meridional transport of heat in the northern Arabian Sea has continued since 16 ka B.P.
6. Further studies linking the influence of Arabian Sea productivity to the atmospheric carbon dioxide concentration during LGM and the effect of lateral advection on meridional heat transport may help us in understanding the regional climate.

## 7.4 Sedimentation in the north-eastern Arabian Sea: Implications to climate, tectonics and sea level

1. The lithogenic sediment flux in the present study shows an inverse relation with the sea level, high sediment flux during low sea level and vice versa.
2. The variation in sea level had significant control on the lithogenic sediment flux to the Indus submarine fan throughout the last 34.6 ka B.P.
3. The comparison of Himalayan climate with Indus submarine fan sedimentation shows, high sediment flux during cold and weak monsoon period (29-26 and 26-17 ka B.P), but low sediment flux during warm and strengthened monsoon period (last-11.7 and 34.6 -29 ka B.P).
4. Detailed study on fluvial deposition would be necessary to understand the Himalayan tectonics and Indus submarine fan sedimentation.