 ISSN 2676-1386 (Print); ISSN 2676-1394 (Online)

Lake Sediment proxies and their response to Indian Summer Monsoon: A Review from the Himalayas

Binija Kaphle[1, 2], *Khum Narayan Paudayal[3], and Binish Raj Khanal[4]

[1]Key Laboratory of Tibetan Environment Changes and Land Surface Processes (TEL), Institute of Tibetan Plateau Research (ITP), Chinese Academy of Sciences, Beijing, 100101, China

[2]University of Chinese Academy of Sciences

[3]Department of Geology, Tribhuvan University, Kathmandu, Nepal

[4]Institute of Engineering, Pulchowk Campus, Kathmandu, Nepal

**Corresponding author: khum99@gmail.com*

ABSTRACT

Environmental changes since different timescales can be exhibited from lacustrine sediment sequences, and the reported changes can be interpreted in terms of environmental fluctuations, change in vegetation patterns, intensification or weakening of weather phenomenon. Paleoclimate can be reconstructed by using different proxies from the lake sediments. There are various scientific tools that can uncover the evidences of past ecological and climate changes. The understanding of global environmental changes can be attended by revealing the climatic and environmental changes since different time scales.

The high-altitude regions of Southern Himalayas are influenced by Indian Summer Monsoon (ISM) and severely affected by the impacts of climate change. However, the available meteorological data are too short for long term trend analysis and influentially forecast future. To fill this data gaps there are prospects of using other multi proxy climatic data including physical proxies such as TOC, C/N ratio, isotopic and elemental analysis and biological proxies such as pollen and diatoms analysis. However, vast knowledge gaps exist in this aspect because very few researches with limited scope have been carried out. There is lack of long instrumental climatic data for enduring trend analysis, and develop suitable adaptation measures to cope with adverse impacts of this climate change. This study aims to review the reconstructed climatic history of various region. The findings of the study will be useful to academia, policy makers and researchers.

Key words: Climate reconstruction, Last glacial period, Pollen ratio, Palynology, Proxies, Lake Rara, Paleo-vegetation

INTRODUCTION

The Himalayan Tibetan plateau, various Indian subcontinents and several regions in south-west China experience Indian summer monsoon and its effects as its dominant climate system in this region (Jin et al., 2009). Due to ISM variability and its interconnected mechanisms (Fig. 1), it serves as a primary source of fresh water for more than 1 billion people in South Asia (Bird et al., 2014a). Many Indian subcontinents receive enough precipitation from the ISM influencing the economic and societal revolutions (Xu et al., 2018).

The composition of lake sediments is spatially heterogeneous in nature. Many researchers thought that the study of one part of the sediment could not lead to the real outcome. The trend of studying multiple cores for sediment deposition in both time and space has started (Engstrom and Swain, 1986; Wang et al., 2009). Various closed and semi-closed lakes in arid and semi-arid regions in the Tibetan Plateau showed deposition of carbonates in the lake bed. Among three forms of carbonate depositing in the sediment, endogenic and authigenic carbonates are mostly used to reconstruct the paleo-environment of the region (Ju et al., 2010). Sediments in the lake can either originate natively i.e. autochthonous source or deposit from other places than its origin known as allochthonous source, serving as a laboratory for local or regional climate archives (Korsman et al., 1999). The sediment depositional process in the bed of the lake is not uniform due to differences in energy and remoteness from sediment input point, resulting in the distribution of fine sediments in the deep water whereas the shallow parts inhabiting granular sediments (proxies like total organic carbon (TOC), total nitrogen (TN), etc. (Schrimm et al., 2004). While there are no sufficient records of such examinations in the lakes of the Southern Himalayas. Similarly, isotopes of oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) values in the lake sediments can be derived as a proxy for temperature and precipitation. These isotopes have high significance in paleo hydrology and reconstructing paleoclimates (Hardenbroek et al., 2018). Likewise, the lithogenic composition of the watershed highly contribute ionic discharge into the lake (Lami et al., 2010). The ion composition of water provides an instinct towards its source and controlling factors. Similarly, the composition of elements in the lake sediment is very informative about its

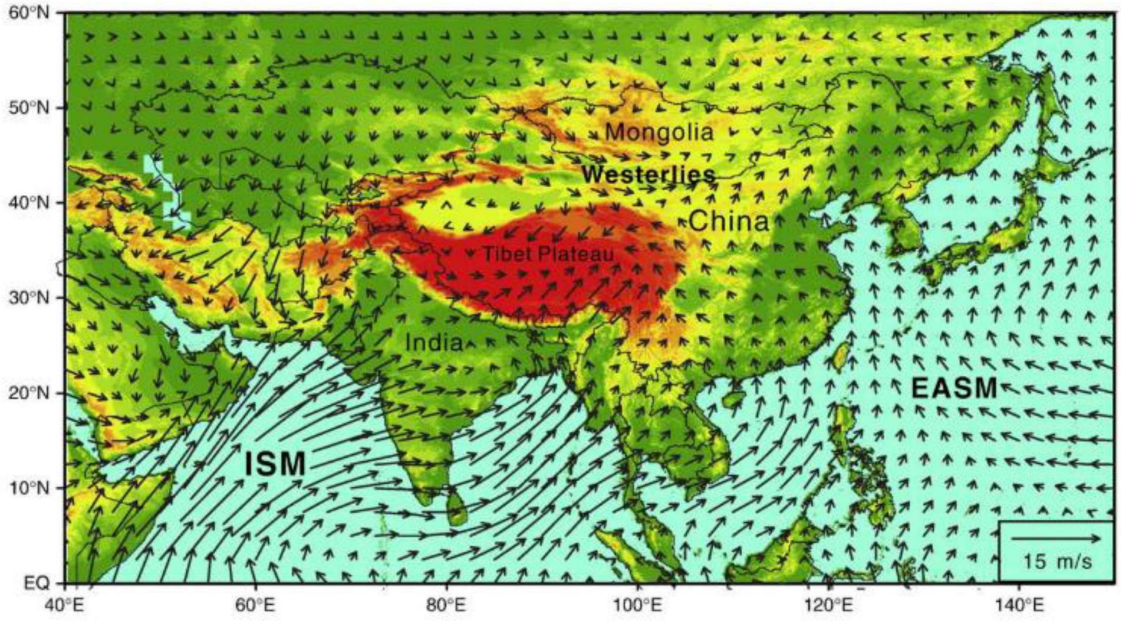

Fig. 1: Overview map showing atmospheric circulation systems (ISM, Indian Summer Monsoon; EASM, East Asian Summer Monsoon; Westerlies in Indian subcontinents (Wang et al., 2010)

origin and is one of the important archives to reconstruct past environmental changes (Li et al., 2008). As anthropogenic changes presently push the climate system into a direction that has not occurred in the last several millions of years, it is essential to know the sensitivity of the various feedback systems in climate. One of them can be achieved by studying different phenomenon of climate like climate archives. Therefore, the aim of many climate studies is to improve our understanding of the mechanisms that drive the Earth's climate, both by investigating past climate changes and by studying modern processes (Dixit and Tandon, 2016; Wang et al., 2016). The alteration in the lake water depth is also resulted due to the change in the climatic factors or dependent on the sedimentation in the lake (Holmes et al., 2009). The water chemistry of the lake can moreover be controlled by the continuous deposition of carbonate minerals and weathering of silicate minerals in limited extent in the lake sediments. This indicates the source of minerals in the lake water and directs the deposition mechanisms into the sediments (Ramanathan, 2007). The seasonal fluctuations of various parameters like temperature, wind speed and precipitation influence the water chemistry and these fluctuations finally shade into the sediments after depositional mechanisms. There are several researches that intended to focus on water-sediment chemistry around the world using several proxies such as pigments (Buchaca and Catalan, 2007), trace elements (Guo et al., 2018), and numerous other elements.

CLIMATIC SIGNIFICANCE OF THE PROXY INDICES

The South Asian highlands have a diversified natural archive suitable for the development of detailed paleo-climatic records (Cook et al., 2003; Gaire et al., 2013). Nearly all of the experimental research performed on the Asian monsoon complex has been derivated mainly from analyses of instrumental meteorological data from India and South Asia (Cook et al., 2003). Evidences of past climate reconstructions can serve as a model or proof to determine the future environmental conditions.

Lacustrine sediments are important archives for paleoclimate reconstructions. Lake sediments are often used to extract and investigate the climate-related information besides it also provides vital information about the paleo-environment changes. Similarly, the sediment accumulation rate in the lake is often high and provides the high-resolution paleo-environmental information (Lu et al., 2018; Sun et al., 2011). Paleo-environmental conditions within the lake's catchment are roughly estimated by the physical and geochemical composition of lake sediments (Eriksson and Olsson, 2015). The organic matter content of lake sediments can be either large or small, but its paleolimnological importance is always great. Its composition includes a variety of elemental, isotopic, and molecular indicators, or proxies that can be used to reconstruct paleoenvironments of lakes and their surrounding land area. Sediments in the lake are slowly deposited, and a huge amount of information of climate and environment changes are hidden inside. The climatic and environmental change recorded by the lakes can be very useful to understand the past climate changes and recover the history of terrestrial and environment deviations.

Dating methods (^{14}C accelerated mass spectrometer dating)

Accurate dating method plays a pivotal role to study the paleoclimate history. There are four categories of dating methods i.e. i) Radio-isotopic methods, ii) Paleo-magnetic methods, iii)

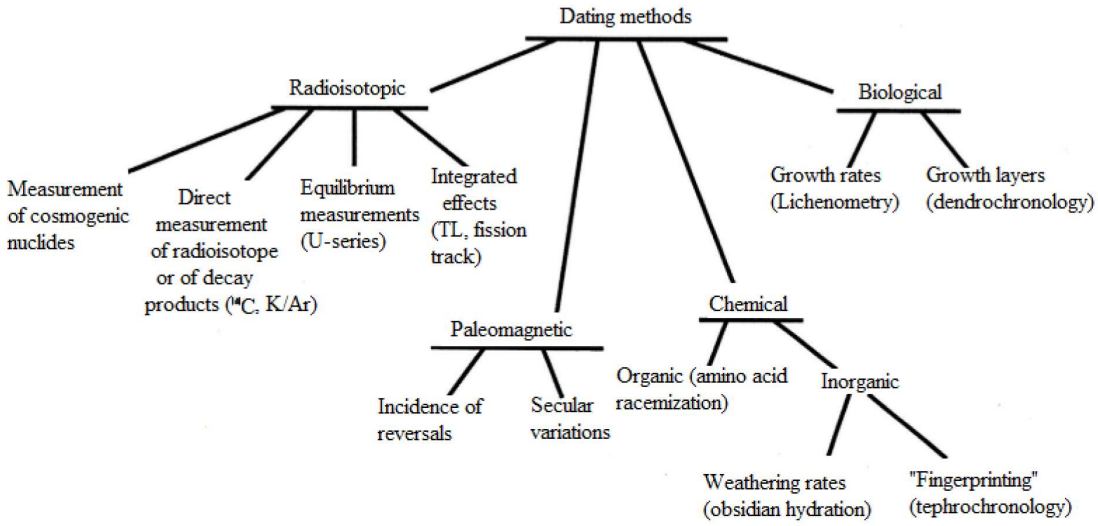

Fig. 2: Principal dating methods used in paleo-climate research, Modified from (Bradley, 2015)

Biological methods, and iv) Chemical methods (Fig. 2). Radio-isotopic method is based on the rate of disintegration of the atoms of the samples which was established in the late 1970s and early 1980s when small organic samples were successfully dated using an accelerator coupled to a mass spectrometer, known as AMS dating (Bradley, 2015). The age of the sediment sample is determined by using ^{14}C dating which is used for the chronology of recent several thousands of years. Similarly, the use of ^{210}Pb and ^{137}Cs can be used to determine the recent 200 years of chronology (Engstroml and Swain, 1986). Paleo-magnetic method depends on the Earth's magnetism phenomena and its connection with the samples. In other hand, biological method is based on the organism's growth occurrences and comparison with the period of their existence. Whereas, the chemical methods are time-dependent and measures the type of chemicals such as organic and inorganic. With advancement in technology, the reconstruction of the influx water signal and the δD of n-C_{29} can be taken as an IOSM proxy (Günther et al., 2015) and also the distribution of glycerol di-alkyl glycerol tetra-ethers (GDGTs) in the samples were used as a proxy for temperature reconstruction (Sun et al., 2011).

Grain-size

The grain-size proxy indicates the millennial-scale variations. It is used as a proxy for wind and monsoonal intensity and transport through the monsoonal phenomena. Mineral matters with different grain sizes and forms can tell us how the climate has changed over time. The origin of the sediments can be determined by the transport mechanisms of the material, past physical conditions at the depositional site in the basin and paleoclimate conditions in the watershed by recognizing the clues from the sediments (Hu et al., 2015). Sequential loss on ignition (LOI) method is widely used to determine the concentration of organic and carbonate matter in the lake sediments (Heiri et al., 2001).

Magnetic susceptibility (χ_{lf})

Since the magnetic susceptibility in the lake sediments varies with the depth, it can be calculated accurately and rapidly by core correlation method by which other biological and chemical characteristics of the lake sediments can be studied (Thompson et al., 1975). The ferromagnetic components in the lacustrine sediments are deposited from highly magnetic soils from the catchments which can be a result of weathering of magnetite rocks due to phase transformation and maghemitization resulting in the decrease in the grain size (Hu et al., 2015). The variation in the magnetic and paramagnetic minerals also highly depends upon the depth of the water (Fig. 3) and circumstances during depositing (Basavaiah et al., 2014). The ferrimagnetic and paramagnetic concentration of the sediment can be determined by magnetic susceptibility (χ_{lf}) serves as a proxy that determines the variations in the environment like increasing amount of debris input from the surrounding and provides an instinct on erosional process (Kumar et al., 2018). The production of magnetosomes by magnetotactic bacteria in the lake sediment due to bacterial activity also produce magnetic minerals in the lake sediments with 0.02-0.1 ìm stable single domain (SSD) grain size (Oldfield et al., 2010). Therefore, the significance of the bacterial magnetite in the lake sediments can be inferred from the ratios of χARM/χlf and χARM/ χfd. If the ratio is greater than 1000, it indicated presence of high magnetic materials contributed from the bacteria (Sandeep et al., 2015).

Stable carbon and nitrogen-isotopes

The source of organic matter in the lake sediments is highly relatable to the variations in the $\delta^{13}C$ values (Fig. 3). The average $\delta^{13}C$ values for C3 and C4 plants are –27% and –14% ranging from –37% to –24% and –19% to –9% respectively (Table 1). In other hand, CAM (Crassulacean acid metabolism) plants have broad ranges of $\delta^{13}C$ from 220% and

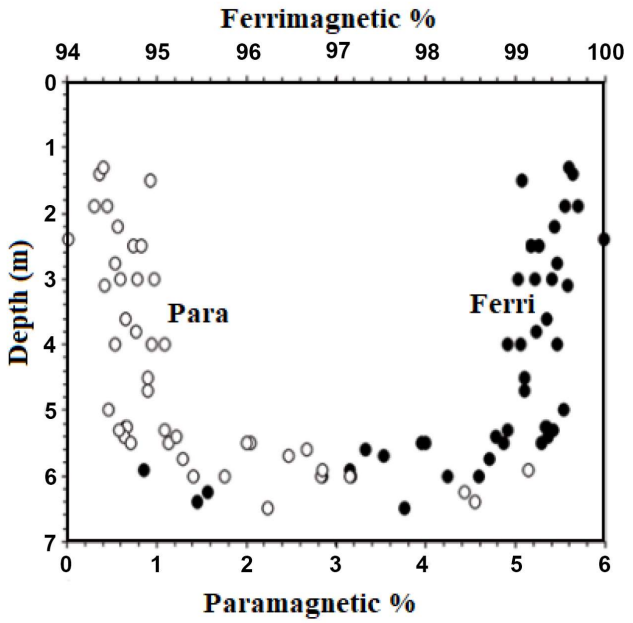

Fig. 3: Variations of ferrimagnetic and paramagnetic minerals with the water depth (Basavaiah et al., 2014)

212% composed of aquatic macrophytes. The HCO_3^- in the water is utilized by these plants for photosynthesis in which case the emergent plants have even more values of $\delta^{13}C$ (230% to 224%). The regional physiochemical processes in the lake itself is the controlling factor that influences $\delta^{15}N$ values in the lake sediments. Likewise, biogeochemical processes like nitrogen-fixation, decomposition by bacteria and several other factors like concentration of dissolved nitrate, kinetic isotopic effects and climate change influence the values of $\delta^{15}N$ (Zhang et al., 2014).

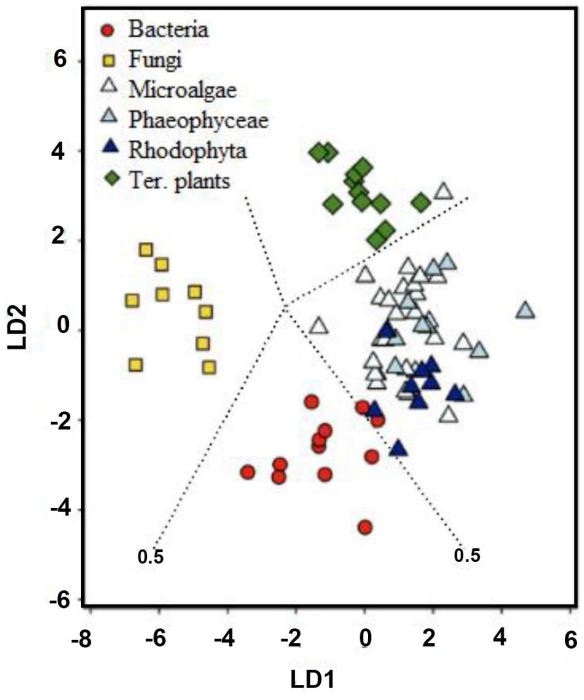

Fig. 4: Linear discriminant (LD) function analysis of the stable carbon isotope composition of essential amino acids demonstrates the "fingerprinting" of a range of primary production sources (Hardenbroek et al., 2018; Larsen et al., 2013)

Total organic carbon and Total Nitrogen (TOC and TN)

The source of TOC in lake sediments can be either the biomass of aquatic algae, aquatic macrophytes or terrestrial plants deposited from the surrounding of the lake. The local climate, anthropogenic influence and catchment condition is an important contributor of organic matter into the TOC (Zhang et al., 2014). The concentration of total organic carbon (TOC) and total nitrogen in lake sediments serve as a proxy for biological productivity as well as paleo-climate. TOC is the representation of the fraction of organic matter that escaped remineralization during sedimentation and describes the richness of organic matter in the sediments (Cook et al., 2003; Meyers and Ishiwatari, 1993). $CaCO_3$ proxy is used to determine the deposition of carbonate and decomposition of organic matter (Sandeep et al., 2017). Similarly, ratio of C: N (Table 2) is used as paleo-climate proxy and its abundance indicates the occurrence of wet, cold, warm, dry or humid conditions (Lone et al., 2018). With high bio-productivity or algal growth, the content of TN is also increasing, so it serves as the trophic level indicator of the lake system (Zhang et al., 2014).

Biological proxies (diatoms, pollens, ostracods, macrofossils)

Lacustrine pollen records provide paleo-climatic data on the shift of vegetation, and can be used as paleo-temperature and precipitation proxy (Li et al., 2011). Hence, pollen studies can provide an improved understanding on the monsoonal variations and can be used as regional elucidation of monsoonal inclinations (Phadtare, 2000). In other hand, diatoms are extensively used as paleoclimate proxy since their siliceous cell walls are largely abundant, diverse, and highly conserved in the sediments and serves as the proxy for aquatic bio-productivity (Axford, Geirsdóttir, Miller, and Langdon, 2009; Krstic and Zech, 2011). Hence, change in diatomic composition in the lake sediments provides information on climate change phenomenon.

Table 1: Showing typical • ^{13}C and C: N values for different organic matter (Eriksson and Olsson, 2015; Meyers and Ishiwatari, 1993)

	Source	Typical $\delta^{13}C$ values (‰)	Typical C:N ratio
C3	Terrestrial	-25 to -27	20 and above
C4	Terrestrial	-14 to -17	20 and above
CAM	Terrestrial	Around -20	20 and above
Algae	Lacustrine	-24 to -27	4 to 10

Table 2: Showing some literatures of C: N ratio and • ^{13}C (‰) around the world (Badejo et al., 2014)

Source	Lake	Location	Reference	C:N ratio	$\delta^{13}C$ (‰)
Surface sediments	Daihai Lake	China	(Hou et al., 2013)	8.2 to 12.1	-
Surface sediments	Baikal Lake	Russia	(Meyers & Ishiwatari, 1993)	11	-29.9
Surface sediments	Michigan Lake	North America	(Meyers & Ishiwatari, 1993)	9	-26.3
Surface sediments	Naples Harbour	Italy	(Rumolo et al., 2011)	0.39 to 68.83	-23.8 to -29.8
Surface sediments	Welwich Marsh	England	(Lamb et al., 2007)	14.7	-21 to -28
Trench sediments	Sangla Lake	India	(Badejo et al., 2014)	9-17	-25 to -23
Surface sediments	Hirekolale Lake	South-India	(Shetty et al., 2018)	-	-28.70
Core sediments	Yellow Sea	East-China	(Lone et al., 2018)	6.15-12.57	-21.6 to -25.84
Core sediments	Xingyun Lake	China	(Zhang et al., 2014)	18.71	-18.37

(Krstic and Zech, 2011). The $\delta^{18}O$ values in ostracods serves as a proxy for strengthening or weakening of monsoon (Kumar et al., 2017). The $\delta^{18}O$ values from the ostracods play a significant role in reconstructing the paleo-temperature and hydrology. According to Dixit et al (2015), the mean value of $\delta^{18}O$ from more than 10 ostracods with higher $\delta^{18}O$ variability can be served as a proxy for reconstructing long term climate changes. Changes in macro-fossils assemblages in the lake sediment is an important environmental proxy for variations in ISM.

MECHANISMS OF ORGANIC MATTER DEPOSITION IN THE LAKE

The study of chronological analysis is the basis for the paleoclimate research from the lake sediments (Chen et al., 2019). The high-altitude areas are highly prone to the impact of climate change and the rate of geo-morphological processes is also in an accelerated level, which endures the information that can predict the future climate variations (Hasholt et al., 2000). Organic matter from long cores are dated using ^{14}C dating based on AMS. The use of single or multiple age-depth model (Fig. 5) depends on the sedimentary changes, since any lithological changes in the sediment core directly affect other parameter like grain-size, there is a high chance of ^{14}C reservoir effect (REs) which influence the correlation between the depth and ^{14}C ages (Chen et al., 2019). The correlation between the ^{137}Cs and ^{210}Pb proxies is used to date the age of the sediments (Kasper et al., 2012).

TRACING THE SOURCE OF ORGANIC MATTER

Carbonates: Calcium, magnesium, iron and manganese carbonates are the major constituents found in the lake sediment bed. Calcite ($CaCO_3$) in the lake sediments mainly have four major sources (Fuhrmann, 2002; Wang et al., 2010) i.e. detrital carbonates, biogenic carbonates, inorganically-precipitated carbonates, diagenetic carbonates. Similarly, dolomite (Ca-Mg $(CO_3)_2$) minerals also have detrital sources. They also have similar deposition mechanism like calcite by fluvial input or by erosional depositions (Fig. 6) (Fuhrmann, 2002; Zhu et al., 2008). Whereas evaporative concentration of ground water and primary dolomites also can be represented as the major source. Dolomites from microbial decomposition and diagenetic carbonates are also major sources for the dolomite precipitation in the lake. Kutnahorite (Ca-Mn $(CO_3)_3$) or (Mn-Ca) carbonates have a huge importance in paleo-environmental reconstruction since during the deposition of anoxic sediments manganese is mostly depleted because Mn2+ ions have high stability in aqueous solutions which results in the leaching of manganese mineral from the sediments (Fuhrmann, 2002). Aragonite (rhombic $CaCO_3$) and Siderite ($FeCO_3$) are also important carbonates precipitating in the sediments from atmospheric interaction of CO_2 in the water and interaction of hydrogen-sulfide (H_2S) with pyrite respectively.

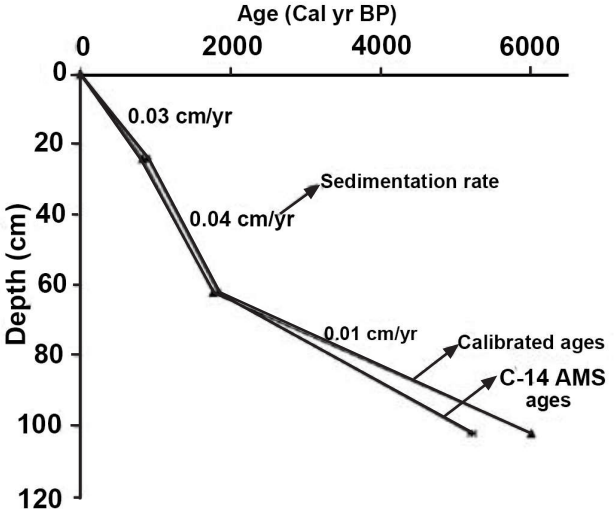

Fig. 5: Age–depth model shows ^{14}C AMS ages (after calibration) and sedimentation rates at different depths (Kumar et al., 2018)

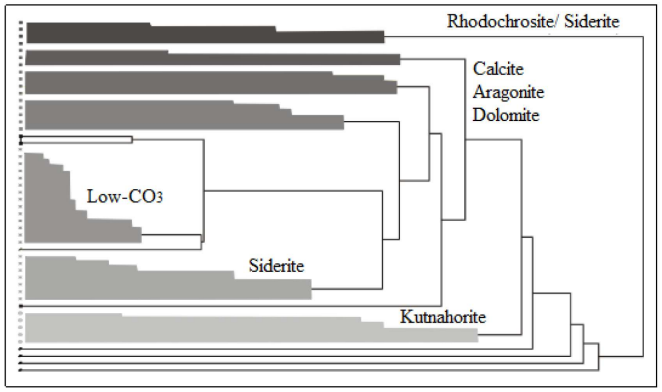

Fig. 6: Cluster analysis of samples based on carbonate mineralogy (Fuhrmann, 2002)

DISCUSSION

Paleo-climate studies from the Himalayas and their implications to ISM

There are very less researches conducted to examine the multi-decadal variability of the ISM (Kaushal et al., 2018). Many researches in the Lake sediments of the Himalayas has been conducted since 1970s in a different time scale (Table 3). Generally, the Pleistocene and the Late Holocene time scales has been covered for the climatic and the environmental changes in the Southern Himalayas. The paleo-climate reconstruction records over 2,500 years from lacustrine sediments in the Himalayan regions. Here is a review from some selected places in the Southern Himalayas and their response to the ISM (Tables 3 and 4; Figs. 7 and 8).

Recent time period

Khumbu valley

The lacustrine sediments from the two Himalayan lakes in Khumbu Valley reconstructed diatoms population which reported the time period between 300–900 AD had an occurrence of cool but inconsistent climate, inferred the climatic enhancement between 900–1400 AD, and the 1400 to 1900 AD had a cool period (Lami et al., 2010; Rowan, 2017).

Pokhara valley

Studies from dolomitic cave recorded the summer

Table 3: List of literatures with the proxies used in this review, shown in Fig. 8

Source	Lake	Location	References	Proxies
Lake sediments	Paru Co	29°46'N, 92°21'E	(Bird et al., 2014)	nC_{29} alkanes
Lake sediments	Qinghai Lake	37°18'N, 90°50'E	(Thomas et al., 2016)	nC_{28} alkanoic acid
Marine sediments	Bay of Bengal	19°58'N,90°2'E	(Contreras-rosales et al., 2014)	nC_{29} alkanes
Lake sediments	Gonghai Lake	38°54'N, 112°14'E	(Chen et al., 2015)	Pollen assemblages
Lake sediments	Shantisagara Lake	14°08'N, 75°52'E	(Sandeep et al., 2015)	AMS-^{14}C, stable carbon isotope, mineral magnetism
Lake sediments	Riwasa Lake	28°47'N, 75°57'E	(Dixit et al., 2014)	AMS-^{14}C, δ^{18}O, Ostracod
Lake sediments	Lonar Lake	19°58'N, 76°30'E	(Menzel et al., 2014)	AMS-^{14}C, δ^{13}C, grains size, δ^{15}N, C/N, AMS - ^{14}C, δ^{18}O, δ^{13}C
Lake sediments	Phewa Lake	28°12'N, 83°56'E	(Sun et al., 2011)	GDGTs
Marine Sediments	Western Arabian Sea	14°19' N, 57°21' E	(Sirocko et al., 2000)	Trace elements
Lake sediments	Rara Lake	29°31' N, 82°04' E	(Nakamura et al., 2012)	Mn/Ti
Marine sediments	Bay of Bengal	19°58'N, 90°2'E	(Rashid et al., 2011)	δ^{18}O, Mg/Ca
Lake sediments	Panch Pokhari Lake	28°02' N, 85°43' E	(Krstic & Zech, 2011)	TOC/N, Diatoms
Lake sediments	Shantisagara Lake	14°08'N, 75°52'E	(Sandeep et al., 2017)	C_{org}/N, δ^{13}C
Lake sediments	Khumbu valley	27°57'N, 86°48'E	(Lami et al., 2010; Rowan, 2017)	Diatoms
Speleothem	Siddha Baba Cave	27°54′N, 83°37E	(Denniston et al., 2000)	^{229}Th, ^{233}U, ^{236}U, Mg/Ca
Lake sediments	Tangra Yumco	30°45'N, 86°23'E	(Ahlborn et al., 2016)	Grain-size, TOC, TN, TIC
Stalagmites	Dongge Cave	25°17′N, 108°5′E	(Yuan et al., 2004)	^{230}Th, δ^{18}O
Lake sediments	Chandra Tal	32°24'N, 77°12'E	(Rawat et al., 2012)	Pollen
Aeolian sediments	Karsandi Lake	28°59'N 74°45' E	(Dixit et al., 2018)	δ^{18}O, δD
Lake sediments	Paleo-Kathmandu Lake	27°49'N, 85°29'E	(Hayashi et al., 2009)	Diatoms, TOC, C/N, and δ^{13}C
Lake sediments	Lake Chen Co	28°53'N, 90°33'E	(Zhu et al., 2009)	TOC, TN, C/N, Fe/Mn, $CaCO_3$, and pollen

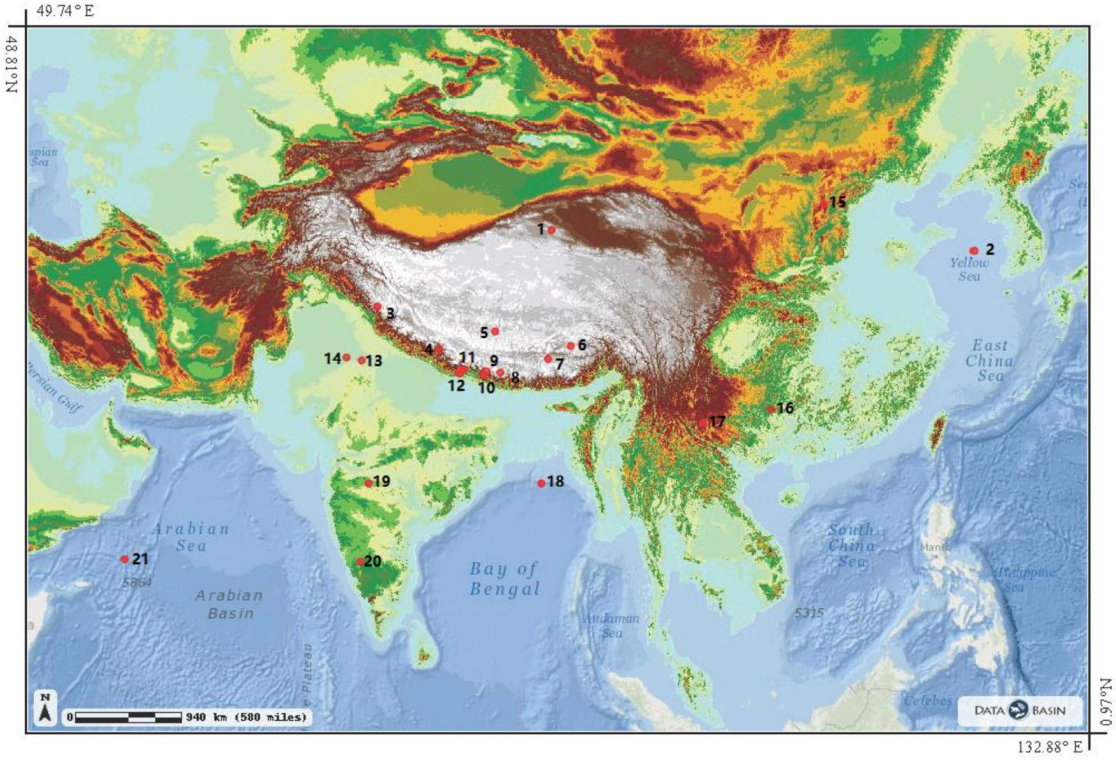

Fig. 7: Showing location of study sites used in this review (1: Qinghai Lake (Thomas et al., 2016), 2: Yellow Sea (Lone et al., 2018), 3: Chandra Tal (Rawat et al., 2012), 4: Lake Rara (Nakamura et al., 2012), 5: Tangra Yumco (Ahlborn et al., 2016), 6: Paru Co (Bird et al., 2014), 7: Lake Chen Co (Zhu et al., 2009), 8: Khumbu Valley (Lami et al., 2010; Rowan, 2017), 9: Panch Pokhari Lake (Krstic and Zech, 2011), 10: Paleo Kathmandu Lake (Hayashi et al., 2009), 11: Phewa Lake (Sun et al., 2011), 12: Siddha Baba Cave (Denniston et al., 2000), 13: Riwasa Lake (Dixit et al., 2014), 14:Karsandi Lake (Dixit et al., 2018), 15: Gonghai Lake (Chen et al., 2015), 16: Dongge Cave (Yuan et al., 2004), 17: Xingyun Lake (Zhang et al., 2014), 18: Bay of Bengal (Contreras-rosales et al., 2014; Rashid et al., 2011), 19: Lonar Lake (Menzel et al., 2014), 20: Shantisagara Lake (Sandeep et al., 2017), 21: Arabian sea (Sirocko et al., 2000).

monsoon variability over the past 2,300 years using speleothem proxy in Pokhara valley. The period between 2300-1500 yr BP indicated the reduction of monsoon precipitation while the monsoon conditions were increased after 1500 yr BP from the records from Pokhara valley (Denniston et al., 2000; Singhvi and Vishwas S, 2009). There are various records covering the Pleistocene to mid to Late Holocene. Such regional paleoclimate records provide important information to predict the proxy data and their response of ISM.

Mid to Late Holocene

Lakes from China

The use of identical proxies for paleoclimate reconstruction were conducted on two lakes namely Nam co and Tangra Yumco on the southern Tibetan plateau. Records from Tangra Yumco was compared with Nam Co, Tso Moriri, and Naleng Co which revealed continuous development of moisture availability on the southern Tibetan plateau. These records along with monsoon intensity report suggested that these lakes were influenced by ISM at 16k yr B.P. (Ahlborn et al., 2016). Another study conducted by An et al. (2012) in Qinghai lake sediments suggested that the ASM was very weak, exhibiting no long-term change in the mean from 32 to 20k yr B.P. using $CaCO_3$, TOC flux as monsoon proxies. Records from Southwest China suggests that the intensity of ISM significantly increased during early Holocene with marked paleo-productivity then decreased during the Heinrich event and the Younger Dryas signified by TOC, and ä 15N isotope, grain-size, $CaCO_3$ proxies (Zhang et al., 2014).

Shantisagara Lake

Study conducted by Sandeep et al. (2017) in Shantisagara Lake, indicated that 11k cal yr B.P. was the longest report from the SS-1 core from peninsular India which explains the weakening of ISM between 11k-10.7k cal yr B.P. with depleted ä13C where C3 plants were higher than C4 plants. Similarly, the researchers conclude that the end of the period may represent the Younger Dryas cold event. The period between 10.7k to 8.6k yr B.P. characterized the Early Holocene period with the intensified ISM with low Corg/N ratio. In contrast to Shantisagara lake records, Rashid et al. (2011) studied VM 29-19 core from Western Bay of Bengal indicated that the intensity of monsoon was stronger in the Bølling/Allerød period and weaker in the

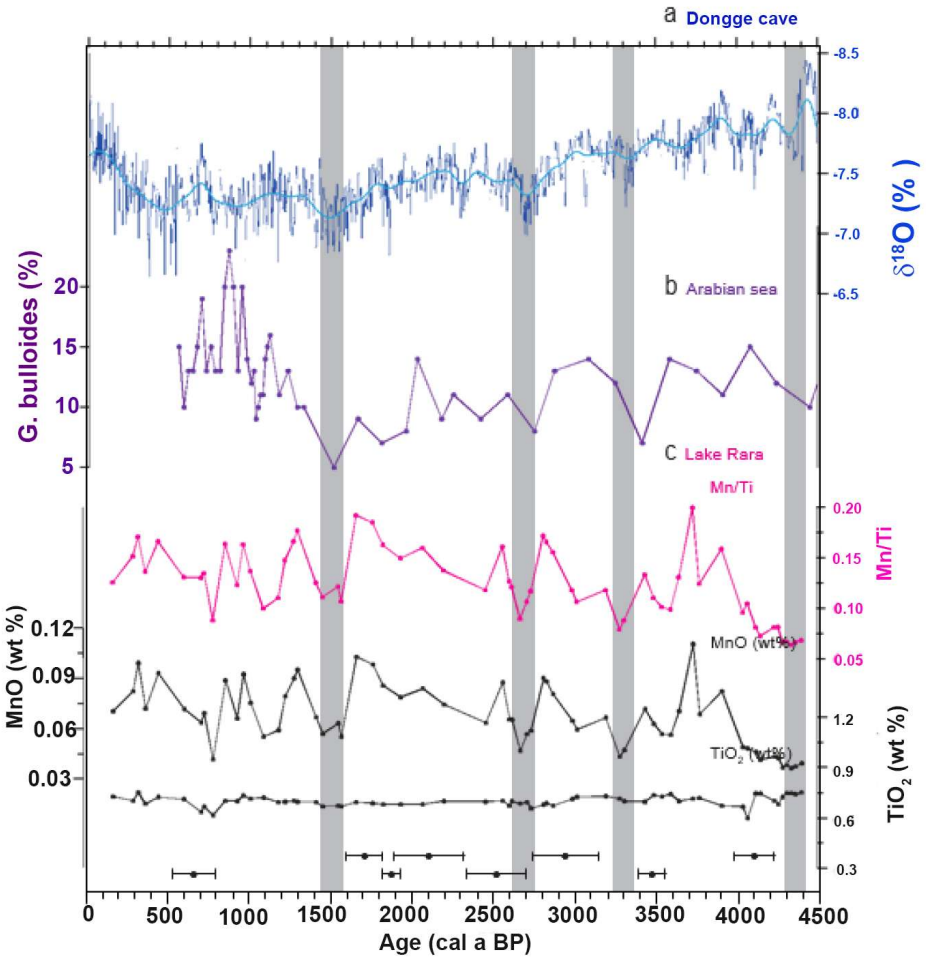

Fig. 8 a) Comparison of stalagmites record from Dongge cave (Yuan et al., 2004), b) Globigerina bulloides occurrence in ODP Hole 723A from the Arabian Sea, and c) Mn/Ti ratio from Lake Rara (Nakamura et al., 2012)

Younger Dryas periods.

Chandra Tal

According to a research conducted on AMS dated pollen samples from Chandra Tal, Himalayas lake sediments, the termination of the Allerød interstadial and the beginning of the Younger Dryas event occurred at 12.8k cal yrs B.P. which is similar to the global Younger Dryas event (Rawat et al., 2012).

Indian Region Lakes

According to the Indian region lake records, the climatic conditions during the early Holocene (10 to 8.2 kyr BP) was reflected to be wet by C: N proxy records. On the contrary, the mid and late Holocene (8.2 to 2.8k yr B.P.) experienced the irregular arid conditions while enhancement of C: N ratio during 7.8-2.3k yr B.P. indicated the lowering of lake level with lowest precipitation. It also suggested the Holocene period had a very strong influence of South-west monsoon and was responsible for the expansion of lakes in the Indian regions. Similarly, the paleo-climatic records from the Indian Lakes suggest the fluctuation of climate during the Holocene from dry, arid and wet phases as an effect of shifting of the monsoonal pattern (Lone et al., 2018).

Lake Rara

Nakamura et al. (2012) compared the ISM wind intensity between the Arabian Sea region with the terrestrial Himalaya region during the Late Holocene and concluded that the long scale variability in those records were contemporaneous with weak wind intervals equivalent to drier period in East-Asia. Nakamura et al. (2012) detected several intervals of weak ISM wind strength at 0.7, 1.1, 1.5, 2.7, 3.3 and 4.3k yr B.P. from profiles of Mn/Ti which was the first evidence of terrestrial summer monsoon wind strength changes from Lake Rara, western Nepal, based on Mn/Ti ratios, a proxy for lake stratification.

The Fig. 8 from the study by Nakamura et al. (2012) suggested that centennial to millennial-scale changes in the strength of wind occurred synchronously between the Arabian Sea and the Himalayas. Studies by Nakamura et al. (2016) reported less abrupt but arid climatic conditions around 4.2-3.7

kyr B.P. from sediment samples from Lake Rara. Similarly, these four weak wind events similar to Lake Rara were also noted in the East Asian summer monsoon U/Th-dated speleothem record from Dongge Cave, southern China (Yuan et al., 2004).

Panch Pokhari Lake

The study of sediment sample from Panch Pokhari Lake in central Nepal indicated the strengthening of summer monsoon at two intervals at 14.8k yr B.P. and in between 13.7 and 12.8k yr B.P. based on the ratio of TOC/N (Krstic and Zech, 2011).

Paleo-Riwasa Lake and Lonar Lake

The use of ä18O record of biogenic carbonate inferred the weakening of the ISM in Indian subcontinent at around 8.2k yr B.P. was recorded and the 8.2-k yr desiccation of paleo-lake Riwasa suggested an abrupt response of the ISM to forcing from the North Atlantic and supports previous results of a strong teleconnection between monsoon Asia and North Atlantic climate (Dixit et al., 2014). In another study by Dixit et al. (2015), the researchers noticed the strengthening of ISM during 9.6 to 8.3 k yr which was indicated by the significant decrease in $\delta^{18}O$ isotope values in ostracods from the same study site.

There are several terrestrial records observed in the Indian subcontinent at around 4.2k yr B.P. The ~4.2 ka B.P. event can be considered as a defining event of the Mid-Late Holocene transition period, and is marked by extreme drought (Giesche et al., 2018). Phadtare (2000) also reported similar findings from Northcentral India where arid conditions prevailed at around 4.0-3.5k yr B.P. Similar findings were documented by (Menzel et al., 2014) using $\delta^{18}O$, $\delta^{13}C$ in central India at around 4.6-3.8k yr B.P. in Lonar Lake supporting the previous findings (Giesche et al., 2018).

Mawmluh cave

Berkelhammer et al. (2012) also reported abrupt climate change event at around 4.1-3.9 k yr B.P. in Mawmluh cave using $\delta^{18}O$ isotopes of precipitation, while Dixit et al. (2014) also reported arid conditions during 4.1k yr B.P. in Kotla Dahar northwest India.

Karsandi Lake

Another study by Dixit et al. (2018) inferred δD, $\delta^{18}O$ and d-excess proxies from Karsandi reported wet conditions during 5.1-4.4k yr B.P and later reported the abrupt dryness of lake during 4.4-3.2k yr B.P. In contrast reports from various studies from the marginal lakes from Thar Desert (Deotare et al., 2004; Enzel et al., 1999; Singh, Wasson, and Agrawal, 1990) suggested the lake dried centuries ago and absence of 4.2k yr B.P. event.

Sahiya cave

Findings by Kathayat et al. (2017) from Sahiya Cave in northwestern India reconstructed the trend of monsoon strength which shows an abrupt decrease in $\delta^{18}O$ reflected an increase in monsoon strength during 4.3-4.15 k yr B.P. and an arid condition occurred after 4.15 k yr B.P.

Last Glacial Maximum

In addition to this, some studies covering Last Glacial Maximum has also been reported in the Himalayas (Sakai et al., 2016). According to some sources, the Last Glacial maximum period must have peaked at around 20 k to 18 k yr B.P. and came to the end about 10,000 years ago (Mead, 1983). The Holocene is an important period causing impacts in ecosystems with changes in climate and environment which is the transition from the Last Glacial to the current Interglacial (Günther et al., 2015).

Paleo-Kathmandu Lake

Paleo-Kathmandu Lake project first reported the terrestrial climatic record in South Asia which was continuous. In the paper, millennial-scale climatic changes in the valley from 50k yr to 12 k yr, was reported and attempted to compare the results with the glaciation in the Himalaya and the ice cores in both Greenland and Antarctica (Fujii et al., 2004). Fujii and Sakai (2002) also studied the lacustrine sediments in the Kathmandu using palynological proxies which reported at least seven repetitions of warm and cold climates, corresponding to the global glacial-interglacial cycles. This study was similar to the result by Maki et al. (2004) suggesting that a wet climate during warm-interglacial and dry climate prevailed during cold-glacial periods in the Kathmandu Valley (Fujii and Sakai, 2002). The co-existence of minor key genera and floral richness are important characteristics of the pollen assemblage to reconstruct the past vegetation and climate. Palynological studies of 200 arboreal pollen grains identified from the sediment samples in the Kathmandu valley suggested the fluvial and lacustrine deposits of the younger stage were dated to the Last Glacial Age by the Radio-carbon method. The Gokarna formation and the Patan formation were dated to about 25 k to 30 k yr. BP and 11 k to 19 k yr. BP, respectively. The paper also concluded that the climate of Kathmandu valley shifted from cold to dry from the past (Igarashi and Yoshida, 1988).

Chen Co

A multi-proxy study conducted in Lake Chen Co in 2009 tried to outline the late glacial environment change since past 30 k yr in Southern Tibet, which concluded that the environment was warm and moderately humid during the 30 k–26.5 k yr BP which shifted to cold and dry in 26.5 k to 20 k yr BP and again deflected to warm and humid phase from 20k to 18k yr BP reported with decline in vegetation pattern (Zhu et al., 2009) .

Arabian Sea

Temporal variations of the trace elements from the Arabian Sea as a function of changing monsoonal intensity, atmospheric circulation and hydrographic conditions during

Table 4: Major Climatic scenarios during different timescales from the Himalayas

Location of proxies	Age Range	Inferences	References	Timeline
Khumbu valley	300-1900 A.D.	300–900 AD had cool inconsistent climate, climatic enhancement between 900–1400 AD, and the 1400 to 1900 AD had a cool period	Lami et al., 2010; Rowan, 2017	
Pokhara Valley	2300 yr BP	2300-1500 yr BP indicated the reduction of monsoon precipitation, increased after 1500 yr BP	(Denniston et al., 2000; Singhvi and Vishwas, 2009)	Recent
Nam Co, Tso Moriri, and Naleng Co		Influence of ISM at 16k yr BP	Ahlborn et al., 2016)	
Shantisagara Lake		Weakening of ISM between 11k-10.7k cal yr B.P.	(Rashid et al., 2011)	
Indian region Lakes		Strong influence of South-west monsoon	(Lone et al., 2018)	
Lake Rara		Weak ISM wind strength at 0.7, 1.1, 1.5, 2.7, 3.3 and 4.3k yr B.P.	(Nakamura et al., 2012)	
Panch Pokhari Lake		Strengthening of summer monsoon at two intervals at 14.8k yr B.P. and in between 13.7 and 12.8k yr B.P.	(Krstic and Zech, 2011)	
Paleo Riwasa, Lonar Lake		Weakening of the ISM in Indian subcontinent at around 8.2k yr B.P. strengthening of ISM during 9.6 to 8.3 k yr	(Dixit et al., 2014; Dixit and Tandon, 2016)	
Karsandi Lake		Strengthening of monsoon at 5.1-4.4k yr B.P, weakening at 4.4-3.2k yr B.P.	(Dixit et al., 2018)	Holocene
Paleo Kathmandu Lake		Seven repetitions of warm and cold climates, corresponding to the global glacial-interglacial cycles.	(Fujii and Sakai, 2002)	
Chen Co		Warm and moderately humid during the 30k–26.5k yr BP, cold and dry in 26.5k to 20k yr BP, warm and humid phase from 20k to 18k yr BP	(Zhu et al., 2009)	Last Glacial maximum
Arabian Sea		Weakening of Indian summer monsoon during LGM	(Chandana et al., 2018)	
Gokarna Valley		Temperature of the Kathmandu valley was lowered by 6-7°C	(Bhandari et al., 2011)	
Lukundol Formation		Warm climate history than present	(Bhandari and Paudayal, 2007)	
Paleo Kathmandu lake		Lake level decreased at 38k yr and 48k yr, Strengthening of ISM	(Sakai et al., 2016) (Hayashi et al., 2009)	
Nal Sarovar Lake		increment of lake level during ~7.2-6.1 kyr BP and the lowering of lake level at ~6.1-5.4 kyr BP	(Prasad et al., 1997)	
Dharmasthali formation		Warm climate at Pleistocene which cooled after 780k yr	Humagain and Paudayal (2018)	Pleistocene

last 25 k yr by Sirocko et al. (2000) have been reported based on sediment core from western Arabian sea (Chandana et al., 2018). The following report suggested the weakening of Indian summer monsoon during LGM. It also suggested the low calcareous productivity could be due to the favoring of silicate over carbonate productivity as a function of ISM strengthening (Sirocko et al., 2000).

Pleistocene

Paleo-Kathmandu Lake

Bhandari et al. (2011) at Gokarna Formation in Kathmandu valley inferred macro-fossils assemblages from the Late Pleistocene time scale, and demonstrated that the temperature of the Kathmandu valley was lowered by 6-7°C. Similar results were obtained by Nakagawa et al. (1996) from pollen samples in the Gokarna formation suggested the domination of cold climatic taxa over warm climatic taxa supporting the preceding study. In contrast, the environment evolution since Pleistocene in the fluvial-lacustrine deposits in the Lukundol formation was revealed to have warm climate history than present (Bhandari and Paudayal, 2007). Study on the basis of two climatic records from BDP99 core and RB core from Paleo-Kathmandu Lake and Lake Baikal discussed regional differences of vegetational responses to glacial/interglacial climate changes in representative areas in Asia. And the researchers referred to the environmental changes during the mid- Pleistocene transition on the basis of the relative abundance of pollen genera in the sample as they recognized nine cycles of warm-wet and cold-dry period during 750 cal kyr (Maki et al., 2004). Sakai et al. (2016) also studied the macro-fossil assemblages and many different proxies in former-Kathmandu Lake and recorded the water events of the lake was dropped in Late-Pleistocene lacustrine sediments at 38k yr and 48k yr. The paper also proposed the tectonic event might be responsible for the lowering of the lake levels and the occurrence of wet and warm climate during the Pleistocene. A multi-proxy analyses of the cores of Paleo- Kathmandu Lake during the last 600k yr were reconstructed and the history of vegetation and monsoon climate, ecological changes of diatom, and changes in TOC, C/N, and $\delta^{13}C$ of organic matter were revealed. Fossil diatom assemblages and biogenic silica revealed bio-productivity variations which might occurred due to summer monsoonal rainfall which can be linked with global and Indian monsoon climate changes on glacial and interglacial time scales which increased the diatoms assemblages (Hayashi et al., 2009).

Nal Sarovar Lake

In contrast reports from Nal Sarovar Lake in the Indian region experienced the increment of lake level during 7.2-6.1 kyr BP and the lowering of lake level at 6.1-5.4 kyr BP (Prasad et al., 1997).

Dharmasthali formation

Similarly, Humagain and Paudayal (2018) inferred the Pleistocene climate of Dharmasthali formation to be warm which later cooled after 780k yr.

North East China

A group of researchers summarized the late-Pleistocene climate of northeast China as periglacial. According to their findings, they described two cold intervals (35 k-26 k yr BP and 23 k-12 k yr BP) characterized by cold-adapted fauna dominated by woolly mammoth and woolly rhinoceros. Their paper also suggested that the vegetation in that region at about 18k yr BP was dominated by tundra north of 45N, open steppe to 42N, and northern conifer forests to 39N. Late glacial temperatures inferred from the bio-geologic evidence were 8-10? lower than the modern temperature at the same regional settings (Winkler and Wang, 2015).

CONCLUSION

Southern Himalayas is highly influenced by the monsoonal influence due to which it serves as a natural laboratory of paleoclimate archives and records the monsoonal influence. Various proxies like grain-size, C: N, TOC, $CaCO_3$, stable isotopes, etc. records the monsoonal response and paleoclimate and environmental changes can be reconstructed from them. According to the literatures, during the Holocene period, the intensity of the Indian summer monsoon was weakened but intensified around 4.2 k yr event. Similarly, there was weakening of ISM during the last glacial maximum which concluded that the weather of Southern Himalaya shifted from cold to dry. While during the Pleistocene, the lake level was distinctly dropped indicating weak ISM intensity.

REFERENCES

Ahlborn, M., Haberzettl, T., Wang, J., Henkel, K., Kasper, T., Daut, G., and Mäusbacher, R. 2016, Synchronous pattern of moisture availability on the southern Tibetan Plateau since 17.5 cal. ka BP – the Tangra Yumco lake sediment record. Boreas, v. 46(2), pp. 229–241. https://doi.org/10.1111/bor.12204

An, Z., Colman, S. M., Zhou, W., Li, X., Brown, E.T., Jull, A J.T., and Xu, X., 2012, Interplay between the Westerlies and Asian monsoon recorded in Lake Qinghai sediments since 32 ka. Scientific Reports, v. 2(619), pp. 1–28. https://doi.org/10.1038/srep00619

Axford, Y., Geirsdóttir, Á., Miller, G. H., and Langdon, P.G., 2009, Climate of the Little Ice Age and the past 2000 years in northeast Iceland inferred from chironomids and other lake sediment proxies. Journal of Paleolimnology, v. 41(1), pp. 7–24. https://doi.org/10.1007/s10933-008-9251-1

Badejo, A.O., Choi, B.H., Cho, H.-G., Yi, H.I., and Shin, K.H., 2014, A paleoenvironmental reconstruction of the last 15 000 cal yr BP via Yellow Sea sediments using biomarkers

and isotopic composition of organic matter. Climate of the Past Discussions, v. 10(2), pp. 1527–1565. https://doi.org/10.5194/cpd-10-1527-2014

Basavaiah, N., Wiesner, M.G., Anoop, A., Menzel, P., Nowaczyk, N.R., Deenadayalan, K., and Prasad, S., 2014, Physicochemical analyses of surface sediments from the Lonar Lake, central India – implications for palaeoenvironmental reconstruction. Fundamentsal Applied Limnology, 184(1), pp. 51–68. https://doi.org/10.1127/1863-9135/2014/0515

Berkelhammer, M., Sinha, A., Stott, L., Cheng, H., Pausata, F.S.R., and Yoshimura, K., 2012, An Abrupt Shift in the Indian Monsoon 4000 Years Ago An Abrupt Shift in the Indian Monsoon 4000 Years Ago. Climates, Landscapes, and Civilizations, v. 198, pp. 75–87.

Bhandari, S, and Paudayal, K.N., 2007, Palynostratigraphy and palaeoclimatic interpretation of the Plio- Pleistocene Palynostratigraphy and palaeoclimatic interpretation of the Plio- Pleistocene Lukundol Formation from the Kathmandu valley , Nepal. Journal of Nepal Geological Society, v. 35, pp. 1–10. https://doi.org/10.3126/jngs.v35i0.23629

Bhandari, Sudarshan, Paudayal, K.N., and Momohara, A., 2011, Late Quaternary plant macrofossil assemblages from the Besigaon section of the Gokarna Formation , Kathmandu Valley , central Nepal. Journal of Nepal Geological Society, v. 42, pp. 1–12.

Bird, B.W., Polisar, P.J., Lei, Y., Thompson, L.G., Yao, T., Finney, B.P., and Steinman, B.A., 2014a, A Tibetan lake sediment record of Holocene Indian summer monsoon variability. Earth and Planetary Science Letters, v. 399, pp. 92–102. https://doi.org/10.1016/j.epsl.2014.05.017

Bird, B.W., Polisar, P.J., Lei, Y., Thompson, L.G., Yao, T., Finney, B.P., and Steinman, B.A., 2014b, A Tibetan lake sediment record of Holocene Indian summer monsoon variability. Earth and Planetary Science Letters, pp. 92–102. https://doi.org/10.1016/j.epsl.2014.05.017

Bradley, R.S., 2015, Dating Methods I. Paleoclimatology (3rd ed.). Elsevier Inc. https://doi.org/10.1016/B978-0-12-386913-5.00003-X

Buchaca, T., and Catalan, J., 2007, Factors influencing the variability of pigments in the surface sediments of mountain lakes. Freshwater Biology, v. 52, pp. 1365–1379. https://doi.org/10.1111/j.1365-2427.2007.01774.x

Chandana, K.R., Banerji, U.S., and Bhushan, R., 2018, Review on Indian Summer Monsoon (ISM) Reconstruction since LGM from Northern Indian Ocean. Earth Science India, v. 11(I), pp.71–84.

Chen, F., Xu, Q., Chen, J., Birks, H.J.B., Liu, J., Zhang, S., and Zheng, Z., 2015, East Asian summer monsoon precipitation variability since the last deglaciation. Scientific Reports, v. 5, pp. 1–11. https://doi.org/10.1038/srep11186

Chen, H., Zhu, L., Ju, J., Wang, J., and Ma, Q., 2019, Temporal variability of 14C reservoir effects and sedimentological chronology analysis in lake sediments from Chibuzhang Co , North Tibet (China). Quaternary Geochronology, v. 52, pp. 88–102. https://doi.org/10.1016/j.quageo.2019.02.009

Contreras-rosales, L.A., Jennerjahn, T., Tharammal, T., Meyer, V., and Lückge, A, 2014, Evolution of the Indian Summer Monsoon and terrestrial vegetation in the Bengal region during the past 18 ka. Quaternary Science Reviews, v. 102, pp. 133–148. https://doi.org/10.1016/j.quascirev.2014.08.010

Cook, E.R., Krusic, P. J., and Jones, P.D., 2003, Dendroclimatic signals in long tree-ring chronologies from the Himalayas of Nepal. International Journal of Climatology, v. 23, pp. 707–732.

Denniston, R. F, Gonzalez, L., Asmerom, Y.H., Sharma, R., and Reagan, M., 2000, Speleothem Evidence for Changes in Indian Summer Monsoon Precipitation over the Last ~2300 Years. Quaternary Research, v. 53, pp. 196–202. https://doi.org/10.1006/qres.1999.2111

Deotare, B.C., Kajale, M.D., Rajaguru, S.N., Kusumgar, S., Jull, A.J.T., and Donahue, J.D., 2004, Palaeoenvironmental history of Bap-Malar and Kanod playas of western Rajasthan , Thar desert. Earth Planet. Sci., v. 113(3), pp. 403–425.

Dixit, Y., Hodell, D.A., Giesche, A., Saini, H. S., Skinner, L.C., Mujtaba, S.A.I., and Petrie, C.A., 2018, Intensified summer monsoon and the urbanization of Indus Civilization in northwest India. Scientific Reports, 8, 1–8. https://doi.org/10.1038/s41598-018-22504-5

Dixit, Y., Hodell, D.A., Sinha, R., and Petrie, C.A., 2014, Abrupt weakening of the Indian summer monsoon at 8.2 kyrB.P. Earth and Planetary Science Letters, pp.16–23. https://doi.org/10.1016/j.epsl.2014.01.026

Dixit, Y., Sinha, R., and Petrie, C.A.,2015, Oxygen isotope analysis of multiple , single ostracod valves as a proxy for combined variability in seasonal temperature and lake water oxygen isotopes Oxygen isotope analysis of multiple , single ostracod valves as a proxy for combined variability in sea. Journal of Paleolimnology, v. 53, pp. 35–45. https://doi.org/10.1007/s10933-014-9805-3

Dixit, Y., and Tandon, S.K., 2016, Hydroclimatic variability on the Indian-subcontinent in the past millennium?: Review and assessment Earth-Science Reviews Hydroclimatic variability on the Indian subcontinent in the past millennium?: Review and assessment. Earth Science Reviews, v. 161, pp. 1–15. https://doi.org/10.1016/j.earscirev.2016.08.001

Engstroml, D.R., and Swain, E.B., 1986, The chemistry of lake sediments in time and space. Hydrobiologia, v. 143, pp. 37–44.

Enzel, Y., Ely, L. L., Mishra, S., Ramesh, R., Amit, R., Lazar, B., and Sandler, A., 1999, High-Resolution Holocene Environmental Changes in the Thar Desert , Northwestern India. Science, v. 284, pp. 125–128.

Eriksson, F., and Olsson, D., 2015, Palaeoenvironmental reconstruction of catchment processes in sediments from.

Fuhrmann, A., 2002, Geochemical Indicators of Paleoenvironmental and Paleoclimatic Change in Ancient and Recent Lake Deposits?: Facies Models , Facies Distributions and Hydrocarbon Aspects. Institute for Petroleum and Organic Geochemistry.

Fujii, R, and Sakai, H., 2002, Paleoclimatic changes during the last 2 . 5 myr recorded in the Kathmandu Basin , Central Nepal Himalayas, v. 20, pp. 255–266.

Fujii, R., Sakai, H., and Miyoshi, N., 2004, Fluctuation of Indian monsoon during the last glacial period revealed by pollen analysis of Kathmandu Basin sediments , Nepal Himalaya, v. 2(4), pp. 133–134.

Gaire, N.P., Bhuju, D.R.A.J., and Koirala, M., 2013, Dendrochronological studies in Nepal: Current status and future prospects, v. 3, pp. 1–9.

Giesche, A., Staubwasser, M., Petrie, C.A., and Hodell, D.A., 2018, Re-examining the 4.2 ka BP event in foraminifer isotope records from the Indus River delta in the Arabian Sea. Climate of the Past Discussions, pp. 1–31. https://doi.org/https://doi.org/10.5194/cp-2018-104

Günther, F., Witt, R., Schouten, S., Mäusbacher, R., Daut, G., Zhu, L., and Gleixner, G., 2015, Quaternary ecological responses and impacts of the Indian Ocean Summer Monsoon at Nam Co, Southern Tibetan Plateau. Quaternary Science Reviews, v. 112, pp. 66–77.

https://doi.org/10.1016/j.quascirev.2015.01.023

Guo, B., Liu, Y., Zhang, F., Hou, J., and Zhang, H., 2018, Heavy metals in the surface sediments of lakes on the Tibetan Plateau , China. Environ Sci Pollut Res, v. 25, pp. 3695–3707. https://doi.org/10.1007/s11356-017-0680-0

Hardenbroek, M. Van, Chakraborty, A., Davies, K.L., Harding, P., Heiri, O., Schilder, J., and Wooller, M. J., 2018, The stable isotope composition of organic and inorganic fossils in lake sediment records?: Current understanding , challenges , and future directions. Quaternary Science Reviews, v. 196, pp. 154–176. https://doi.org/10.1016/j.quascirev.2018.08.003

Hasholt, B., Walling, D.E., and Owens, P.N.,2000, Sedimentation in arctic proglacial lakes: Mittivakkat Glacier, south-east Greenland. Hydrological Processes, v. 14(4), pp. 679–699.

Hayashi, T., Tanimura, Y., Kuwahara, Y., Ohno, M., Mampuku, M., Fujii, R., and Sakai, H., 2009, Ecological variations in diatom assemblages in the Paleo-Kathmandu Lake linked with global and Indian monsoon climate changes for the last 600,000Êyears. Quaternary Research, v. 72(3), pp. 377–387. https://doi.org/DOI: 10.1016/j.yqres.2009.07.003

Heiri, Oliver; Lotter, Andre; Lemcke, G., 2001, Loss on ignition as a method for estimating organic and carbonate content in sediments. Journal of Paleolimnology, v. 25, pp. 101–110. https://doi.org/10.1017/CBO9781107415324.004

Holmes, N., Langdon, Æ.P.G., and Caseldine, C. J., 2009, Subfossil chironomid variability in surface sediment samples from Icelandic lakes?: implications for the development and use of training sets. Journall of Paleolimnology, v. 42, pp. 281–295. https://doi.org/10.1007/s10933-008-9276-5

Hou, D., He, J., Lü, C., Sun, Y., Zhang, F., and Otgonbayar, K., 2013, Effects of Environmental Factors on Nutrients Release at Sediment-Water Interface and Assessment of Trophic Status for a Typical Shallow Lake , Northwest China. The Scientific World Journal, pp. 1–16.

Hu, S., Goddu, S.R., Herb, C., Appel, E., Gleixner, G., Wang, S., and Zhu, X., 2015, Climate variability and its magnetic response recorded in a lacustrine sequence in Heqing basin at the SE Tibetan Plateau since 900 ka. Geophysical Journal International, v. 201, pp. 444–458.

https://doi.org/10.1093/gji/ggv033

Humagain, S., and Paudayal, K.N., 2018, Vegetation and climate around 780 kyrs BP in northern Kathmandu valley, central Nepal. Bulletin of Department of Geology, pp. 37–48. https://doi.org/10.3126/bdg.v20i0.20722

Igarashi, Y., and Yoshida, M., 1988, History of Vegetation and Climate in the Kathmandu Valley. Proc Indian Natn Sci Acad, v. 54(4), pp. 550–563.

Jin, Z., Bickle, M. J., Chapman, H. J., Yu, J., Wang, S., and Chen, S., 2009, Early to mid-Pleistocene ostracod ä18O and ä13C in the central Tibetan Plateau: Implication for Indian monsoon change. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 280(3–4), pp. 406–414.

https://doi.org/10.1016/j.palaeo.2009.06.028

Ju, J., Wang, J., Xie, M., and Wang, Y., 2010, Water and sediment chemistry of Lake Pumayum Co , South Tibet , China?: Implications for interpreting sediment carbonate Water and sediment chemistry of Lake Pumayum Co , South Tibet , China?: implications for interpreting sediment carbonate. Journal of Paleolimnology, v. 43(3), pp. 463–474. https://doi.org/10.1007/s10933-009-9343-6

Kasper, T., Haberzettl, T., Doberschütz, S., Daut, G., Wang, J., Zhu, L., and Mäusbacher, R., 2012, Indian Ocean Summer Monsoon (IOSM)-dynamics within the past 4 ka recorded in the sediments of Lake Nam Co, central Tibetan Plateau (China). Quaternary Science Reviews, v. 39, pp. 73–85. https://doi.org/10.1016/j.quascirev.2012.02.011

Kathayat, G., Cheng, H., Sinha, A., Yi, L., Li, X., Zhang, H., and Edwards, R. L., 2017, The Indian monsoon variability and civilization changes in the Indian subcontinent. Science Advances, v. 3, pp. 1–9.

Kaushal, N., Breitenbach, S.F.M., Lechleitner, F.A., Sinha, A., Tewari, V. C., Ahmad, S. M., and Band, S., 2018, The Indian Summer Monsoon from a Speleothem $\delta^{18}O$ Perspective — A Review. Quaternary, v. 1(29), pp. 1–25. https://doi.org/10.3390/quat1030029

Korsman, T., Nilsson, M.B., Landgren, K., and Renberg, I., 1999, Spatial variability in surface sediment composition characterised by near-infrared (NIR) reflectance spectroscopy. Journal of Paleolimnology, v. 21, pp. 61–71.

Krstic, S.S., and Zech, W. et al., 2011, Late Quaternary environmental changes in Helambu Himal , Central Nepal , recorded in the diatom flora assemblage composition and geochemistry of Lake Panch Pokhari. Journal of Paleolimnology, v. 47(1), pp. 113–124. https://doi.org/10.1007/s10933-011-9563-4

Kumar, K., Agrawal, S., and Sharma, A., 2018, Indian summer monsoon variability and vegetation changes in the core monsoon zone , India , during the Holocene?: A multiproxy

study. The Holocene, v. 29(1), pp. 110–119. https://doi.org/10.1177/0959683618804641

Kumar, O., Devrani, R., and Ramanathan, A.L., 2017, Deciphering the Past Climate and Monsoon Variability from Lake Sediment Archives of India?: A Review. Journal of Climate Change, (August), pp. 10–24. https://doi.org/10.3233/JCC-170011

Lamb, A.L., Vane, C.H., Wilson, G.P., Rees, Jo. G., and Moss-Hayes, V. L., 2007, Assessing $\delta^{13}C$ and CbyN ratios from organic material in archived cores as Holocene sea level and palaeoenvironmental indicators in the Humber Estuary, UK.pdf. Marine Geology, v. 244, pp. 109–128.

Lami, A., Marchetto, A., Musazzi, S., Guilizzoni, P., Marchetto, A., and Bettinetti, R. et al., 2010, Chemical and biological response of two small lakes in the Khumbu Valley, Himalayas (Nepal) to short-term variability and climatic change as detected by long-term monitoring and paleolimnological methods. Hydrobiologia, v. 648, pp. 189–205.

Larsen, T., Ventura, M., Andersen, N., Brien, D.M.O., Piatkowski, U., and Mccarthy, M.D., 2013, Tracing Carbon Sources through Aquatic and Terrestrial Food Webs Using Amino Acid Stable Isotope Fingerprinting. PLoS ONE, v. 8(9). https://doi.org/10.1371/journal.pone.0073441

Li, M., Wang, J., Zhu, L., Wang, L., and Yi, C., 2008, Distribution and formation of monohydrocalcite from surface sediments in Nam Co Lake, Tibet. Quaternary International, v. 263, pp. 85–92. https://doi.org/10.1016/j.quaint.2012.01.035

Li, Q., Lu, H., Zhu, L., Wu, N., Wang, J., and Lu, X., 2011, Pollen-inferred climate changes and vertical shifts of alpine vegetation belts on the northern slope of the Nyainqentanglha Mountains (central Tibetan Plateau) since 8 . 4 kyr BP. The Holocene, v. 21(6), pp. 939–950.

https://doi.org/10.1177/0959683611400218

Lone, A., Fousiya, A.A., Shah, R., and Achyuthan, H., 2018, Reconstruction of Paleoclimate and Environmental Fluctuations Since the Early Holocene Period Using Organic Matter and C:N Proxy Records: A Review. Journal of the Geological Society of India, v. 91(2), pp. 209–214. https://doi.org/10.1007/s12594-018-0837-6

Lu, Y., Fang, X., Friedrich, O., and Song, C., 2018, Characteristic grain-size component - A useful process-related parameter for grain-size analysis of lacustrine clastics? Quaternary International, v. 479, pp. 90–99. https://doi.org/10.1016/j.quaint.2017.07.027

Maki, T., Fujii, R., Umeda, H., Sakai, H., Hase, Y., and Shichi, K., 2004, Paleovegetation and paleoclimate in the Kathmandu Valley and Lake Baikal during the Late Quaternary, v. 2(4).

Mead, J.I., 1983, Environmental Change , 2nd edition . An- (Vol. 1).

Menzel, P., Gaye, B., Mishra, P.K., Anoop, A., Marwan, N., Plessen, B., and Wiesner, M.G. , 2014, Linking Holocene drying trends from Lonar Lake in monsoonal central India to North Atlantic cooling events. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 410, pp. 164–168. https://doi.org/10.1016/j.palaeo.2014.05.044

Meyers, P.A., and Ishiwatari, R., 1993, Lacustrine organic geochemistryman overview of indicators of organic matter sources and diagenesis in lake sediments. Organic Geochemistry, v. 20(7), pp. 867–900.

Nakagawa, T., Yasuda, Y., and Tabata, H., 1996, Pollen morphology of Himalayan Pinus and Quercus and its importance in palynological studies in Himalayan area. Review of Palaeobotany and Palynology, v. 91, pp. 317–329.

Nakamura, A., Yokoyama, Y., Maemoku, H., Yagi, H., Okamura, M., Matsuoka, H., and Matsuzaki, H., 2012, Late Holocene Asian monsoon variations recorded in Lake Rara sediment, western Nepal. Journal of Quaternary Science, v. 27(2), pp. 125–128. https://doi.org/10.1002/jqs.1568

Nakamura, A., Yokoyama, Y., Maemoku, H., Yagi, H., Okamura, M., Matsuoka, H., and Matsuzaki, H., 2016, Weak monsoon event at 4.2 ka recorded in sediment from Lake Rara, Himalayas. Quaternary International, v.397, pp. 349–359. https://doi.org/10.1016/j.quaint.2015.05.053

Oldfield, F., Battarbee, R.W., Boyle, J.F., Cameron, N.G., Davis, B., Evershed, R.P., and Walker, R., 2010, Terrestrial and aquatic ecosystem responses to late Holocene climate change recorded in the sediments of Lochan Uaine , Cairngorms , Scotland. Quaternary Science Reviews, v. 29, pp. 1040–1054. https://doi.org/10.1016/j.quascirev.2010.01.007

Phadtare, N.R., 2000, Sharp Decrease in Summer Monsoon Strength 4000 – 3500 cal yr B . P . in the Central Higher Himalaya of India Based on Pollen Evidence from Alpine Peat. Quaternary Research, v. 129, pp. 122–129. https://doi.org/10.1006/qres.1999.2108

Prasad, S., Kusumgar, S., and Gupta, S.K., 1997, A mid to late Holocene record of palaeoclimatic changes from Nal Sarovar?: a palaeodesert margin lake in western India. Journal of Quaternary Science, v. 12(2), pp. 153–159.

Ramanathan, A.L., 2007, Seasonal variation in the major ion chemistry of Pandoh Lake ,. Applied Geochemistry, 22, 1736–1747. https://doi.org/10.1016/j.apgeochem.2007.03.045

Rashid, H., England, E., Thompson, L., and Polyak, L., 2011a, Late Glacial to Holocene Indian Summer Monsoon Variability Based upon Sediment Records Taken from the Bay of Bengal. Terr. Atmos. Ocean. Sci, v. 22(2), pp. 215–228. https://doi.org/10.3319/TAO.2010.09.17.02(TibXS)1.

Rashid, H., England, E., Thompson, L., and Polyak, L., 2011b, Late Glacial to Holocene Indian Summer Monsoon Variability Based upon Sediment Records Taken from the Bay of Bengal Late Glacial to Holocene Indian Summer Monsoon Variability Based upon Sediment Records Taken from the Bay of Bengal. Terr. Atmos. Ocean. Sci., v. 22(2), pp. 215–228. https://doi.org/10.3319/TAO.2010.09.17.02(TibXS)1.

Rawat, S., Phadtare, N., and Sangode, S., 2012, The Younger Dryas cold event in NW Himalaya based on pollen record from the Chandra Tal area in Himachal. Research Communications, v. 102(8), pp. 120–123. https://doi.org/10.1007/s12524-011-0134-y.10.

Rowan, A.V., 2017, The ‘ Little Ice Age ’ in the Himalaya?: A review of glacier advance driven by Northern Hemisphere temperature change. The Holocene, v. 27(2).

https://doi.org/10.1177/0959683616658530

Rumolo, P., National, I., Barra, M., National, I., Gherardi, S., National, I., and National, I., 2011, Stable isotopes and C / N ratios in marine sediments as a tool for discriminating. Journal of Environmental Monitoring, v. 13, pp. 3399–3408. https://doi.org/10.1039/c1em10568j

Sakai, H., Fujii, R., Sugimoto, M., Setoguchi, R., and Paudel, M.R., 2016, Two times lowering of lake water at around 48 and 38 ka , caused by possible earthquakes , recorded in the Paleo - Kathmandu lake , central Nepal Himalaya. Earth, Planets and Space, v. 68(1), pp. 1–10. https://doi.org/10.1186/s40623-016-0413-5

Sandeep, K., Shankar, R., Kumar, A., Yadava, M.G., Ramesh, R., and Jani, R.A., 2017, A multi-proxy lake sediment record of Indian summer monsoon variability during the holocene in Southern India. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 476, pp. 1–14.

https://doi.org/10.1016/j.palaeo.2017.03.021

Sandeep, K., Shankar, R., Warrier, A.K., Weijian, Z., and Xuefeng, L., 2015, The environmental magnetic record of palaeoenvironmental variations during the past 3100 years?: A possible solar in fl uence?? Journal of Applied Geophysics, v. 118, pp. 24–36.

https://doi.org/10.1016/j.jappgeo.2015.03.023

Schrimm, M., Buscail, R., and Adjeroud, M., 2004, Spatial variability of the biogeochemical composition of surface sediments in an insular coral reef ecosystem?: Moorea , French Polynesia. Estuarine, Coastal and Shelf Science, v. 60, pp. 515–528. https://doi.org/10.1016/j.ecss.2003.11.025

Shetty, S.B., Shankar, R., Weijian, Z., and Peng, C., 2018, Magnetic Susceptibility as a Proxy for Rainfall in the Tropics?: New Data from Hirekolale Lake Sediments , Southern India. International Journal of Scientific Research in Science and Technology, v. 4(5), pp. 1354–1369.

Singh, G., Wasson, R., and Agrawal, D., 1990, Vegetational and seasonal climatic changes since the last full glacial in the Thar Desert , northwestern India. Review of Palaeobotany and Palynology, v. 64(January 1980), pp. 351–358.

Singhvi, A., and Vishwas S.K., 2009, Paleoclimate Studies in India?: Last Ice Age to the Present.

Sirocko, F., Garbe-schonberg, D., and Devey, C., 2000, Processes controlling trace element geochemistry of Arabian Sea sediments during the last 25 , 000 years. Global and Planetary Change, v. 26, pp. 217–303.

Sun, Q., Chu, G., Liu, M., Xie, M., Li, S., Ling, Y., and Lü, H., 2011, Distributions and temperature dependence of branched glycerol dialkyl glycerol tetraethers in recent lacustrine sediments from China and Nepal, v. 116, pp. 1–12. https://doi.org/10.1029/2010JG001365

Thomas, E.K., Huang, Y., Clemens, S.C., Colman, S.M., Morrill, C., Wegener, P., and Zhao, J., 2016, Changes in dominant moisture sources and the consequences for hydroclimate on the northeastern Tibetan Plateau during the past 32 kyr. Quaternary Science Reviews, v. 131, pp. 157–167.

https://doi.org/10.1016/j.quascirev.2015.11.003

Thompson, R., Battarbee, R.W., O'Sullivan, P., and Oldfield, F., 1975, Magnetic susceptibility of lake sediments. Limnology and Oceanography, 20(5), 687–698.

Wang, J., Zhu, L., Nishimura, M., Nakamura, T., Ju, J., Xie, M., and Testsuya, M., 2009, Spatial variability and correlation of environmental proxies during the past 18,000 years among multiple cores from Lake Pumoyum Co, Tibet, China. Journal of Paleolimnology, v. 42(3), pp. 303–315. https://doi.org/10.1007/s10933-008-9277-4

Wang, J., Zhu, L., Wang, Y., Ju, J., Xie, M., and Daut, G., 2010, Comparisons between the chemical compositions of lake water , in fl owing river water , and lake sediment in Nam Co , central Tibetan Plateau , China and their controlling mechanisms. Journal of Great Lakes Research, v. 36(4), pp. 587–595. https://doi.org/10.1016/j.jglr.2010.06.013

Wang, R., Liu, Z., Jiang, L., Yao, Z., Wang, J., and Ju, J., 2016, Comparison of surface water chemistry and weathering effects of two lake basins in the Changtang Nature Reserve , China. Journal of Environmental Sciences, v. 41, pp. 183–194.

Wang, Y., Liu, X., and Herzschuh, U., 2010, Earth-Science Reviews Asynchronous evolution of the Indian and East Asian Summer Monsoon indicated by Holocene moisture patterns in monsoonal central Asia. Earth Science Reviews, v. 103(3–4), pp. 135–153. https://doi.org/10.1016/j.earscirev.2010.09.004

Winkler, M.G., and Wang, P.K., 2015, The Late-Quaternary Vegetation and Climate of China. In The late-quaternary vegetation and climate of china, global climates since the last glacial maximum, pp. 221–264.

Xu, C., Sano, M., Dimri, A.P., Ramesh, R., and Nakatsuka, T., 2018, Decreasing Indian summer monsoon on the northern Indian sub-continent during the last 180 years?: evidence from five tree-ring cellulose oxygen isotope chronologies. Climate of the Past, v. 14, pp. 653–664.

Yuan, D., Cheng, H., Edwards, R.L., Dykoski, C.A., Kelly, M.J., Zhang, M., and Cai, Y., 2004, Transitions of the Last Interglacial Asian Monsoon. Science, 304.

Zhang, W., Ming, Q., Shi, Z., Chen, G., Niu, J., Lei, G., and Zhang, H., 2014, Lake sediment records on climate change and human activities in the Xingyun Lake catchment, SW China. PLoS ONE, 9(7).

https://doi.org/10.1371/journal.pone.0102167

Zhu, L., Wu, Y., Wang, J., Lin, X., Ju, J., Xie, M., and Daut, G., 2008,Environmental changes since 8.4 ka reflected in the lacustrine core sediments from Nam Co, central Tibetan Plateau, China. Holocene, v. 18(5), pp. 831–839. https://doi.org/10.1177/0959683608091801

Zhu, L., Zhen, X., Wang, J., Xie, M., and Kitagawa, H., 2009, A ~ 30 , 000-year record of environmental changes inferred from Lake Chen A ~ 30 , 000-year record of environmental changes inferred from Lake Chen Co , Southern Tibet. Journal of Paleolimnology, v. 42, pp. 343–358. https://doi.org/10.1007/s10933-008-9280-9