Quaternary International 507 (2019) 217–223

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Contribution of diverse monsoon precipitation over Central and Northern India during mid to Late Holocene

P. Kumar[a], J. Sanwal[b], A.P. Dimri[a,*], R. Ramesh[c,1]

[a] School of Environmental Sciences, Jawaharlal Nehru University, New Delhi, India
[b] Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore, India
[c] National Institute of Science Education and Research, Odisha, India

ARTICLE INFO

Keywords:
Indian summer monsoon (ISM)
Oxygen isotope
Inter tropical convergence zone (ITCZ)
Western disturbances (WD)
Core monsoon zone (CMZ)

ABSTRACTS

The Indian summer monsoon (ISM) precipitation pattern over Indian subcontinent is looked through various high resolution speleothem oxygen ($\delta^{18}O$) isotope records from Mid to Late Holocene. The six cave locations distributed from central to northern India describing regional climatic conditions due to stalagmite deposition are considered. The stalagmite deposition reflects precipitation patterns by temporal variations of $\delta^{18}O$ values. Oxygen isotope values reflect cumulative precipitation that is basically interpreted by averaged latitudinal site of inter tropical convergence zone (ITCZ). Under the Paleoclimate Modelling Intercomparison Project Phase III (PMIP3) simulation, Commonwealth Scientific and Industrial Research Organisation Mk3L version 1.0 – Part 2 (CSIRO-Mk3L-1-2) model output shows ITCZ movement from Bay of Bengal (BoB) to Arabian Sea (AS) during Mid to Late Holocene which resulted due to solar insolation changes. It reflects precipitation shift from BoB to AS as well as to core monsoon zone (CMZ) to the western Himalayas. The past millennium epoch, which consists little ice age (LIA) and middle warm period (MWP), shows large variations in 850 hPa geopotential height leading to high anomalous precipitation variability all over India during ISM. The high fluctuation in $\delta^{18}O$ values during Mid Holocene over northern India led to drought conditions due to which Indus valley civilization vanished. The present study shows that the Himalayas received higher precipitation during late Holocene. That is basically governed by western disturbances (WD) as well as ISM. Present study summarizes that the mean annual precipitation cycle for entire epoch was roughly similar, but spatial distribution of precipitation during various epoch was quite divergent from Mid to Late Holocene. The onset of ISM was also similar but, withdrawal was comparatively unalike. Wherever, peaks of seasonal precipitation were alike over Indian subcontinent region, spatial distribution of precipitation were unlike.

1. Introduction

The diverse annual precipitation over Indian subcontinent is derived through seasonal shifting of Inter Tropical Convergence Zone (ITCZ). Indian summer monsoon (ISM) occurs due to northward shifting of ITCZ. It is created due to intense low pressure over Indian subcontinent and thus pulling moisture from Indian Ocean (IO) and Arabian Sea (AS), converging over India. The maximum precipitation during ISM occurs through southwest wind (Kotlia et al., 2012, 2015). That is a reversal of wind from southwest of Indian subcontinent during Northern Hemispheric summer (Krishnamurti and Bhalme, 1976 and Roja Raman et al., 2009). ISM is strengthened/weakened by the positioning of permanent and temporary jet streams (referred in the supplementry Fig. (S1a) and (S1b)) (Chang, 1967; Pai and Bhan, 2015: monsoon_report_2014). However, the precipitation pattern over the Himalayas is quite different. The maximum precipitation occurs through Western Disturbances (WD, Dimri et al., 2015). The variability in monsoonal precipitation over Indian subcontinent during past climate scenarios, as Mid Holocene, is reported in some of the recent studies (Gupta et al., 2003; Agnihotri et al., 2003; Bhattacharya et al., 2003; Staubwasser et al., 2003; Fleitmann et al., 2007; Prasad et al., 2014; Duan et al., 2014, 2015; Dixit et al., 2014; Kotlia et al., 2015; Tejavth et al., 2017). Though, there is no proper testimony regarding the late Holocene ISM precipitation there is some controversy regarding Mid to Late Holocene ISM precipitation over the Himalayas (Prasad et al., 2014). Some of the studies show that ISM precipitation mostly sustain by southwest monsoonal flow, while rest of the studies says about the WD. The some of studies show that Mid Holocene

* Corresponding author.
E-mail address: apdimri@hotmail.com (A.P. Dimri).
[1] Deceased.

https://doi.org/10.1016/j.quaint.2018.10.003
Received 29 January 2018; Received in revised form 1 October 2018; Accepted 1 October 2018
Available online 02 October 2018

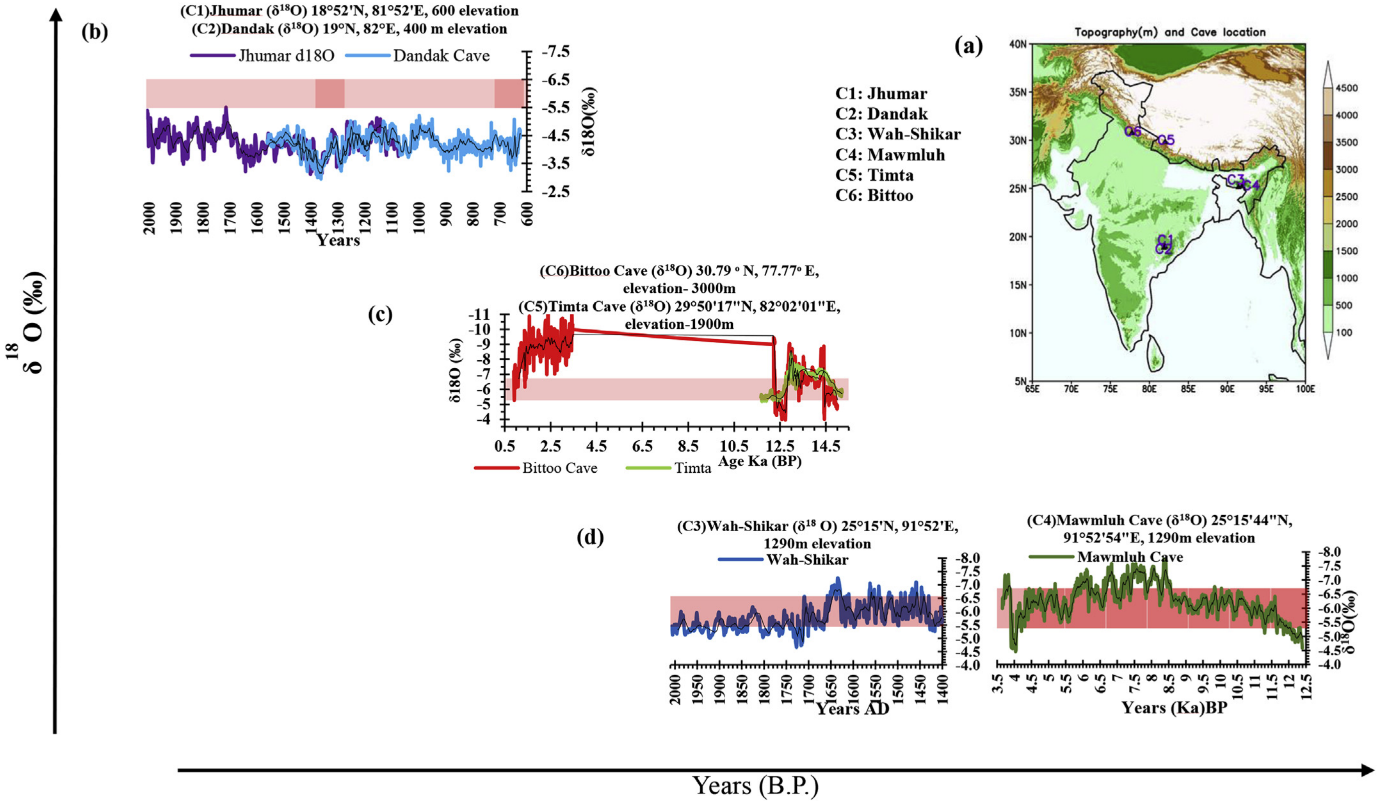

Fig. 1. The cave locations (a) and δ^{18} O values corresponding (b), (c) and (d) respectively for the diverse monsoon precipitation assessment is shown during the period Mid to Late Holocene. The red shading in Fig. (b), (c) and (d) shows present climate value δ^{18} O, which is varies from −5.5 to −6.5‰ (Sanwal et al., 2013). The black line shows 11 years moving average over corresponding period. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

precipitation is gradually decreased (Prasad et al., 2014; Dixit et al., 2014; Bertaux et al., 2002) due to continuous decrease in summer insolation over Indian subcontinent (Neff et al., 2001; Fleitmann et al., 2007; Tiwari et al., 2010). The extreme low precipitation during Mid Holocene is reported as a possible cause for the vanishing of Indus valley civilization (Singh, 1971; Singh et al., 1974; Dixit et al., 2014; Prasad et al., 2014; Sarkar et al., 2016). The western Himalayas precipitation is currently postured through ISM as well as WDs. While, during early Holocene, it was basically sustained by dominant westerlies (Kotlia et al., 1997, 2017; Sanwal et al., 2013; Huang et al., 2009). However, core monsoon zone (CMZ) is defined by Sinha et al. (2007). The CMZ precipitation reconstruction during Holocene is reported by some of the paleoclimatologist (Sinha et al., 2007, 2011a; 2011b; Berkelhammer et al., 2010; Walker et al., 2012). The CMZ precipitation was discussed through the various caves and lakes deposit analysis that shows dry Mid Holocene (Chen et al., 2008; Prasad and Enzel, 2006). Howerver, precipitation dynamics over the Himalayas is mechanized by various factors as orographic lifting, rain shadow, lifting condensation level (LCL) and elevation dependency etc. And ISM is influenced by various factors such as Indian Ocean dipole (IOD) (Bala and Singh, 2008), El Nino-Southern Oscillation (ENSO) (Ashok et al., 2001), Jet streams (Ramaswamy, 1962), Quasi-Biennial Oscillation (QBO) (Chattopadhyay and Bhatla, 2002) and Land Ocean temperature contrast (Li and Yanai, 1996) etc. The precipitation dynamics over Indian subcontinent is a complex mechanism. Hence, the current study shows how diverse precipitation occurred during Mid to Late Holocene epoch over Indian subcontinent by using proxy (stalagmite) data as well as climate model data from Commonwealth Scientific and Industrial Research Organisation Mk3L version 1.0 – Part 2 (CSIRO-Mk3L-1-2), coupled with preindustrial atmospheric CO_2, ocean, sea ice, land surface and atmosphere (Phipps et al., 2011, 2012) simulated under the Paleoclimate Modelling Intercomparison Project Phase III (PMIP3).

2. Material and methodology

The current study uses cave deposit (speleothems) data, from various caves in central, eastern and northern India. In this study the central India, as CMZ, having Jhumar and Dandak caves δ^{18}O‰ Vienna Pee Dee Belemnite (VPDB) (C1 & C2) record (Sinha et al., 2007; Berkelhammer et al., 2010) and eastern region, which represent, maximum rainfall region of Assam (Mawsynram, Meghalaya), having Wah-Shikar and Mawmluh cave δ^{18}O‰ (VPDB) (C3 & C4) record (Berkelhammer et al., 2010) are considered. However, for northern India, as westerlies influenced rainfall, Timta (Sinha et al., 2007, 2011a) (C5) and Bittoo cave (C6) (Kathayat et al., 2016) δ^{18}O‰ (VPDB) record are considered. The speleothem data is taken from National Oceanic and Atmospheric Administration/National Climatic Data Center (NOAA/NCDC). These speleothems data are used for the model comparison as well. The CSIRO-Mk3L-1-2 model is used in the present study to estimate the diverse precipitation pattern over Indian subcontinent during Mid to Late Holocene epoch. A CSIRO-Mk3L-1-2 climate model is simulated under PMIP3 for the millennial timescale paleoclimate research purpose (Abram et al., 2014; McGregor et al., 2015; Brown et al., 2016). This is a coupled general circulation model (GCM), which includes atmosphere, land surface, ocean, and sea ice with stable computation, realistic controlled climatology (Phipps et al., 2012; Le, 2015; Tejavath et al., 2017). Model is forced with solar insolation, volcanic emission and greenhouse gases. However, model has bias and underestimation of warming compare to current scenario because of lacking dynamic vegetation (Phipps et al., 2011, 2012). The observational datasets are also used for the comparative study of the model (CSIRO-Mk3L-1-2) output. The observation data for the present instrumental representation for precipitation, mean sea level pressure and geopotential height is taken from the Climatic Research Unit (CRU) (http://www.cru.uea.ac.uk/data) (1901–present) and National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis (1948–present) (https://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html) (Sinha et al., 2007; Tejavath et al., 2017) respectively. In present study Historical time span is considered as 1850-2000 AD, past millennium as 850-1850 AD and Mid Holocene as 8.2 to 4.2 Kyears BP approximately. However, late Holocene epoch includes Historical and past millennium too.

3. Results and discussion

The precipitation over India from past to recent climate is quite vacillating and its diverse distribution in magnitude as well as frequency causes various ruinous episodes. Figure (1a, 1b, 1c and 1d) shows cave locations and their corresponding $\delta^{18}O$ from Mid to Late Holocene. Figure (1b, 1c and 1d) shows temporal changes in cave deposit ($\delta^{18}O$ value). From figure (1d) C5 cave shows greater negative values of $\delta^{18}O$ during 13 K years (before present: BP) and beyond but a sharp increase in $\delta^{18}O$ values during the 12.5–11.5 K years (BP) shows that precipitation over C5 region decreased during late Pleistocene to the early Holocene epoch (Sinha et al., 2007). However, cave C4 shows nearly similar $\delta^{18}O$ values till the present years i.e., current year's precipitation similarity (Sanwal et al., 2013). While the sharp decrease in precipitation is observed during start of late Holocene (4.5–3.5 K years BP). Which is well known centuries for the Indus valley civilization ruins (Dixit et al., 2014). The C6 cave $\delta^{18}O$ value showed abrupt fluctuation from 2.4 to 3.5 K years BP meaning higher precipitation than C4 region (Fig. (1c)). Increase of $\delta^{18}O$ values (from −8.5‰ to −5.5‰) over C6 region after 1.5 K year (BP) suggests a record decrease in precipitation leading to drier decades. In figure (1b), the current precipitation record suggests that the caves C1 and C2 have similar precipitation. This is because C1 and C2 are lying in the same region (CMZ) (Sinha et al., 2007). But C3 cave deposition shows higher negative values of $\delta^{18}O$ showing comparatively higher precipitation over C3 region during the same period (~1440–1880 AD) than C1 and C2 (i.e., the Little Ice Age: LIA) (Sanwal et al., 2013). This fact shows diverse monsoon precipitation over considered caves during ISM. Higher precipitation over C3 is seen (i.e., $\delta^{18}O$ value −5.0‰ to −7.5‰) than over C1 and C2 (i.e., $\delta^{18}O$ values from −3.0‰ to −5.0‰) in current scenario too (Yadava, 2002; 2005). During LIA moist climate over C3 region is observed than over C1 and C2. It suggests CMZ was drier than the Himalayan region during ~1440–1880 AD. It is basically attributed to influence by westerlies precipitation over the Himalayas (Kotlia et al., 2012, 2015; 2017; Sanwal et al., 2013) (refer to the supplimentry fig. S1a and S1b). The precipitation during ISM is maximum over cave C4, C5 and C6 in comparison to C1 and C2 from Mid to Late Holocene. The precipitation over the Himalayas was greater than the Indian peninsula during late Holocene (Tripathi et al., 2004; Sanwal et al., 2013; Kotlia et al., 2015).

The model (CSIRO-Mk3L) precipitation anomaly over the Indian monsoon region (67-98 ˚E; 7-38 ˚N) is described in Figure (2). In figure (2a, 2b and 2c) anomalous precipitation is observed during the Mid Holocene to Historical. The interannual variability of anomalous precipitation increased from Mid Holocene to Late Holocene (i.e., σ value) (Fig. 2). The past millennium span of time shows decreased precipitation interannual variability than Mid Holocene and Late Holocene. The annual precipitation fluctuations were observed maximum during Late Holocene. In addition, strong precipitation interannual variability during current scenario (Late Holocene) is seen which influenced whole Indian crop productivity as well (Yadav et al., 2014, 2015). It is also found that ISM collapsed enduring ~30 years occurred over every 150 years over with Indian subcontinent and IO (Meehl and Hu, 2006; Sinha et al., 2007). Figure (3) shows June, July, August and September (JJAS) precipitation pattern from Mid to Late Holocene. From figure (3a, 3b, 3c and 3d), spatial extent of precipitation encroached over and towards the western part of the Himalayas during Mid to Late Holocene (Kotlia et al., 2015). The precipitation intensity enhanced over the AS during the Late Holocene (Tiwari et al., 2010). The mean sea level pressure (MSLP) climatology for JJAS from Mid to Late Holocene is depicted in Figure (4). Figure (4a) illustrates MSLP climatology for 50 years (1948–2000 AD) that delineates present scenario of ISM stability and basic concepts of ocean and continent pressure difference. It is a main driving force for ISM mass movements. From figure (4a, 4b, 4c and 4d), the intensity of low pressure over India and Tibetan are dampened from Mid to Late Holocene. The changed spatial extent of MSLP suggests monsoon progression and reconstruction over the period from Bay of Bengal (BoB) to AS (Tiwari et al., 2010). Figure (5) is a simple narration of 850 hPa geopotential height for Mid to Late Holocene. The changing pattern of decreased geopotential heights clearly suggests the troughs progression and/or low-pressure propagation. The spatial extent of decreased geopotential height expanded from Mid Holocene to past millennium but shrank from Mid to Late Holocene suggesting troughs propagation towards the western Himalayas (Fig. (5d)–a). The largest spatial distribution of decreased geopotential height revealing LIA and diverse precipitation over the Indian subcontinent (Fig. (5c)). The solar insolation was a major factor for changing precipitation pattern from Mid to Late Holocene (Sinha et al., 2007). It directly governed intertropical convergence zone (ITCZ) (Newton et al., 2006; Sinha et al., 2007). Figure (6a) describes the ITCZ, which is calculated from minimum values of the outgoing longwave radiation (OLR) climatology during JJAS, for various epoch. In figure (6a) Mid Holocene line of ITCZ is quite different from past millennium and Historical. It clearly explains about JJAS OLR shifting from BoB to AS during Mid to Late Holocene because of decreasing solar insolation (Fleitmann et al., 2003). Hence, the precipitation pattern over Indian subcontinent is shifted from Mid to Late Holocene. However, past millennium and Historical have similar pattern of ITCZ basically because past millennium, consisting LIA and MWP, nullify to each other once climatological average is taken (Tejavath et al., 2017). The area average mean annual precipitation over (67-98°E, 7-38°N) Indian subcontinent region is illustrated in Figure (6b). In brief it explains onset-withdrawal of monsoon and precipitation intensification during various time periods. The monsoon precipitation onset in all the epoch was similar, while withdrawal of past millennium, Historical and present (CRU) (1901-2000) have similar patterns. The precipitation intensity peak of Mid Holocene, past millennium and Historical were similar and higher than observation. Figure (6) presents the mean annual precipitation cycle for all epoch which were approximately similar, but spatial extent of precipitation for various epoch was quite different from Mid to Late Holocene. The onset of ISM was a similar, while withdrawal was comparatively varying.

4. Conclusions

The present study concludes diverse precipitation over the Indian subcontinent from Mid to Late Holocene epoch. The various cave deposits (stalagmite) which are situated at different places in all over India (from CMZ to northern part of India) show relatively high fluctuation in $\delta^{18}O$ values, It reveals precipitation pattern variability over India from Mid to Late Holocene epoch. The basic findings are

1. Precipitation shifted from BoB to AS,
2. A good amount of precipitation along the Himalayas and
3. Precipitation shift from central to the western Himalayas during Mid to Late Holocene.

The Himalayan region shows more humid climate during Late Holocene epoch (Kotlia et al., 2017). The model output also shows similar results. The 850 hPa geopotential height also indicates that the height of 850 hPa isobar is decreased due to strong troughs over Indian

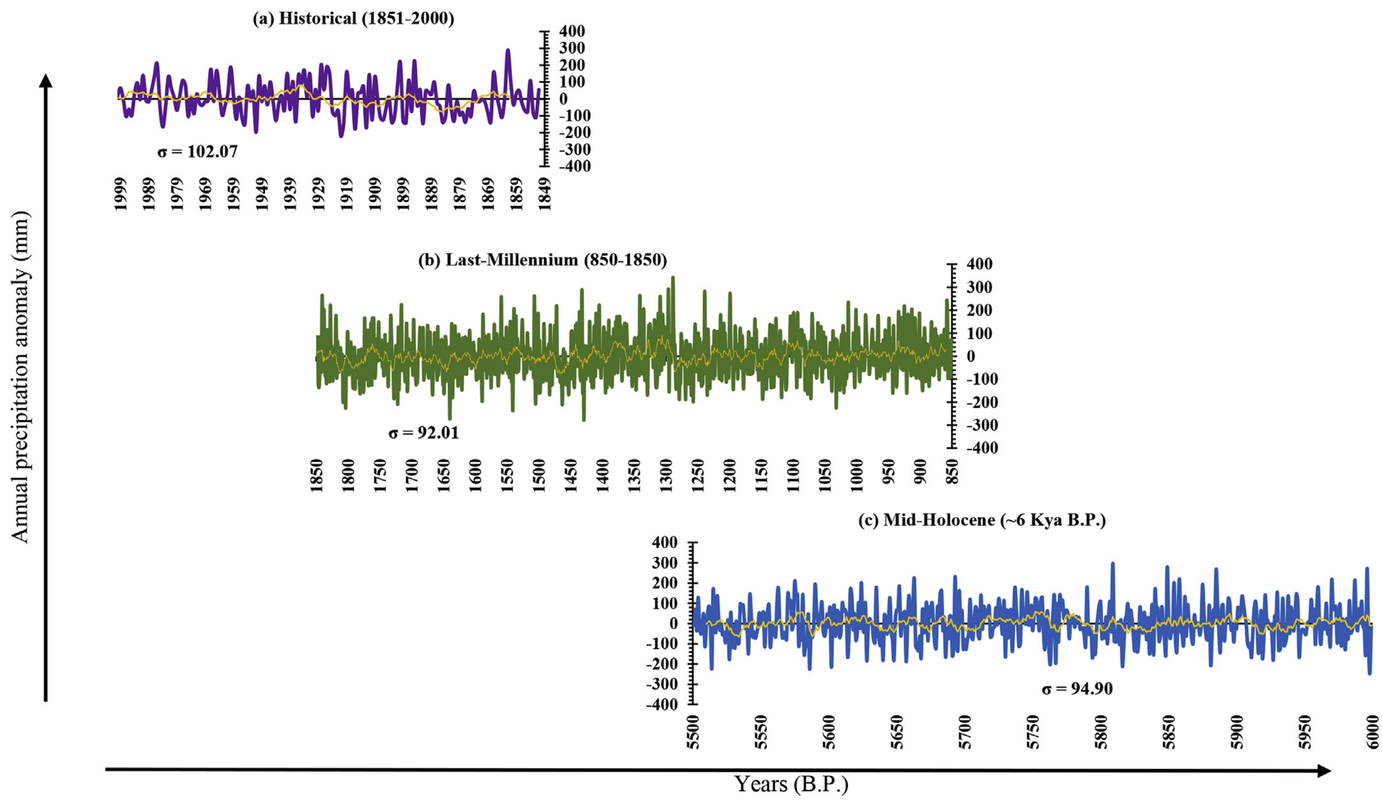

Fig. 2. Variations of annual rainfall anomaly (mm) averaged over Indian monsoon region (67-98 °E; 7-38 °N) during (a) Historical (1850-2005), (b) Past Millennium (850-1849), (c) Mid-Holocene (~6kya before present (B.P.)); over Indian region from CSIRO-Mk3L for (a), (b) and (c) global climate models respectively. For Mid-Holocene variation is shown over a period of 500 years. For each period, 'σ' represents the standard deviation over the years while the yellow curve shows the 11 years moving average over that period. The inter-annual variability of rainfall gradually decreased from mid Holocene to historical as is clearly evident from 'σ' value. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

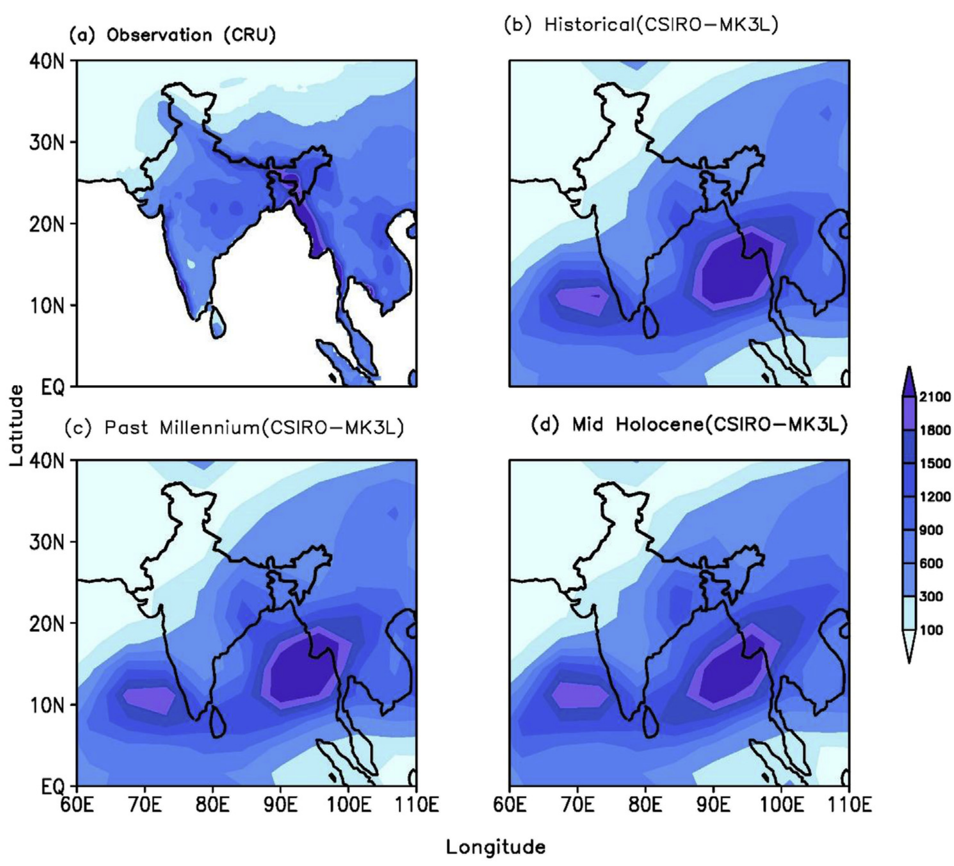

Fig. 3. Indian summer monsoon (ISM) precipitation variability for the various time period. Fig. (a) CRU (observational for 1901-2000), (b) Historical (1851-2000), (c) Past Millennium (850-1850) and (d) Mid Holocene (500 years) for the model CSIRO-MK3L. Fig. shows JJAS (June, July, August and September) precipitation (mm) pattern from mid to late Holocene. From Fig. (d) to (a) spatial extent of precipitation climatology encroached over the western part of the Himalayas. The precipitation intensity gets enhanced over the Arabian Sea during Historical.

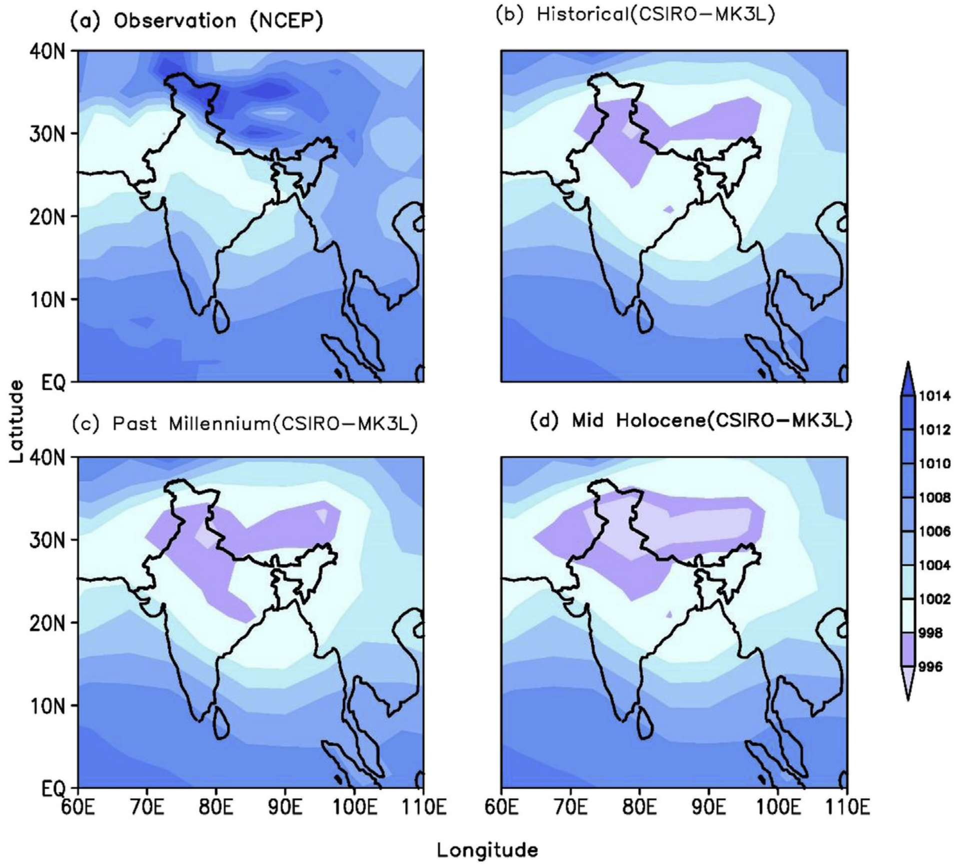

Fig. 4. ISM mean sea level pressure (MSLP) (hPa) for various scenario. Fig. (a) NCEP (observational for 1948-2000), (b) Historical (1851-2000), (c) Past Millennium (850-1850) and (d) Mid Holocene (500years) for the model CSIRO-MK3L. MSLP have nearly similar pattern from mid Holocene to Historical period, but intensity of low pressure shifted from north to south. The intensity of low pressure also gets dampened from Fig. (d) to (a).

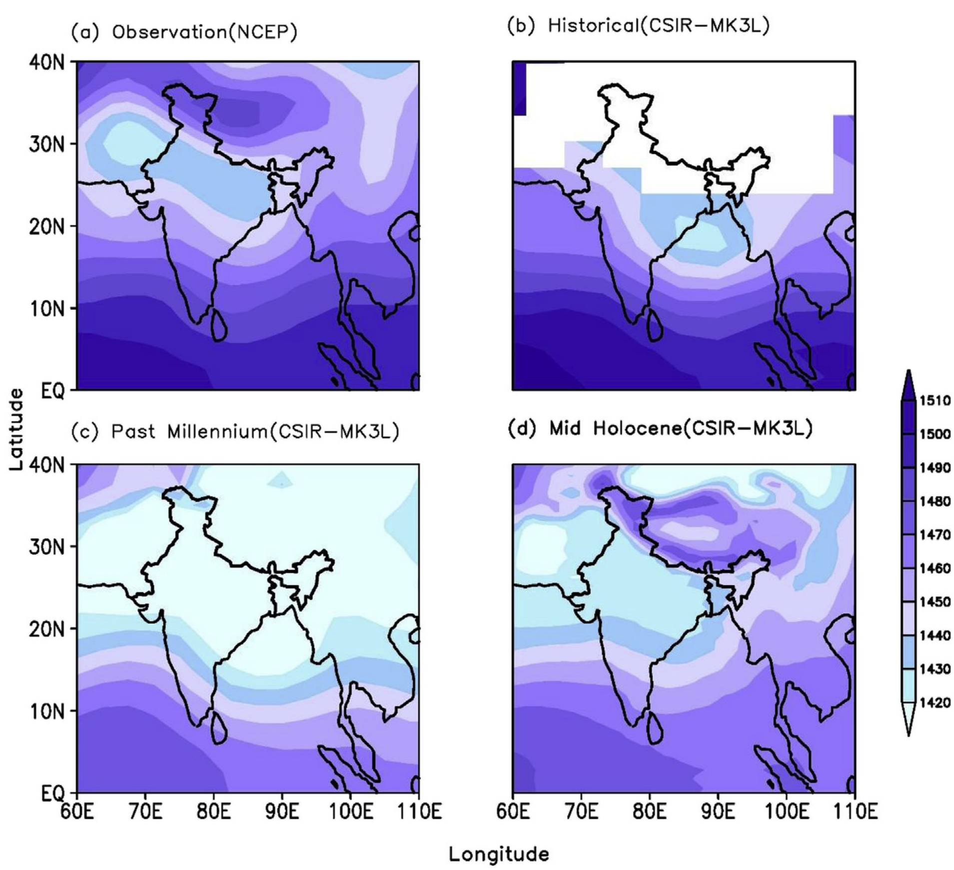

Fig. 5. ISM geopotential height (m) of 850 hPa for various scenario. Fig. (a) NCEP (observational for 1948-2000), (b) Historical (1851-2000); white area shows missing data, (c) Past Millennium (850-1850) and (d) Mid Holocene (500years) for the model CSIRO-MK3L. The geopotential height climatology of 850 hPa shows quite different pattern during past Millennium than others.

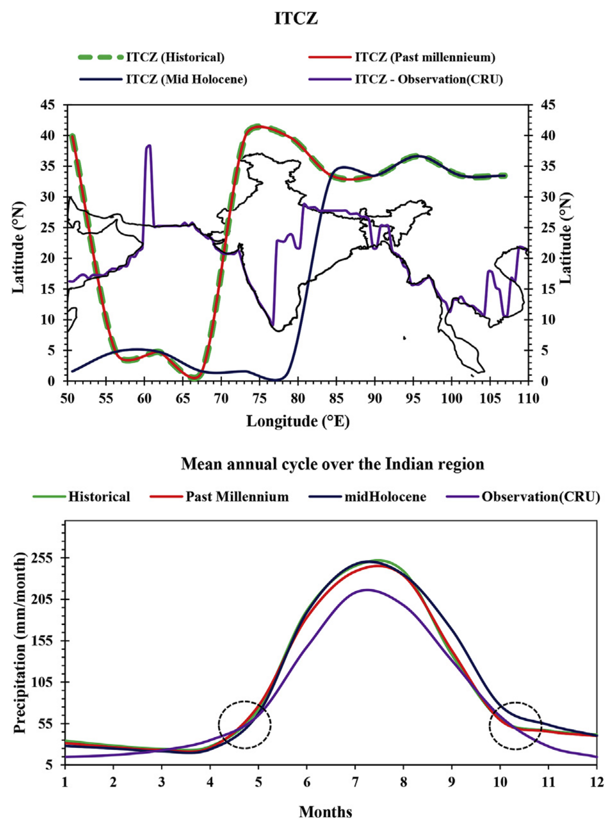

Fig. 6. (a) ISM Inter Tropical Convergence Zone (ITCZ) for various time period. Fig. (b) shows mean annual precipitation cycle over (67-98°E, 7-38°N) for CRU (observational) violate line, Historical green line, Past Millennium red line and Mid Holocene blue line for the model CSIRO-MK3L. The black dashed circle shows onset and withdrawal of monsoon. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

subcontinent. However, it is apparently seen that past millennium has the highest spatial extent of troughs. It suggests about LIA and MWP incidents during this period. The ITCZ is shifted from BoB to AS for Mid to Late Holocene. It defiantly influenced whole Indian subcontinent precipitation and again revival of monsoon occurred during Late Holocene epoch. It is also observed that the Himalayas are getting more precipitation during Late Holocene which is influenced by westerlies wind gust as well (Tripathi et al., 2004; Sanwal et al., 2013; Kotlia et al., 2012) (refered to the supplimentry fig. S1a and S1b). Hence, the current study also summaries the mean annual precipitation cycle for all epoch was approximately similar, but spatial extent of precipitation for various epoch was quite divergent from Mid to Late Holocene. The onset of ISM was a similar while, withdrawal was comparatively unlike. However, the peaks of seasonal precipitation were alike.

Acknowledgement

We highly appreciated Jawaharlal Nehru University for providing the high performance computing facility for computations. The authors also acknowledge NOAA/NCDC (https://www.ncdc.noaa.gov/data-access) for speleothem datasets. The authors appreciates and acknowledge NCEP/NCAR for mean sea level pressure and geopotential height dataset (observational) (https://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html). Authors also appreciated for CRU precipitation datasets (https://climatedataguide.ucar.edu/climate-data/cru-ts-gridded-precipitation-and-other-meteorological-variables-1901) and ESGF-DKRZ (https://esgf-data.dkrz.de/projects/esgf-dkrz/) for model output datasets, free data portals for providing data, used in the present study. Pramod Kumar also acknowledge to CSIR-UGC for funding support for the study.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quaint.2018.10.003.

References

Abram, N.J., Mulvaney, R., Vimeux, F., Phipps, S.J., Turner, J., England, M.H., 2014. Evolution of the southern annular mode during the past millennium. Nat. Clim. Change 4 (7), 564–569.
Agnihotri, R., Bhattacharya, S.K., Sarin, M.M., Somayajulu, B.L.K., 2003. Changes in surface productivity and subsurface denitrification during the Holocene: a multiproxy study from the eastern Arabian Sea. Holocene 13 (5), 701–713.
Ashok, K., Guan, Z., Yamagata, T., 2001. Impact of the Indian Ocean dipole on the relationship between the Indian monsoon rainfall and ENSO. Geophys. Res. Lett. 28 (23), 4499–4502.
Bala, I., Singh, O.P., 2008. Relationship between Indian Ocean dipole mode and summer monsoon. Mausam 59 (2), 167.
Bertaux, J., Sondag, F., Santos, R., Soubiès, F., Causse, C., Plagnes, V., Seidel, A., 2002. Paleoclimatic record of speleothems in a tropical region: a study of laminated sequences from a Holocene stalagmite in Central–West Brazil. Quat. Int. 89 (1), 3–16.
Berkelhammer, M., Sinha, A., Mudelsee, M., Cheng, H., Edwards, R.L., Cannariato, K., 2010. Persistent multidecadal power of the indian summer monsoon. Earth Planet Sci. Lett. 290 (1), 166–172.
Bhattacharya, S.K., Froehlich, K., Aggarwal, P.K., Kulkarni, K.M., 2003. Isotopic variation in Indian Monsoon precipitation: records from Bombay and New Delhi. Geophys. Res. Lett. 30 (24).
Brown, J.R., Hope, P., Gergis, J., Henley, B.J., 2016. ENSO teleconnections with Australian rainfall in coupled model simulations of the last millennium. Clim. Dynam. 47 (1–2), 79–93.
Chang, J.H., 1967. The Indian summer monsoon. Geogr. Rev. 373–396.
Chattopadhyay, J., Bhatla, R., 2002. Possible influence of QBO on teleconnections relating Indian summer monsoon rainfall and sea-surface temperature anomalies across the equatorial pacific. Int. J. Climatol.: A J. Royal Meteorol. Soc. 22 (1), 121–127.
Chen, F., Yu, Z., Yang, M., Ito, E., Wang, S., Madsen, D.B., Boomer, I., 2008. Holocene moisture evolution in arid central Asia and its out-of-phase relationship with Asian monsoon history. Quat. Sci. Rev. 27 (3), 351–364.
Dimri, A.P., Niyogi, D., Barros, A.P., Ridley, J., Mohanty, U.C., Yasunari, T., Sikka, D.R., 2015. Western disturbances: a review. Rev. Geophys. 53 (2), 225–246.
Dixit, Y., Hodell, D.A., Petrie, C.A., 2014. Abrupt weakening of the summer monsoon in northwest Indiã 4100 yr ago. Geology 42 (4), 339–342.
Duan, F., Wang, Y., Shen, C.C., Wang, Y., Cheng, H., Wu, C.C., Zhao, K., 2014. Evidence for solar cycles in a late Holocene speleothem record from Dongge Cave, China. Sci. Rep. 4.
Duan, F., Wu, J., Wang, Y., Edwards, R.L., Cheng, H., Kong, X., Zhang, W., 2015. A 3000-yr annually laminated stalagmite record of the last glacial maximum from Hulu cave, China. Quat. Res. 83 (2), 360–369.
Fleitmann, D., Burns, S.J., Mudelsee, M., Neff, U., Kramers, J., Mangini, A., Matter, A., 2003. Holocene forcing of the Indian monsoon recorded in a stalagmite from southern Oman. Science 300 (5626), 1737–1739.
Fleitmann, D., Burns, S.J., Mangini, A., Mudelsee, M., Kramers, J., Villa, I., Matter, A., 2007. Holocene ITCZ and Indian monsoon dynamics recorded in stalagmites from Oman and Yemen (Socotra). Quat. Sci. Rev. 26 (1), 170–188.
Gupta, A.K., Anderson, D.M., Overpeck, J.T., 2003. Abrupt changes in the Asian southwest monsoon during the Holocene and their links to the North Atlantic Ocean. Nature 421 (6921), 354.
Huang, X.Z., Chen, F.H., Fan, Y.X., Yang, M.L., 2009. Dry late-glacial and early Holocene climate in arid central Asia indicated by lithological and palynological evidence from Bosten Lake, China. Quat. Int. 194 (1), 19–27.
https://climatedataguide.ucar.edu/climate-data/cru-ts-gridded-precipitation-and-other-meteorological-variables-1901.
https://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html.
https://esgf-data.dkrz.de/projects/esgf-dkrz/.
Kathayat, G., Cheng, H., Sinha, A., Spötl, C., Edwards, R.L., Zhang, H., Lui, W.L., 2016. Indian monsoon variability on millennial-orbital timescales. Sci. Rep. 6, 24374.
Kotlia, B.S., Ahmad, S.M., Zhao, J.X., Raza, W., Collerson, K.D., Joshi, L.M., Sanwal, J., 2012. Climatic fluctuations during the LIA and post-LIA in the Kumaun Lesser Himalaya, India: evidence from a 400 y old stalagmite record. Quat. Int. 263, 129–138.
Kotlia, B.S., Singh, A.K., Joshi, L.M., Dhaila, B.S., 2015. Precipitation variability in the indian central Himalaya during last ca. 4,000 years inferred from a speleothem record: impact of indian summer monsoon (ISM) and westerlies. Quat. Int. 371, 244–253.
Kotlia, B.S., Bhalla, M.S., Sharma, C., Rajagopalan, G., Ramesh, R., Chauhan, M.S., Chacko, S.T., 1997. Palaeoclimatic conditions in the upper Pleistocene and Holocene Bhimtal-Naukuchiatal lake basin in south-central Kumaun, north India. Palaeogeogr. Palaeoclimatol. Palaeoecol. 130 (1–4), 307–322.
Kotlia, B.S., Singh, A.K., Zhao, J.X., Duan, W., Tan, M., Sharma, A.K., Raza, W., 2017. Stalagmite based high resolution precipitation variability for past four centuries in the Indian Central Himalaya: Chulerasim cave re-visited and data re-interpretation.

Quat. Int. 444, 35–43.
Krishnamurti, T.N., Bhalme, H.N., 1976. Oscillations of a monsoon system. Part I. Observational aspects. J. Atmos. Sci. 33 (10), 1937–1954.
Li, C., Yanai, M., 1996. The onset and interannual variability of the Asian summer monsoon in relation to land–sea thermal contrast. J. Clim. 9 (2), 358–375.
McGregor, H.V., Evans, M.N., Goosse, H., Leduc, G., Martrat, B., Addison, J.A., Phipps, S.J., 2015. Robust global ocean cooling trend for the pre-industrial Common Era. Nat. Geosci. 8 (9), 671–677.
Meehl, G.A., Hu, A., 2006. Megadroughts in the Indian monsoon region and southwest North America and a mechanism for associated multidecadal Pacific sea surface temperature anomalies. J. Clim. 19 (9), 1605–1623.
Neff, U., Burns, S.J., Mangini, A., Mudelsee, M., Fleitmann, D., Matter, A., 2001. Strong coherence between solar variability and the monsoon in Oman between 9 and 6 kyr ago. Nature 411 (6835), 290–293.
Newton, A., Thunell, R., Stott, L., 2006. Climate and hydrographic variability in the indo-pacific warm pool during the last millennium. Geophys. Res. Lett. 33 (19).
Pai, S., Bhan, S.C., 2015. Monsoon_report_2014. . www.imd.gov.in/section/nhac/monsoon_report_2014.pdf.
Phipps, S.J., Rotstayn, L.D., Gordon, H.B., Roberts, J.L., Hirst, A.C., Budd, W.F., 2011. The CSIRO Mk3L climate system model version 1.0-Part 1: description and evaluation. Geosci. Model Dev. (GMD) 4 (2), 483.
Phipps, S.J., Rotstayn, L.D., Gordon, H.B., Roberts, J.L., Hirst, A.C., Budd, W.F., 2012. The CSIRO Mk3L climate system model version 1.0-Part 2: response to external forcings. Geosci. Model Dev. (GMD) 5 (3), 649.
Prasad, S., Enzel, Y., 2006. Holocene paleoclimates of India. Quat. Res. 66 (3), 442–453. https://doi.org/10.1016/j.yqres.2006.05.008.
Prasad, V., Farooqui, A., Sharma, A., Phartiyal, B., Chakraborty, S., Bhandari, S., Singh, A., 2014. Mid–late Holocene monsoonal variations from mainland Gujarat, India: a multi-proxy study for evaluating climate culture relationship. Palaeogeogr. Palaeoclimatol. Palaeoecol. 397, 38–51.
Ramaswamy, C., 1962. Breaks in the Indian summer monsoon as a phenomenon of interaction between the easterly and the sub-tropical westerly jet streams. Tellus 14 (3), 337–349.
Roja Raman, M., Jagannadha Rao, V.V.M., Venkat Ratnam, M., Rajeevan, M., Rao, S.V.B., Narayana Rao, D., Prabhakara Rao, N., 2009. Characteristics of the Tropical Easterly Jet: long-term trends and their features during active and break monsoon phases. J. Geophys. Res.: Atmosphere 114 (D19).
Sanwal, J., Kotlia, B.S., Rajendran, C., Ahmad, S.M., Rajendran, K., Sandiford, M., 2013. Climatic variability in Central Indian Himalaya during the last ~ 1800 years: evidence from a high resolution speleothem record. Quat. Int. 304, 183–192.
Sarkar, A., Mukherjee, A.D., Bera, M.K., Das, B., Juyal, N., Morthekai, P., Rao, L.S., 2016. Oxygen isotope in archaeological bioapatites from India: implications to climate change and decline of Bronze Age Harappan civilization. Sci. Rep. 6, 26555.
Singh, G., 1971. The Indus valley culture. Archaeol. Ocean. 6 (2), 177–189.
Singh, G., Joshi, R.D., Chopra, S.K., Singh, A.B., 1974. Late Quaternary history of vegetation and climate of the Rajasthan Desert, India. Phil. Trans. Roy. Soc. Lond. B 267 (889), 467–501.
Sinha, A., Cannariato, K.G., Stott, L.D., Cheng, H., Edwards, R.L., Yadava, M.G., Singh, I.B., 2007. A 900-year (600 to 1500 AD) record of the Indian summer monsoon precipitation from the core monsoon zone of India. Geophys. Res. Lett. 34 (16).
Sinha, A., Berkelhammer, M., Stott, L., Mudelsee, M., Cheng, H., Biswas, J., 2011a. The leading mode of Indian Summer Monsoon precipitation variability during the last millennium. Geophys. Res. Lett. 38 (15).
Sinha, A., Stott, L., Berkelhammer, M., Cheng, H., Edwards, R.L., Buckley, B., Mudelsee, M., 2011b. A global context for megadroughts in monsoon Asia during the past millennium. Quat. Sci. Rev. 30 (1), 47–62.
Staubwasser, M., Sirocko, F., Grootes, P.M., Segl, M., 2003. Climate change at the 4.2 ka BP termination of the Indus valley civilization and Holocene south Asian monsoon variability. Geophys. Res. Lett. 30 (8).
Tejavath, C.T., Ashoka, K., Chakrabortyb, S., Rameshc, R., 2017. The Indian Summer Monsoon Climate during the Last Millennium, as Simulated by the PMIP3.
Tiwari, M., Ramesh, R., Bhushan, R., Sheshshayee, M.S., Somayajulu, B.L., Jull, A.J., Burr, G.S., 2010. Did the Indo-Asian summer monsoon decrease during the Holocene following insolation? J. Quat. Sci. 25 (7), 1179–1188.
Tripathi, J.K., Bock, B., Rajamani, V., Eisenhauer, A., 2004. Is river Ghaggar, Saraswati? Curr. Sci. 87 (8).
Walker, M.J., Berkelhammer, M., Björck, S., Cwynar, L.C., Fisher, D.A., Long, A.J., Weiss, H., 2012. Formal subdivision of the Holocene Series/epoch: a discussion paper by a working Group of INTIMATE (integration of ice-core, marine and terrestrial records) and the Subcommission on quaternary Stratigraphy (international Commission on Stratigraphy). J. Quat. Sci. 27 (7), 649–659.
Yadav, R.R., Misra, K.G., Kotlia, B.S., Upreti, N., 2014. Premonsoon precipitation variability in Kumaon Himalaya, India over a perspective of ~ 300 years. Quat. Int. 325, 213–219.
Yadav, R.R., Misra, K.G., Yadava, A.K., Kotlia, B.S., Misra, S., 2015. Tree-ring footprints of drought variability in last ~ 300 years over Kumaun Himalaya, India and its relationship with crop productivity. Quat. Sci. Rev. 117, 113–123.