Quaternary International 680 (2024) 1–16

Contents lists available at ScienceDirect

Quaternary International

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

Late Quaternary human-environment relationship in the Ganga Plain, India

Deepak Kumar Jha[a,b,c,*], Hemant Kumar Vaishnav[d], Nigamasish Roy[c]

[a] Department of Archaeology, Max Planck Institute of Geoanthropology, Jena, 07745, Germany
[b] Department of Earth and Environmental Sciences, Indian Institute of Science Education and Research Mohali, Sector-81, Mohali, Punjab, 140306, India
[c] Department of Earth Sciences, Indian Institute of Science Education and Research Kolkata, Mohanpur, 741246, India
[d] Department of Ancient Indian History, Culture and Archaeology, Indira Gandhi National Tribal University, Amarkantak, 484886, India

ARTICLE INFO

Keywords:
Geoarchaeology
Neolithic
Mesolithic
Palaeoclimate
Palaeolithic

ABSTRACT

Here, we present the first-ever attempt to combine palaeoenvironmental records (n = 17) from dated stratigraphic sequences with Geographic Information System (GIS) spatial modelling of archaeological sites (3 phases; n = 306 sites) in the Ganga Plain. The spatial modelling assesses the distribution of archaeological sites and phases on maps showing changing elevation, geology, geomorphology, biome, and rainfall variability within the Ganga Plain, aiming to evaluate the human-environment relationship during the Late Quaternary Period.

The compilation of oxygen and hydrogen isotopic composition ($\delta^{18}O$ and δD values) and pollen-based environment reconstructions for the last ~100 ka indicates high rainfall conditions during ~100–75 ka, ~10–5 ka, and ~3.6–1.3 ka. Fluctuating rainfall conditions were observed during ~75–25 ka and ~18–15 ka, while the period from ~25 to 18 ka was the weakest monsoon phase, marking the Last Glacial Maximum. Arid conditions were also observed during ~15–10 ka and ~5–3.6 ka. The archaeological review suggests the presence of the Acheulian culture, diverse Mesolithic cultures, and the Neolithic phase marked by advanced agriculture and pottery production in the Ganga Plain. The past environmental analyses show changes in settlement areas correlating with rainfall variations. Frequent climate changes and increasing population density during the Late Pleistocene-Early Holocene boundary probably forced prehistoric humans to adopt agricultural practices. The distribution of archaeological sites representing different cultural phases on the modern spatial maps of landscape variability (e.g., elevation, rainfall, geomorphology, and geology) reflects an intricate relationship between prehistoric human settlements, monsoonal rainfall, and climate-driven landform processes.

Our assessment suggests that the integration of archaeological sites, geological mapping, vegetation analysis, and palaeoclimate records has the potential to provide valuable insights into ancient human-environment interactions. Therefore, we recommend continued interdisciplinary research in these fields to further enhance our knowledge of prehistoric societies and their responses to changing landscapes and climates in the Ganga Plain.

1. Introduction

The Quaternary, representing the most recent geological period, holds significance in the evolution of prehistoric humans, coinciding with notable global climate fluctuations (Petraglia and Allchin, 2007; Maslin et al., 2014). Within the Indian subcontinent, the Ganga Plain stands as an essential region to understand the relationships between prehistoric humans and the dynamic climate at local and regional scales (Sharma, 1973, 1980; Sharma et al., 1980, Sharma et al., 2004a,b, 2006; Pal, 1980, 1986, 1987, 1988, 1990, 2007, 2016, 2019; Williams and Clarke, 1984; Pandey, 1990, 2005; Williams et al., 2006; Petraglia and Allchin, 2007; Gibling et al., 2008; Pokharia et al., 2009; Jha et al., 2020, 2021; Jha, 2021). The abundance of archaeological sites in the Ganga River basin suggests its significant role in the history and archaeology of the Indian subcontinent (Fig. 1; Pal, 1980, 1986, 1987, 1988, 1990, 2007, 2016, 2019; Pandey, 1990, 2005; Pokharia et al., 2009, 2017; Jha et al., 2020, 2021; Jha, 2021). Research on archaeological sites in this region involves the thorough examination of artefacts and the contextual interpretation of stone tools, providing insights into prehistoric cultural phases (Pant, 1982; Gupta, 1985; Pandey, 1990, 2005; Ansari, 2005; Pal, 2007; Tewari et al., 2002).

The discovery of stone tools within sedimentary deposits spanning the Quaternary Period suggests the existence of prehistoric human populations along the Ganga River channel (Fig. 1; Tables 1 and 2;

* Corresponding author. Department of Archaeology, Max Planck Institute of Geoanthropology, Jena, 07745, Germany.
E-mail address: jha@gea.mpg.de (D.K. Jha).

https://doi.org/10.1016/j.quaint.2024.01.002
Received 3 August 2023; Received in revised form 28 October 2023; Accepted 5 January 2024
Available online 12 January 2024

Sharma et al., 1980; Williams and Clarke, 1984; Gupta, 1985; Pandey, 1990; Ansari, 2005; Williams et al., 2006). These findings were rich in different cultural phases encompassing the Pleistocene and Holocene epochs, representing cultural advancements from the Lower Palaeolithic to the Neolithic periods (Tables 1 and 2; Sharma et al., 1980; Pal, 2007; Williams et al., 2006; Pokharia et al., 2009; Jha et al., 2020, 2021; Jha, 2021). Contextualising the settlement patterns, hunting practices, and habitation tendencies of these prehistoric humans within the ever-changing climate and geography of the Ganga Plain undertakes critical importance and needs a systematic evaluation (Williams et al., 2006; Pokharia et al., 2009; Jha et al., 2020, 2021; Jha, 2021).

The Ganga Plain, characterised by the seasonal monsoon phenomenon (Fig. 2; Gadgil et al., 1984), occupies a crucial position in shaping the lifestyles and societal developments of prehistoric communities (Singh, 1996, 2004; Singh et al., 1999; Pal, 2007; Jha et al., 2020, 2021; Jha, 2021). Through multi-proxy analyses from lake, riverine, and floodplain deposits, including sediment laminations, grain size distribution, and pollen records, we can effectively reconstruct terrestrial climatic conditions and unravel the vegetation composition in the past (Sharma et al., 2004a,b, 2006; Gibling et al., 2008; Williams et al., 2006; Saxena et al., 2013, 2015; Agrawal et al., 2012, 2013; Trivedi et al., 2013, 2019; Quamar and Kar, 2022). Moreover, understanding the variability in monsoonal rainfall and shifts in plant photosynthetic pathways are gathered from isotopic compositions of soil organic matter, soil carbonates, and plant wax biomarkers preserved in the soil/-sediment/palaeosols (Agrawal et al., 2012, 2013; Pillai et al., 2017; Sarangi et al., 2021; Jha et al., 2020, 2021; Jha, 2021; Kumar et al., 2022). The details of past vegetational communities at the species level are obtained from the analysis of preserved pollen grains in sediment samples. When combined with the isotope-based data on changes in rainfall condition, this information can offer valuable insights into past environments and how prehistoric humans adapted them (Trivedi et al.,

Table 1
Number and distribution of prehistoric cultural sites in the Ganga Plain.

Phase	Culture	No. of sites	Dated sites
Palaeolithic	Lower Palaeolithic	20	2
	Middle Palaeolithic	24	
	Upper Palaeolithic	39	
Microlithic/Mesolithic	Microlithic/Mesolithic	121	6
Neolithic	Neolithic	34	5
Multi-Cultural	Palaeolithic to Neolihtic	68	5
Total	Total	306	18

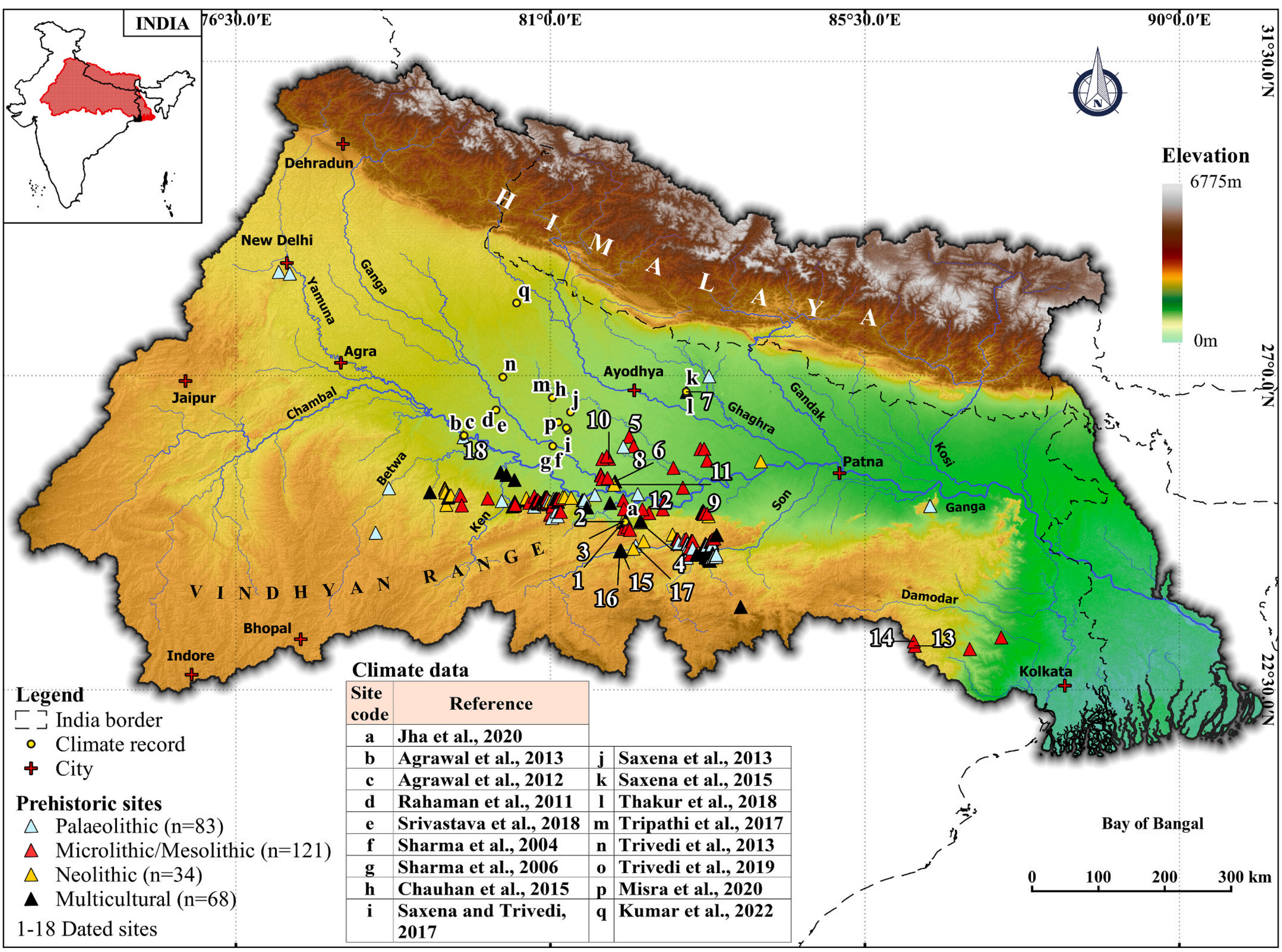

Fig. 1. The Digital Elevation Model (DEM) of the Ganga Basin (Source: https://www.usgs.gov/) depicts its major tributaries. The map shows a significant concentration of prehistoric sites in the Middle Ganga Plain. The study area is situated in a large, flat landscape, mostly on the floodplain, and is abundant in water resources, such as oxbow lakes, providing favorable conditions for agricultural practices in both modern and prehistoric eras. The majority of Palaeolithic sites are located around the transitional topographic region centered in the middle reaches of the Ganga Plain and the south-trending Vindhyan hill range. The transition of settlement from hilly terrain to floodplain is clearly visible in the region. Please note that numerical notation (1–18) was used for the dated archaeological sites in the region (see Table 1 for descriptions).

2013, 2019; Saxena et al., 2013, 2015; Saxena and Trivedi, 2017; Chauhan et al., 2015; Tripathi et al., 2017, 2021; Thakur et al., 2018; Kumar et al., 2022).

Furthermore, the use of remote sensing and Geographic Information System (GIS) techniques for reconstructing and understanding the distribution of archaeological sites from various cultural phases has provided insight into prehistoric humans adaptation to certain landscape and historical land utilisation (e.g., Bauer et al., 2004; Breeze et al., 2015; Jennings et al., 2015; Shoaee et al., 2023). When the GIS approach combined with palaeoenvironmental records, it can offer additional information into the prehistoric selection of ecologically diverse regions and provide a deeper understanding of human-environment interactions in the past (Shoaee et al., 2023). However, the application of such a multi-disciplinary approach has not been common in South Asian regions.

The abundance of qualitative and quantitative climate and vegetation records from the Late Quaternary Period, documented from the Ganga Plains, has provided substantial information upon the past environmental dynamics of the region (Sharma et al., 2004a,b, 2006; Rahaman et al., 2011; Agrawal et al., 2012, 2013; Trivedi et al., 2013, 2019; Saxena et al., 2013, 2015, 2017; Chauhan et al., 2015; Tripathi et al., 2017, 2021; Thakur et al., 2018; Srivastava et al., 2018; Jha et al., 2020, 2021; Jha, 2021). Utilising these extensive records, the Ganga Plains present a favorable research domain to explore the complex interplay between climate and culture, providing insights into the conditions that have directed prehistoric settlements in India (Jha et al., 2020). Hence, this study is focused on the Ganga Plain, synthesising existing climate, vegetation, and archaeological records, to unravel the multifaceted human-environment dynamics that have shaped prehistoric human settlements in this historically significant region, thereby augmenting our comprehension of the ever-changing natural environment of the Ganga Plain. Here, we present the first-ever attempt to combine palaeoenvironmental records (n = 17) and dated stratigraphic sequences with GIS spatial modeling of archaeological sites representing cultural phases (3 phases representing n = 306 archaeological sites). This study incorporates the spatial distribution of archaeological sites along with elevation, geology, geomorphology, biome, and rainfall data to provide a better understanding of the human-environment relationship in the Ganga Plain, India.

2. Study area

The Ganga Plain is a part of the Himalayan foreland basin, shaped by climate and tectonics during the Late Quaternary (Fig. 1; Singh, 1996,

Table 2
List of dated archaeological sites in the Ganga Plain.

No.	Site name	Culture	Chronology	Dating Method (material)	River valley/Hill	Reference
1	Belan Valley (Main Belan (Daiya), Chillahia, Chopani-mando	Palaeolithic to Neolithic	100 - 3 ka	OSL/TL/IRSL/Radiocarbon	Belan	Sharma et al. (1980) Jha et al. (2020) Jha et al. (2021)
2	Koldihwa	Neolithic	6570 ± 210 BCE	Radiocarbon	Belan	Pokharia et al. (2017)
3	Mahagara	Neolithic	5440 ± 240 BCE	Radiocarbon	Belan	Pokharia et al. (2017)
4	Tokwa	Neolithic	5976 - 1464 cal BC	Radiocarbon	Belan	Pokharia, 2008
5	Damdama	Microlithic	5550 ± 60 BP 5250 ± 70 BP 5430 ± 60 BP	Radiocarbon (Bovid enamel)	Ganga	Lukacs and Pal (2003)
6	Hetapatti	Neolithic to Chalcolithic	7230 - 2250 cal BP	Radiocarbon	Ganga	Tripathi et al. (2021)
7	Lahuradeva	Neolithic to Chalcolithic	7414 - 3317 cal BP	Radiocarbon (Charcoal)	Ganga	Tewari et al., 2006 Pokharia, 2011
8	Mahadaha	Microlithic	4010 ± 120 BP 2880 ± 125 BP 3840 ± 130 BP	Radiocarbon (Charred bone)	Ganga	Pandey (1990)
9	Malhar	Neolithic	4620 ± 110 BCE	Radiocarbon	Ganga	Pokharia et al., (2017)
10	Sarai Nahar Rai	Microlithic	10345 ± 110 BP 13592 ± 125 BP	Radiocarbon (Charred bone)	Ganga	Pandey (1990)
11	Jhusi	Neolithic	7106 - 7080 cal BC 5660 - 5642 cal BC 5990 - 5932 cal BC	Radiocarbon (Charcoal)	Ganga-Yamuna confluence	Pokharia et al. (2009)
12	Lekhahia	Microlithic	6420 ± 75 BCE 6050 ± 75 BCE	Radiocarbon	Kaimur Hill	Pal (2016)
13	Kana	Microlithic	42 ka	OSL	Kumari	Chauhan (2020) Basak and Srivastava, 2017
14	Mahadebbera	Microlithic	34 ka	OSL	Kumari	Chauhan (2020) Basak and Srivastava, 2017
15	Dhaba	Middle Palaeolithic to Microlithic	79.6 ± 3.2 – 65 ± 3.1 ka 55.0 ± 2.7 – 37.1 ± 2.1 ka 55.1 ± 2.4 – 26.9 ± 3.8 ka	IRSL (MET-pIRIR)	Son	Clarkson et al. (2020) Chauhan (2020)
16	Son Valley (Sihawal, Patpara, Baghor, Khetaunhi)	Lower Palaeolithic to Neolithic	140 ± 11.0 – 3.215 ± 0.07 ka cal BP	Radiocarbon (Shell), IRSL (Coarse-grained feldspar), OSL (Quartz)	Son	Mandal (1983) Williams and Clarke (1984) Williams et al. (2006) Jones and Pal (2009) Haslam et al. (2011) Neudorf et al. (2014)
17	Bamburi	Late Acheulean	131 ± 10.0 – 125 ± 13.0 ka	OSL (Quartz)	Son	Haslam et al. (2011)
18	Kalpi	Middle Palaeolithic	45 ka	IRSL (MET-pIRIR)	Yamuna	Tewari et al. (2002) Chauhan (2020)

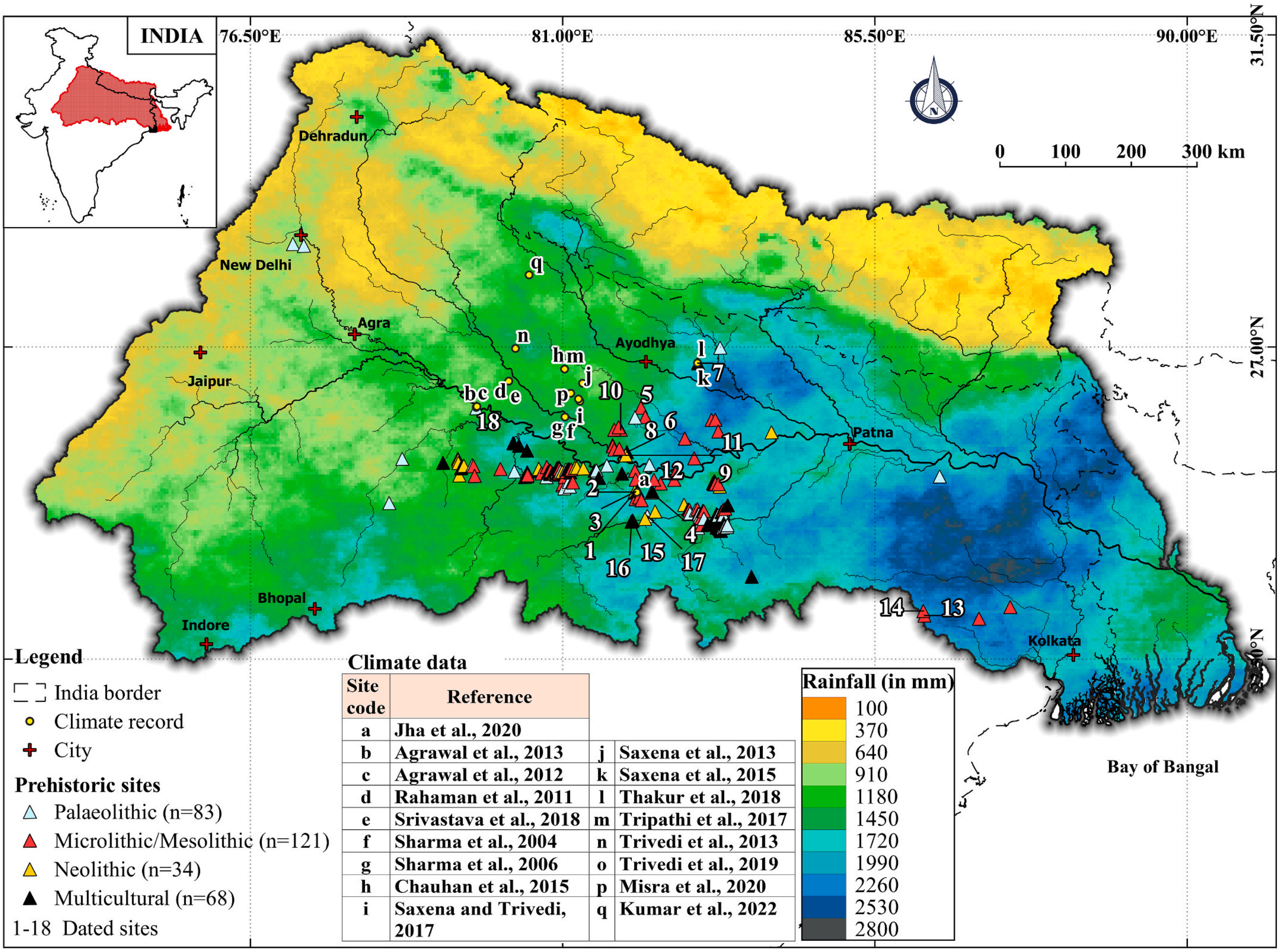

Fig. 2. Modern rainfall map (2019) of the Ganga basin (Source: http://chrsdata.eng.uci.edu/) shows that the region experiences a variable monsoonal climate, would have played a critical role in determining the availability and distribution of water resources in the region, and would have influenced the settlement patterns and subsistence strategies of prehistoric humans. Moving westwards, the rainfall decreases gradually, with the central parts of the basin receiving between 1000 and 1500 mm seems more attractive for prehistoric settlement, as they would have had a greater abundance of water and other natural resources. These areas may have also been more conducive to the development of agriculture. The distribution of known sites from this region suggests a preference for a locality with rainfall ranges between 1000 and 2000 mm. Note: The numerical notation (1–18) was used for the dated archaeological sites in the region (see Table 1 for description).

2004; Tandon et al., 2006; Sinha et al., 2006, Agrawal et al., 2012, 2013). This interaction between climate and tectonics resulted in the development of a wide range of alluvial geomorphic features (Rahaman et al., 2011).

The Ganga Plain is bounded by the foothills of the Himalayas and the peninsular India plateau, with the boundary broadening towards the west and narrowing towards the east (Fig. 1). The Ganga River originates from the Gomukh glaciers in Uttarakhand at an elevation of approximately 6.4 km above mean sea level (Fig. 1). The Plain is drained by an extensive network of rivers and is considered an extensive sediment dispersal system (Singh, 1996, 2004; Tandon et al., 2006; Sinha et al., 2006), with the Ganga drainage system estimated to carry 524 Mt/year of suspended load (Milliman and Meade, 1983). The Ganga Plain is divided into three divisions.

(i) Upper Ganga Plain (73°03′-82°21′E and 25°01′-30°01′N)
(ii) Middle Ganga Plain (24°03′-27°05′N and 81°04′-87°05′E)
(iii) Lower Ganga Plain (21°02′-26°05′N and 86°03′-89°05′E)

For this study, our focus is on the middle stretch of the Ganga Plain, covering an area of approximately 144,409 km^2 (Figs. 1–5). It includes the eastern side of Uttar Pradesh and some parts of Bihar along the river Ganga, as well as minor portions of the Siwaliks and peninsular formations (Vindhyan range). The major rivers flowing through the Middle Plains are Ganga, Betwa, Ghaghara, Gandak, Kosi, Belan and Son (Fig. 1).

The environmental conditions in the Ganga Plain differ from the Upper and Lower Plains, particularly in terms of rainfall variation (Fig. 2; Kumar et al., 2019)). The mean annual temperature is around 16.6 °C in the winter months (November to February) to approximately 32.8 °C in July, based on IMD dataset (https://mausam.imd.gov.in/). The western area of the Ganga Plain receives less rainfall compared to the eastern area (Fig. 2), with the entire study region experiencing 600–1300 mm of rainfall in modern times (Fig. 2).

3. Data and methods

We collected archaeological site data through a literature review of ≥124 articles encompassing excavation and survey details from the Ganga Plain since 1879 (Cockburn, 1879). This article presents a review of 306 archaeological sites (Table 1), characterising 83 Palaeolithic sites, 121 Microlithic/Mesolithic sites, and 34 Neolithic sites (Fig. 1;

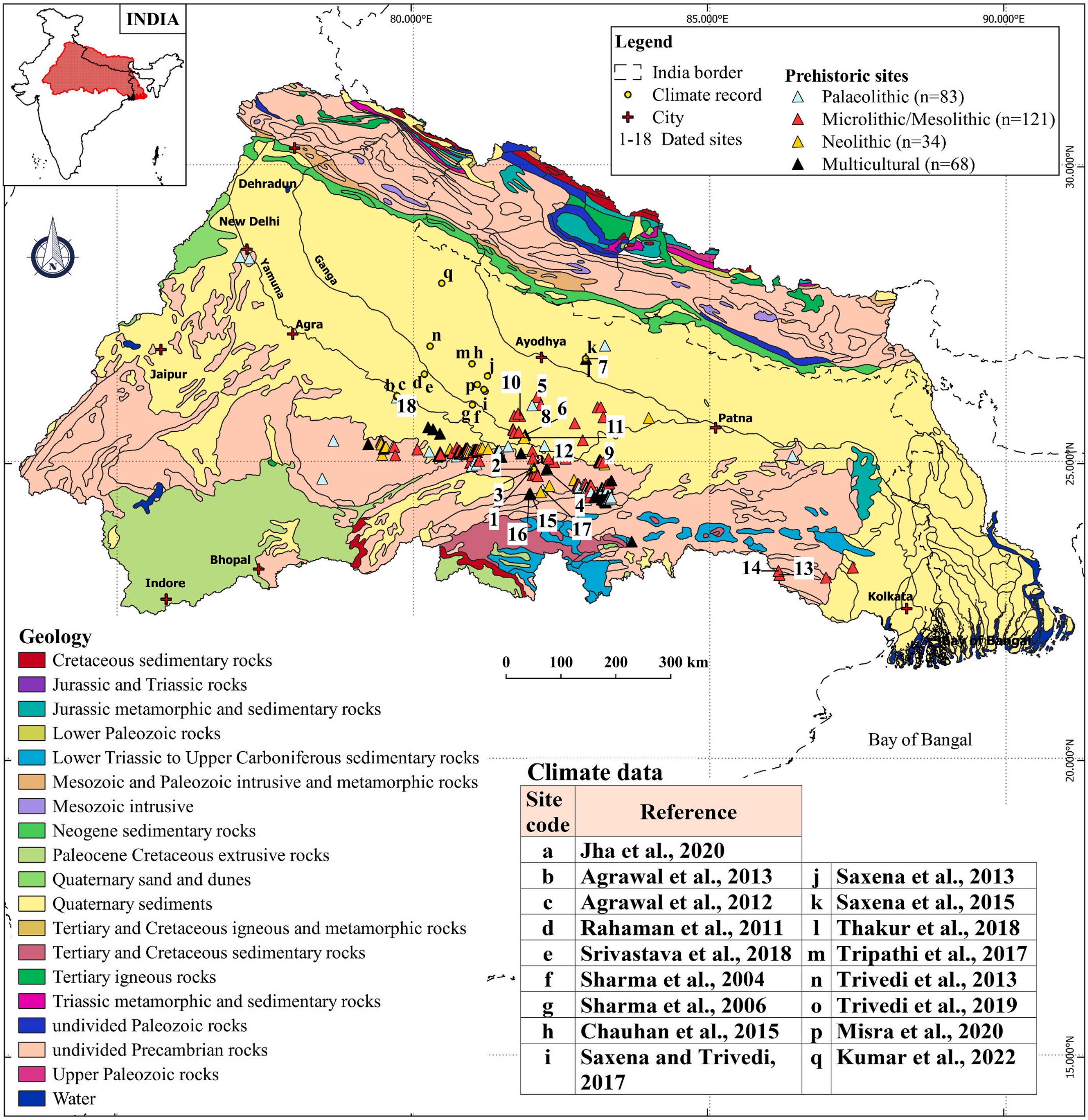

Fig. 3. The map of the Ganga Basin displays geological features, showing the various rock types (Source: https://certmapper.cr.usgs.gov/data/apps/world-maps/). It is noteworthy that the undivided Precambrian rocks, abundant in quartzite and siliceous materials, were the most suitable raw materials for stone tool manufacturing during the Palaeolithic phase. Interestingly, most of the prehistoric sites are situated where the rivers Ganga and Yamuna approach the Precambrian rocks on the south bank. This proximity indicates easy access to major food resources and raw materials.

Table 1). Additionally, we gathered data from 68 multi-cultural sites, 18 of which were dated sites (Table 2; Fig. 1).

To explore the Ganga Plain's characteristics, we conducted GIS analyses. These analyses focused on elevation (Fig. 1; https://www.usgs.gov/), rainfall (Fig. 2; http://chrsdata.eng.uci.edu/), geology (Fig. 3; https://certmapper.cr.usgs.gov/data/apps/world-maps/), geomorphology (Fig. 4; https://bhuvan.nrsc.gov.in), and biome (Fig. 5; https://ecoregions.appspot.com/). The spatial analyses tool in the Quantum Geographic Information System (QGIS) platform allowed us to study the distribution pattern of the 306 archaeological sites across three cultural phases, considering changing elevation profiles, rainfall regimes, geological formations, geomorphological landscape features, and biome selectivity (Figs. 1–5). We also included the distribution of dated archaeological sites (n = 18) and the location of palaeoenvironmental data (n = 17) on the spatial maps (Figs. 1–5).

In this study, we synthesised 17 palaeoenvironmental data of the last ~100 ka from the Ganga Plain (Figs. 6 and 7). This dataset includes quantitative isotopes (δD and $\delta^{18}O$ values) of rainfall and qualitative

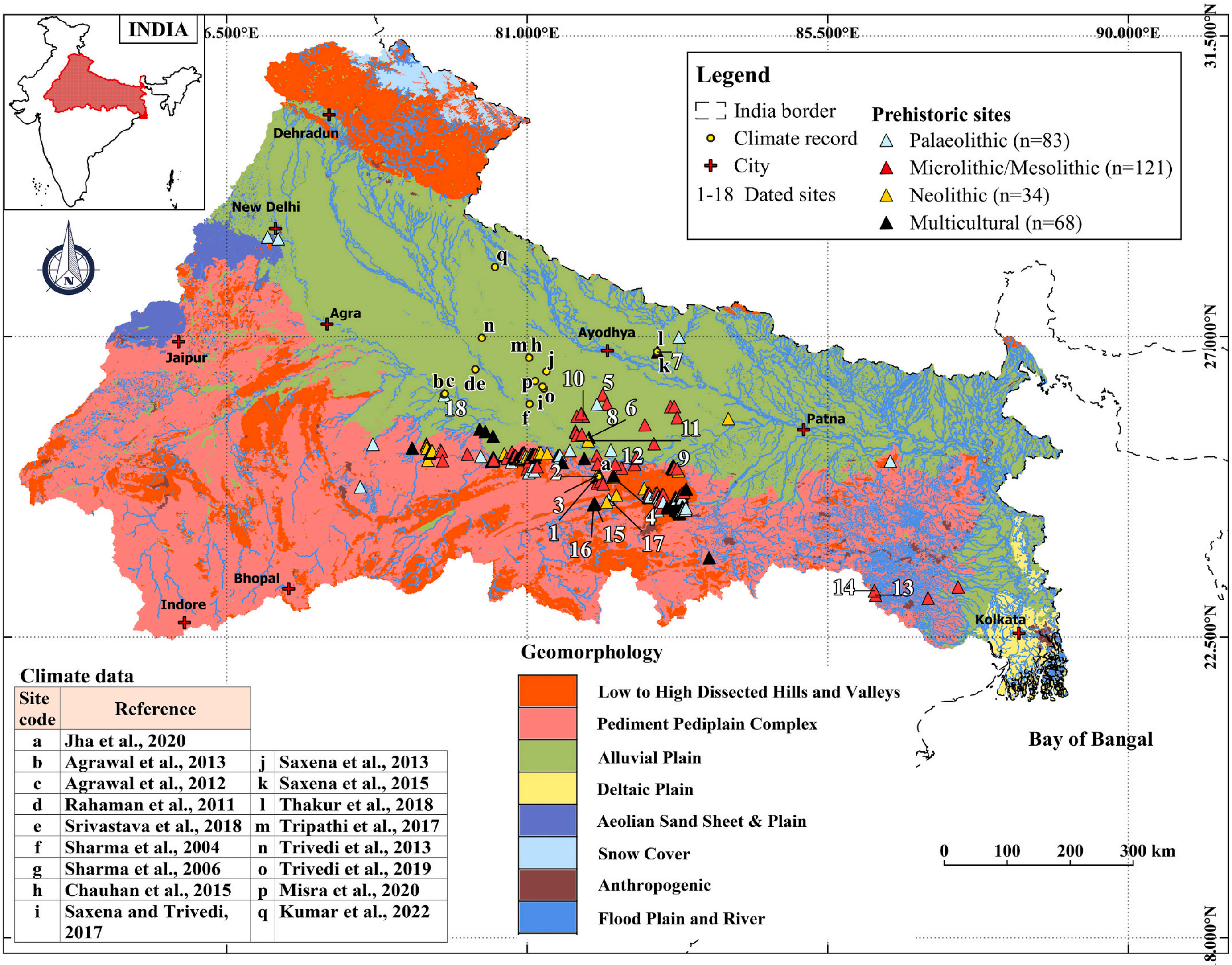

Fig. 4. Map of the Ganga basin represented by geomorphological features (Source: https://bhuvan.nrsc.gov.in) with the major prehistoric sites in the Ganga plain. Illustrating dissected hills and valleys to the south and alluvial plain to the north. The alluvial plain with a rich alluvial soil that is ideal for agriculture. The region has been an important centre of agricultural production since the Neolithic period. Most of the Palaeolithic sites are laying on the pediment-pediplain complex whereas the Microlithic and Neolithic sites are located in the Gangetic alluvial plain, reflecting transitional selection of localities based on resources. Note: The numerical notation (1–18) was used for the dated archaeological sites in the region (see Table 1 for description).

pollen data for vegetation changes, enabling the reconstruction of past environmental conditions in the studied region.

4. Stratigraphic and chronological sections of the Ganga Plain

Several cliff sections in the Ganga Plain offer valuable insights into the fluvial geomorphology and climate of the region. Previous studies (Tandon et al., 2006; Sinha et al., 2006, 2007; Agrawal et al., 2012, 2013; Srivastava et al., 2018) have made efforts to comprehend the complex dynamics, and multiple drill cores have been extracted to quantify the fluvial environment of the past. To establish the chronology and context for future research, optically stimulated luminescence (OSL) and infrared stimulated luminescence (IRSL) dating techniques have been utilised to date the sediments obtained from these fluvial cliff sections and drill cores. The following presents a description of the sedimentary characteristics and chronology of specific cliff sections and drill cores in the Ganga Plain.

i). **Kalpi core**: Located on the southern bank of the Yamuna River (26° 07.80′N and 79° 45.60′E), the Kalpi core consists of alternating units of channel sand and mud/fine sand strata. The presence of rhizoconcretions mottles and Fe/Mn nodules indicates pedogenic alteration of fluvial sediments (Sinha et al., 2006, 2007; Agrawal et al., 2012, 2013). OSL dating techniques have been used to determine three ages: 20 ± 4 ka, 46 ± 8 ka, and 84 ± 18 ka from the Kalpi core at depths of 10.3 m, 30.6 m, and 50.2 m, respectively (Agrawal et al., 2012).

ii). **Bhognipur core:** Drilled near the Kalpi core on the southern bank of the Yamuna River (26° 07.97′N and 79° 45.50′E), the Bhognipur core exhibits alternating units of channel and floodplain deposits. It comprises a lower channel deposit with feldspar-rich sand capped by an erosional surface. The upper portion consists of a thick floodplain deposit with illuvial clay coatings, Fe/Mn nodules, and pedogenic carbonates (Agrawal et al., 2013; Srivastava et al., 2018). The chronology for this core is not available. However, based on lithology, it was considered to be chronologically similar to the Kalpi core (Agrawal et al., 2012; Srivastava et al., 2018).

iii). **IITK core:** Located in the southern interfluve region of the Ganga Plain (26° 28.80′N and 80° 15.60′E), the IITK core comprises

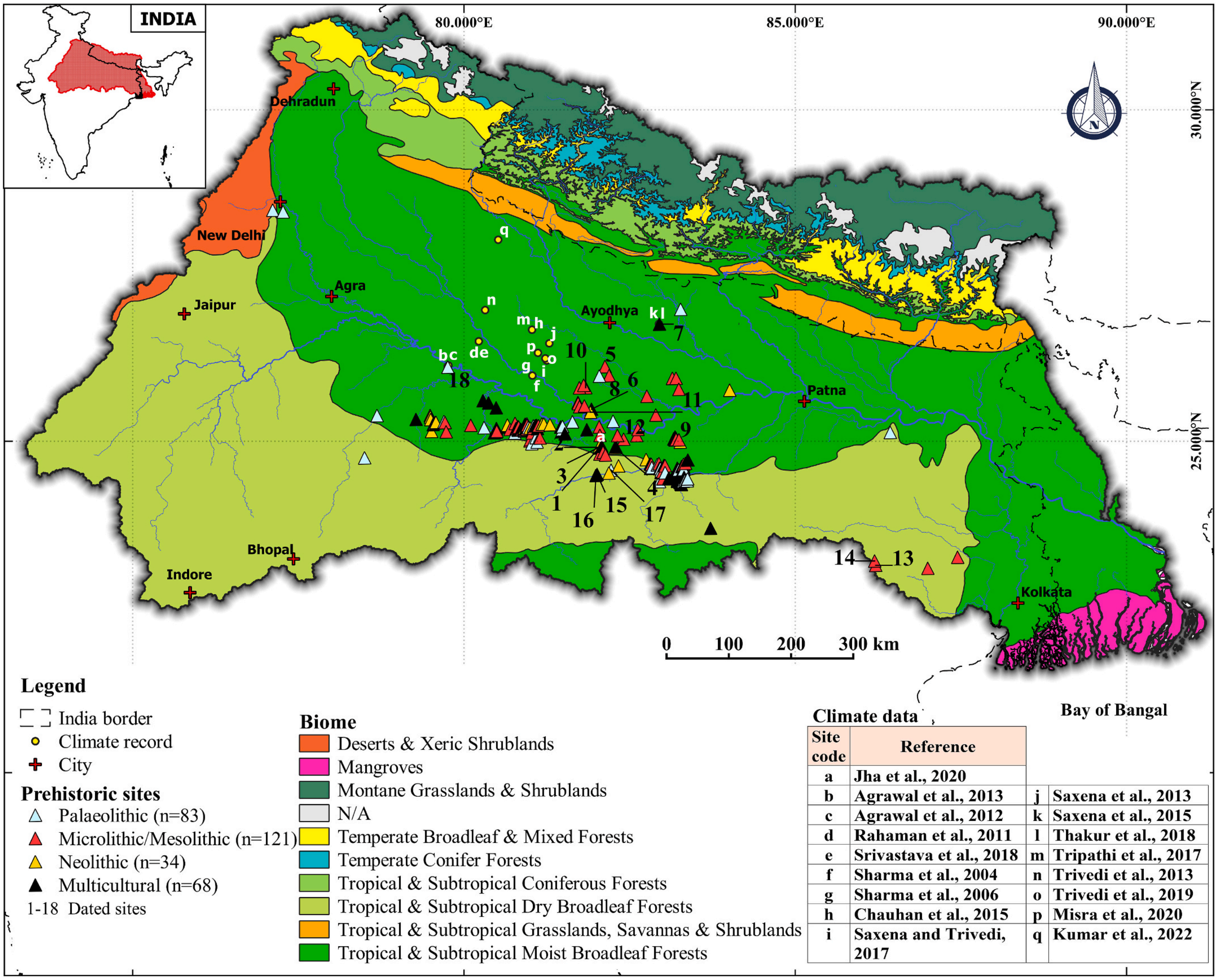

Fig. 5. Map of modern biome variability within the Ganga basin (Source: https://ecoregions.appspot.com/) showing the distribution of different types of vegetation and ecosystems across the region. The dominant vegetation in the Ganga Plain is deciduous forest, which is characterised by a mix of broadleaf trees, such as *Shorea robusta* (sal), *Tectona grandis* (teak), and *Mangifera indica* (mango), as well as smaller shrubs and grasses. These forests are typically found in areas that receive adequate rainfall and are home to a variety of wildlife, including deer, monkeys, and various bird species that provide major food resources for prehistoric hunter-gatherers. The tropical & Subtropical echo diversity consisting of moist and dry broadleaf forests cover a large area of the basin, temperate broadleaf, conifer and mixed forests to the north. Prehistoric sites are located around the transitional area between the tropical and subtropical moist and dry broadleaf forests. Note: The numerical notation (1–18) was used for the dated archaeological sites in the region (see Table 1 for description).

floodplain sediments intercalated with channel sand beds. Dark mottles, rhizoconcretions, and a robust magnetic signature indicate significant pedogenic activity (Sinha et al., 2007). The IRSL technique has been used to date four depths in the core samples using feldspar grains. These points were located at 11.6 m, 21.5 m, 31.8 m, and 41.9 m, with estimated ages of 30.3 ka, 38.7 ka, 63.0 ka, and 86 ka, respectively (Sinha et al., 2007).

iv). **Firozpur core:** Drilled at Firozpur village in a valley fill deposit of the Ganga Plain (26° 39.90′N and 80° 26.64′E), the Firozpur core displays alternating channel and floodplain deposit units. Two significant upward fining episodes suggest valley aggradation on multiple occasions. The channel sand and floodplain mud/fine sand deposits contain dispersed carbonate nodules, black mottles, and rhizoconcretions, indicating pedogenic alterations (Sinha et al., 2007; Agrawal et al., 2012). By using the OSL technique on quartz grains from the Firozpur core, ages of 8.5 ± 1.2 ka, 10.5 ± 1.7 ka, and >31.6 ± 2.7 ka were determined at depths of 5 m, 8.5 m, and 21 m, respectively (Sinha et al., 2007).

v). **Ramnagar cliff section:** The Ramnagar cliff section along the Ganga River in Varanasi, Uttar Pradesh, is part of a large point bar deposit. The sedimentology of the cliff has been extensively studied, and carbonate nodules, palustrine carbonate, calcretised mud, and rhizoconcretions are abundant. In the Ramnagar section, OSL dating reveals the following ages: 7 ± 1 ka at 4 m, 26 ± 4 ka at 1 0m, 39 ± 5 ka at 17.5 m, 46 ± 5 ka at 18.5 m, and 59 ± 6 ka at 20 m depth. These findings offer valuable insights into the geological history of the area (Shukla et al., 2012).

vi). **Belan valley cliff sections:** The Belan River has preserved several cliff sections, including Mahagara, Koldihwa, Chopani-Mando, Chillahia, Deoghat, and Main Belan (Daiya section). These cliff sections have archaeological significance, spanning from the Palaeolithic to Neolithic phases (Sharma et al., 1980; Pal, 2007; Williams et al., 2006; Gibling et al., 2008; Jha et al.,

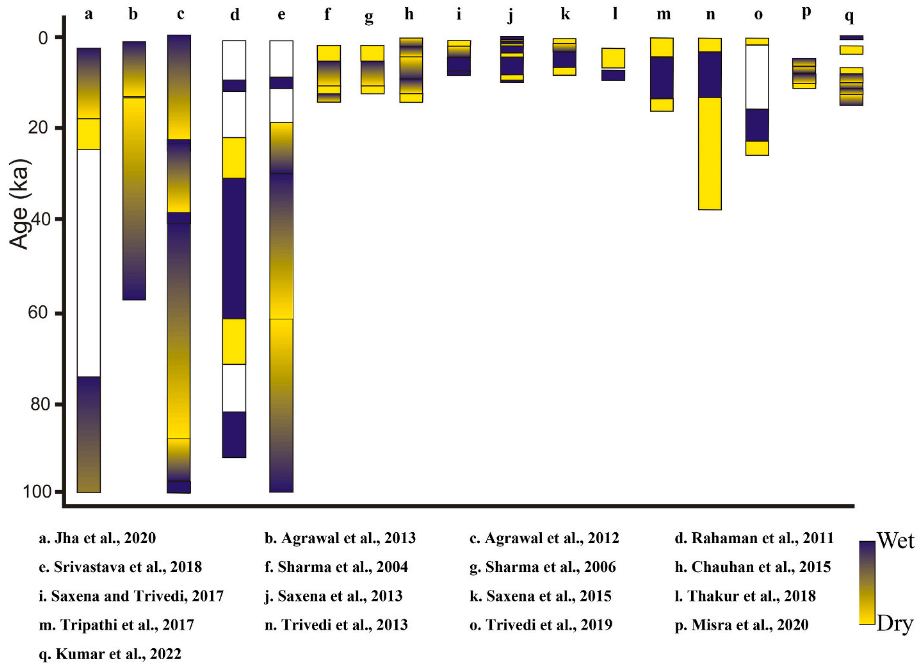

Fig. 6. The palaeoenvironmental records (n = 17) from the Ganga plain. The data includes the climate (dry vs wet) phase for the last ~100 ka and is reconstructed from the different proxies such as isotopes (δD and $\delta^{18}O$ values), pollen, elemental geochemistry and sedimentology facies analyses in the Ganga Plain. The fluctuation in the wet and dry phases in the region is discrete and shows a similar pattern as modern rainfall of spatial distribution. This variability when coupled with archaeological evidence suggests a role of micro-climate in settlement patterns and exploitation of selective environment.

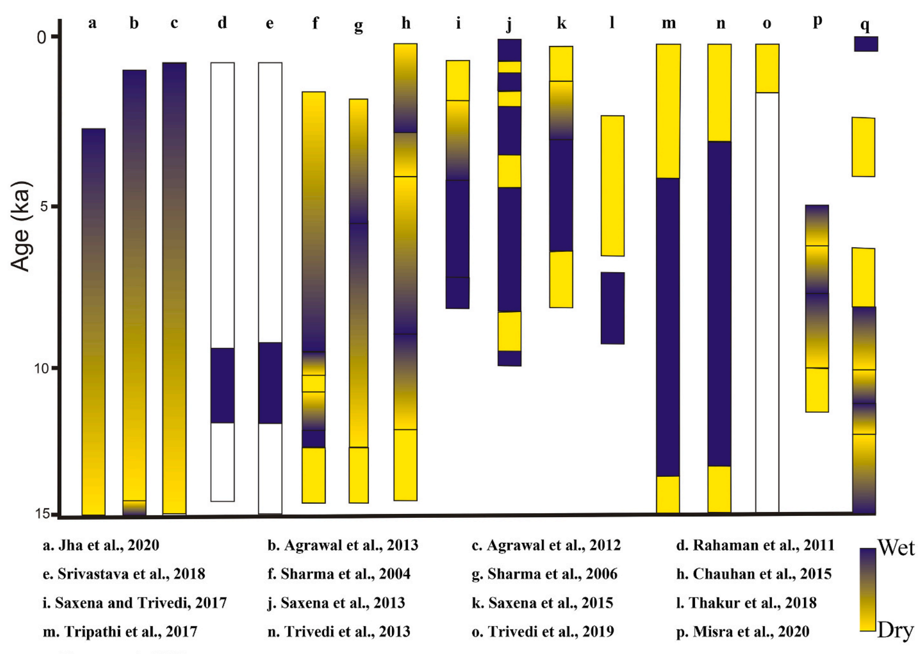

Fig. 7. The palaeoenvironmental records of the last ~15 ka in the Ganga plain (n = 17). The map suggests the prevalence of spatial variability in the rainfall in the Ganga plain in the past which affected the distribution and selection of landscape for hunter-gathering and settlement. The intensified monsoonal rainfall was observed in the last ~10 ka, which must have supported the agricultural activity and sedentary lifestyle of the Neolithic communities of the Ganga Plain.

2020, 2021; Jha, 2021). The age of the cliff sections ranges from ~100 ka to 3 ka (Gibling et al., 2008; Jha et al., 2020, 2021; Jha, 2021).

These descriptions provide an overview of the sedimentary characteristics and chronology of various cliff sections and drill cores in the Ganga Plain (Sarangi et al., 2021), contributing to our understanding of the region's fluvial history and its implications for climate and archaeology.

5. Archaeological evidences from Ganga Plain

Several excavations of prehistoric sites have been conducted in the Ganga Plain in the last decade particularly focused in middle stretch of the basin (Table 2). All these excavations suggests a continuity of the cultural evolution in the Ganga Plain ranging from the Palaeolithic to Iron age (Table 2). The Vindhyan Hills (Fig. 1) situated at the southern boundary of the Ganga Plain was vital as the region provided the abundant and suitable raw materials for making stone implements (Banerjee et al., 2018). Therefore, we tried to understand the richness of different cultural phases in the Ganga Plain by providing a systematic review in this section.

5.1. Palaeolithic culture

The Lower Palaeolithic is generally characterised by the Acheulian techno-complex. The Acheulian is categorised by the distinctive oval and pear-shaped "handaxes" generally associated with *Homo erectus* and derived species such as *Homo heidelbergensis* (Lepre et al., 2011). The Lower Palaeolithic in Indian subcontinent has been segregated into core-and-flake and Acheulean lithic industries with a diverse array of stone tools, including handaxes, cleavers, miscellaneous bifaces (Chauhan, 2009, 2010, 2020). The evidence of Acheulian techno-complex was found in a few sites in the Upper Ganga Plain (Khansili, 2014; Sharma and Ota, 1991). For example, a spectacular late Acheulian site was found at the Anangpur located between Delhi and Faridabad (Sharma and Ota, 1991). Further, the excavation in the region revealed significant discoveries of numerous Acheulean sites distributed across the interfluves connecting the Betwa and the Shahzad rivers (Singh, 1965; IAR, 1964). Subsequent excavations conducted by Deccan College (IAR, 1964) and Archaeological Survey of India (ASI; IAR, 1967) revealed a remarkable abundance of large flakes, bifaces, and debitage. Lalitpur is a significant Acheulian site of the Ganga Plain due to its unique characteristic of predominantly containing tools made from granite rocks (Agrawal, 2014).

The culture sequence of the Ganga Plain is considered to have no known Lower Palaeolithic sites on the northern bank of the Ganga River (Fig. 1). The observation shows that the Lower Palaeolithic sites are largely confined to the major tributaries in the southern bank of the Ganga River (Fig. 1; Table 2). The Lower Palaeolithic sites in the Ganga Plain are spread from the foothills to the northern fringe of the Kaimur range along with the major tributaries of the Ganga River (Pal, 2019; Pant, 1982). The nearest known Lower Palaeolithic site is located in the Belan valley, which lies in the Vindhyan range (Pal, 2019; Williams and Clarke, 1984; Williams et al., 2006; Gibling et al., 2008). However, the Palaeolithic artefacts were also collected earlier from the Singrauli Basin and the Mirzapur district during excavation in 1883 (Krishnaswami and Rajan, 1951). Interestingly, all those records are dominantly reported from the major tributaries of the Ganga River, such as Yamuna, Son and Belan River (Figs. 1–5). For example, a total number of 44 Lower Palaeolithic sites were reported in the Belan valley and 47 sites from the Son valley (Sharma et al., 1980; Misra, 1997; Pal, 2007, 2019). The Lower Palaeolithic tool assemblages were identified as pebble tools, handaxe and cleaver, which were prepared from the raw materials available from outcrops of Vindhyan rocks (Sharma et al., 1980; Misra, 1997). It was observed that the mostly Lower Palaeolithic artefacts were produced from quartzite rocks as they are abundantly available from the Vindhyan Hills (Misra, 1997; Pal, 2019). However, the Lower Palaeolithic tools and artefacts are absent from the channel deposit of Ganga River (Figs. 1–5). The reason for such non-availability has been related to the absence of raw material rocks along the Ganga River (Dennell, 2007). The Ganga Plain is entirely dominated by thick alluvium, which was initially considered not suitable for habitational zone for the Palaeolithic population (Pal, 2007, 2019; Dennell, 2007).

The Middle Palaeolithic artefacts started to unearthed in the middle reaches of the Ganga Plain (Tewari et al., 2002). The most important Middle Palaeolithic site is “Kalpi” situated in the Yamuna valley, which dated to ~45 ka (by IRSL method; Tewari et al., 2002). It is the only chronologically known earliest Middle Palaeolithic site in the Ganga Plain (Tewari et al., 2002). The stratigraphic horizons containing Middle Palaeolithic artefacts have also yielded a rich assemblage of vertebrate faunal remains (Singh et al., 1999; Tewari et al., 2002; Islam, 2016). Hence, this becomes valuable and first dated record of the Middle Palaeolithic human occupation of the Ganga Plain (Singh et al., 1999; Tewari et al., 2002; Islam, 2016). It has opened a new chapter in the prehistoric archaeology of the Ganga Plain to correlate it with the faunal data providing on-site environmental context of Middle Palaeolithic in the region (Singh et al., 1999; Tewari et al., 2002). Other Middle Palaeolithic sites are located on the northern margin of the Vindhyan range mostly from a second gravel deposit of the Belan valley (Sharma et al., 1980; Misra, 1997; Pal, 2007, 2019). The earliest date obtained from the Son valley containing large flake Acheulian culture is 140 ± 1.0 ka and the Neolithic culture is dated to 3.2 ± 0.07 ka (Williams and Clarke, 1984; Williams et al., 2006; Haslam et al., 2011; Neudorf et al., 2014; Clarkson et al., 2020). Similarly, the Belan valley’s dates range between ~100 ka and 3 ka representing multicultural sequence from the Lower Palaeolithic to Neolithic phase (Sharma et al., 1980; Pal, 1980, 2007; Williams et al., 2006; Gibling et al., 2008; Jha et al., 2020, 2021; Jha, 2021).

The evidence of Upper Palaeolithic culture is mostly absent from the Ganga River channel (Figs. 1–5; Table 2). Although a number of sites have been reported from surface collection (Banerjee, 1987). The only evidence of Upper Palaeolithic assemblage in the stratified context was recovered from the third gravel deposit from the Main Belan section (Sharma, 1980; Misra, 1997; Jha et al., 2020, 2021; Jha, 2021). Whereas, Baghor-I is an excavated site in the Son Valley yielded Upper Palaeolithic artefacts (IAR, 1973). However, the chronology of the Upper Palaeolithic remains unclear and need further assessment in the region.

5.2. Microlithic/Mesolithic culture

The term "Microlithic" has been used to designate sites lacking precise chronological status and the sites with known chronological framework is termed as "Mesolithic" in this study.

The Microlithic/Mesolithic culture of the Ganga Plain can be categorised into two types: open air and rock shelters sites (Sharma, 1973; Sharma et al., 1980; Pal, 2007). The stone industries found in the Ganga Plain exhibits an advanced form of Microlithic tool technology (Pandey, 1990; Sharma, 1973; Sharma et al., 1980; Pal, 2007; Chatterjee, 2019). The Pratapgarh district situated in the Ganga Plain has reported a significant number of Mesolithic sites along oxbow lakes and northern boundaries of the Vindhyan Hills (Pandey, 1990; Chatterjee, 2019). Detailed studies of Mesolithic sites along the northern bank of the Ganga river include Sarai Nahar Rai, Mahdaha, and Damdama (Pal, 1986, 1994, 2007; Pandey, 1990; Sharma, 1973; Sharma et al., 1980). Additionally, various sites can be found in the Vindhyan region, such as rock shelters at Morhana Pahar, Baghaikhor, and Lekhahia, as well as an open-air site at Chopani Mando (Sharma et al., 1980; Misra, 1997; Jha et al., 2020, 2021). These sites have been excavated over several seasons by multiple team of archaeologists (Chattopadhyaya, 1996; Pal, 1986, 1994, 2007; Pandey, 1990; Sharma, 1973; Sharma et al., 1980; Varma, 1983, 1989; Varma et al., 1985), which provided an extensive data on Mesolithic culture of Ganga Plain.

The Mesolithic sites in the Ganga Plain have revealed several archaeological remains, including burned plaster floors, post holes, graves, hearths, charred seeds, animal bones, and a variety of artefacts such as microliths, bone and antler tools, querns, mullers, ring stones, sling stones, hammer stones and anvils (Pal, 1986, 2007; Misra, 1997; Sharma et al., 1980). The Microlithic tools found consist of retouched blades, points, awls, lunates, triangles and trapezes from the Ganga Plain (Pal, 1986). It is noteworthy that the Ganga River channel lacks suitable rock formations (Pal, 2007), and the closest available sources of materials like chert, and chalcedony as raw materials are available in the Vindhyan Hills for the utilisation to make Microlithic tools (Pal, 1980, 2007). Another distinguishing feature of the Microlithic assemblages in the Ganga Plain is the size difference between the tools found near Oxbow lakes and those found in the Vindhyan region (Fig. 1; Chatterjee, 2019) and suggests technological variations between those groups. It was also observed that the prepared cores found near the Oxbow lakes in the Ganga Plain have been used extensively and perhaps due to scarcity of raw materials (Pal, 1980, 2007; Chatterjee, 2019).

There are evidences of Mesolithic inhabitants utilising bone materials for crafting tools and ornaments (Pandey, 1990; Varma et al., 1985; Sharma, 1973; Sharma et al., 1980; Chattopadhyaya, 1996). It is important to mention that bone tools and decorations have been discovered exclusively at the excavated sites such as Sarai Nahar Rai, Mahadaha, and Damdama in the Ganga Plain (Pandey, 1990; Varma et al., 1985; Sharma, 1980; Chattopadhyaya, 1996; Pal, 2007). The assortment of bone tools includes arrowheads, points, blades, knives, scrapers, chisels, and saws (Pandey, 1990; Pal, 2007). Arrowheads and points were the most common types of bone tools used in the Ganga Plain (Pandey, 1990). The Mesolithic people living in the Ganga Plain displayed a clear fondness for adorning themselves with various ornaments, including earrings, necklaces and pendants (Pandey, 1990; Pal, 2007). These ornaments were skillfully crafted using materials like bone, antler and ivory, showcasing the artistic and creative abilities of the Mesolithic community (Pandey, 1990; Pal, 2007). It is plausible to interpret these ornaments as markers of identity, symbolising both social distinctions and individual differences within the community (Pandey, 1990; Pal, 2007, 2016). Several bone arrowheads indicate the use of bow and arrow technology, showcasing the technological advancement of the Mesolithic culture in the Ganga region (Pal, 2016).

Excavations at Chopani Mando, a Mesolithic site in the Belan valley have provided evidence of human habitation, including huts, Microlithic tools and grains (Misra, 1997; Sharma et al., 1980; Pal, 2007; Jha et al., 2020, 2021; Jha, 2021). The remains of the huts, in the form of post holes, suggest that Mesolithic people lived in small circular huts made of wattle and daub, with shallow pits and post holes (Misra, 1997; Sharma et al., 1980; Pal, 2007). The artefacts found at the site include querns, mullers, anvils, hammer stones and Microlithic tools (Misra, 1997; Sharma et al., 1980; Pal, 2007). During the Mesolithic phase, querns and mullers were primarily used for grinding wild grains, such as wheat, barley and millet, into flour or meal, which was crucial for food production (Misra, 1997; Sharma et al., 1980; Pal, 2007). Additionally, these tools were occasionally employed for grinding pigments and dyes, enabling the creation of paints, inks and colorants for artistic and decorative purposes (Misra, 1997; Sharma et al., 1980; Pal, 2007). Moreover, querns and mullers were utilised for grinding a wide range of materials, including nuts, seeds, roots and other substances, based on local needs and available resources (Sharma et al., 1980). The evidence of wild rice "Oryza *rufipogon*" was found at Chopani-Mando preserved in the burned clay lumps of pottery (Pal, 1980, 2007; Sharma et al., 1980; Sharma et al., 2004a).

The Mesolithic sites of the Ganga Plain have yielded several pottery sherds from sites such as Morhana Pahar, Baghaikhor, Lekhahia, and Chopani Mando, with majority being deep shallow rimless bowls (Chatterjee, 2019; Misra, 1997, 1999; Pal, 1980, 2007). These pottery pieces were likely used for storing food items such as grains and seeds. The occurrence of charred animal bones found in hearths from Damdama, Mahadaha and Sarai Nahar Rai suggests that animals were a significant source of food for the Mesolithic people living in the Ganga Plain (Pal, 2007).

The burials are commonly discovered in the habitation area and are typically located in close proximity to the hearths (Sharma, 1973; Pal, 1985, 1988, 1992, 1994; Pandey, 1990; Sharma et al., 2004a,b). The burial practices revealed significant evidence of the social organization within the Mesolithic culture (Sharma, 1973; Pal, 1985, 1988, 1992, 1994; Pandey, 1990; Sharma et al., 2004a,b). The significant discovery of Mesolithic culture in the Ganga Plain appears to have a strong association with the deceased, as revealed by the presence of ninety individual burials in eighty graves discovered at the Sarai Nahar Rai lake, Mahadaha lake, and Damdama lake (Pal, 1985; Chattopadhyaya, 1996). Among these burials, there were seven instances of double burials, one triple burial, and one quadruple burial (Chattopadhyaya, 1996). Bone ornaments were found in three burials from Mahadaha and one from Damdama (Pal, 2002). In most cases, the buried individuals were oriented in a west-east direction, which suggest socio-cultural practice in the group of habitants of Mesolithic phase in the Ganga Plain.

Further, extended human burials have been reported in Baghaikhor and Lekhahia rock shelters of the Vindhyan region (Misra, 2002). The majority of these burials were oriented with the head towards the west, except for two burials with a south-north orientation (Misra, 2002). The human skeletons found in these sites are often individual burials or joint and multiple burials, associated with ritual materials like offered meat (Misra, 2002). Evidence of providing meat to the deceased as a ritual has been reported from Lekhahia (Lukacs and Misra, 1996; Lukacs and Pal, 2003). A female skeleton from Baghaikhor, studied by Kennedy (1990), exhibited signs of porotic hyperostosis disease on the frontal and parietal bones. Lukacs (2007) provides evidence suggesting that the hunter-gatherer communities residing in the Ganga Plain were generally in good health and successfully adapted to their environment. This is supported by the low occurrence of dental decay, the absence of signs indicating nutritional and infectious ailments, and infrequent indications of physical injuries and occupational strain (Petraglia and Allchin, 2007).

Several dates from various sites suggest that the Mesolithic occupation in the Ganga Plain occurred during the early to mid-Holocene (Misra, 2007; Pandey, 2005; 2016; Islam, 2016). The collective evidence strongly indicates that the emergence of Mesolithic culture in the Ganga Plain took place between 10 ka and 8 ka BP (Misra, 2007; Pandey, 2005; Pal, 2016; Islam, 2016). For instance, the Mesolithic human activity at Sarai Nahar Rai lake was dated to 8395 $\pm$ 110 BCE by radiocarbon (^{14}C) method, while thermo-luminescence (TL) and AMS dates obtained from the Damdama lake suggest a range from 7000 BCE to 9000 BCE (Misra, 2007; Pal, 1986, 1988, 2007). Similarly, researchers have proposed a broader time span for the Mesolithic cultures of Belan and Son valleys, suggesting a chronological framework from the 10,000 to 8000 BCE. (Pal, 1986, 1988; Pandey, 2005; Tewari et al., 2002; Neudorf et al., 2014; Clarkson et al., 2020; Chauhan, 2020).

5.3. Neolithic culture

The earliest collection of Neolithic tools in the Ganga Plain was discovered in the Banda district around ~1800 BCE (Cockburn, 1879). Further excavations at major tributaries of the Ganga, such as Belan and Son, also revealed several Neolithic sites (Williams and Clarke, 1984; Williams et al., 2006; Sharma et al., 1980; Jha et al., 2020, 2021; Pokharia et al., 2017; Pokharia, 2008). These sites demonstrated a shift from hunter-gatherer lifestyles to settled agricultural communities due to the fertile floodplains suitable for agriculture (Sharma et al., 1980; Misra, 1997; Jha et al., 2020, 2021; Jha, 2021; Quamar and Kar, 2022). The cultural sequences unearthed from excavations in the Ganga Plain and Vindhyan region displayed a stratified development from the Neolithic to the early historical phase (Tripathi et al., 2021; Tewari et al., 2002, 2006; Pokharia, 2011; Pokharia et al., 2017; Misra et al., 1996). The most important excavated Neolithic sites in the Ganga Plain are Jhusi, Hetapatti, Bhunadih, Waina, Sahgora, Imalidih, Chechar Kutubpur, Taradih, Senuwar and Maner (Misra et al., 1996; Misra, 1997, 2002). The excavation at site Chirand by Archaeological Survey of India (ASI) suggested presence of full-fledged Neolithic settlement characterised by the presence of domesticated animals, plants, pottery and smoothed stone tools in the Ganga Plain (IAR, 1973; Sinha, 1979). Extensive array of bone tools was recovered from the Chirand excavation suggests that the Neolithic community relied heavily on animal bones as a raw material for crafting these implements, possibly due to a scarcity of suitable stone resources in the region (Sinha, 1979). Alongside the bone tools, a significant number of Microlithic tools have also been discovered at Chirand (Sinha, 1979). These Microlithic tools were crafted from siliceous stones readily available in the riverbed (Sinha, 1979). The abundance of such tools indicates a sophisticated knowledge of stone knapping techniques and further highlights the resourcefulness of the Neolithic inhabitants in utilising available materials for tool production (Sinha, 1979). Moreover, the discovery of bone ornaments like bangles, combs, and pendants at Chirand (IAR, 1973) demonstrate that the Neolithic people have developed a sense of beauty and an appreciation for the arts. Notably, the presence of unfinished beads in the archaeological findings of Chirand indicates the existence of a local bead-making industry within the region. This industry likely played a role in producing intricate and aesthetically pleasing beads, which could have held cultural and economic significance within the Neolithic community.

Further excavation in the Vindhyan range at site Koldihawa, Mahagara, Kunjhun, Panchoh, Indaari, Tokwa, Mahagara, revealed Neolithic cultural materials along with evidence of hutments, cattle pens and post holes (Sharma et al., 1980; Misra, 1997; Jha et al., 2020, 2021; Jha, 2021). Evidence of plant domestication is also reported from this region (Misra, 1997). The Neolithic deposits yielded various stone tools, including celts, mullers, ring stones, and querns, often associated with pottery (Sharma et al., 1980; Misra, 1997; Jha et al., 2020). Additionally, the introduction of round varieties of stone celts in the Belan valley indicated technological advancements (Pal, 1990; Misra et al., 2001). The raw material source to craft heavy-duty tools was basalt, sandstone, granite, and quartzite, which support the socio-cultural behaviour of Neolithic settlers in the region (Islam, 2016).

The pottery culture was introduced in Neolithic phase in the Ganga Plain (Sharma et al., 1980). Among the pottery types discovered in Neolithic deposits across several sites are cord impressed pottery, rusticated pottery, burnished Redware, and burnished black ware (Pal, 1987; Hazarika, 2012). The process of pottery production involved a combination of various materials, including rice and millet husk, chopped straw, and leaves. The pottery was meticulously handcrafted and poorly fired, leading to distinctive palm and finger impressions on the surfaces. The practice of cord impressed pottery continued into the Chalcolithic phase, representing a continuation of this pottery making technique beyond the Neolithic culture (Pal, 1987; Hazarika, 2012). Early Neolithic pottery from the Ganga Plain was primarily characterised by bowls and cooking vessels, suggesting their practical use in daily life (Pal, 1987; Hazarika, 2012). Excavation at Chirand also yielded a rich ceramic industry consisting of spout vessels, bowls, spoons and knobbed vessels. The occurrence of diverse ceramic traditions demonstrates the evolving pottery-making techniques of the Neolithic communities (Sinha, 1979). Additionally, terracotta art was also introduced into the Neolithic culture of Chirand (Sinha, 1979). The terracotta art form involved crafting figurines made of fired clay depicted female figures, bulls, snakes, birds, and various coiled and uncoiled symbolic artefacts (Sinha, 1979). The diversity and complexity of the pottery found in Chirand demonstrate the technological advancements and artistic expressions of the Neolithic communities exploiting the local environment of the Ganga Plain.

The Neolithic culture of the Ganga Plain holds immense importance as a significant cultural stage in India. During this phase, agricultural activities were practiced by the communities, marking a fundamental shift from a nomadic, hunter-gatherer lifestyle to settled farming practices. The Neolithic culture in the Ganga Plain is characterised by the development of an advanced agricultural society (Sharma et al., 1980; Tewari et al., 2006; Quamar and Kar, 2022). The Chopani Mando site from Belan valley holds particular significance as it is considered a probable indicator of the early stages of rice cultivation (Sharma et al., 1980). Evidence suggests that the initial cultivation of rice involved the exploitation of wild rice, which gradually evolved into a more organised agricultural practice at nearby Neolithic sites like Koldihwa and Mahagara (Sharma et al., 1980; Kumar and Pant, 2000; Kumar, 2001; Harvey, 2006). The cultivation of rice and domestication of cattle were major characteristics of this Neolithic culture. Carbonised domestic rice dating back to the 7000 BCE has been found at Lahuradewa, providing concrete evidence of rice production (Tewari et al., 2006). The agricultural development in the Ganga Plain was facilitated by the high rate of natural fertilization from the periodic flooding of the soil during the region's monsoon season (Quamar and Kar, 2022).

Alongside agriculture, animal husbandry was another essential aspect of the Neolithic society in the Ganga Plain. Excavations at Mahagara site unearthed a long cattle pen enclosed by 28 post holes, suggesting the domestication and management of livestock (Pal, 1990; Saraswat, 1991; Misra et al., 2001; Vikrama and Chattopadhyaya, 2002; Harvey and Fuller, 2005; Kingwell-Banham and Fuller, 2012; Korisettar, 2020; Jha et al., 2020, 2021; Jha, 2021). The Neolithic communities in the Ganga Plain also demonstrated an understanding of the diverse plant resources available in their environment. Surprisingly, evidence of burial practices is entirely absent from the Ganga Neolithic culture which needs to be explored further in future excavation. The Neolithic culture of the Ganga Plain Vindhyan region emerged around the 8000 BCE based on ^{14}C dating of various sites, including Lahuradeva, Jhusi, Koldihawa, Tokwa and Mahagara (Pokharia, 2008, 2011; Pokharia et al., 2009, 2017; Tewari et al., 2002, 2006).

6. GIS analysis: settlement pattern and landscape preference in the Ganga Plain

The Ganga Basin, particularly the Ganga Plain (Fig. 1), has been a focal point for extensive prehistoric research due to its favorable conditions for agriculture and abundant water resources. The region's large flat Plain with numerous water sources has provided suitable conditions for early farming practices (Harvey, 2006; Jha et al., 2020; Misra, 2002; Pal, 1990). Notably, the Neolithic site of Lahuradewa has yielded crucial insights into early farming and plant domestication in the area (Tewari et al., 2006). The majority of prehistoric sites are concentrated in the transitional topographic region of the Ganga Plain (Fig. 1), centered around the middle reaches and extending southward to the Vindhyan hill range (Sharma et al., 1980).

The modern rainfall patterns in the Ganga Basin exhibit a variable monsoonal climate, with the majority of rainfall occurring during the southwest summer monsoon season (Fig. 2; Gadgil et al., 1984; Kumar et al., 2019). Rainfall distribution varies across the basin, with higher amounts in the eastern and central parts compared to the western and northern regions (Fig. 2). Areas with higher rainfall have been more favorable for human settlement, providing abundant water and natural resources. Although the western and northern parts receive lower rainfall (Fig. 2), it is still sufficient to support agriculture and other human activities. Archaeological sites in the region suggest a preference for localities with rainfall ranging between 1000 and 2000 mm (Fig. 2).

Geological mapping of the Ganga Basin (Fig. 3) reveals the prevalence of sedimentary deposits from the Quaternary Period, covering a significant area alongside the major rivers. The undivided Precambrian rocks, rich in quartzite and siliceous materials, have served as ideal raw materials for manufacturing stone tools (Fig. 3). The close proximity of prehistoric sites to the Ganga and Yamuna rivers, which reach the Precambrian rocks on the south bank, suggests easy access to major food resources and raw materials during the Palaeolithic cultural phase (Fig. 3). In contrast, Mesolithic sites located in the northern part of the Ganga River, lacking suitable raw materials, relied on transportation from the Vindhyan region (Fig. 3). The typo-statistical study of the stone tools in the Middle Ganga Plain from the Upper Palaeolithic to Mesolithic demonstrates the lithic technology development through the refinement of blade production (Banerjee, 1987).

During the Neolithic phase, human dispersal greatly expanded in the Ganga Plain. The region's geomorphological features, characterised by dissected hills and valleys to the south and an alluvial Plain to the north (Fig. 4), have contributed to its significance as an agricultural center since the Neolithic phase. The Palaeolithic sites predominantly lie on the pediment pediplain complex (Fig. 4), while the Microlithic and Neolithic sites are situated in the Ganga alluvial Plain.

The dominant vegetation in the Ganga Plain consists of deciduous forests, including *Shorea robusta* (sal), *Tectona grandis* (teak), and *Mangifera indica* (mango) trees, as well as shrubs and grasses (Fig. 5). These forests, thriving in areas with sufficient rainfall, have provided a significant food resource for prehistoric hunter-gatherers. The Ganga Basin exhibits various vegetation types, such as tropical and subtropical moist and dry broadleaf forests, temperate broadleaf, conifer, and mixed forests in the north (Fig. 5). Prehistoric sites are often found in the transitional areas between these vegetation types (Fig. 5).

7. Palaeoenvironment in the Ganga Plain

7.1. Stable isotope-based palaeoenvironment conditions

Over the past few decades, geoarchaeological studies in the Ganga Plain have contributed valuable scientific data on climate and vegetation changes during the late Pleistocene and Holocene epochs. These studies have been based on a range of investigations, including geomorphological, palaeobotanical, geochemical, and stable isotope studies conducted on palaeosols, soil carbonates, lake sediments, and fossils (e.g., Williams et al., 2006; Rahaman et al., 2011; Agrawal et al., 2012; Quamar and Kar, 2020; 2022; Jha et al., 2020). The synthesis of these studies is outlined below:

Between approximately ~100 and 75 ka (Fig. 6), high rainfall conditions have been inferred from $\delta^{18}O$ values of soil carbonates in the central Ganga Plain (Fig. 6; Jha et al., 2020; Srivastava et al., 2018; Rahaman et al., 2011). A study in the Belan valley, based on plant wax biomarkers (*n*-alkanes) and δD_{C29} values, suggests an intensification of the monsoon during this time interval (Fig. 6; Jha et al., 2020). Matured palaeosol units, typically formed under sub-humid to humid climatic conditions, were also observed during ~100 to 75 ka (Fig. 6; Srivastava et al., 2018). Proxy data available from this time frame collectively indicate prevailing high rainfall conditions in the Ganga Plains. Present-day records of average rainfall in the Belan valley (Fig. 2), which is significantly higher than other middle reaches of the Ganga Plain (around 1500 mm), may provide insights into the past environmental conditions (Fig. 6). The utilisation of $\delta^{13}C$ values in plant wax (*n*-alkane) and soil carbonate has enabled the inference of C_3-dominated vegetation, with proportions of C_3 vegetation ranging from 40 to 60% (based on soil carbonate $\delta^{13}C$ values) to 60–80% (based on *n*-alkane $\delta^{13}C$ values) (Jha et al., 2020).

Between ~75 and 25 ka (Fig. 6), the climate exhibited variability as indicated by fluctuations in δD_{C29} values of *n*-alkane and $\delta^{18}O$ values of soil carbonates from the Belan valley (Jha et al., 2020). Multiple phases of aggradation and incision of river valleys observed in previous studies correspond to fluctuating climate (Fig. 6; Gibling et al., 2008; Williams et al., 2006; Srivastava et al., 2018). During the Marine Isotope Stage (MIS) 4, an absence of matured palaeosol, few pedogenic carbonates, and weakly developed soil features indicated arid conditions (Srivastava et al., 2018). In the interfluvial region of the central Ganga Plain, the middle part showed well-matured palaeosols, while the marginal part exhibited weakly developed palaeosols during MIS 3 (Srivastava et al., 2018). The abundance of C_4 vegetation increased during this interval, as evidenced by higher $\delta^{13}C$ values recorded in soil carbonates and C_{29} *n*-alkane from the archaeological sites situated in the Belan valley (Jha et al., 2020). The $\delta^{13}C$ of C_{32} *n*-alkanoic acid obtained from Kalpi Core located from the southern part of the Ganga Plain reveals a mixed (C_3–C_4) vegetation components with rapid increase in C_4 vegetation at 45 ka (Agrawal et al., 2014).

During the Last Glacial Maximum (LGM; ~25 to 18 ka; Fig. 6), the temperature decreased by 3–4 °C, leading to significant variations in $\delta^{18}O$ values of soil carbonates (Agrawal et al., 2012). The variations in $\delta^{18}O$ values of soil carbonates were mainly attributed to changes in rainfall amounts and evaporative influence, resulting in approximately 35% less rainfall in North-Central India during the LGM (Jha et al., 2020). Higher values of δD_{C29} of *n*-alkane and $\delta^{18}O$ of soil carbonate during the LGM indicated an arid climatic condition (Fig. 6; Agrawal et al., 2012; Jha et al., 2020). Pedogenic activity during the LGM was more pronounced in the middle part of the interfluve than in the marginal part (Srivastava et al., 2018). The C_3 type vegetation dominated during the LGM in the central Ganga Plain (Agrawal et al., 2012). However, minimal fluctuation observed between C_3 and C_4 type vegetation in the south-central Ganga Plain (Jha et al., 2020). The variability in the abundance of C_3 and C_4 type vegetation during LGM can be linked to proxy sensitivity and depositional settings of the studied samples (Breecker et al., 2009; Sarangi et al., 2019, 2021; Jha et al., 2020).

The environment conditions during the last ~15 ka is well-documented through various stable isotopic studies on lake sediment and fossilised bones (Fig. 7; Sharma et al., 2004a,b, 2006; Misra et al., 2020). The $\delta^{18}O$ values of gastropod shell from the Sanai Lake deposit indicated an arid climate between ~15 and 10 ka, followed by increased monsoonal activity between ~10 ka and 5 ka (Sharma et al., 2004a,b, 2006). A humid condition returned around 3.6 ka (Patel et al., 2022, Fig. 7), as evident from the $\delta^{18}O$ composition of fossilised mammal teeth, followed by a dry event after ~1.3 ka to the present (Fig. 7; Sharma et al., 2004a,b, 2006; Singh, 2004; Sinha and Sarkar, 2009). Present-day climatic conditions around Sanai Lake, with recorded annual rainfall of 1200–1500 mm (Fig. 5), were compared with modern-day rainfall isotope data (Kumar et al., 2019), potentially matching with the climate conditions that prevailed during ~3.6 to 1.3 ka in the Ganga Plain (Patel et al., 2022, Fig. 7).

7.2. Pollen-based palaeoenvironment conditions

In the previous decade, various studies using isotopic proxies have been conducted in the Ganga Plain to gain insights into past climate and vegetation (Fig. 6; Rahaman et al., 2011; Agrawal et al., 2012, 2013; Srivastava et al., 2018; Jha et al., 2020), building a robust database of palaeo-monsoon records. To reconstruct ancient climate-vegetation relationships, researchers have employed biotic proxies such as pollen (Quamar and Bera, 2017). Plants have different tolerance levels in response to climate change, making fossil pollen a valuable proxy for understanding past vegetational landscape under changing climate (Quamar and Kar, 2020). However, reconstructing past climate using fossil pollen requires correlating modern pollen data with climate parameters and calibrating the same in fossil pollen taxa (Brewer et al., 2007; Quamar and Kar, 2020; 2022).

By tracing the abundance and distribution of pollen taxa in palaeo-sedimentary records, researchers can reconstruct the climate by comparing the same pollen taxa in the modern environment and their response to present-day climate (Trivedi et al., 2013, 2019; Saxena and Trivedi, 2017; Quamar and Kar, 2020; 2022; Quamar and Bera, 2017). Numerous pollen-based climate studies have been carried out in the Ganga Plain (Chauhan et al., 2015; Trivedi et al., 2013, 2019; Misra et al., 2020). The modern pollen record in the central Ganga Plain is dominated by non-arboreal pollen taxa, constituting 75% of the total pollen taxa (Trivedi et al., 2013, 2019). Analysis of pollen records from the Quaternary sedimentary archives in the Ganga Plain indicates variations between humid and dry climatic conditions (Chauhan et al., 2015; Trivedi et al., 2013, 2019; Misra et al., 2020).

From ~42.5 to 22.2 cal ka (Fig. 6), a cool and dry climatic condition prevailed in the Ganga Plain, as suggested by grassland-based pollen taxa studied at Jalesar Tal, Uttar Pradesh (Trivedi et al., 2013). Similarly, the pollen profile of Karela Jheel in the central Ganga Plain indicates a cold and dry climate dominated by herbaceous pollen taxa between ~25.5 and 22.0 cal ka BP (Fig. 6; Trivedi et al., 2019). The absence of tree-based pollen and *Thecamoeba* taxa further supports the non-humid climate between ~25.5 and 22.0 cal ka BP (Fig. 6; Trivedi et al., 2019). It is worth noting that the pollen-based vegetation reconstruction during LGM is different from isotope-based interpretation, which could be explained by proxy sensitivity and preservation biases during arid climate conditions (Wasson et al., 1984; Breecker et al., 2009; Sarangi et al., 2019, 2021; Jha et al., 2020). However, the observation of arid climatic condition is aligned with the LGM event in the world (Bradley, 1999). Similar LGM events are recorded in other parts of India, such as Central India (Patnaik et al., 2019), Eastern India (Sharma and Chauhan, 1994), Southern India (Sukumar et al., 1993), and Thar Desert, Western India (Wasson et al., 1984).

From ~22.2 to 14.3 cal ka, the pollen zone is dominated by open grassland vegetation with sporadic occurrences of tree-based vegetation, suggesting an increase in rainfall in an overall cool and dry climatic system (Fig. 6; Trivedi et al., 2019). This increase in rainfall is supported by depleted $\delta^{18}O$ values of soil carbonate from the IIT Kanpur core at ~17.5 cal ka BP (Fig. 6; Rahaman et al., 2011).

During the interval ~14.3 to 7.1 cal ka BP (Fig. 7), a warm and humid climate prevailed, dominated by tree taxa such as *Madhuca indica, Acacia nilotica, Holoptelea integrifolia*, and *Syzygium cumini*, indicating an expansion of forests and scattered occurrences of grassland vegetation (Trivedi et al., 2019). The increase in rainfall during this time interval is also supported by the expansion of Sanai Tal Lake area (Sharma et al., 2004a,b, 2006) and fluvial geomorphology studies supporting incision event in the Ganga River (Srivastava et al., 2018). Recent studies in Baraila Tal of Central Ganga show mixed deciduous vegetation types, both dry and moist condition, in the interval 12 to 7 ka (Fig. 7; Misra et al., 2020).

From ~7 ka cal BP to the present, there is an increase in forest groves and prevalence of warm and humid climates (Fig. 7; Trivedi et al., 2019; Quamar and Kar, 2022). The pollen composition of Lahuradewa Lake, Sant Kabir Nagar District (Chauhan et al., 2015), Meander Lake, Pratapgarh District (Gupta, 1985), and Jalesar Lake, Unnao District (Trivedi et al., 2013) also indicates a warm and humid climate condition prevailed after ~7 ka cal BP (Thakur et al., 2018). The increased abundance of sponge spicules from ~7 to 5 ka cal BP indicates an expansion of the lake and a more vigorous monsoonal rainfall (Fig. 7; Thakur et al., 2018; Misra et al., 2020; Patel et al., 2022).

7.3. Natural controls over prehistoric settlement in Ganga Plain

Environment and geology of the region is considered to be an essential factor in determining where prehistoric humans made their settlement and hunted and lived (Singh, 1996, 2004; Singh et al., 1999; Jha et al., 2020, 2021; Jha, 2021). It is, therefore, necessary to understand the geological, geomorphological and biomes of the studied region before establishing past human-environment relationship. Fossils of hominin remains dating from the Mesolithic to Neolithic periods, along with stone tools spanning from the Acheulean to Neolithic phases, have helped archaeologists, geologists, palaeontologists, and various specialists in documenting the cultural evolution of human settlements (Sharma et al., 1980; Singh et al., 1999; Misra, 1997; Pal, 2007; Jha et al., 2020, 2021; Jha, 2021; Quamar and Kar, 2022). Here, we focus on the nucleus zones of the earliest settlers in the Ganga Plain to comprehend the selection and exploitation of environment by prehistoric humans.

Prehistoric human settlements in Ganga Plain have been governed essentially by changes in river course, abandonment of river channels, formation of large lakes or shrinkage and siltation of lakes, which occurred in quick succession in response to base-level, water budget changes, aridity, and supply of sediments (Singh et al., 1999, Figs. 1–5). Suitable land for agriculture practices and the availability of high grounds to live safely during floods were also factors influencing early humans' settlement choices (Figs. 1–5).

Changes in occupation history, as well as variations in settlement areas, could potentially be linked to past environmental fluctuations (Table 3). These fluctuations can be compared with the modern rainfall zones in the Ganga Plain, such as areas with high rainfall (e.g., high rainfall; Fig. 2; Sharma et al., 2004a,b, 2006; Jha et al., 2020).

Table 3
Relationship between climate and culture in the Ganga Plain.

Chronological boundary	Climate	Cultural phase
~100 to 75 ka	Humid and sub humid	Lower to Middle Palaeolithic
~75 to 45 ka	Fluctuating	Middle Palaeolithic
~45 to 25 ka	Dry to Wet trend	Middle Palaeolithic to Microlithic
~25 to 18 ka	Cold and Arid	Upper Palaeolithic to Microlithic
~18 to 15 ka	Dry to Wet trend	
~15 to 7 ka	Fluctuating	Microlithic to Neolithic
~7 ka to present	Warm and humid	Microlithic to Modern

Prominent changes in the monsoon rainfall in the Ganga Plain have been identified, namely ~100–75 ka - humid climate; ~75–25 ka - fluctuating rainfall; ~25–18 ka – arid climate; ~18–10 ka - low rainfall; ~10–5 ka – intensification in rainfall; ~5–3.6 ka – fluctuating low rainfall; 3.6–1.3 ka - high rainfall and ~1.3 ka–present- low rainfall (Figs. 6 and 7; Singh, 1996, 2004; Sharma et al., 2004a,b, 2006; Agrawal et al., 2012; Chauhan et al., 2015; Srivastava et al., 2018; Trivedi et al., ; 2019; Jha et al., 2020; Kumar et al., 2022). Recent studies have indicated a period of increased aridity with fluctuating rainfall regimes during the mid-late Holocene (5.8–2.0 ka; Sharma et al., 2004a,b, 2006; Chauhan et al., 2015; Srivastava et al., 2018; Trivedi et al., ; 2019; Jha et al., 2020; Kumar et al., 2022; Patel et al., 2022), which is related to the weakening of the southwest monsoon system and corresponds to the global 4.2 ka aridity events in South Asia (Chauhan et al., 2015; Srivastava et al., 2018; Trivedi et al., 2019; Kumar et al., 2022; Quamar and Kar, 2022). The event must have caused the drying of small water bodies and river channels and thus influenced humans' settlement patterns and migration in the Ganga Plain (Singh, 1996; Trivedi et al., 2019; Kumar et al., 2022). Palaeovegetation studies indicate that Ganga Plain was grassland for at least ~45 ka (Tewari et al., 2002), where C_4-type vegetation dominated the landscape (Jha et al., 2020, 2021). Frequent monsoonal rainfall changes in the latest Pleistocene-early Holocene probably led to an adaptation of agricultural practices by humans (Figs. 6 and 7). There is an evidence of Middle Palaeolithic occupation in the Ganga Plain by at least 45 ka supported by fluctuating rainfall and C_4 dominated landscape (Table 3; Tewari et al., 2002; Agrawal et al., 2012; Jha et al., 2020; Kumar et al., 2022).

In the present study, 306 archaeological sites (Table 1) from the Ganga Plain have been studied in which 18 sites have well-dated chronology (Table 2; Figs. 1–5). Types of cultural remains of archaeological importance were studied, and their geomorphic setting and river valley was also noted to understand the local landscape role in site distribution and selection (Table 2; Figs. 1–5). This analysis shows that Older Alluvial Plain was preferred for settlement by Palaeolithic populations (Fig. 3) under humid to sub-humid and fluctuating climate conditions between ~100 and 45 ka (Table 3). The Older Alluvial Plain was the suitable area for water needs and the safest for habitation, with small streams supporting transportation (Fig. 3; Singh, 1996). Therefore, the initial hypothesis that the Ganga Plain was unsuitable for Stone Age human habitation, as proposed by Pal (2007), need further exploration and survey in future studies. The discoveries of a series of stone age sites of Lower and Middle Palaeolithic phase in the Ganga Plain, strongly support a hypothesis that the prehistoric humans had intermittent settlement during Middle Pleistocene and properly inhabited by the late Pleistocene (Singh, 1996, 2004; Tewari et al., 2002; Jha et al., 2020, Tables 1 and 3). Palaeonevironmental records from the Ganga Plain demonstrate fluctuations between wet and dry phases over the past 100 ka (Table 3), exhibiting patterns similar to the modern rainfall distribution (Figs. 6 and 7). These environmental variations (Figs. 6 and 7), coupled with archaeological evidence (Tables 1–3), suggest that micro-climatic factors played a significant role in settlement patterns and the exploitation of the environment (Figs. 1–5). Moreover, palaeoclimate records from the past ~15 ka indicate spatial variability in rainfall across the Ganga Plain (Fig. 7; Table 3), which has impacted the distribution of land for hunter-gatherers and settlement patterns.

Overall, the Lower to Middle Palaeolithic settlement flourished under humid to sub-humid climate conditions (Table 3). The occurrence of the Microlithic culture coincided with a drying phase, which quickly recovered under fluctuating rainfall conditions (~25–7 ka). The fluctuating rainfall pattern, with abundant water on the landscape, forced Mesolithic hunter-gatherers to adopt a sedentary lifestyle, leading to the adaptation of agriculture during the last ~7 ka in the Ganga Plain (Table 3).

8. Summary and future directions

The compilation of stable isotopes ($\delta^{18}O$ and δD values) and pollen-based environment reconstructions record spanning approximately the last 100 ka indicates periods of high rainfall conditions during three distinct intervals: ~100 to 75 ka, ~10 to 5 ka, and ~3.6 to 1.3 ka. Fluctuating rainfall conditions were observed during approximately ~75 ka to 25 ka and ~18 to 15 ka. The period from about ~25 to 18 ka marked the LGM, characterised by the weakest monsoon phase. Arid conditions were also identified during approximately ~15 to 10 ka and ~5 to 3.6 ka.

Through archaeological review, evidence of the Acheulian culture, diverse Mesolithic cultures, and the Neolithic phase, featuring advanced agriculture and pottery production, has been found in the Ganga Plain. Analyses of past environments revealed changes in settlement areas that correlated with variations in rainfall patterns. It is likely that frequent climate changes and increasing population density during the Late Pleistocene-Early Holocene boundary compelled prehistoric humans to adopt agricultural practices.

The distribution of archaeological cultural phases on modern spatial maps of landscape variability highlights a complex relationship between prehistoric human settlements and landscape selection based on various factors, such as geomorphology, elevation profile, and geological formations. During the Palaeolithic phase, older alluvial plains and higher hills with abundant rocks were preferred. However, at a later stage, prehistoric humans shifted their preference to the fertile Ganga plain due to the presence of abundant water, vegetation, and food resources.

Overall, the Ganga Basin, particularly the Ganga Plain, holds immense importance for understanding prehistoric cultures and their adaptation to the region's geological, ecological, and climatic dynamics. We recommend that future studies in the Ganga Plain to involve more detailed analyses of multi-faceted datasets to produce in-depth spatio-temporal variations in the environment and archaeology. Continued interdisciplinary research in these fields will further enhance our understanding of prehistoric societies and their responses to changing landscapes and climates in the Ganga Basin.

9. Data availability

All the data used in present study are acquired from published papers and are presented in table and figure formats within this manuscript.

CRediT authorship contribution statement

Deepak Kumar Jha: Conceptualization, Methodology, Software, Visualization, Funding acquisition, Administration, Resources, Writing – original draft, Writing – review & editing. **Hemant Kumar Vaishnav:** Data curation, Software, Visualization, Writing – review & editing. **Nigamasish Roy:** Data curation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The funding for this work was provided by the Max Planck Society, Germany, to D.K. Jha as a postdoctoral fellow, and by IISER Mohali and IISER Kolkata, India, supporting D.K Jha as a postdoctoral fellow and PhD fellow, respectively. H.K Vaishnav would like to acknowledge University Grant Commission (UGC) for UGC National Fellowship (Ref. No. 210510827924) for his PhD program. We would also like to extend our thanks to Prof. Prasanta Sanyal (IISER Kolkata), Dr. Anoop Ambili (IISER Mohali) and Dr. Janardhana B (IGNTU, Amarkantak) for encouraging us to write this article. Additionally, we acknowledge the researchers working on past environment reconstruction and archaeology in the Ganga Basin region for their valuable contributions, without which this review would not have been possible. We also acknowledge the handling Editor, Prof. Pierluigi Pieruccini, and two anonymous reviewers for providing insightful suggestions that improved the manuscript.

References

Agrawal, N., 2014. Technology of Large Flake Acheulean at Lalitpur, Central India. Universitat Rovira I Virgili, Tarragona. Unpublished PhD Thesis.

Agrawal, S., Sanyal, P., Bera, M.K., Dash, J.K., Balakrishnan, S., 2013. Palaeoclimatic, palaeovegetational and provenance change in the Ganga Plain during the late Quaternary. J. Earth Syst. Sci. 122, 1141–1152.

Agrawal, S., Sanyal, P., Sarkar, A., Jaiswal, M.K., Dutta, K., 2012. Variability of Indian monsoonal rainfall over the past 100 ka and its implication for C3–C4 vegetational change. Quat. Res. 77 (1), 159–170.

Agrawal, S., Galy, V., Sanyal, P., Eglinton, T., 2014. C4 plant expansion in the Ganga Plain during the last glacial cycle: insights from isotopic composition of vascular plant biomarkers. Org. Geochem. 67, 58–71.

Ansari, S., 2005. Prehistoric settlement pattern of south-central Ganga valley: an Ethnoarchaeological Perspective. Bull. Dec. Coll. Res. Inst 64, 327–331.

Banerjee, R., Srivastava, P.K., Pike, A.W.G., Petropoulos, G.P., 2018. Identification of painted rock-shelter sites using GIS integrated with a decision support system and fuzzy logic. ISPRS Int. J. Geo-Inf. 7 (8), 326.

Banerjee, Tulika, 1987. The developmental stages of blade tool industries of south Uttar Pradesh from the upper palaeolithic to the mesolithic. Man and Environment 11 (2), 25–34.

Basak, Bishnupriya, Srivastava, Pradeep, 2017. Earliest dates of microlithic industries (42–25 ka) from West Bengal, eastern India: new light on modern human occupation in the Indian subcontinent. Asian Perspect. 56, 237–259.

Bauer, A., Nicoll, K., Park, L., Matney, T., 2004. Archaeological site distribution by geomorphic setting in the southern lower Cuyahoga River Valley, northeastern Ohio: initial observations from a GIS database. Geoarchaeology: Int. J. 19 (8), 711–729.

Bradley, R.S., 1999. Paleoclimatology: Reconstructing Climates of the Quaternary. Elsevier.

Breecker, D.O., Sharp, Z.D., McFadden, L.D., 2009. Seasonal bias in the formation and stable isotopic composition of pedogenic carbonate in modern soils from central New Mexico, USA. Geol. Soc. Am. Bull. 121 (3–4), 630–640.

Brewer, S., Guiot, J., Barboni, D., 2007. Pollen data as climate proxies. In: Elias, S.A. (Ed.), Encyclopedia of Quaternary Science, vol. 4. Elsevier, New York, pp. 2498–2510.

Breeze, P.S., Drake, N.A., Groucutt, H.S., Parton, A., Jennings, R.P., White, T.S., Clark-Balzan, L., Shipton, C., Scerri, E.M., Stimpson, C.M., Crassard, R., 2015. Remote sensing and GIS techniques for reconstructing Arabian palaeohydrology and identifying archaeological sites. Quat. Int. 382, 98–119.

Chatterjee, Gargi, 2019. Mesolithic life at Vindhya - Gangetic region: a Re-evaluation. Heritage J. Multidisp. Stud. Archeol 7, 471–492.

Chattopadhyaya, U.C., 1996. Settlement pattern and the spatial organization of subsistence and mortuary practices in the Mesolithic Ganga valley, north-Central India. World Archaeol. 27 (3), 461–476.

Chauhan, M.S., Pokharia, A.K., Srivastava, R.K., 2015. Late Quaternary vegetation history, climatic variability and human activity in the Central Ganga Plain, deduced by pollen proxy records from Karela Jheel, India. Quat. Int. 371, 144–156.

Chauhan, P.R., 2010. Metrical variability between South Asian handaxe assemblages: preliminary observations. In: Lycett, S.J., Chauhan, P.R. (Eds.), New Perspectives on Old Stones. Springer, New York, pp. 119–166.

Chauhan, P.R., 2009. The lower Paleolithic of the Indian subcontinent. Evol. Anthropol. 18 (2), 62–78.

Chauhan, P.R., 2020. Human evolution in the center of the old world: an updated review of the south Asian Paleolithic. In: Ono, Rintaro, Pawlik, Alfred (Eds.), Pleistocene Archaeology. IntechOpen. https://doi.org/10.5772/intechopen.94265.

Clarkson, C., Harris, C., Li, B., et al., 2020. Human occupation of northern India spans the Toba super-eruption ~74,000 years ago. Nat. Commun. 11, 961.

Cockburn, J., 1879. Notes on stone age implements from Kasi hills and the Banda Vellore districts. J. Asiatic Soc.Bengal 48 (2), 133–143.

Dennell, R.W., 2007. Resource-rich, stone poor: early hominin land use in large river systems of northern India and Pakistan. In: Petraglia, M., Allchin, B. (Eds.), The Evolution and History of Human Populations in South Asia. Springer, Netherlands, pp. 41–68.
Gadgil, S., Joseph, P.V., Joshi, N.V., 1984. Ocean–atmosphere coupling over monsoon regions. Nature 312 (5990), 141–143.
Gibling, M.R., Sinha, R., Roy, N.G., Tandon, S.K., Jain, M., 2008. Quaternary fluvial and aeolian deposits on the Belan river, India: palaeoclimatic setting of Palaeolithic to Neolithic archeological sites over the past 85,000 years. Quat. Sci. Rev. 27 (3–4), 391–410.
Gupta, P.S., 1985. Scientific reconstruction of archaeological evidence of Ganga Valley. Curr. Sci. 74–79.
Harvey, E.L., Fuller, D.Q., 2005. Investigating crop processing using phytolith analysis: the example of rice and millets. J. Archaeol. Sci. 32 (5), 739–752.
Harvey, E.L., 2006. Early Agricultural Communities in Northern and Eastern India: an Archaeobotanical Investigation. University of London, University, College London (United Kingdom).
Haslam, M., Roberts, R.G., Shipton, C., Pal, J.N., Fenwick, J., Ditchfield, P., Boivin, N., Dubey, A.K., Gupta, M.C., Petraglia, M., 2011. Late Acheulean hominins at the Marine Isotope stage 6/5e transition in north-central India. Quat. Res. 75, 670–682.
Hazarika, M., 2012. In: Dikshit, K.N. (Ed.), Cord-impressed Pottery in Neolithic-Chalcolithic Context of Eastern India, pp. 78–110.
IAR, 1964. Indian Archaeology 1961-62-A Review. Archaeological Survey of India, New Delhi, p. 57.
IAR, 1967. Indian Archaeology 1963-64-A Review. Archaeological Survey of India, New Delhi, pp. 49–50.
IAR, 1973. Indian Archaeology 1969-70-A Review. Archaeological Survey of India, New Delhi, p. 36.
Islam, Zeba, 2016. Evolution of Culture in the Upper Ganga Valley. International E–Publication, Indore.
Jennings, R.P., Shipton, C., Breeze, P., Cuthbertson, P., Bernal, M.A., Wedage, W.O., Drake, N.A., White, T.S., Groucutt, H.S., Parton, A., Clark-Balzan, L., 2015. Multi-scale Acheulean landscape survey in the Arabian Desert. Quat. Int. 382, 58–81.
Jha, D.K., 2021. Reconstruction of Late Quaternary Climate, Vegetation, Fire and Sediment Provenance of Indo-Gangetic Floodplains and its Implication for the Paleolithic to Neolithic Phases of the Indian Subcontinent (Doctoral Dissertation. Indian Institute of Science Education and Research Kolkata).
Jha, D.K., Samrat, R., Sanyal, P., 2021. The first evidence of controlled use of fire by prehistoric humans during the Middle Palaeolithic phase from the Indian subcontinent. Palaeogeogr. Palaeoclimatol. Palaeoecol. 562, 110151.
Jha, D.K., Sanyal, P., Philippe, A., 2020. Multi-proxy evidence of Late Quaternary climate and vegetational history of north-central India: implication for the Palaeolithic to Neolithic phases. Quat. Sci. Rev. 229, 106121.
Jones, S.C., Pal, J.N., 2009. The Palaeolithic of the Middle Son valley, north-central India: changes in hominin lithic technology and behaviour during the Upper Pleistocene. J. Anthropol. Archaeol. 28, 323–341.
Kennedy, K.A., 1990. Porotic Hyperostosis on Human Remains from Mesolithic Baghai Khor. Bulletin of the Deccan College Research Institute, pp. 183–198.
Khansili, G., 2014. Palaeolithic Locality Near Delhi (Gurgaon, NCR): Preliminary Observations, vol. 74. Bulletin of the Deccan College Research Institute, pp. 1–8.
Kingwell-Banham, E., Fuller, D.Q., 2012. Shifting cultivators in South Asia: expansion, marginalisation and specialisation over the long term. Quat. Int. 249, 84–95.
Korisettar, R., 2020. Ancient agriculture in the Indian subcontinent: the Archaeobotanical evidence. A Companion to Ancient Agri 575–610.
Krishnaswami, V.D., Rajan, K.S., 1951. The Lithic Tool Industries of the Singrauli Basin, vol. 7. Ancient India, pp. 40–65.
Kumar, A., Pant, P.C., 2000. Economy of the Neolithic cultures of southern Uttar Pradesh and western Bihar. Puratattva 30, 25–29.
Kumar, A., 2001. Origin, development, and growth of the Mahagara Neolithic complex. Pragdhara 11, 119–124.
Kumar, A., Sanyal, P., Agrawal, S., 2019. Spatial distribution of δ18O values of water in the Ganga river basin: insight into the hydrological processes. J. Hydrol. 571, 225–234.
Kumar, M., Saikia, K., Agrawal, S., Ghosh, R., Ali, S.N., Arif, M., Singh, D.S., Sharma, A., Phartiyal, B., Bajpai, S., 2022. Climatic control on the C3 and C4 plant abundance during the late Pleistocene–Holocene in the northern Gangetic Plain, India. Palaeogeogr. Palaeoclimatol. Palaeoecol. 591, 110890.
Lepre, C.J., Roche, H., Kent, D.V., Harmand, S., Quinn, R.L., Brugal, J.P., Texier, P.J., Lenoble, A., Feibel, C.S., 2011. An earlier origin for the Acheulian. Nature 477 (7362), 82–85.
Lukacs, J.R., Pal, J.N., 2003. Skeletal variation among Mesolithic people of the Ganga Plains: new evidence of habitual activity and adaptation to climate. Asian Perspect. 42 (2), 329–351.
Lukacs, J.R., 2007. Interpreting biological diversity in South Asian prehistory: early Holocene population affinities and subsistence adaptations. In the Evolution and History of Human Populations in South Asia: Inter-disciplinary Studies in Archaeology, Biological Anthropology, Linguistics and Genetics. Springer Netherlands, Dordrecht, pp. 271–296. https://doi.org/10.1007/1-4020-5562-5_12.
Lukacs, J.R., Misra, V.D., 1996. The people of Lekhahia: a bio-cultural portrait of Mesolithic hunter-foragers of north India. In: Allchin, B., Allchin, F.R. (Eds.), South Asian Archaeology 1995. Oxford and IBH, New Delhi.
Mandal, D., 1983. A note of the radiocarbon dates from the Middle Son Valley. In: Sharma, G.R., Clark, J.D. (Eds.), Palaeoenvironments and Prehistory in the Middle Son Valley. Abinash Prakashan, Allahabad, pp. 285–289.
Maslin, M.A., Brierley, C.M., Milner, A.M., Shultz, S., Trauth, M.H., Wilson, K.E., 2014. East African climate pulses and early human evolution. Quat. Sci. Rev. 101, 1–17.
Milliman, J.D., Meade, R.H., 1983. World-wide delivery of river sediment to the oceans. J. Geol. 91 (1), 1–21.
Misra, B.B., 2002. In: Misra, V.D., Pal, J.N. (Eds.), The Mesolithic Culture of the Belan Valley. Mesolithic India. Department of Ancient History, Culture and Archaeology, Allahabad, pp. 216–236.
Misra, V.D., Pal, J.N., Gupta, M.C., 2001. Neolithic Culture of the Northern Vindhyas with Special Reference to Tokwa, vol. 25. Bharti: Bulletin of The Department of Ancient Indian History, Culture & Archaeology, pp. 211–233.
Misra, P., Farooqui, A., Sinha, R., Khanolkar, S., Tandon, S.K., 2020. Millennial-scale vegetation and climatic changes from an Early to Mid-Holocene lacustrine archive in Central Ganga Plains using multiple biotic proxies. Quat. Sci. Rev. 243, 106474.
Misra, V.D., Misra, B.B., Pandey, J.N., Pal, J.N., 1996. A preliminary report on the excavations at Jhusi 1995. Pragdhara 6, 63–66.
Misra, V.D., 1999. Agriculture, domestication of animals and ceramic and other industries in prehistoric India: Mesolithic and Neolithic. In: Pande, G.C. (Ed.), The Dawn of Civilization up to 600 BC. Centre for Studies in Civilization, Delhi, pp. 233–266.
Misra, V.D., 2007. Stone age cultures, their chronology and beginnings of agriculture in the north-Central India. Man and Environment 32 (1), 1–14.
Misra, V.N., 1997. Early Man and his environment in Central India. J. Palaeontol. Soc. India 42, 1–18.
Neudorf, C.M., Roberts, R.G., Jacobs, Z., 2014. Testing a model of alluvial deposition in the Middle Son Valley, Madhya Pradesh, India - IRSL dating of terraced alluvial sediments and implications for archaeological surveys and palaeoclimatic reconstructions. Quat. Sci. Rev. 89, 56–69.
Pal, J.N., 2007. Mesolithic foragers of the Ganges Plain and adjoining hilly regions of the Vindhyas. In: Petraglia, M., Allchin, B. (Eds.), The Evolution and History of Human Populations in South Asia. Springer, Netherlands, pp. 41–68.
Pal, J.N., 1980. Beginnings of Agriculture (Epi-Palaeolithic to Neolithic: Excavations at Chopani Mando, Mahadaha, and Mahagara). Abinash Prakashan, Allahabad.
Pal, J.N., 1985. Some new light on the Mesolithic burial practices of the Ganga Valley: evidence from Mahadaha. Pratapgarh, Uttar Pradesh. Man and Environ 9 (1), 28–37.
Pal, J.N., 1986. Microlithic industry of Damdama – Pratapgarh, U.P.: a preliminary analysis. Puratattva 16, 1–5.
Pal, J.N., 1987. Neolithic cord-impressed ware of the Vindhyas. Man and Environment 11, 61–65.
Pal, J.N., 1988. Mesolithic double burials from recent excavations at Damdama. Man and environment 12 (1), 115–122.
Pal, J.N., 1990. The early farming culture of the Northern Vindhyas. Bull. Dec. Coll. Res. Inst 49, 297–309.
Pal, J.N., 1992. Mesolithic human burials from the Ganga Plain. North India Man and Environment 17 (2), 35–44.
Pal, J.N., 1994. Mesolithic settlements in the Ganga Plain. Man and Environment 19 (1–2), 91–101.
Pal, J.N., 2002. Mesolithic Gangetic Plain. Mesolithic India, Allahabad, pp. 289–305.
Pal, J.N., 2016. Mesolithic foragers of the Gangetic Plain and adjoining hilly regions of the Vindhyas. In: Schug, G.R., Walimbe, S.R. (Eds.), A Companion to South Asia in the Past: Archaeological and Bioarchaeological Perspectives. Wiley-Blackwell, Chichester, pp. 86–100.
Pal, J.N., 2019. A review of the research on the Acheulian culture in the Vindhyas, north-central India. Indian Journal of Archaeology 7 (2), 1–10.
Pandey, J.N., 1990. Mesolithic in the middle Ganga valley. Bull. Dec. Coll. Res. Inst 49, 311–316.
Pandey, J.N., 2005. Ecology, Settlement Pattern and Population in the Gangetic Plains during Mesolithic Phase. River Valley Cultures of India. Rashtriya Manav Sangrahalaya, Bhopal (Bhopal).
Pant, P.C., 1982. Prehistoric Uttar Pradesh: (A Study of Old Stone Age). Agam Kala Prakashan, Delhi.
Patel, N., Gahluad, S., Saxena, A., Thakur, B., Bharti, N., Dabhi, A.K.J., Bhushan, R., Agnihotri, R., 2022. Revised chronology and stable isotopic (carbon and nitrogen) characterization of Lahuradewa lake sediment (Ganga-plain, India): insights into biogeochemistry leading to peat formation in the lake. J. Palaeontol. Soc. India 67 (1), 113–125.
Patnaik, R., Li, H.C., Lin, J.P., Bansal, M., Chauhan, P.R., 2019. Microlithic, faunal, floral and isotopic data from an archaeological site 14C dated to LGM in the eastern state of Odisha, India. Quat. Int. 528, 138–146.
Petraglia, M.D., Allchin, B., 2007. Human evolution and culture change in the Indian subcontinent. In: The Evolution and History of Human Populations in South Asia: Inter-disciplinary Studies in Archaeology, Biological Anthropology, Linguistics and Genetics. Springer Netherlands, Dordrecht, pp. 1–20.
Pillai, A.A., Anoop, A., Sankaran, M., Sanyal, P., Jha, D.K., Ratnam, J., 2017. Mid-late Holocene vegetation response to climatic drivers and biotic disturbances in the Banni grasslands of western India. Palaeogeogr. Palaeoclimatol. Palaeoecol. 485, 869–878.
Pokharia, A.K., 2008. Palaeoethnobotanical record of cultivated crops and associated weeds and wild taxa from Neolithic site, Tokwa, Uttar Pradesh, India. Curr. Sci. 248–255.
Pokharia, A.K., 2011. Palaeoethnobotany at Lahuradewa: a contribution to the 2nd millennium BC agriculture of the Ganga Plain, India. Curr. Sci. 1569–1578.
Pokharia, A.K., Pal, J.N., Srivastava, A., 2009. Plant macro-remains from Neolithic Jhusi in Ganga Plain: evidence for grain-based agriculture. Curr. Sci. 564–572.
Pokharia, A.K., Sharma, S., Tripathi, D., Mishra, N., Pal, J.N., Vinay, R., Srivastava, A., 2017. Neolithic– Early historic (2500–200 BC) plant use: the archaeobotany of Ganga Plain, India. Quat. Int. 443, 223–237.

Quamar, M.F., Bera, S.K., 2017. Pollen records related to vegetation and climate change from northern Chhattisgarh, central India during the late Quaternary. Palynology 41 (1), 17–30.
Quamar, M.F., Kar, R., 2020. Modern pollen dispersal studies in India: a detailed synthesis and review. Palynology 44 (2), 217–236.
Quamar, M.F., Kar, R., 2022. Agricultural practices in India during the Holocene: a pollen view point and a critical appraisal. Holocene 32 (11), 1340–1357.
Rahaman, W., Singh, S.K., Sinha, R., Tandon, S.K., 2011. Sr, C and O isotopes in carbonate nodules from the Ganga Plain: evidence for recent abrupt rise in dissolved 87Sr/86Sr ratios of the Ganga. Chem. Geol. 285 (1–4), 184–193.
Sarangi, V., Kumar, A., Sanyal, P., 2019. Effect of pedogenesis on the stable isotopic composition of calcretes and n-alkanes: implications for palaeoenvironmental reconstruction. Sedimentology 66 (5), 1560–1579.
Sarangi, V., Agrawal, S., Sanyal, P., 2021. The disparity in the abundance of C4 plants estimated using the carbon isotopic composition of palaeosol components. Palaeogeogr. Palaeoclimatol. Palaeoecol. 561, 110068.
Saraswat, K.S., 1991. Archaeobotanical remains in ancient cultural and socioeconomical dynamics of the Indian subcontinent. JPalaeosciences 40, 514–545.
Saxena, A., Prasad, V., Singh, I.B., 2013. Holocene palaeoclimate reconstruction from the phytoliths of the lake-fill sequence of Ganga Plain. Curr. Sci. 1054–1062.
Saxena, A., Trivedi, A., Chauhan, M.S., Sharma, A., 2015. Holocene vegetation and climate change in Central Ganga Plain: a study based on multiproxy records from Chaudhary-Ka-Tal, Raebareli District, Uttar Pradesh, India. Quat. Int. 371, 164–174.
Saxena, A., Trivedi, A., 2017. Pollen based vegetation and climate change records deduced from the lacustrine sediments of Kikar Tal (Lake), Central Ganga Plain, India. J Palaeosciences 66 (1–2), 37–46.
Sharma, A.K., Ota, S.B., 1991. Anangpur- the Palaeolithic site near Delhi. Puratattva 21, 73.
Sharma, C., Chauhan, M., 1994. In: Proc. 29th Int'l. Geol. Congr., Part B, Pp. 279-288 VSP 1994. Reconstruction of the Paleo-Asian Ocean, p. 279.
Sharma, G.R., 1973. Mesolithic lake cultures in the Ganga valley, India. In: Proceedings of the Prehistoric Society, vol. 39. Cambridge University Press, pp. 129–146.
Sharma, G.R., 1980. History to Prehistory: Archaeology of the Ganga Valley and the Vindhyas. University of Allahabad, Allahabad.
Sharma, G.R., Misra, V.D., Mandal, D., Misra, B.B., Pal, J.N., 1980. Beginnings of Agriculture. Abinash Prakashan, Allahabad.
Sharma, G.R., Misra, V.D., Mandal, D., Misra, B.B., Singh, I.B., 2004a. Late Quaternary history of the Ganga plain. J. Geol. Soc. India 64 (4), 431–454.
Sharma, S., Joachimski, M., Sharma, M., Tobschall, H.J., Singh, I.B., Sharma, C., Chauhan, M.S., Morgenroth, G., 2004b. Lateglacial and Holocene environmental changes in Ganga plain, northern India. Quat. Sci. Rev. 23 (1–2), 145–159.
Sharma, S., Joachimski, M.M., Tobschall, H.J., Singh, I.B., Sharma, C., Chauhan, M.S., 2006. Correlative evidences of monsoon variability, vegetation change and human inhabitation in Sanai lake deposit: Ganga Plain, India. Curr. Sci. 973–978.
Shoaee, M.J., Breeze, P.S., Drake, N.A., Hashemi, S.M., Nasab, H.V., Breitenbach, S.F., Stevens, T., Boivin, N., Petraglia, M.D., 2023. Defining paleoclimatic routes and opportunities for hominin dispersals across Iran. PLoS One 18 (3), e0281872.
Shukla, U.K., Srivastava, P., Singh, I.B., 2012. Migration of the Ganga River and development of cliffs in the Varanasi region, India during the late Quaternary: role of active tectonics. Geomorphology 171, 101–113.
Singh, I.B., 1996. Geological evolution of Ganga Plain—an overview. J. Palaeontol. Soc. India 41, 99–137.
Singh, I.B., 2004. Late Quaternary history of the Ganga Plain. J. Geol. Soc. India 64, 431–454.
Singh, I.B., Sharma, S., Sharma, M., Srivastava, P., Rajagopalan, G., 1999. Evidence of human occupation and humid climate of 30 ka in the alluvium of southern Ganga Plain. Curr. Sci. 1022–1026.
Singh, R., 1965. Palaeolithic Industries of Northern Bundelkhand. Unpublished Ph. D. thesis, Poona University, Pune.
Sinha, B.P., 1979. Archaeology and Art of India. Sundeep Prakashan, New Delhi.
Sinha, R., Tandon, S.K., Sanyal, P., Gibling, M.R., Stuben, D., Berner, Z., Ghazanfari, P., 2006. Calcretes from a Late Quaternary interfluve in the Ganga Plains, India: carbonate types and isotopic systems in a monsoonal setting. Palaeogeogr. Palaeoclimatol. Palaeoecol. 242 (3–4), 214–239.
Sinha, R., Bhattacharjee, P.S., Sangode, S.J., Gibling, M.R., Tandon, S.K., Jain, M., Godfrey-Smith, D., 2007. Valley and interfluve sediments in the southern Ganga plains, India: exploring facies and magnetic signatures. Sediment. Geol. 201 (3–4), 386–411.
Sinha, R., Sarkar, S., 2009. Climate-induced variability in the Late Pleistocene–Holocene fluvial and fluvio-deltaic successions in the Ganga plains, India: a synthesis. Geomorphology 113 (3–4), 173–188.
Srivastava, P., Sinha, R., Deep, V., Singh, A., Upreti, N., 2018. Micromorphology and sequence stratigraphy of the interfluve palaeosols from the Ganga Plains: a record of alluvial cyclicity and palaeoclimate during the Late Quaternary. J. Sediment. Res. 88 (1), 105–128.
Sukumar, R., Ramesh, R., Pant, R.K., Rajagopalan, G., 1993. A δ13C record of late Quaternary climate change from tropical peats in southern India. Nature 364 (6439), 703–706.
Tandon, S.K., Gibling, M.R., Sinha, R., Singh, V., Ghazanfari, P., Dasgupta, A., Jain, M., Jain, V., 2006. Alluvial Valleys of the Ganga Plains, India: Timing and Causes of Incision.
Tewari, R., Pant, P.C., Singh, I.B., Sharma, S., Sharma, M., Srivastava, P., Singhvi, A.K., Misra, P.K., Tobschall, H.J., 2002. Middle Palaeolithic human activity and palaeoclimate at Kalpi in Yamuna valley. Man and Environment 27 (2), 1–13.
Tewari, R., Srivastava, R.K., Singh, K.K., Saraswat, K.S., Singh, I.B., Chauhan, M.S., Pokharia, A.K., Saxena, A., Prasad, V., Sharma, M., 2006. Second preliminary report of the excavations at Lahuradewa, district sant Kabir Nagar, UP: 2002–2003–2004 & 2005–06. Pragdhara 16, 35–68.
Thakur, B., Saxena, A., Singh, I.B., 2018. Paddy cultivation during early Holocene: evidence from diatoms in Lahuradewa lake sediments, Ganga Plain. Curr. Sci. 2106–2115.
Tripathi, D., Chauhan, D.K., Farooqui, A., Kotlia, B.S., Thakur, B., Morthekai, P., Long, T., Chauhan, M.S., Pokharia, A.K., 2017. Late Quaternary climatic variability in the central Ganga Plain: a multi-proxy record from Karela Jheel (lake). Quat. Int. 443, 70–85.
Tripathi, D., Kotlia, B.S., Tiwari, M., Pokharia, A.K., Agrawal, S., Kumar, P., Long, T., Paulramasamy, M., Thakur, B., Pal, J., Singh Mahar, K., Chauhan, D.K., 2021. New evidence of mid- to late- Holocene vegetation and climate change from a Neolithic settlement in western fringe of Central Ganga Plain: implications for Neolithic to Historic phases. Holocene 31 (3), 392–408.
Trivedi, A., Chauhan, M.S., Sharma, A., Nautiyal, C.M., Tiwari, D.P., 2013. Record of vegetation and climate during late Pleistocene–Holocene in Central Ganga Plain, based on multiproxy data from Jalesar lake, Uttar Pradesh, India. Quat. Int. 306, 97–106.
Trivedi, A., Saxena, A., Chauhan, M.S., Sharma, A., Farooqui, A., Nautiyal, C.M., Yao, Y. F., Wang, Y.F., Li, C.S., Tiwari, D.P., 2019. Vegetation, climate and culture in central Ganga plain, India: a multi-proxy record for last glacial Maximum. Quat. Int. 507, 134–147.
Varma, R.K., 1983. The Mesolithic cultures of India. Puratattva 13/14, 27–36.
Varma, R.K., 1989. Pre-agricultural Mesolithic society of the Ganga valley. In: Kenoyer, J.M. (Ed.), Old Problems and New Perspectives in the Archaeology of South Asia, vol. 2. Wisconsin Archaeological Reports.
Varma, R.K., Misra, V.D., Pandey, J.N., Pal, J.N., 1985. A Preliminary Report on the Excavations at Damdama (1982–1984), vol. 9. Man and Environment, pp. 45–65.
Vikrama, B., Chattopadhyaya, U., 2002. Ganges Neolithic: Ganges Neolithic-Chalcolithic. In: Encyclopedia of Prehistory: Volume 8: South and Southwest Asia. Springer US, Boston, MA, pp. 127–132.
Wasson, R.J., Smith, G.I., Agrawal, D.P., 1984. Late Quaternary sediments, minerals, and inferred geochemical history of Didwana lake, Thar Desert, India. Palaeogeogr. Palaeoclimatol. Palaeoecol. 46 (4), 345–372.
Williams, M., Clarke, M., 1984. Late Quaternary environments in north-central India. Nature 308, 633–635.
Williams, M.A.J., Pal, J.N., Jaiswal, M., Singhvi, A.K., 2006. River response to Quaternary climatic fluctuations: evidence from the Son and Belan valleys, north-central India. Quat. Sci. Rev. 25 (19–20), 2619–2631.