

Holocene vegetation, climate and human habitation in the Central Ganga Plain, based on pollen records from the lake deposits

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ABSTRACT

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The paper encompasses the Quaternary vegetation and climatic inferences drawn through the investigations on three lakes, viz. Lahuradewa, Sant Kabir Nagar District; Basaha, Unnao District and Misa Tal, Lucknow District, all located close to settlements in the Central Ganga Plain. The pollen sequence from Lahuradewa Lake has revealed that between 10600 and 9250 yr BP, open vegetation largely comprising grasses, Chenop/Am, *Artemisia*, etc. together with scanty trees of *Aegle marmelos*, *Holoptelea*, *Terminalia*, etc. grew in the region under a cool and dry climate. The record of aquatic taxa indicates the existence of lake. Between 9250 and 6400 yr BP, with the amelioration of climate a few more trees, viz. *Bombax*, *Embllica officinalis*, *Syzygium*, *Lagerstroemia*, etc. also invaded the region. The increase in aquatic taxa implies that the lake turned wider owing to improved monsoon rain. The appearance of *Cerealia* pollen around 7000 yr BP depicts the initiation of agricultural practices. During 6400 to 4050 yr BP, the much expansion of *Bombax*, *Madhuca indica*, *Holoptelea*, etc. suggests the establishment of forest groves with the further increase in monsoon precipitation. The expansion of agricultural practices is reflected by steady presence of *Cerealia* and other culture pollen. Between 4050 and 1300 yr BP, the enrichment of forest groves denotes the further enhancement in monsoon rainfall. The more frequent record of culture pollen portrays the acceleration in agriculture. Since 1300 yr BP onwards, the climate turned dry as indicated by sparse presence of trees in the forest groves. However, the agricultural practices continued with same intensity as before.

The studies on two other lakes, viz. Basaha Jheel and Misa Tal in the region of Unnao and Lucknow, respectively have deciphered the short-term climatic variability and vegetation in the much later phases during 3300 yr BP to present. At Basaha Jheel, open vegetation dominated by grasses with sprinkled trees of *Bauhinia*, *Holoptelea*, Sapotaceae, etc. occupied the region under a semi-humid climate around 3300 yr BP. The record of *Cerealia* and other culture pollen is indicative of moderate agricultural practices. During 3200 to 2800 yr BP, the climate changed to humid as inferred by the improvement in the arboreals. Between 2800 and 2200 yr BP the decline in trees and culture pollen taxa suggests the onset of dry climate and depletion in agricultural practices. From 2200 yr BP onwards, the further decline in trees and lack of *Cerealia* pollen imply the reduced precipitation and desertion of settlement by the inhabitants.

Pollen data from Misa Tal has deduced the scanty vegetation indicative of low rainfall and the occupancy of agriculture during 2000 to 1850 yr BP. This time is marked by the ruling of Kushanas. The rulings of Gupta, Turkic and Mughal dynasties spanning from 1850 to 300 yr BP, are manifested by the climatic improvement and prosperity in agriculture as reflected by the rise of trees and aquatics as well as better representation of *Cerealia* and other culture pollen taxa. The British Period faced the decline in rainfall and agricultural prosperity.

Key-words—Holocene, Pollen Sequences, Vegetation, Climate, Human habitation, Central Ganga Plain.

पराग अभिलेखों पर आधारित मध्य गंगा मैदान में झील निक्षेपों से प्राप्त होलोसीन वनस्पति, जलवायु एवं मानव वास स्थान
मोहन सिंह चौहान एवं शांतनु चटर्जी

सारांश

शोध-पत्र तीन झीलों अर्थात् लहुरादेवा, संत कबीर नगर जिला, बसहा, उन्नाव जिला और मीसा ताल, लखनऊ जिला जो कि सभी मध्य गंगा मैदान की बस्ती के समीप स्थित थे पर किए गए अन्वेषण से चतुर्थ महाकल्प वनस्पति एवं जलवायु अनुमान परिवेष्टित करता है। लहुरादेवा झील से प्राप्त पराग अनुक्रम से उद्घाटित हुआ है कि 10600 एवं 9250 वर्ष पूर्व के मध्य, शीत एवं शुष्क जलवायु के अंतर्गत क्षेत्र में एगालि, मारमेलोस, होलोप्टेलिया, टर्मिनेलिया इत्यादि के साथ खुली वनस्पति बृहत रूप से घास, चीनो/एम, आर्टिमिज़िया, इत्यादि घिरले वृक्ष उपजे। जलीय टेक्सा का अभिलेख झील की विद्यमानता इंगति करता है। जलवायु में सुधार के साथ 9250 एवं 6400 वर्ष पूर्व के मध्य कुछ अन्य वृक्ष अर्थात् बॉम्बेक्स, ऐंबलिका ऑफिसिनेलिस, सायजीजियम, लेजरस्ट्रोएमिया, इत्यादि में भी क्षेत्र, में घुसपैठ कर ली। जलीय टेक्सा में वृद्धि इंगति करती है कि मानसून वर्ष में सुधार की वजह से झील चौड़ी हो गई। 7000 ईसा पूर्व के आस पास अनाज पराग की बाह्यावृत्ति कृषि व्यवसाय का प्रारंभ चित्रित करती है। 6400 से 4050 वर्ष पूर्व के दौरान, सेमल, मधुका इंडिका, होलोप्टेलिया इत्यादि का अति प्रसरण मानसून वर्षण में आगे वृद्धि के साथ वृक्ष-समूह वन की स्थापना सुझाता है। अनाज एवं अन्य संबन्धन पराग की स्थिर घिर-उपस्थिति से कृषि प्रचलन-पद्धति का विस्तार पता चलता है। 4050 एवं 1300 वर्ष ईसा पूर्व के मध्य, वृक्ष-समूह वन की प्रचुरता मानसून वर्षा में और वृद्धि सूचित करती है। संबंधित पराग का महत्वपूर्ण बारंबार अभिलेख कृषि में त्वरित विकास प्रदर्शित करता है। 1300 ईसा पूर्व वर्ष से जलवायु शुष्क हो गई। जैसाकि वन वृक्ष-समूह में वृक्षों की विरल विद्यमानता से संकेत है, फिर भी, कृषि प्रचलन-पद्धति पूर्व की भाँति प्रबलता से होती रही।

उन्नाव एवं लखनऊ क्षेत्रों की दो अन्य झीलों क्रमशः बसहा झील एवं मीसा ताल के अध्ययनों से वर्तमान से 3300 वर्ष ईसा पूर्व के दौरान के और बाद की प्रावस्थाओं में अल्पावधि जलवायु परिवर्तनीयता एवं वनस्पति को आँका गया है। बसहा झील में, 3300 वर्ष ईसा पूर्व के आस-पास अर्ध-आर्द्र जलवायु के अंतर्गत क्षेत्र बौहिनिया, होलोप्टेलिया, सैपोटेसी इत्यादि के छितरे हुए पेड़ों सहित घास प्रभुत्व की खुली वनस्पति से घिरा हुआ था। अनाज एवं अन्य संवर्धन पराग का अभिलेख आधुनिक कृषि अभ्यासों का द्योतक है। 3200 से 2800 वर्ष ईसा पूर्व के दौरान, जलवायु आर्द्र हो गई जैसाकि वृक्षों के विकास से निष्कर्ष निकला है। 2800 से 2200 वर्ष ईसा पूर्व के मध्य वृक्षों तथा संवर्धन पराग टेक्सा में ह्वास शुष्क जलवायु का प्रारंभ और कृषि अभ्यासों का समाप्तीकरण दर्शाता है। 2200 वर्ष ईसा पूर्व से, वृक्षों की ओर कमी तथा अनाज पराग की कमी निवासियों द्वारा लघुकृत अवक्षेपण और निवास के स्थानों से पलायन का संकेत देती है।

मीसा ताल से प्राप्त पराग आँकड़े ने अल्प वर्षा के सूचक तथा 2000 से 1850 वर्ष ईसा पूर्व के दौरान कृषि की दखल की विरली वनस्पति निगमित की है। यह काल कुषाणों के शासन द्वारा चिह्नित है। 1850 से 300 वर्ष ईसा पूर्व की अवधि में गुप्त, तुर्की एवं मुगल वंशों के शासन के दौरान जलवायु सुधार एवं कृषि में समृद्धि स्पष्ट होती है जैसाकि वृक्षों एवं जलीय के उत्थान के साथ-साथ अनाज एवं अन्य संवर्धन पराग वर्गों के बेहतर प्रतिनिधित्वीकरण से प्रतिबिंबित है। ब्रिटिश काल ने वर्षा एवं कृषि समृद्धि में ह्वास का सामना किया।

संकेत-शब्द—होलोसीन, परागकण अनुक्रम, वनस्पतिजात, जलवायु, मानव वास-स्थान, मध्य गंगा मैदान।

INTRODUCTION

THE Ganga Plain, one of the major alluvial plains of the country, extends from the Aravalli-Delhi ridge in the west to the Rajmahal hills in the east, Himalayan foot hills in the north to the Bundelkhand-Vindhyan Plateau-Hazaribag Plateau in the south between 77°-88° Long. and 24°-30° Lat. This region abounds with a large number of potential extinct and extant lakes of varying dimensions for Quaternary palaeoclimatic studies. However, this aspect has not yet received due attention, except for some scattered information available from the Central Ganga Plain. The pollen, isotope and geochemical studies conducted from Sanai Tal, Rae Bareli District have provided some interesting data concerning the monsoon variability, lake level fluctuations and human habitation in the Central Ganga Plain (Sharma *et al.*, 2004, 2006; Srivastava *et al.*, 2003). The early agricultural practices and contemporary climatic changes have been brought out from Lahuradewa Lake, Sant Kabir Nagar District (Chauhan *et al.*, 2004a, 2005, 2006; Saxena *et al.*, 2006) and the Meander Lake, Pratapgarh District (Gupta, 1978). Besides, the pollen analytical studies

on some lakes, viz. Basaha Jheel, Unnao District; Misa Tal and Kathauta Tal, Lucknow District have unfolded the short-term climatic variability, pace of agricultural activities in this region during last three millennia or so (Chauhan *et al.*, 1990; Chauhan *et al.*, 2004b; Tewari, 2004; Wasson *et al.*, MS). Interestingly, most of the lakes lie in the proximity of the ancient settlement sites, where extensive archaeological excavations have been conducted in order to infer the cultural history of this most fertile alluvial tract. Appending with the generation of archaeological information at these settlements, the palynological approach is rewarding to reconstruct the models of early land use and subsistence strategies in the region. In the present communication, the inferences mainly on the inception of agricultural practices in the Ganga Plain and its subsequent course as well as contemporary climatic and vegetation scenario since early Holocene in historical perspective, drawn through the Quaternary palynological investigations on three lakes, viz. Lahuradewa Lake, Sant Kabir Nagar District; Basaha Jheel, Unnao District and Misa Tal, Lucknow District, all situated close to ancient settlements, have been discussed.

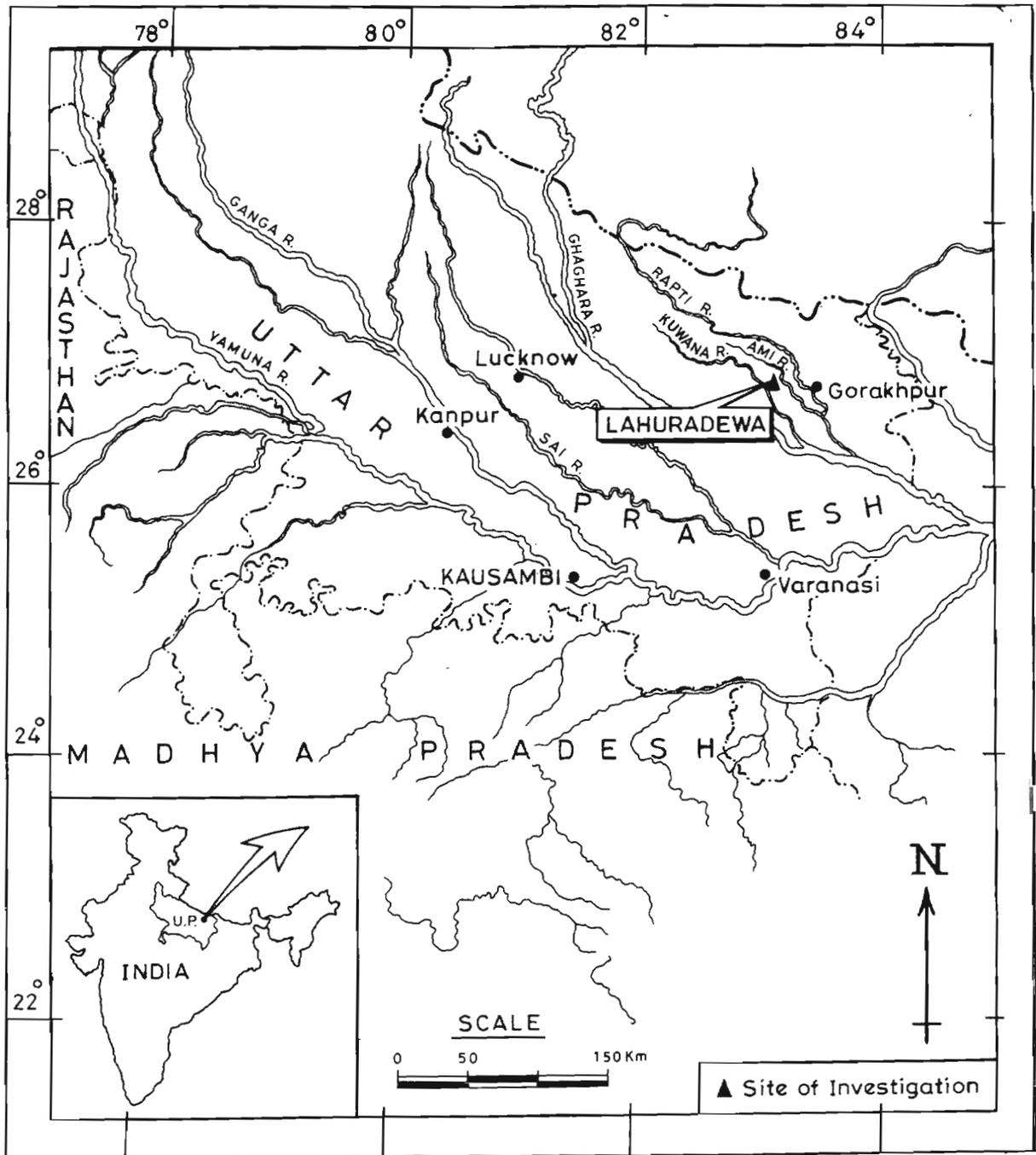


Fig. 1—Map showing Lahuradewa Lake at Sant Kabir Nagar District (U.P.) (After Chauhan *et al.*, 2005).

STUDY AREAS, RADIOCARBON DATES AND POLLEN RESULTS

The pollen data retrieved from the above said localities of the Central Ganga Plain are dealt in details separately as below:

1. Lahuradewa Lake, Sant Kabir Nagar District

The Lahuradewa Lake (82°50'30" Long. & 26°46' Lat.) lies adjacent to a Neolithic-Chalcolithic (9000 to 3200 yr BP) archaeological site, 5 km south of Bhujaini Railway Crossing in the vicinity of Lahuradewa Village, Sant Kabir Nagar District (U.P.). The lake is perennial and holds enough water through

out the year (Fig. 1). However, at present it has receded westwards. The eastern flank of the lake has got dried and this part seldom gets filled with water during the rainy season. The superfluous water of the lake drains out into the Katanalia River, which merges with the Kuwano River, a tributary of Ghaghara. The lake on the northern, the western and the southern sides surrounds the excavation site.

A 2.8 m deep trench profile was taken on dried margin of the lake for pollen analytical investigation. The profile is clearly divisible into three conspicuous lithozones, i.e. dark mud with clay and rootlets (0-0.90 m depth), dark mud with clay (0.90-2.00 m depth) and blackish organic mud (2.00-2.80 m depth). In all, six radiocarbon dates (Fig. 2) have been obtained for this profile at broader intervals to understand precisely the vegetation and climatic shifts in the region in term of definite time-frame (Chauhan *et al.*, 2004a).

Depth	Lab. Ref. No.	Radiocarbon dates	Cal. dates
0.50-0.60 m	BS-2300	1040±100 yr BP	950 yr BP
0.75-1.00 m	BS-2302	1810±100 yr BP	1714 yr BP
1.25-1.30 m	BS-2299	2180±90 yr BP	2188 yr BP
2.30-2.40 m	BS-2981	7010±170 yr BP	7822 yr BP
2.50-2.60 m	BS-2215	8710±90 yr BP	9720 yr BP
2.70-2.80 m	BS-2211	9210±170 yr BP	10425 yr BP

Fig. 2—Chauhan *et al.*, 2005.

The pollen sequence emerged out from Lahuradewa Lake, situated close to a Neolithic-Chalcolithic (9000 to 3200 yr BP) site has provided information on palaeovegetation and palaeoclimatic changes in the region since early Holocene (Fig. 3). From the study it has been unravelled that during 10600 to 9250 yr BP, open vegetation chiefly constituted of grasses, Chenopodiaceae/Amaranthaceae, *Artemisia*, sedges, etc. together with meagrely distributed trees, viz. *Aegle marmelos*, *Holoptelea*, *Terminalia* and thickets of Fabaceae and Tiliaceae occurred in the region under cool and dry climatic conditions (Chauhan *et al.*, 2004a, 2006). The recovery of pollen of aquatic plants such as *Potamogeton* and *Typha* with frequent presence of fresh-water alga-*Botryococcus* indicates the existence of the lake, extending up to the present dried investigated part. Some sort of human activities in the vicinity of the lake are manifested by the presence of pollen of ruderal/culture plants, viz. Brassicaceae, Caryophyllaceae, *Artemisia*, *Rumex*, etc. during this early part of the Holocene.

Later on, between 9250 and 6400 yr BP, the open vegetation was invaded by a few more trees such as *Bombax*, *Emblica officinalis*, *Syzygium*, *Lagerstroemia* and *Dodonea*, though sporadically, because of an amelioration in the climate. The abundance of *Botryococcus* and improved frequencies of other aquatic elements portray that the lake got wider in expanse as a result of increased monsoon rainfall. Amazingly, the first appearance of characteristic Cerealia pollen at the level (2.40 m depth) dated to 7000 yr BP depicts unexpectedly

the early activities of the man associated with some kind of cereal-based agriculture practices in the region. Recently, for the first time the data generated from the studies of phytoliths (Tewari *et al.*, 2006; Saxena *et al.*, 2006) from the same lake bed and archaeobotanical remains (Saraswat & Pokharia, 2004) from the adjoining excavation site have also substantiated a close synchronicity with pollen evidence regarding the incipient agricultural activities in this part of the Central Ganga Plain. The present finding on the beginning of agricultural practice has also superseded the earlier such record, dated to *ca.* 4500 yr BP from the meander lake in Pratapgarh area of the Central Ganga Plain (Gupta, 1978).

During the time bracket of 6400 to 4050 yr BP, the considerable enhancement of *Bombax*, better representation of *Holoptelea*, *Terminalia* and shrubby elements of *Trewia*, *Melastoma*-a riverine element and Fabaceae coupled with the advent of *Madhuca indica*, albeit sporadically, denotes the establishment of groves of tropical deciduous forests interspersed with stretches of open grassland vegetation. Such a drastic change in the overall floristic pattern obviously would have occurred in response to intensification of monsoon rainfall with the beginning of this phase. Interestingly, the consistent presence of *Trapa* (Singhara) pollen between 2.00 and 1.50 m depths tentatively dated from 5800 to 2900 yr BP reveals that the lake possibly would have been quite deep and perpetually extending even in the close proximity of human settlement at the excavation site because of prevalence of favourable climatic conditions. The Singhara (*Trapa*) fruits would have been exploited by the ancient settlers as a means of livelihood. Chronologically this event of the expanded status of the lake corresponds with the period of climatic optimum, which has been known globally between 7000 and 4000 yr BP (Benarde, 1996). The further intensification of agricultural practices in the region is reflected by well-marked and steady occurrence of Cerealia along with other culture pollen taxa. This might have occurred with the prevalence of favourable climatic conditions in the region. In addition, the first record of *Cannabis sativa*, tentatively dated to 5000 yr BP also supports the increasing anthropogenic/human impact in the region.

Between 4050 and 1300 yr BP, the increase in *Madhuca indica* together with other arboreals, viz. *Holoptelea*, *Syzygium*, Sapotaceae, Meliaceae and the swampy element-*Barringtonia* as well as contemporary sharp decline in grasses and the associated terrestrial herbs implies that the area supported localized groves of much dense deciduous forests with diverse floristic composition than witnessed earlier. The overall enrichment in the vegetation mosaic, more particularly arboreals, reflects the further pronounced rainfall in the region, attributable to prevailing active summer monsoon. The steady acceleration of agricultural practice is registered from the enhanced frequencies and consistent presence of Cerealia and other culture pollen taxa. This would have occurred in order to sustain the increasing human population in the region. The

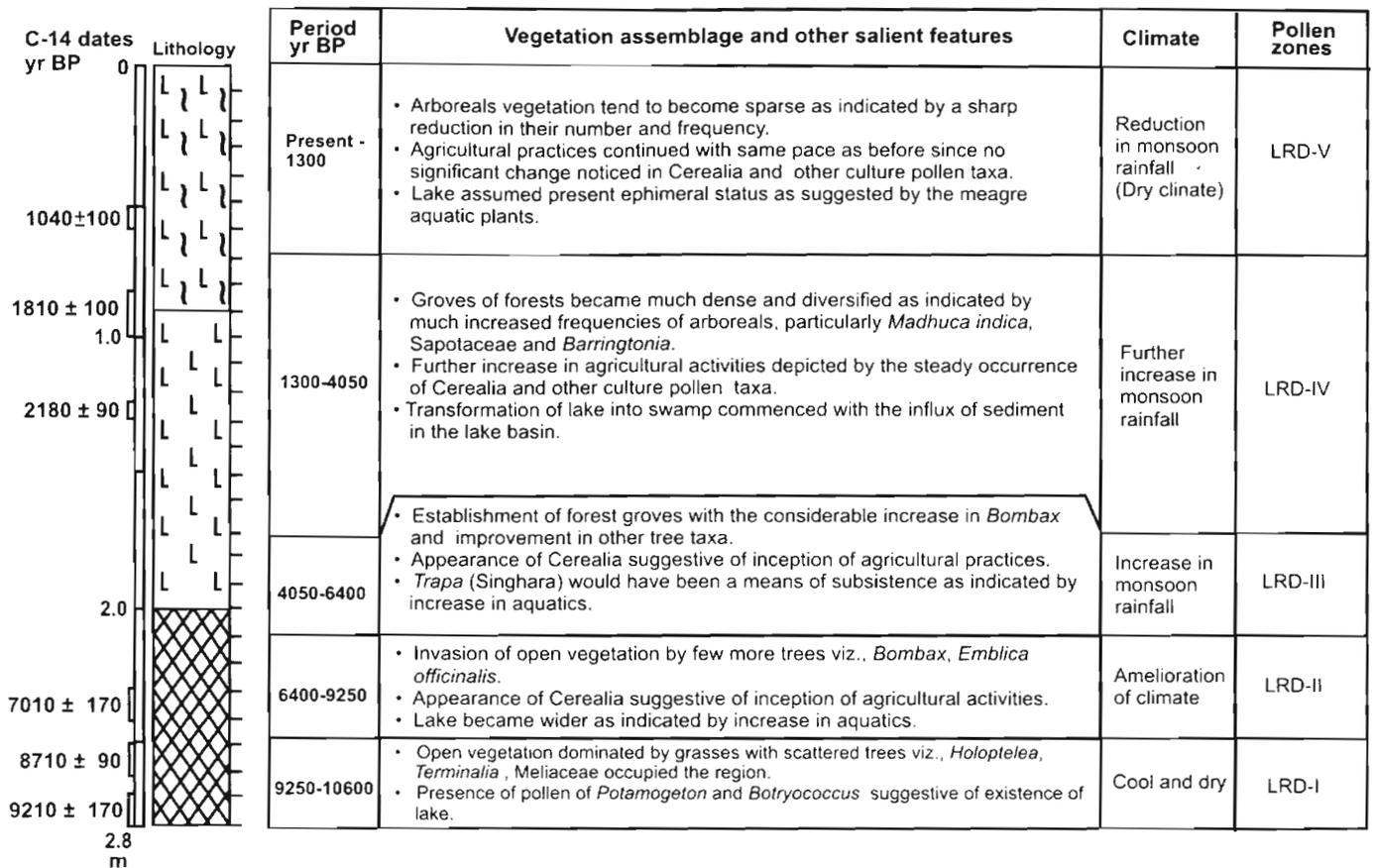


Fig. 3—Schematic diagram of Lahuradewa pollen profile showing major palaeoclimatic inferences.

transformation of the lake into a swamp commenced by this time as depicted by the expansion of marshy elements, viz. sedges and *Polygonum* sp. and a contrary sharp declining trend of *Botryococcus*, in particular, and other aquatic elements. This change in the status of the lake might have occurred with the increase of sediment influx in the lake basin as a consequence of excessive precipitation in the region.

Since 1300 yr BP onwards, the decline in the frequencies of trees, particularly *Madhuca indica* and others such as *Holoptelea*, *Syzygium*, *Dalbergia*, barring the dry element-*Acacia* with improved values, indicates that the arboreal vegetation turned sparse in the forest groves as a result of reduction in rainfall with the prevalence of weak summer monsoon. The exploitation of the vegetation by the increasing human population cannot be denied. The lake gradually shrunk and assumed its present small dimension and ephemeral status on account of extension of swampy condition around the water body and increase in sediment input. This is also well corroborated by the severe decline and ultimate disappearance of *Botryococcus* and other aquatics. The agricultural practice in the region continued with more or less same pace as before, since Cerealia and other culture pollen taxa are recovered in similar proportion. This could perhaps be attributed to technological advancement during recent past.

The consistent occurrence of pollen of *Pinus* in high frequency along with other temperate elements, viz. *Cedrus*, *Alnus*, *Betula* and *Carpinus* indicates their transportation by wind or water from the nearby Himalayan region where all these taxa grow abundantly.

2. Basaha Jheel, Unnao District

Basaha Jheel, an ancient lake basin, is situated about 60 km southwest of Lucknow in Unnao District near Sonik Railway Station. The site is in the vicinity of villages-Itkuti and Jamanwa between 80°15' Long. and 26°30' Lat., originating as an abandoned channel (Fig. 4). On the margin of Basaha Lake a single culture archaeological site is present, which was deserted around 2200 yr BP by the settlers.

A 2.6 m deep trench profile comprising three distinct lithologies, viz. subsoil, black loamy soil and marl from top downward, was collected from this ancient lake basin for Quaternary pollen analytical investigation.

Radiocarbon dating of the samples was carried out at AMS Laboratory, Institute of Physics, University of Erlangen-Nuremberg, Germany (Chauhan *et al.*, 2004b). In all, four radiocarbon dates have been determined for this profile at broader intervals to understand the changing vegetation scenario, lake level fluctuations and the climatic events the

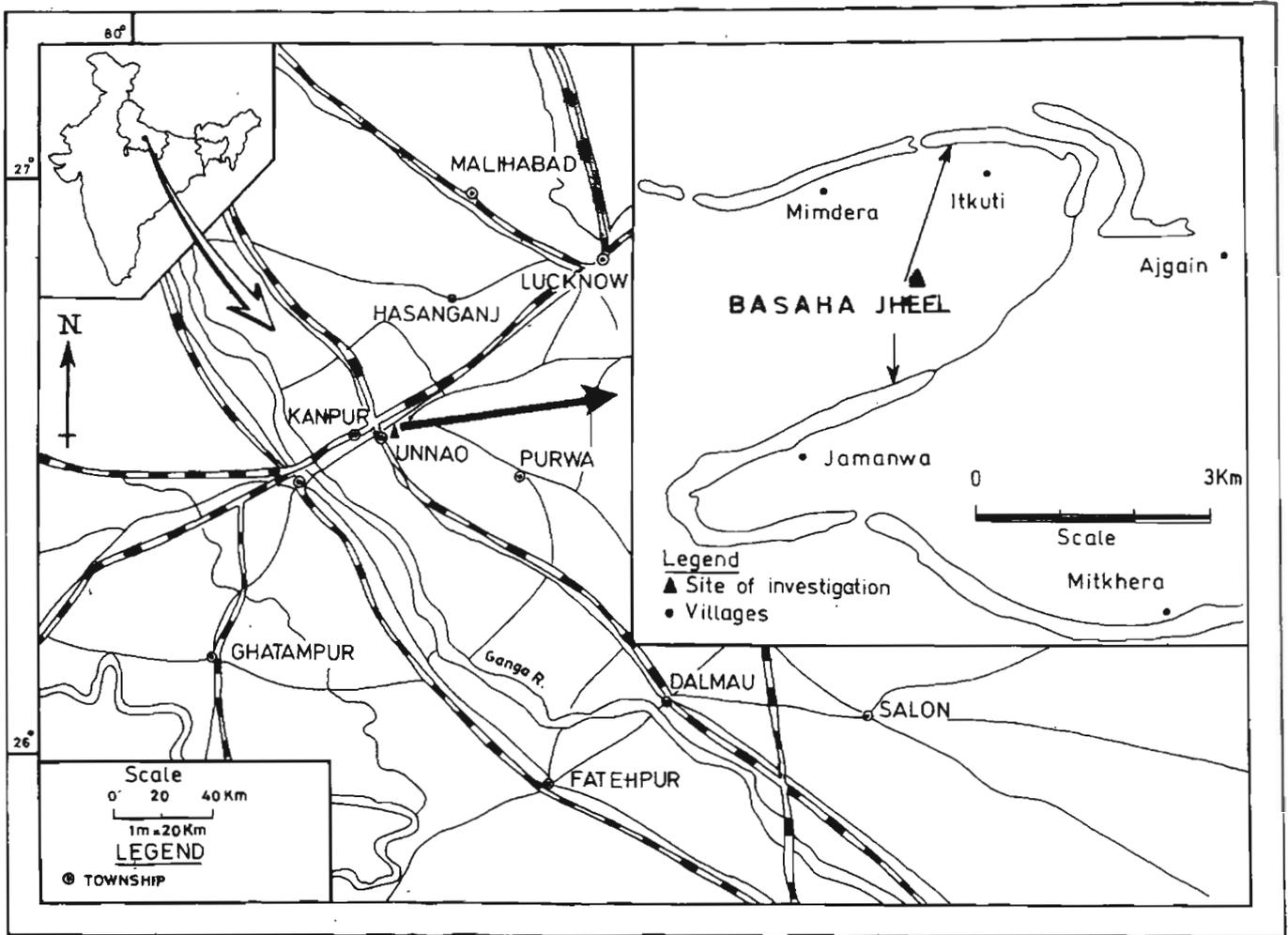


Fig. 4—Map showing the study site-Basaha Jheel in Unnao District (U.P.) (After Chauhan *et al.*, 2004).

region came across in a chronological order (Fig. 5). These are as follows:

Depth (m)	Laboratory Reference No.	AMS dates
0.24m	HOLMONBASAHA-6	1712± 65 yr BP
1.15 m	HOLMONBASAHA-4	2149± 56 yr BP
1.79m	HOLMONBASAHA-3	2736± 57 yr BP
2.15 m	HOLMONBASAHA-2	2995± 63 yr BP

Fig. 5—After Chauhan *et al.*, 2004b.

The pollen proxy data generated from the investigation of the trench profile has clearly demonstrated five well-defined phases (Fig. 6) of vegetation succession and coeval climatic oscillations associated with lake level changes and agricultural practices in this part of Central Ganga Plain during the Holocene (Chauhan *et al.*, 2004b).

Around 3300 yr BP, open vegetation comprising mainly grasses associated with elements of Ranunculaceae, Malvaceae, Chenopodiaceae/Amaranthaceae, etc. together with sparsely distributed arboreals such as *Bauhinia*, Sapotaceae, *Aegle marmelos*, *Holoptelea* and Meliaceae occupied the region under semi-humid climatic regime (Fig. 7). The retrieval of *Cerealia* together with other culture pollen taxa such as *Artemisia* and *Urticaceae* signifies that this region was under the impact of anthropogenic activities. The prolonged existence of a lake is attested by the presence of pollen of aquatic plants such as *Lemna*, *Nymphoides*, *Myriophyllum* and *Potamogeton* as well as fresh-water alga, *Botryococcus*.

Between 3200 and 2800 yr BP, open vegetation dominated by grasses and other non-arboreals continued to thrive in the region, with a corresponding overall improvement in arboreals. Excessively high frequencies of *Bauhinia* demonstrates that this tree might have been growing preponderantly in the area,

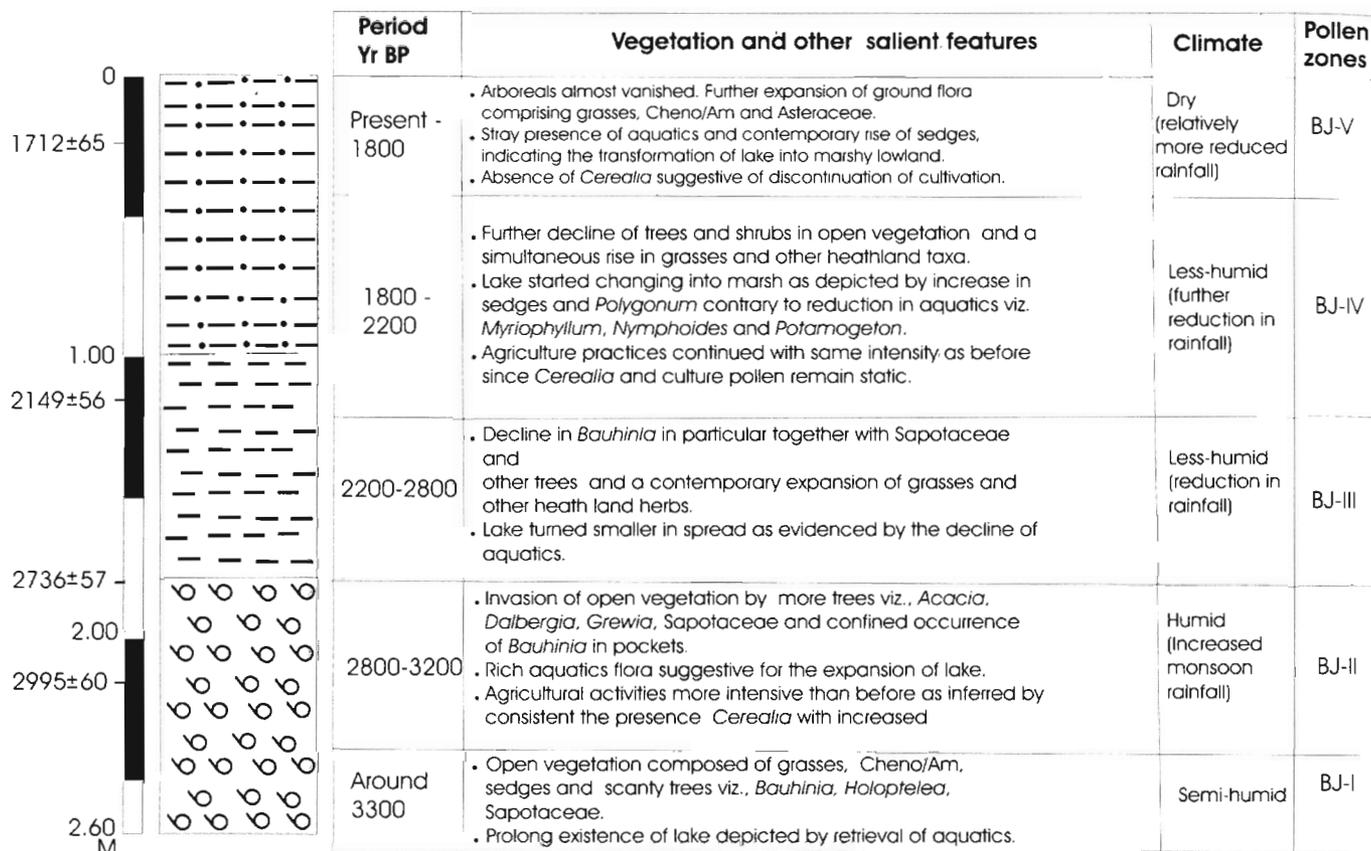


Fig. 7—Schematic diagram of Basaha Jheel pollen profile showing major palaeoclimatic inferences.

corroborated by the scanty occurrence of aquatic flora as well as a sharp decline in *Botryococcus*, in particular, as compared to that witnessed in the earlier phase. With the prevailing adverse climatic conditions, the lake also got smaller in dimension. A simultaneous and progressive improvement in the sedges also provides the evidence for the extension of swampy condition around the lake. The disappearance of *Cerealia* pollen and a gradual decline in other ruderal/culture pollen taxa, viz. Chenopodiaceae/Amaranthaceae and Caryophyllaceae are convincingly suggestive for the abandonment of cultivation in the adjoining area of the lake by the local inhabitants. The prevailing harsh climatic conditions also induced the soil salinity, which turned detrimental for the growth and proliferation of arboreal vegetation.

The archaeological study executed in Basaha Lake area has shown the presence of a single cultural settlement, which flourished here during 3000 to 2200 yr BP. Subsequently, the site was abandoned by the settlers around 2200 yr BP probably because of reduction in monsoon rainfall and increased soil salinity near the site as well. Presently, a large tract of alkaline soil with scanty vegetation cover occupies most of the area adjoining to Basaha Lake. Hence, it may be presumed that edaphic condition in the proximity of Basaha Jheel gradually

became saline around 2200 yr BP and thereafter in the due course of time turned more acute since 1800 yr BP onwards.

3. Misa Tal, Lucknow District

There are several lakes and ponds of different dimensions on the interfluvies between the Gomti and Sai rivers in Lucknow District (Srivastava *et al.*, 2003). They are supposed to be formed as abandoned channels of river meanders (Fig. 8). The lake (tal) in the vicinity of the village of Misa is about 15 km east-south-east and 6 km south of Gomti River between 80° Long. & 26° Lat. Misa Tal is arcuate in outline, measuring 100 m and 150 m wide and 1500 m long. The catchment area of Misa Tal is about 7.26 km². The excavation of habitation mounds studded to the lake has furnished the evidence of human settlement in this area at least for the last 1700 years (Wasson *et al.*, MS). There is no natural vegetation in the area surrounding the tal and most of the land is being used for cultivation and pasturing.

A 1.40 m deep trench was exposed near the lake for detailed investigations of pollen and geochronology (Wasson *et al.*, MS). The trench profile is divided into two lithounits. The sediments between 1.40 m and 1.03 m depths are constituted of dark brown granular clay loam. The upper horizon with a thickness of 1.03 m contains yellow to grey polyhedral clay

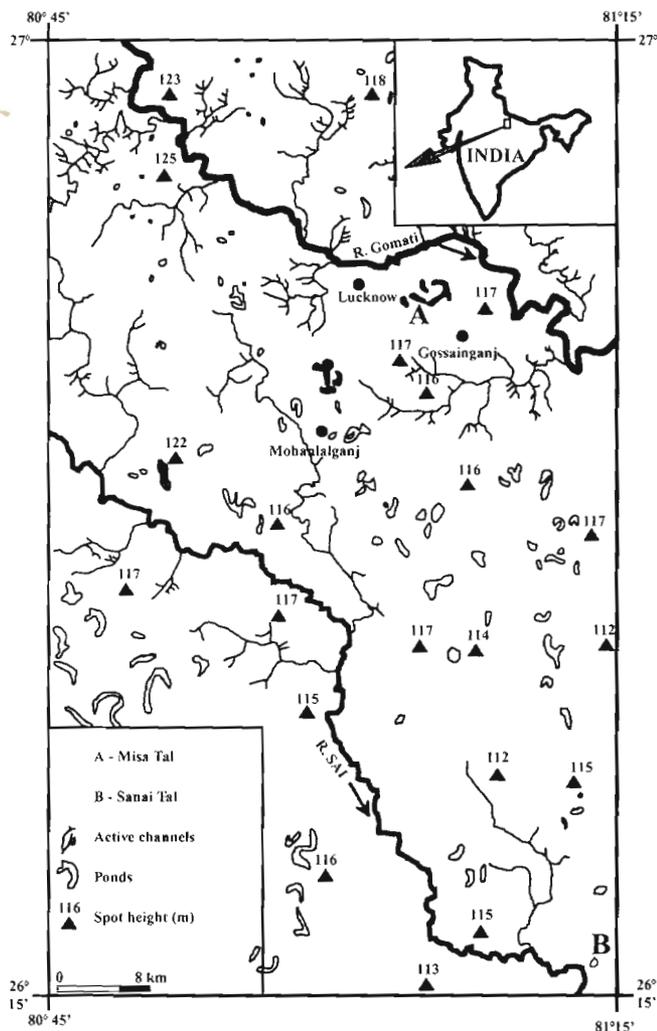


Fig. 8—Map showing the study site-Misa Tal in Lucknow District (U.P.) (After Wasson *et al.*, 2008).

loam. Only one OSL date of 2000±500 yr BP has been determined at 1.5 m depth for the earlier profile (Srivastava *et al.*, 2003), picked up close to the present one. Hence, assuming the surface modern and a more or less uniform sediment composition with minor variability, the sedimentation rate of 1cm/13.5 years has been calibrated for this profile. This sedimentation rate has been taken for extrapolation of other dates at larger intervals from this trench profile in order to demarcate the temporal changes pertaining to the vegetation pattern, climate and agricultural activities in the region during last 2 millennia.

The pollen proxy data retrieved from the Misa Tal profile has portrayed out very significant inferences concerning the short-term climatic variability, contemporary vegetation scenario and amplitude of agricultural activities in relation to cultural shifts this region has witnessed since last 2 millennia (Wasson *et al.*, MS).

The pollen sequence has unravelled that between 2000 and 1850 yr BP (150-0CE), open grassland vegetation dominated by grasses followed by Asteraceae with sprinklings of *Bombax* trees and shrubs occurred in the surrounding area of the lake. The preponderance of sedges, *Polygonum plebeium* and *Polygonum sp.* suggests that the lake was encircled with a wide swampy margin. The pollen assemblage depicts the prevalence of a drier climate than that which followed. The region was under agricultural practices, though at smaller scale, as depicted by the encounter of sporadic pollen of *Cerealia* and other culture pollen such as *Chenopodiaceae/Amaranthaceae*, *Caryophyllaceae* and *Urticaceae* right from the beginning of this phase. During this period the region was under the ruling of Kushana dynasty. It is worth to mention here that the archaeological evidence from habitation mounds at Misa Tal has indicated the human settlement at least for the last 1700 years (Srivastava *et al.*, 2003). However, the pollen records have divulged the agriculture related human activities from the beginning of last 2 millennia (Fig. 9).

Subsequently, between 1850 and 1400 yr BP (150-600 CE), the open vegetation continued to grow with scanty trees, however, ground cover became more profuse as evidenced by the increased frequencies of grasses, Asteraceae, *Chenopodiaceae/Amaranthaceae*, *Caryophyllaceae*, etc. The improvement in aquatic taxa, viz. *Potamogeton*, *Lemna* and the fresh-water alga, *Botryococcus* and a simultaneous decline in marshy elements namely sedges, *Polygonum plebeium* and *Polygonum sp.* reveal the existence of a lake of larger dimension than before. The change in the overall vegetation assemblage implies the increase in monsoon rainfall. According to the available historical account, the Gupta Empire succeeded the Kushana rule by this time.

From 1400 to 950 yr BP (600-1050CE), few more trees such as *Meliaceae*, *Syzygium* and *Embllica officinalis* together with shrubby elements of *Acanthaceae* invaded the open grassland vegetation. Grasses and terrestrial herbs also turned more luxuriant. The lake also became wider than before as demonstrated by the increase in aquatic plants at the expense of marshy taxa, which declined drastically. The overall enrichment in the terrestrial and aquatic vegetation infers that this region experienced relatively higher rainfall than earlier. The further augmentation in agricultural activities is evidenced by the improvement and steady presence of *Cerealia* and culture pollen. During this phase, the Gupta Empire was de-established by the Turkic invasion. A more or less similar type of vegetation scenario also existed between 950 and 300 yr BP (1050-1700 CE), however, the further increase in *Botryococcus* gives an indication for the much expansion of the lake owing to increase in rainfall. The Mughal replaced the Turkic during this period.

During the last 300 years (1700-2000 CE), the arboreals almost vanished, except for the meagre presence of *Meliaceae*

and Myrtaceae. The ground vegetation also got less profuse as compared to the preceding phase as evidenced from the relatively lower frequencies of grasses, sedges, etc. The overall decline in the floristic composition occurred due to reduction in the rainfall. The lake also became smaller in expanse as indicated by the scarce presence of aquatic taxa. The swampy margin around the lake got much wider as a consequence of shrinkage of the lake due to prevalence of dry climatic condition. This is clearly evident from the expansion of marshy taxa, viz. sedges, *Polygonum plebeium*, *Polygonum* sp., etc. With the prevailing unfavourable climatic conditions, the depletion in the agricultural practices also took place as marked by the much low frequency of Cerealia and other culture pollen taxa, viz. Chen/Am and Caryophyllaceae, in particular. In the historical perspective this phase is characterized by the colonization of Britishers after succeeding the Mughals.

CONCLUSIONS

Thus, the pollen analytical investigations conducted on the above mentioned lacustrine profiles from the Central Ganga Plain have revealed the changing vegetation scenario, climate as well as inception of agriculture and its later course since early Holocene. The pollen data retrieved from Lahuradewa Lake has deciphered that between 10600 and 9250 yr BP, open vegetation with scantily distributed trees occurred in the region under cool and dry climatic conditions. Lake did exist and it was extending up to the present investigated dried part. Between 9250 and 6400 yr BP, a few more trees invaded the open vegetation with amelioration in climate. Surprisingly, the first record of Cerealia pollen at the level dated 7000 yr BP suggests the beginning of cereal-based crop economy. Subsequently, between 6400 and 4050 yr BP, the considerable expansion of *Bombax* and other deciduous trees denotes the

establishment of forest groves interspersed by open grasslands. This significant change in the floristic composition took place in response to increased precipitation. The acceleration in agricultural practice is indicated by the steady presence of Cerealia pollen. During the following phase spanning 4050 to 1300 yr BP, the forest groves turned dense and diversified, attributable to further increase in monsoon rainfall. Agricultural activities continued with same pace as before. However, the decline in aquatics and a simultaneous expansion of marshy taxa are indicative of reduction in lake dimension owing to increase in sediment influx. Since 1400 yr BP onwards, the arboreals (trees & shrubs) became sparse as a consequence of onset of a dry climate. On account of prevailing adverse climate the lake also attained its present ephemeral status.

On the other hand, the pollen evidence from the shallow lakes, viz. Basaha Jheel, Unnao District and Misa Tal, Lucknow District have provided insights on the short-term climatic variability in the Central Ganga Plain since late Holocene, which could not be unfolded in the Lahuradewa Lake profile due to relatively much compressed nature of sediments. The study has brought out the existence of open vegetation in the region around 3300 yr BP under semi-humid climate. The recovery of the aquatic pollen suggests the existence of the lake. The area was under agricultural practices as inferred by the record of Cerealia and other culture pollen. The climate changed to humid between 3200 and 2800 yr BP with the increase in precipitation as clearly evidenced from the immigration of more trees and expansion of *Bauhinia* trees in localized pockets. The lake also turned wider in expanse by this time as deduced from the improvement of aquatics. Prosperity in crop economy is marked by the more frequent encountered in Cerealia and other culture pollen. However, during 2800 to 1800 yr BP, the arboreals in the open vegetation got scarcer as a result of prevalence of

Period	Vegetation	Climate	Social History	Pollen Zones
0-300 BP (2000-1700 CE)	Few trees, low ground cover, sporadic aquatics, low agricultural pollen	Low rainfall	Mughal Empire replaced by British; then Independence	MT-V
300-950 BP (1700-1050 CE)	Scattered trees, good ground cover, moderate aquatics; abundant agricultural pollen	High rainfall	Invasions leading to formation of Mughal Empire; Mughals established by 1200 CE	MT-IV
950-1400 BP (1050-600 CE)	Invasion of a few more trees, non-arboreals dominant, aquatics abundant, agricultural pollen more frequent	High rainfall	Endemic warfare between rival feudal dynasties; Turkic invasions begin in 1000CE	MT-III
1400-1850 BP (600-150 CE)	Scattered trees, expansion of ground cover, increasing aquatics and agricultural pollen	High rainfall	Kusana rule replaced by small feudal states; Gupta Empire 320 to 450 CE, destabilised by Huna invasion; return to small warring states	MT-II
1850-2000 BP (150-0 CE)	Stretch of grassland with scanty trees, shrubs and few aquatics; moderate representation of agricultural pollen	Low rainfall	Mauryan Empire destabilized, then Kusana rule	MT-I

Fig. 9—After Wasson *et al.*, 2008.

less humid climate, because of reduced rainfall. The lake also began transforming into swamp and consequently more terrestrial land got available for the further expansion of cultivation in the vicinity of the lake. From 1800 to present, due to prevailing dry climate the arboreals almost vanished from region and the lake altogether got transformed into a swamp. The agricultural practice also discontinued by the local inhabitants, most probably due increase in salinity. Similarly, the Misa Tal profile has revealed further fine resolution climatic and vegetation changes during last 2 millennia in relation to cultural shifts.

It is needless to emphasize here that the palynological approach in resolving the intricate problems of the early cultures in relation to the contemporary climatic shifts in the Ganga Plain, is nothing but only a beginning at present. The region is vast and the scope of future studies is quite far to be closed. Hence, the comprehensive Quaternary palaeoclimatic studies on the lakes of other sectors of the Ganga Plain are imperative in order to reconstruct a very precise picture of past landscape, climate and the course of crop economy in a definite time frame in historical perspective. In addition, the pollen sequences to be generated from different sectors on correlation can provide very valuable information to simulate the common climatic models, depicting the long and short-term monsoon variability in the Ganga Plain during the Quaternary Period. Being in a transitional position between the Himalaya and the peninsular India, the studies from the Ganga Plain are expected to decipher the impact of various global events such as Glacial and Interglacial phases, Last Glacial Maximum, Period of Climatic Optimum, Medieval Warm Period and Little Ice Age using pollen, isotope and geochemical evidence, which are yet untraced from this region.

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