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Pollen based vegetation and climate change records deduced from the lacustrine sediments of Kikar Tal (Lake), Central Ganga Plain, India

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ABSTRACT

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A 2.0 m thick sediment profile from Kikar Tal, Raebareli District is studied for the pollen assemblage to infer the vegetation and climate variability scenario during the Holocene period. Four distinct palynozones were demarcated based on the palynological succession in the core sediment. However, the radiocarbon dates for the profile could not be procured; therefore, the lake profile is corroborated with the chronology of adjacent lake 'Chaudhary–Ka–Tal', Raebareli District. It is envisaged that during 8,000–7,200 cal yrs BP, (Pollen Zone KT–I), forest groves with *Holoptelea*, *Acacia, Madhuca indica, Syzygium* and *Prosopis* as major tree taxa were present in the adjoining area of the lake. The forest groves were interspersed with wider stretches of open vegetation comprising grasses, Tubuliflorae, Liguliflorae, Chenopodiaceae/Amaranthaceae, etc. and shrubs of *Adhatoda vasica* and Acanthaceae. This vegetation scenario reflects that the region was under a warm and humid climate during that time. The existence of lake is also envisaged by the presence of aquatic elements, *Lemna* and *Typha*. Subsequently, during 7,200–4,200 cal yrs BP (Pollen Zone KT–II), the forest groves became more diversified and dense in composition as evidenced by the expansion of most of the existing trees as well as presence of *Emblica officinalis, Aegle, Adina cordifolia*, *Symplocos* and Sapotaceae and thickets of *Adhatoda vasica* and *Mimosa pudica*. This significant change in the vegetation mosaic as a whole implies the initiation of a warm and more–humid climatic condition, owing to climate amelioration. The encounter of Cerealia and concomitant cropland weeds, viz. Cheno/Am. *Cannabis sativa*, *Brassica*, etc. suggests that the vicinity of the lake was under agrarian practice and other anthropogenic activities. The ground flora was still dominated by grasses; however, it also turned more profuse than before. The increasing trend of Cerealia coupled with concomitant cropland weeds signifies the augmentation in Cereal–based agrarian practice owing to favourable climatic condition. The lake expanded as manifested by the increase in aquatic elements, such as *Typha*, *Potamogeton* and *Lemna* during this period. During the time bracket of 4,200–1,800 cal yrs BP (Pollen Zone KT–III), the arboreals reveal a decrease in their frequency and diversity of major tree taxa with incursion of *Moringa* and *Bombax ceiba* suggesting warm and moderately humid climate with reduced monsoon. The last zone (Pollen Zone KT–IV), from 1,800 cal yrs BP–Present, elucidates open grassland vegetation corresponding to reduced monsoon precipitation, with the shrinkage of lake area. The presence of Cerealia and other culture pollen taxa suggests the prevalence of intense agrarian practice in the vicinity of the lake.

Key–words—Pollen, Vegetation, Lake sediment, Holocene, Ganga Plain.

भारत के मध्य गंगा के मैदानों की कीकर ताल (झील) के सरोवरी अवसादों से निगमित पराग आधारित वनस्पति एवं जलवायु परिवर्तन अभिलेख

अंजु सक्सेना एवं अंजलि त्रिवेदी

सारांश

अंतिम चतुर्थमहाकल्प अवधि के दरम्यान वनस्पति व जलवायु बदलाव परिदृश्य का अनुमान लगाने हेतु कीकर ताल, जिला रायबरेली से एक 2.0 मीटर मोटी अवसाद परिच्छेदिका से प्राप्त पराग समुच्चय का अध्ययन किया गया है। पूरी अवसाद परिच्छेदिका के पराग समुच्चय में प्रमुख वृक्षीय (वृक्ष व झाड़ी) और गैर–वृक्षीय (शाक) परागाणुओं के बदलते विन्यास पर आधारित समूचा पराग अनुक्रम चार विशिष्ट पराग मंडलों

में विभाजित किया गया है। चूंकि, परिच्छेदिका हेतु रेडियोकार्बन आयुनिर्धारण प्राप्त न हो सका; अतैव, इस झील परिच्छेदिका के निकटस्थ झील 'चौधरी– का–ताल' के कालानुक्रम से संपुष्ट किया गया है। परिकल्पित किया जाता है कि अब से 8,000–7,200 वर्ष पूर्व, (पराग मंडल के टी–I) *होलोप्टेलिया, एकैसिया, मधुका इंडिका, सायज़ीजियम* व *प्रोसोपिसस* विशाल वृक्ष टैक्सा के साथ जंगल कुंज झील के निकटवर्ती क्षेत्र में विद्‌यमान थे। जंगल कुंज घास, टुब्लीफ्लोरे, लिगुलीफ्लोरे, चीनोपोडिएसी/अमरेंथेसी इत्यादि तथा *अधाटोडा वेसिका* की झाड़ियों व एकेंथेसी सन्निहित खुली वनस्पति के व्यापक प्रसरण सहित अंतःप्रकीर्ण हो गए थे। यह वनस्पति परिदृश्य प्रतिबिंबित करता है कि उस समय के दरम्यान अंचल में कोष्ण व आर्द्र जलवायु थी। जलीय तत्वों, *लेम्ना* एवं *टायफा* की विद्‌यमानता से भी झील का अस्तित्व परिकल्पित होता है। 7,200–4,200 वर्ष पूर्व (पराग मंडल के टी–2) परिवर्ती रूप से, ज़्यादातर मौजूदा पेड़ों के प्रसरण साथ ही साथ *एम्बलिका ऑफिसिनेलिस, एग्ले, एडिना कॉर्डीफोलिया, सिम्पलोकॉज* व सपोटेसी और *अधेटोडा वेसिका* व *मिमोसा पुडिका* की विद्‌यमानता से यथासाक्ष्यित वन कुंज संघटन में अति विविधरूपायित एवं घना हो गया। जलवायु बेहतरी की वजह से समग्रतः चित्रित वनस्पति में सार्थक परिवर्तन कोष्ण एवं अति–आर्द्र जलवायवी स्थिति का संकेत देता है। अनाज एवं सहवर्ती फसल घास–फूसों अर्थात चीनों/एम, *भॉग, ब्रैसिका* इत्यादि के समागम सुझाते हैं कि झील के आस–पास कृषि अभ्यास और अन्य मानवजनिक गतिविधियाँ व्याप्त थीं। भू–वनस्पति में घासों का प्रभुत्व था; फिर भी यह पहले की अपेक्षा अति विपुल हो गई। सहगामी फसल पतवार से युग्मित अनाज की बढ़ती प्रवृत्ति अनुकूल जलवायवी स्थिति की वजह से अनाज–आधारित कृषि में वृद्‌धि द्‌योतित करती है। *टायफा, पोटामोगेटन* एवं *लेम्ना* जैसे जलीय तत्वों में वृद्‌धि से यथा झील व्यापक हो गई। 4,200–1,800 वर्ष पूर्व (पराग मंडल के टी–III) के समय बंधनी के दौरान, वानस्पतिक वृत्ति में ह्रास का पता चलता है तथा *मोरिंगा* एवं *बम्बैक्सा सीबा* के अंतर्वेशन सहित प्रधान वृक्ष टैक्सा की विविधता सुझाती है कि अंचल में कोष्ण एवं मध्यम आर्द्र जलवायु की प्राप्ति संभवतः लघुकृत मानसून वर्षण की वजह से है। 1,800 वर्ष पूर्व–मौजूदा समय तक अंतिम मंडल (पराग मंडल के टी–IV), मानसून वर्षण में और न्यूनीकरण के उपलक्ष में, अंचल में वर्तमान वनस्पति परिदृश्य के सुसंगत खुला घास स्थल वनस्पति प्रदर्शित करते हुए वृक्षीय (वृक्ष एवं झाडियां) में अनवरत ह्रास प्रवृत्ति स्पष्ट करता है, अंचल में कोष्ण और अल्प आर्द्र जलवायु का प्रभाव है। अवसाद संचयन के इस समय के दौरान जलीय तत्वों में ह्रास भी झील के संकुचन को दिखाता है। तथापि, अनाज एवं अन्य कृषि पराग टैक्सा की अनवरत और स्थिर विद्‌यमानता अंचल में झील के चहुंओर प्रबल खेती–बाड़ी की प्रबलता दर्शाती है।

सूचक शब्द—पराग, वनस्पति, झील अवसाद, होलोसीन, गंगा के मैदान।

INTRODUCTION

THE Ganga Plain is a vast fluvial geomorphic landscape characterized by intricate network of river channels, their valleys and intervening large raised areas (interfluves). It sustains hundreds of meters thick unconsolidated sediments which are drained by active river networks, abandoned channel segments, numerous stagnant water bodies (lakes and ponds) and other related microgeomorphic features (Singh, 2004). In the Ganga Plain also, ubiquitous occurrence of lakes and ponds often records complete and continuous Holocene history. The upland interfluve surface of the Ganga Plain sustains many lakes as hydrologically 'closed–system' recording the archives for climate perturbations, biodiversity and anthropogenic interventions (Saxena & Singh, 2017). These lacustrine sediments are the 'store–house' of remarkable material of multiproxy information and represent one of the richest geological archives.

A number of studies have been conducted from the Late Quaternary lake–fill sequences appended with chronology to reconstruct the past vegetation, its dynamics and related palaeoclimatic conditions from the different parts of Indian subcontinent. In comparison to the core monsoon zones (Chauhan & Quamar, 2010; Chauhan *et al*., 2013), Southern India (Farooqui & Achyuthan, 2006) and western regions of India, very little attention has been given to the vast fluvial landscape of the Ganga Plain in this perspective, which has entirely different floristic setup. However, in the past decade several multiproxy studies pertaining to palaeoclimate and palaeovegetation reconstructions have been carried out from the lake–fill sequences (Chauhan & Bera, 1990; Chauhan *et al*., 2004, 2009, 2015; Sharma *et al*., 2004, Singh *et al*., 2015, Saxena *et al*., 2013, 2015; Saxena & Singh, 2016; Trivedi *et al*., 2011, 2013). These multidisciplinary studies have provided some valuable database regarding the vegetation shift, lake level fluctuations and commencement of agricultural practices owing to the changing climatic scenario of the Ganga Plain since the beginning of the Holocene. In addition to the study of lake fill sequences, little attention has also been given to study the modern pollen rain vegetation relationship which have been used as modern analogue for the precise assessment of the pollen sequences from sediment deposits in terms of sequential vegetation succession and climatic events in the studied regions during the Holocene. In this pursuit a few studies have so far been conducted from some areas of Central Ganga Plain such as Jalesar Tal in Unnao District (Trivedi & Chauhan, 2011), Bari Tal, Lucknow District (Trivedi *et al*., 2014), Chaudhary Ka Tal, Raebareli District (Trivedi *et al*., 2016) and the present studied lake, i.e. Kikar Tal (Saxena *et al*., 2017); inferences drawn from these studies has been useful for the judicious appraisal of pollen sequences of the past.

Study Area

The study site–Kikar Tal is located about 55 km southwest of Lucknow City and 2 km north–west of Bachharawan at Long. 81º6'37.78" and Lat. 26º28'47" in Raebareli District at an altitude of 63 m amsl (Fig. 1). The lake is perennial in nature having about 250 m^2 aerial expanse. It is circular in outline with gradual slope and 10–12 m wide marshy margin all around. It is fed by the monsoon rainfall and subterranean water. However, during the monsoon season it gets inundated

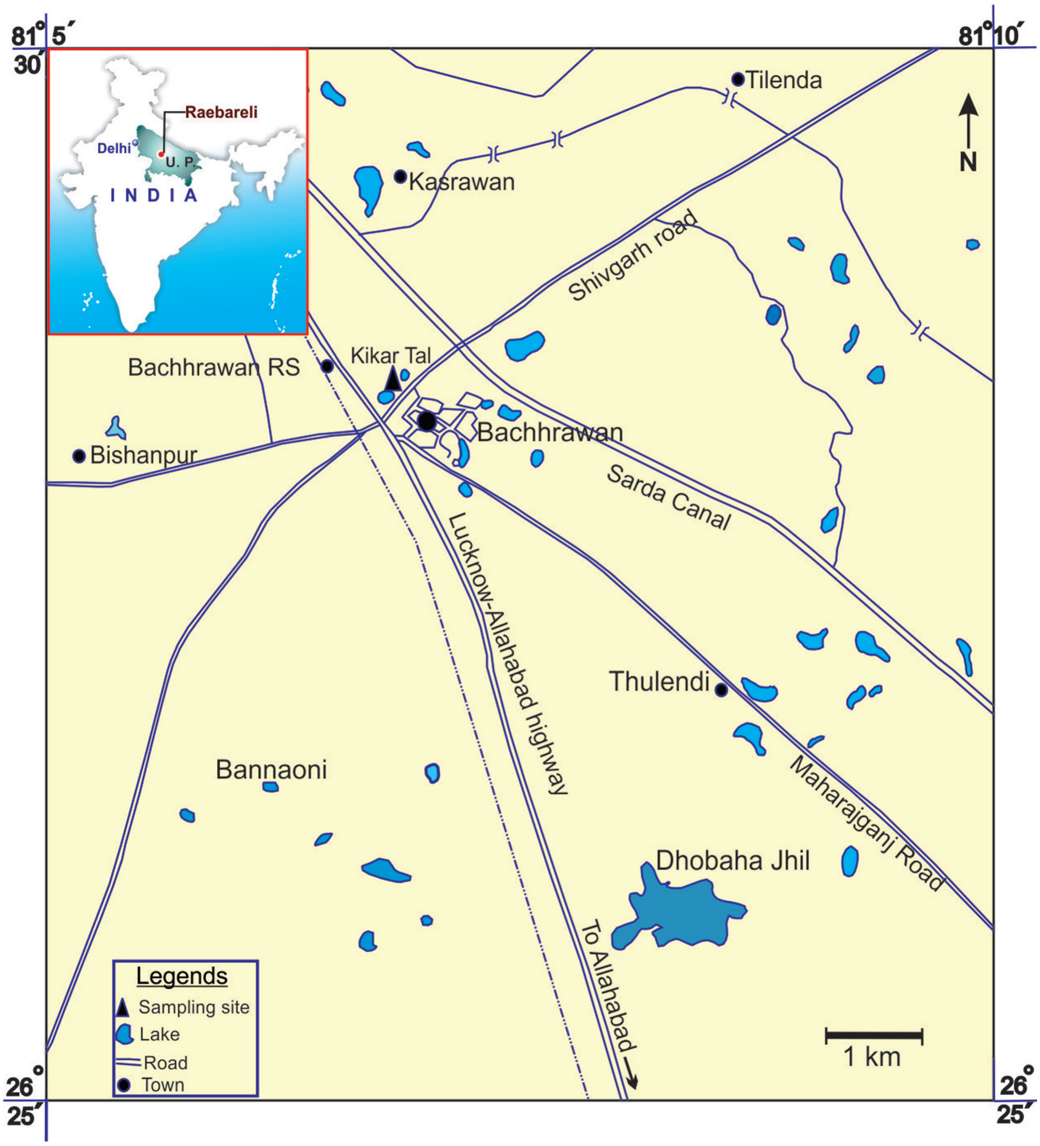

Fig. 1—Map showing study site Kikar Tal in Raebareli District, Uttar Pradesh.

and attains the wider extent. Most of the areas around the lake is under extensive agricultural practices, though, the immediate vicinity of the lake supports dense forest stands. The western and northern flanks have forest groves comprising *Syzygium cumini, Cassia fistula, Mangifera indica, Aegale marmelos* and *Madhuca indica,* whereas eastern flank is partly cultivated with open vegetation and southern flank is under intense agricultural activities. Besides, the dried swampy margin of the lake is overgrown with reed–swamp (tall perennial) grasses, *Phragmites karka* and *Typha latifolia,* a semi aquatic element. The adjoining area of the lake is under intensive cultivation of the conventional crops, viz. wheat, rice together with pulses and sugarcane. Presently, mint is grown by the local people as a cash crop.

Climate

Climate of the region, in general, is humid and largely influenced by southwest monsoon (Chauhan *et al*., 1990). Winter season from November to February is characterized by average minimum and maximum temperatures of 7.6ºC and 21ºC respectively. The temperature seldom descends to 0ºC during the severe cold months of December and January. The average minimum and maximum summer temperatures are 27ºC and 32.5ºC respectively. The temperature ascends up to 46ºC in the month of June. Monsoon season commences in the mid–June and continues till mid–September. The mean average annual rainfall recorded for the nearest city Lucknow is 1020–1140 mm. About 75% rainfall occurs during the monsoon season.

Vegetation

The vicinity of the lake is marked by the patchy occurrence of stands or groves of forest interspersed with stretches of herbaceous vegetation, dominated by grasses (Champion & Seth, 1968). Thus, the landscape imparts a view of open vegetation. The trees, viz. *Syzygium cumini*, *Madhuca indica*, *Holoptelea integrifolia, Acacia arabica*, *A. nilotica*, *Cordia dichotoma*, *Capparis decidua*, *Butea monosperma*, *Symplocos racemosa*, *Ailanthus excelsa*, *Melia azardirach*, *Aegle marmelos*, *Bauhinia variegata*, *Albizia lebbek*, *Flacourtia indica*, *Terminalia arjuna*, *Dalbergia sissoo*, etc. together with thickets of *Ziziphus mauritiana*, *Carissa spinarum*, *Adhatoda vasica*, *Indigofera himalayensis*, *Nyctanthes arbor–tritis*, etc. occur sparingly distributed in the scrub forests. However, in the wasteland adjoining to the cultivated fields and along the dry sandy river beds, *Acacia*–scrub forests dominated by *Acacia nilotica* with scattered thickets of *Prosopis spicigera*, *Ziziphus mauritiana*, *Carissa spinarum* and *Abrus precatoris* can be seen in pockets. Around the habitations *Adhatoda vasica*, *Ricinus communis* and *Mimosa pudica* are frequent. *Mangifera indica*, *Melia azedirach*, *Tamarindus indica*, *Syzygium cumini*, *Dalbergia sisso, Eucalyptus globulus* and *Ficus religiosa* are the common avenue trees.

The herbaceous vegetation constitutes, *Amaranthus*, *Ajuga bracteosa*, *Mazus japonicus*, *Oxalis acetosella, Ageratum conyzoides*, *Vernonia cinerea*, *Sonchus oleraceus*, *Euphorbia hirta*, *E. thymifolia*, *Sida rhombifolia*, *Micromeria biflora*, *Lueca saspera*, *Blumea eriantha*, *Argemone mexicana*, *Parthenium* sp., etc. Sedges such as *Cyperus rotundus*, *Scirpus mucronatus* and *Fimbristyli smiliacea* together with *Polygonum* (now name changed to *Persicaria*) *plebeium*, *Ammania baccifera*, *Rotala rotundifolia*, *Hygrophilla auriculata* and *Alternanthera sessilis* are the major components of the marshy vegetation along the lake margin and banks of streams and rivulets. The aquatic elements including, *Trapa natans*, *Lemna polyrriza*, *Potamogeton cristatum*, *Nymphoides cristata*, *Nelumbo nucifera*, etc. are common in lakes, ponds and ditches. *Eichornea crassipes*, *Trapa natans* and *Chara* sp. form thick and extensive mats on the surface of lentic water bodies throughout the post–monsoon seasons.

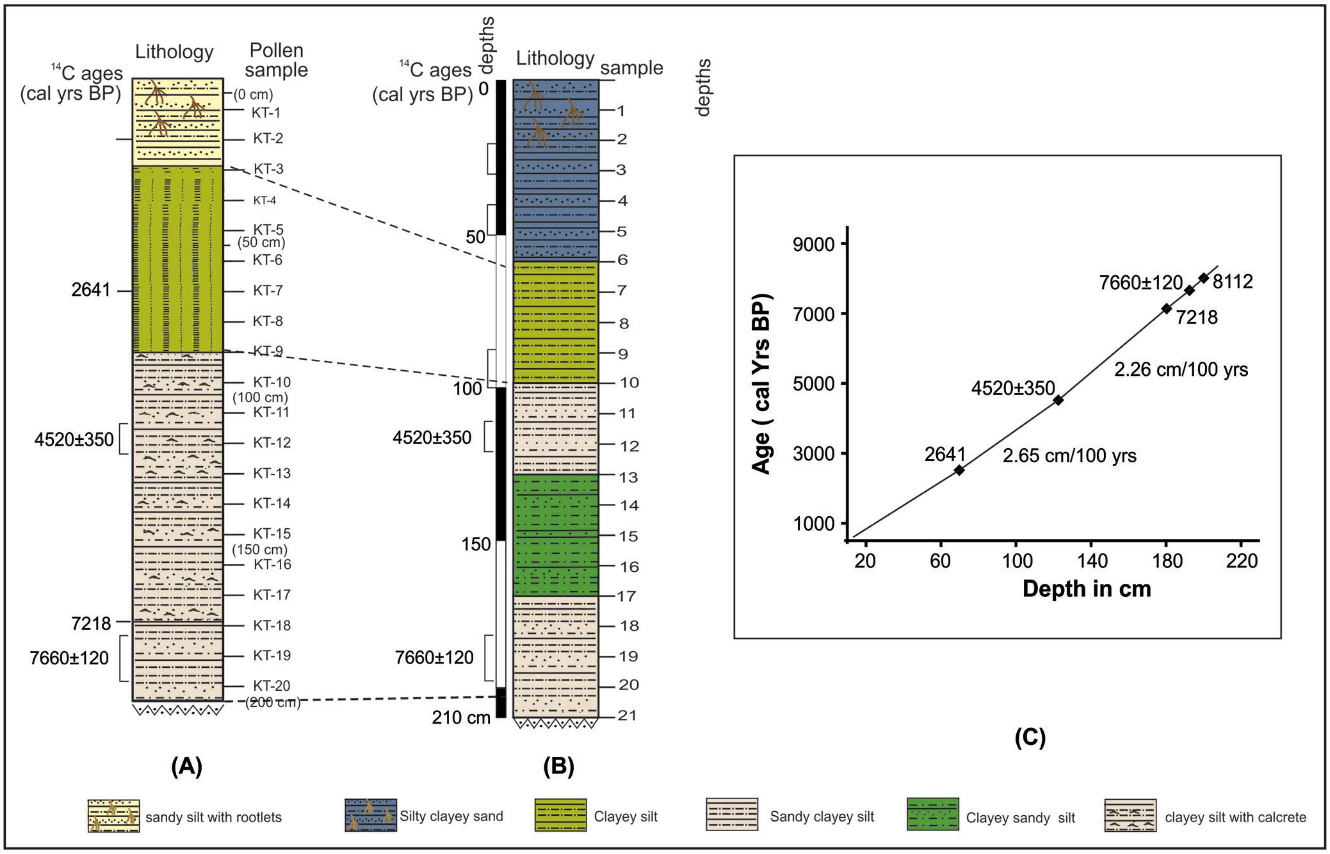

Fig. 2—Lithologs and age correlation of the sedimentary profiles of Kikar Tal and Chaudhary–Ka–Tal, Raebareli District. 2A) Litholog of the Kikar Tal profile with interpolated ages derived from the corroboration with CKT profile (ages given in cal yrs BP). 2B) Litholog of the Chaudhary–Ka–Tal profile with the calibrated ages. 2C) Age–depth plot of sedimentary profile of Kikar Tal based on the corroboration of the chronology of the Chaudhary–Ka–Tal. Rates of sedimentation are also shown (after Saxena *et al.* 2015).

METHODOLOGY

The material for present study includes 10 surface sediment samples and 20 sub–samples from a 200 cm deep trench at 10 cm interval. The data for modern pollen rain analyzed has been dealt elsewhere, significant inferences are discussed here (Saxena *et al.*, 2017).

The ages for the lake profile of Kikar Tal could not be ascertained due to low carbon content by conventional C–14 methods. Therefore, to ascertain the chronology for this profile, we have compared and corroborated the litholgy and depths of Kikar Tal with adjacent lake profile of 2.10 m thick sediment profile of Chaudhary–Ka–Tal (CKT) (about 1.5 km away towards east of Kikar Tal. The same methodology has been used earlier by Saxena & Singh (2016). The 2.10 m thick CKT profile has two calibrated radiocarbon dates:–7,660 ± 120 cal yr BP (BS–3580) at 185–200 cm depth and 4,520 ± 350 cal yr BP (BS–3581) at 115–130 cm depth (Saxena *et al.*, 2015). The lithological variations in both the profiles are very similar and are easily co–relatable (Fig. 2). A close correlation and comparison has been made between the chronology and lithology of both the profiles which suggests that near similar conditions were prevailing during the deposition of sedimentary sequences in both the lakes. This very fact has facilitated us to corroborate the chronology and sedimentation rates. Sedimentation rate is calculated on the basis of these two dates. Respective lithologs and details of the chronology correlation, interpolated ages and sedimentation rates are represented in the Fig. 2.

For the palynological study, 10 gm sediment was boiled with 10% aqueous KOH to deflocculate pollen/spores from the sediment and to dissolve the humic acid. This is followed by the treatment of samples with 40% HF in order to remove silica present in the surface sediments. Thereafter, the standard procedure of acetolysis (Erdtman, 1943) using acetolysing mixture (9: 1 ratio of acetic anhydride and concentrated sulphuric acid) was followed. Finally, the samples for microscopic examination were prepared in 50% glycerin solution.

All the samples analyzed have yielded sufficient number of pollen/spore content. Depending upon the pollen yield of the samples, pollen sums range from 190 to 340. Percentage frequencies of the recovered pollen taxa have been calculated in terms of total terrestrial plant pollen. The pollen of aquatic plants and spores of ferns and other lower cryptogams (algal remains) have been debarred from the pollen sums because of their origin from the local provenances. The precise identification of the recovered pollen/spores–in the sediment was carried out by consulting the reference pollen slides available in the sporothek of BSIP, Herbarium as well as comparing the pollen photographs in the published literature (Chauhan & Bera, 1990; Nayar, 1990). The plant taxa classified as trees, shrubs, herbs, ferns and algal remains

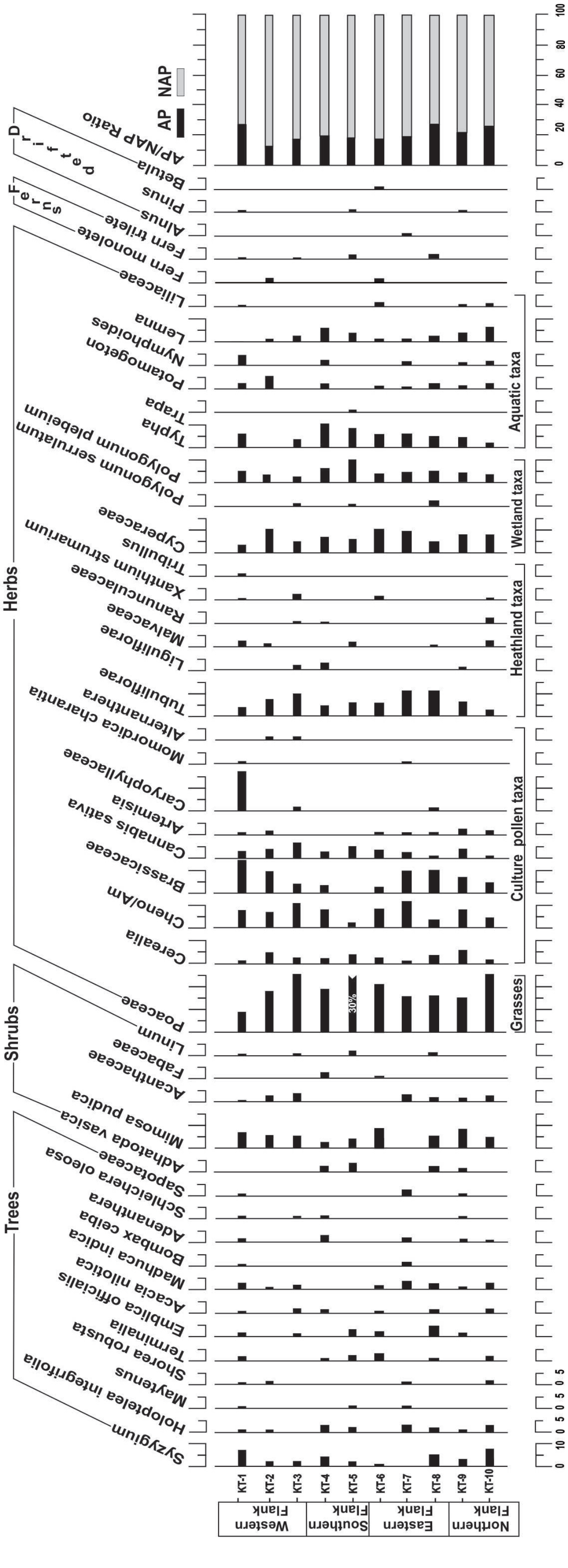

Fig. 3—Pollen spectra derived from the surface sediments of Kikar Tal (Lake).

and are arranged in the same sequence in the pollen spectra. The modern pollen spectra is shown in Fig. 3, and pollen composition recovered from the sediment profile is shown in Fig. 4.

RESULTS

Modern Pollen rain composition

To have an idea about the modern pollen rain vegetation relationship, ten surface sediment samples were also analyzed for their pollen composition. The pollen rain composition of the samples from different flanks has been discussed and described in detail elsewhere (Saxena *et al.*, 2017). The overall dominance of non–arboreals and relatively reduced number and frequencies of arboreals (trees & shrubs) in the assemblage retrieved depicts the much open nature of vegetation around the study site. Trees are few and among them the consistent record of *Syzygium cumini* with av. 3% pollen corresponds to some extent with its presence in the regional floristics (Fig. 3). However, *Madhuca indica* and *Acacia nilotica*, which are also common in the region along with other trees, viz. *Emblica officinalis*, *Holoptelea integrifolia*, *Terminalia*, *Bombax ceiba*, etc. are extremely sporadic, albeit their sparse occurrence in the region, representing a trivial amount of av. 9% pollen only. The under–representation of most of the trees could be ascribed to their low pollen productivity as well as selective preservation of pollen in the sediments. In all, trees are represented by a small fraction of av. 12% pollen and together with av., 3% shrubby elements; they constitute av. 15% arboreal pollen only. Among the non–arboreals (herbs) the preponderance of grasses coupled with appreciable encounter of culture pollen; heathland and wetland taxa portray truly their composition in the ground flora. They constitute the largest chunk of av. 85% pollen. The ground vegetation as usual is dominated by grasses encompassing av. 21% pollen of the total pollen rain in the region. However, the consistent recovery of Cerealia and other culture pollen taxa such as Cheno/Am, *Cannabis sativa*, Brassicaceae, *Artemisia*, etc. with a cumbersome av. 21.6% suggests the extensive cultivation and human interference in the area adjoining to the lake as well as much open nature of the vegetation. The frequent encounter of Cerealia and other culture pollen taxa elucidates the intensive agrarian practice and other human activities in the vicinity of the lake. The consistent record of aquatic elements, particularly *Typha latifolia* and *Lemna* suggests the frequent presence of good numbers of ponds/lakes interspersed in the open vegetation. This comparative database on pollen rain vis–à–vis vegetation serves as modern analogue for the appropriate appraisal of the pollen sequence from the sediment deposits in terms of past vegetation and climate change in the region.

Pollen assemblage from sediment profile

Based on the variations in the pollen composition, the lake profile of Kikar Tal has been subdivided into the four distinct pollen zones. The pollen zones are designated as KT–I, KT–II, KT–III and KT–IV from bottom to top. The zone wise description is given in the followings.

Pollen Zone KT–I (200–180 cm) — *Holoptelea integrifolia–Madhuca indica–Prosopis–Acacia–Poaceae–Tubuliflorae–Cheno/Am–Cyperaceae–Lemna Assemblage*

In the beginning (Pollen Zone KT–I), having the corroborated chronology of ~ 8100 to 7200 cal yrs BP, has the dominance of non–arboreals (herbs) over the arboreals (trees and shrubs). Among the tree taxa, *Holoptelea integrifolia* (3.5–6.2%), *Madhuca indica* (1.5–3.5%), *Acacia* (1.8–3.6%), and *Prosopis* (1.5–3.6%) are the major tree taxa which were present in the area adjoining to the lake, followed by *Syzygium cumini* (0.5–1.5%). The other tree taxa such as *Terminalia* (0.5%) and *Bombax* (0.5%) are recovered in extremely low frequencies. *Mimosa pudica* (2.6–6.5%), Acanthaceae (1.0–3.2%) and *Adhatoda vasica* with moderate values represent the shrubby vegetation.

The non–arboreals are characterized by high frequencies of Poaceae (20.5–25.6%) followed by Tubuliflorae (1.8–14.6%), Cheno/Am (4.2–10.2%). *Cannabis sativa* (3.2%) and *Brassica* (1.2–1.6%) are frequent as compared to *Artemisia* (1.2%) and Caryophyllaceae (1.2%) and *Alternanthera* (0.6%), which are encountered sporadically. The heathland taxa such as Tubuliflorae (4.6–19.6%) is maximum followed by Liguliflorae (4.2%), and Malvaceae (0.5–1.6%) which are recorded in variable frequencies. The marshy element, Cyperaceae (2.2–5.9%) is retrieved in moderate frequencies. *Polygonum (Persicaria) plebeium* (1.2–1.8%) and Liliaceae are recorded in low frequencies. *Lemna* (8.6–14.6%) and *Typha* (1.4–9.2%) are the major aquatic elements with high values. Pollen of drifted elements such as *Pinus* (0.6–1.2%) and *Betula* (0.6%) are rare. Fern monolete and trilete spores (0.6%) are also recorded.

Pollen Zone KT–II (180–120 cm) — *Holoptelea integrifolia–Madhuca indica–Acacia–Syzygium–Poaceae–Cerealia–Cheno/Am–Tubuliflorae––Cyperaceae–Typha–Lemna Assemblage*

Subsequently in the (Pollen Zone KT–II), between the time interval of 7200–4500 cal yrs BP, the forest groves became more diversified and dense in composition as evidenced by the expansion of most of the existing trees such as *H. integrifolia* (1.6–16.6%), *Madhuca indica* (0.6–2.8%) and *Acacia* (0.6–2.6%) as well as presence of *Prosopis* (1.6%), *Moringa* (0.6–1.2%), *Terminalia* (1.6%) and Sapotaceae (0.6–2.1%) in low to moderate frequencies. Shrubby vegetation is represented by thickets of *Mimosa pudica* (0.6–6.2%) and Acanthaceae (1.2–3.2%) in moderate values whereas Fabaceae (0.6%) is

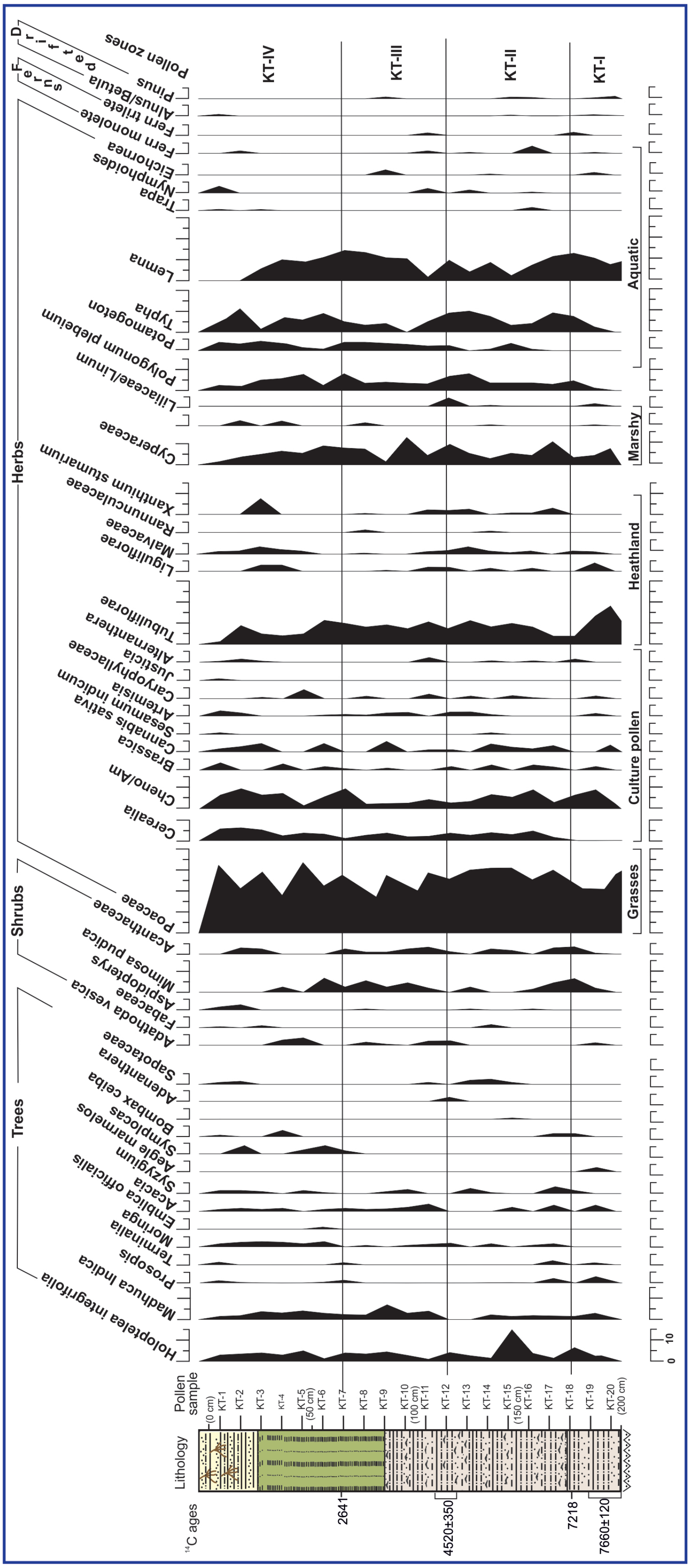

Fig. 4—Pollen diagram derived from the sediment profile of Kikar Tal, Raebareli District.

represented in stray values. The ground flora is dominated by Poaceae (16–23.2%) followed by Cheno/Am (2.8–10.6%) and *Cannabis sativa* (0.6–3%). Cerealia is encounterd first time in this pollen zone and has steady presence (1–4.8%). *Brassica* (0.6–1.8%), *Artemisia* (1.4%) and Caryophyllaceae (0.6–2%) are recovered in sporadic values. *Sesamum indicum* (0.5%) is recorded in one sample only. Among the heathland taxa, Tubuliflorae (4.4–15.2%) shows consistent presence with high values. Malvaceae (0.6–3%), Liguliflorae (0.4–2%) and *Xanthium strumarium* (0.6–2.6%) are also recorded. The marshy elements, Cyperaceae (2.6–11.2%) and *Polygonum plebeium* (1.2–9.3%) show much improvement throughout. Liliaceae is encountered in very low values. There is substantial increase in the aquatic flora as indicated by the significant rise in *Typha* (2.6–11.6%). *Lemna* (1.9–10.8%) and *Potamogeton* (0.8–3%) exhibits fluctuating trends. *Trapa* and *Nymphoides* appear for the first time, though infrequently. Ferns spores are met in very low frequencies. The drifted elements such as *Alnus* (0.5%) and *Pinus* (0.4–1%) are rare.

Pollen Zone KT–III (120–70 cm) — *Holoptelea integrifolia–Madhuca indica–Acacia–Moringa–Mimosa–Poaceae–Cerealia–Cheno/Am–Tubuliflorae—Cyperaceae–Polygonum plebeium–Typha–Lemna Assemblage*

The pollen zone KT–III represents the time interval of 4500 to 2600 cal yr BP, and reveals a decrease in the frequency and diversity of major tree taxa in comparison to the previous pollen zone. *Madhuca indica* (1.8–6.2%) exhibits an increase in its frequency, whereas, *Holoptelea integrifolia* (1.2–3.9%), *Acacia* (1–1.5%), *Moringa* (0.6–2.1%) and *Syzygium* (0.6–2.2%) demonstrate relatively reduced frequencies. *Adenanthera* (0.9%) and Sapotaceae (0.6%) are recorded occasionally. The shrubby elements show decline in *Mimosa pudica* (2.4–4.2%) and Acanthaceae (1.0–2.4%).

The herbaceous vegetation maintains steady presence as in the case of previous zone but with an overall declining trend. Poaceae (14.2–20%) is the dominant element as usual. Cerealia and other culture pollen taxa, such as Cheno/Am (1.8–7.9%) and *Cannabis sativa* (0.6–5%) are moderately present and their frequencies increase in the upper part of this zone. *Artemisia* and Caryophyllaceae are also recorded sporadically. *Brassica* is recorded intermittently. Heathland taxa Tubuliflorae is steadily present. The other terrestrial herbs, viz. Liguliflorae and Malvaceae are poorly represented. Cyperaceae (1–14.2%) and *Polygonum plebeium* (3.3–11.1%) are recorded in high frequencies. The aquatic vegetation is represented by *Potamogeton*, *Typha* (0.6–13.9%) and *Lemna* (1.2–14.2%). *Nymphoides* and *Eichornia* are represented in low values.

Pollen Zone CKT–IV (70–0 cm) — *Holoptelea integrifolia–Madhuca indica–Moringa–Syzygium–Mimosa pudica–Poaceae–Cerealia–Cheno/Am–Tubuliflorae–Malvaceae–Cyperaceae–Polygonum plebieum–Potamogeton–Typha–Lemna Assemblage*

The terminal zone (Pollen Zone KT–IV), encompasses the time span since last 2600 cal yrs BP to Present, elucidates continued declining trend in the arboreal (trees and shrubs). *Holoptelea integrifolia* (1.2–3.2%), *Madhuca indica* (0.6–3.2%), *Acacia* (0.6–1.2%) have much lower frequencies as compared to the previous pollen zone. However, *Moringa* (1–2.2) and Symplocas (2.2–2.9%) reappear in this zone and denotes increasing frequencies. Sapotaceae (1.2%) and *Bombax* (2.2%) reappear in this zone, though very scarcely. *Emblica officinalis* appears for the first time in this zone. The shrubby element, viz. *Mimosa* represent considerable decline and disappear in the upper part of this pollen zone. *Aspidopterys* (0.8–2.2%) and Acanthaceae (1.1–1.8%) are poorly represented.

The ground vegetation has expanded and diversified during this time interval. Poaceae (18–27.2%) has enhanced values. Cerealia (3–6.8%), Cheno/Am (1.6–8.9%), *Brassica* (2.3–3.2%) and *Cannabis sativa* (1.8–3.2%) show remarkable increase in their frequencies. *Alternanthera, Justicia,* Caryophyllaceae and *Sesamum indicum* (0.6%) are sporadically represented in this zone. The heathland taxa, viz. Tubuliflorae also reveals decline in their number; whereas, Malvaceae Liguliflorae and *Xanthium strumarium* have slightly increased values though occur intermittently. The marshy elements, viz. Cyperaceae (0.6–10.9%) and *Polygonum plebeium* (1.2–7.2%) decline in the upper part of this zone. The aquatic taxa, *Typha* (1.1–14.6%) and *Potamogeton* is marked by some enhanced values, whereas, *Lemna* declines considerably and disappear altogether in the upper part of this zone. *Nymphoides* (2.5%) is recorded in one sample only. *Alnus* (0.4%) is recorded scantily.

DISCUSSION

The pollen analysis of the lake sediment profile of the Kikar Tal coupled with corroborated radiocarbon ages has led to envisage four different phases of changing climatic conditions and vegetation pattern since early Holocene in the Ganga Plain.

It is envisaged that in the beginning around ~8100–7200 cal yrs BP, (Pollen Zone KT–I), forest groves with *Holoptelea*, *Acacia, Madhuca indica, Syzygium* and *Prosopis* as major tree taxa were present in the area adjoining to the lake. The forest groves were interspersed with wider stretches of open vegetation comprising grasses, and elements of heathland taxa, Chenopodiaceae/Amaranthaceae, (Cheno/Am), etc. and scanty shrubs of *Mimosa pudica*, *Adhatoda vasica* and Acanthaceae. The open herbaceous vegetation was largely constituted of grasses, members of Tubuliflorae, Liguliflorae, Cheno/Am with moderate presence of *Cannabis sativa, Brassica*, followed by scattered occurrence of Malvaceae, Caryophyllaceae and *Artemisia*. The considerable record of pollen of aquatic elements, such as *Lemna* and *Typha* denotes the existence of the lake during this early part of the Holocene.

In addition, the lake had a well–developed marshy fringe all around as manifested by the consistent presence of wetland elements, such as Cyperaceae and *Polygonum plebeium*. This vegetation scenario reflects that the region was under a warm and humid climate during that time. Similar kind of climatic condition has also been interpreted from the other adjoining records of Central Ganga Plain (Chauhan *et al.*, 2009; Saxena *et al.*, 2013, 2015; Sharma *et al.*, 2004; Trivedi *et al.*, 2013). Interestingly, the abundance of Asteraceae (Tubuliflorae) throughout this phase infers that the region was also under intensive pastoral activities, because the plants of this family are unpalatable to goats and cattle (Vinscens *et al.*, 1997); hence more pollen abundance is observed in the sediments.

In the overlying pollen zone (Pollen Zone KT–II), during the time bracket of 7,200 and 4,200 cal yrs BP, there was an expansion and diversification of the forest groves. This is very well substantiated by the incursion of many new tree taxa, such as *Moringa*, *Bombax ceiba* and members of Sapotaceae along with the significant improvement in the prior existing tree taxa, viz. *Holoptelea intigrifolia*, *Madhuca indica*, *Terminalia*, *Acacia* and *Syzygium* in the region coupled with the thickets of *Mimosa pudica*, *Adhatoda vasica*, Acanathaceae and Fabaceae. However, the diversity and expansion is much more pronounced in the beginning of the zone, and towards the upper part of the zone the frequency in tree taxa decline. This change in the vegetation pattern might be the result of initiation of a warm and more–humid climatic condition due to the active SW monsoon. Similar vegetation scenario and climatic condition has been inferred from Lahuradewa pollen sequence in eastern Uttar Pradesh for almost same time bracket (Chauhan *et al.*, 2009) and Chaudhary–Ka–Tal (Saxena *et al.*, 2015). In global context, this phase of expansion of trees corresponds with the Period of Climatic Optimum, which is well known between 7,000 and 4,000 yr BP (Bradley, 1999). The herbaceous vegetation was dominated by grasses as usual. Though in comparison to the previous pollen zone, it became more prolific as evidenced by the significant improvement in Poaceae and other herbs including *Brassica, Cannabis sativa, Justicia*, *Sesamum* and members of Caryophyllaceae with heathland taxa, such as Tubuliflorae, Liguliflorae, Malvaceae and *Xanthium strumarium*. The first occurrence of Cerealia pollen in this zone together with other concomitant cropland weeds, such as Cheno/Am, *Cannabis sativa*, *Brassica*, etc. suggests the commencement of cereal–based agricultural practice in the vicinity of the lake as well as other kinds of anthropogenic activities in the adjoining region. This might have occurred on account of extension of cultivated land in response to prevailing favourable climatic condition in the region. The consistent presence of marshy and aquatic elements, such as Cyperaceae, *Typha*, *Potamogeton* and *Lemna* indicates the expansion in the lake area and wetland/marshy conditions along the lake margin.

Subsequently, between the time bracket of 4,200 and 1,800 cal yrs BP (Pollen Zone KT–III) more or less similar kind of vegetation scenario continued to flourish in the region. The forest groves continued to flourish with expansion in *Holoptelea*, *Madhuca*, *Acacia* and *Syzygium* with decline in few trees, such as *Terminalia*, *Prosopis* and *Bombax. Madhuca indica* attained significant improvement. Likewise, the shrubby vegetation also continued to thrive significantly in this phase. Thickest of *Mimosa pudica* and Acanthaceae have attained their acme. The herbaceous vegetation reflects considerable fluctuations with overall declining trend in the diversity and frequency. Similar trends are also noticed in the marshy and aquatic vegetation. Though Cyperaceae and *Lemna* had attained their maximum frequency, yet their overall pattern exhibits diminishing pattern. Thus, by and large the decline in the non–arboreal vegetation might have occurred on account of change in climate, which became warm and relatively less–humid, attributable to weakening of SW monsoon. Similar vegetation scenario and climatic condition have been noticed at Lahuradeva in Sant Nagar District (Chauhan *et al.*, 2009) and Jalesar Lake in Unnao District (Trivedi *et al.*, 2013), Chaudhary–Ka–Tal, Raebareli District (Saxena *et al.*, 2015) based on pollen and geochemical evidence. The agricultural practice continued to thrive in the region, as evidenced by presence of Cerealia and other culture pollen taxa representing subtle changes.

In the topmost pollen zone (Pollen Zone KT–IV), from 1,800 cal yrs BP to Present, significant expansion and diversification is encountered in the trend of the prominent arboreals, such as *Holoptelea*, *Madhuca indica*, *Acacia, Moringa* and *Syzygium* along with new incursion of *Symplocas* and *Emblica officinalis*. The increase in the tree taxa might be the result of conservation and cropping by the local folks for its multifaceted use, such as fodder, food, fuel, etc. (Saxena *et al.*, 2015). The overall depletion in the shrubby vegetation with the exception of *Aspidopterys* suggests that the open vegetation with sparingly distributed trees was established due to the reduction in the monsoon precipitation. The herbaceous vegetation is much diverse in composition with the dominance of grasses and was growing steadily as in the previous phases. The upsurge in the Cerealia pollen and other culture pollen taxa suggest the continuation of increased agrarian practices in the region. The open grassland vegetation corresponding to the present vegetation scenario in the region on account of further reduction in monsoon precipitation, resulting into a warm and less–humid climate in the region. The decline in the aquatic elements also exhibits the shrinkage of lake during this time of sediment accumulation. A concurrent vegetation scenario, indicating equivalent climatic condition have been noticed from Lahuradewa Lake in Sant Kabir Nagar District (Chauhan *et al.*, 2009) and Jalesar Lake, Unnao District (Trivedi *et al.*, 2013).

CONCLUSIONS

The palynological analysis and corroborated chronology of lacustrine sedimentary profile of Kikar Tal has provided important outcome about the vegetational history and corresponding climatic events since the early Holocene.

It is envisaged that during 8,000–7,200 cal yrs BP, forest groves were present in the adjoining area of the lake, which were interspersed with wider stretches of open vegetation. This vegetation scenario reflects prevalence of warm and humid climate during that time. The existence of lake is manifested by the presence of aquatic elements.

During 7,200–4,200 cal yrs BP, the forest groves became more diversified and dense in composition as evidenced by the expansion of most of the existing trees and shrubby elements owing to climate amelioration and suggesting the continuation of a warm and more–humid climatic condition.

The increasing trend of Cerealia coupled with concomitant cropland weeds signifies the augmentation in Cereal–based agrarian practice owing to favourable climatic condition.

The lake also expanded as manifested by the increase in aquatic elements, such as *Typha*, *Potamogeton* and *Lemna* during this period.

During the time bracket of 4,200–1,800 cal yrs BP, the arboreal reveals a decrease in their frequency and diversity indicating reduced monsoon.

From 1,800 cal yrs BP–Present, palynological data elucidates open grassland vegetation and significant decline in the marshy and aquatic elements corresponding to reduced monsoon precipitation, with the shrinkage of lake area.

The presence of Cerealia and other culture pollen taxa suggests the prevalence of intense agrarian practice in the vicinity of the lake during the late Holocene.

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