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POLLEN-BASED VEGETATION AND CLIMATE CHANGE IN SOUTHWESTERN MADHYA PRADESH (INDIA) DURING THE LAST 3300 YEARS

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ABSTRACT

Pollen analysis of a 1.25 m deep sediment core from Kachia Jhora-Lake, Sehore District, southwestern Madhya Pradesh (India) has displayed that between 3350 and 2250 yr BP, the vicinity of the lake supported open mixed tropical deciduous forest comprising mainly *Madhuca indica*, *Acacia*, *Terminalia*, Sapotaceae, *Grewia*, *Aegle marmelos*, *Tectona grandis*, etc. together with the scanty presence of *Emblica officinalis*, *Syzygium*, *Holoptelea*, *Lagerstroemia parviflora*, thickets (a few) of Fabaceae, Acanthaceae and *Ziziphus*. The overall vegetation scenario implies that the area experienced a warm and less humid climate than today owing to reduced monsoon precipitation. Between 2250 and 800 yr BP, with the invasion of a few more arboreals viz. *Mitragyna parvifolia*, *Delonix regia*, *Schleichera oleosa*, *Legerstroemia parviflora*, *Shorea robusta*, *Haldina cordifolia* and improvement in the already existing taxa viz. *Madhuca indica*, *Terminalia*, *Acacia*, *Holoptelea*, etc., the forest became dense and varied in composition. This transformation in the floristics could be attributed to the prevalence of a warm and relatively more humid climate in response to increased monsoon precipitation. Since 800 yr BP onwards, the considerable decline in the forest is manifested by the reduced frequencies of most of the forest constituents such as *Acacia*, *Mitragyna*, *Terminalia*, *Grewia*, *Holoptelea* and *Lannea coromandelica* except for *Madhuca indica*, *Aegle marmelos* and *Ailanthus excelsa* which remained static. This diminution in the forest composition infers the onset of a warm and moderately humid climate most likely due to reduction in monsoon precipitation. Cereal-based agriculture practice was present in every phase but its pace increased in the latter two phases.

Keywords: Pollen analysis, Vegetation, Climate, Southwestern Madhya Pradesh, India

INTRODUCTION

With the prime objective of reconstructing the palaeovegetation and palaeoclimate from one of the core monsoon zones of India, the present study was carried out. On the basis of pollen, the palaeoclimatic studies have been carried out from the various regions of India such as from the higher elevation of the western Himalaya (Bhattacharayya, 1988, 1989; Sharma, 1992; Chauhan *et al*., 1997, 2000; Phadtare, 2000; Kar *et al*., 2002; Chakraborty *et al*., 2006; Chauhan, 2006; Bhattacharayya *et al*., 2006a, 2006b, 2011a); temperate belt of the Eastern Himalaya (Sharma and Chauhan, 1994, 2001; Ghosh *et al*., 2014; Bhattacharrya *et al*., 2014); south-central and central Kumaun, North India (Kotlia *et al*., 1997, 2000) and the alpine area of Northeast Himalaya (Bhattachrayya *et al*., 2007). However, the tropical regions covering the major landscape of peninsular and some parts of extra peninsular India with a large number of potential lakes/swamps for Quaternary palaeoclimatic studies have not yet achieved due attention barring information from Rajasthan Desert (Singh *et al*., 1972, 1974, 1990; Bryson and Swain, 1981; Enzel *et al*., 1999; Sharma et al., 2003); southern India (Sukumar *et al*., 1993); south Indian mountains (Vishnu-Mittre, 1962, Vishnu-Mittre and Gupta, 1968, 1971; Bera *et al*., 1997; Bera and Farooqui, 2000); east coast (Farooqui and Vaz, 2000); West coast (Farooqui *et al*., 2010); south-eastern Arabian Sea (Farooqui *et al*., 2014); western coast (van Campo, 1983; Tissot, 1996; Caratini *et al*., 1991); eastern coast (Vishnu-Mittre and Gupta, 1972; Gupta, 1981; Gupta and Khandelwal, 1992); Ganga Plain (Sharma *et al*., 2004, 2006, Chauhan *et al*., 2003, 2009; Trivedi *et al*., 2012); southwest Tripura (Bhattacharayya *et al*., 2011b); Assam (Dixit and Bera, 2011, 2012, 2013), Gujarat (Prasad *et al*., 2013), Odisha (Tripathi *et al*., 2014), Chhattisgarh (Quamar and Bera, 2014a, 2015, *in press*), etc. However, Madhya Pradesh, one of the richest botanical provinces, possessing about 24-26% of the total forest flora of the country and also abounds with a large number of natural potential lakes/swamps of varying dimensions for Quaternary palaeovegetation and palaeoclimatic studies. It has been, nonetheless, paid no due attention and the studies carried out only from north-eastern (Chauhan, 1995, 2000, 2004, 2005; Yadav *et al*., 2006; Chauhan *et al*., 2013), south-eastern (Chauhan, 2002; Chauhan and Quamar, 2010), as well as from the central regions (Shaw *et al*., 2007) of this phytogeographycally-rich state have provided valuable insights related to the changing scenarios of the vegetation and contemporary climate during the Late Quaternary Period (especially the Holocene). The southwestern Madhya Pradesh has also, so far, received less attention on this aspect, except few (Quamar and Chauhan, 2011, 2012, 2014; Chauhan and Quamar, 2012a, 2012b). Hence, in the present paper an endeavour has been made to extend such studies to other areas in order to unravel the changing vegetation scenarios and coeval climatic episodes owing to the fluctuating trend of southwest monsoon since the last 3300 years in southwestern Madhya Pradesh through the pollen analysis of a 1.25 m deep sediment core from Kachia Jhora, Sehore District. In addition, the pollen proxy records have also enabled to understand lake-level changes and intensity of agriculture practice in the region, which is solely dependent on monsoon fluctuations (Quamar and Chauhan, 2011, 2012, 2014; Chauhan and Quamar, 2012a, 2012b).

STUDY AREA

Kachia Jhora-Lake lies about 25 km east of Budhani township in the vicinity of Shahganj in Sehore District between 77° 40' E Long. & 22° 52' 25" N Lat. on the right bank of the Narmada River (Fig.1). The lake is small and shallow with highly waterlogged swampy margin and measures about 15m

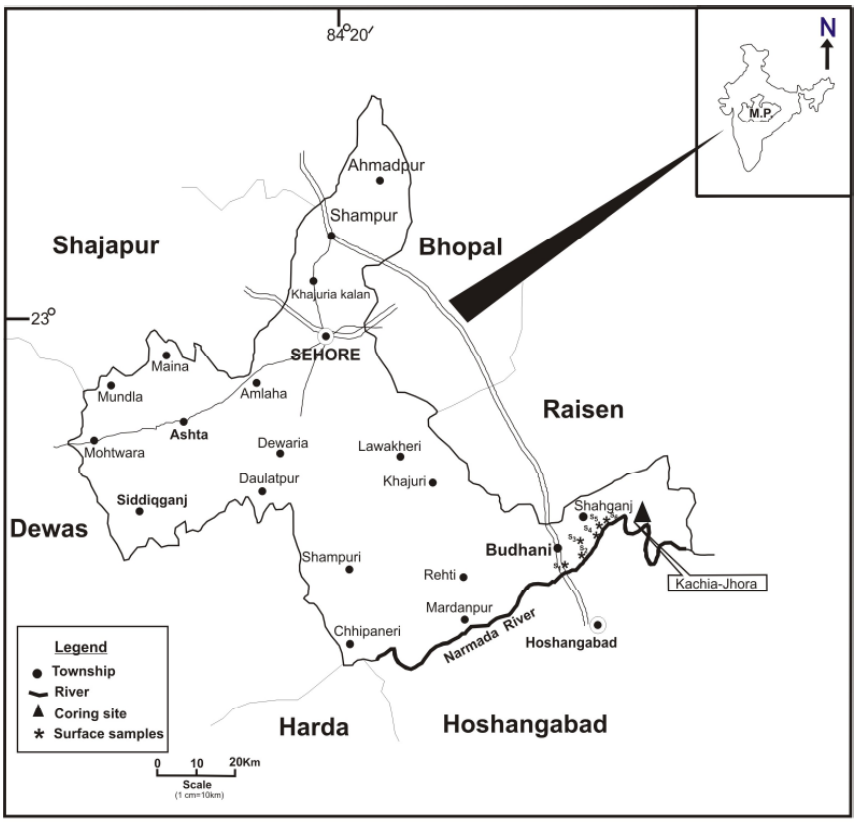

Fig. 1. Map showing the investigation site in Sehore District.

long and 4 m wide. The immediate proximity of the lake has gentle slopes and the flat area on its north is under intense agricultural practice by the local folks. The geomorphological features and the general landscape of the area give an impression of the prolonged existence of the lake. However, the plateau region extending from east to west with altitude ranging from approximate 1800' to 2000' amsl, supports the dense tropical deciduous teak forest.

VEGETATION AND CLIMATE

The vegetation around the lake and the adjoining hill slopes is characterisd by the presence of tropical deciduous teak (*Tectona grandis*) forests (Champion and Seth, 1968). Apart from teak, *Madhuca indica*, *Diospyros melanoxylon*, *Terminalia arjuna*, *T. tomentosa, Butea monosperma*, *Buchanania lanzan*, *Syzygium cumini*, *Emblica officinalis*. *Adina cordifolia*, *Lagerstroemia parviflora*, *Mitragyna parvifolia*, *Anogeissus latifolia* and *Schleichera oleosa* are the other prominent constituents of these forests. *Wrightia tinctoria, Kydia calycina, Bridelia retusa, Bauhinia retusa, B. integrifolia, B. malabarica, B. racemosa, B. purpurea*, *Elaeodendron glaucum, Aegle marmelos, Chloroxylon sweitenia, Melia azedarach*, *Ficus benghalensis*, etc. occur occasionally in the forests. *Ziziphus mauritiana*, *Melastoma malabathricum*, *Woodfordia fruticosa*, *Strobilanthes angustifrons*, etc. are the common shrubs in the forest, whereas *Ricinus communis*, *Adhatoda vasica*, *Carissa opaca*, etc. are frequent around the habitations.

The terrestrial herbaceous vegetation comprises grasses, *Sida rhombifolia*, *S. cordifolia*, *Argemone mexicana*, *Blumea eriantha*, *Oxalis acetocella*, *Leucas aspera*, *Mazus japonicas*, *Euphorbia hirta*, *E. thymifolia*, *Sonchus* sp., *Achyranthes aspara*, *Cynodon dactylon*, *Trigonella foenum*, *T. occulata*, etc. However, reed swamp grass-*Phragmites vulgaris* and *Typha latifolia* grow profusely over the swamps. *Hydrocotyle sibthorpioides*, *Ammania baccifera*, *Hygrophila auriculata*, *Polygonum plebeium, Centella defformis*, *C. verticillata*, *Rotala rotundifolia*, *Cyperus rotundus, Carex speciosa*, *Scirpus triangulatus*, etc. are the other swampy taxa, which occur preponderantly along the lake margins as well as water courses. The aquatic elements such as *Lemna paucicostata*, *Potamogeton nodosus*, *Nymphoides cristata*, *N. stellata*, etc. dwell commonly in the lake, ditches and water accumulated areas. The pteridophytic taxa growing in damp and shady situations includes *Adiantum philippensis*, *Dryopteris prolifera*, *Ceratopteris thelictroides Ophioglossum reticulatum*, *Equisetum debile*, *Selaginella lepidophylla*, *Lycopodium clavatum*, etc.

The area experiences a warm and humid climate. The mean average summer maximum and minimum temperatures are 32º C and 27º C, respectively. However, temperature seldom shoots up to 48º C during the hottest month of June. The mean average winter maximum and minimum temperatures are 17º C and 7º C, respectively, however, the temperature descends to 1º C during the extreme cold month of January. The average annual rainfall recorded is approximately 1340 mm. About 92 % rainfall, out of the total annual precipitation, occurs during the rainy season.

MATERIAL AND METHODS

Material for the present study includes both surface samples and a sediment core. Six surface samples were collected randomly from the mixed teak tropical deciduous forest in a linear transect at an interval of 100 m each to study the pollen deposition pattern in the region. A 1.25 m thick sediment core was collected from the south bank of Kachia-Jhora using Hiller's peat augur. A total number of 25 samples were extracted from the core at an interval of 5cm each for pollen analysis.

Four distinct lithological zones are discernible from top to bottom in the core, based on the variable sediment texture at different depths. The topmost lithozone is thickest and composed of greyish clay. This is followed by blackish grey clay with coarse sand. Underlying this is the greyish clay zone with pebbles. The bottommost stratum is made up of greyish clay with sand. The depth-wise lithostratigraphical details of the core are set out in the Table 1:

Table 1: Showing lithologic details of the sediment core.

Depth (in cm)	Lithology
0-75	Greyish clay
75-90	Blackish grey clay with coarse sand
90-100	Greyish clay with pebbles
100-125	Greyish clay with sand

One sample at the depth of 80 to 100 cm has been dated as 2,400±100 (BS-2965) by radiocarbon method. Hence, based on this single date and considering the surface as modern, the

sedimentation rate has been calibrated to 27 yrs/1cm for this core. Assuming this as constant for the whole sediment core, three more dates, i.e. 3350 yr BP at 125 cm depth, 2250 yr BP at 90 cm depth and 800 yr BP at 30 cm depth, have been extrapolated in order to delineate the sequential vegetation changes and coeval climatic events in the region in a definite time frame.

Ten grams of samples were boiled in 10% aqueous KOH solution for 5 minutes to deflocculate the pollen/spores from the sediments and to dissolve the humus. This is followed by treatment of the samples with 40% HF solution in order to remove the silica. Subsequently, the samples were acetolysed (Erdtman, 1943), using acetolysing mixture (9:1 ratio of acetic anhydride and concentrated sulphuric acid). Finally, the sample was prepared in 50% glycerin solution for microscopic examination.

The surface and core samples analyzed were found quite prospective in their pollen/spore content. The pollen sums vary from 396 to 726 for surface samples and 167 to 363 for core samples, depending upon their pollen productivity. The pollen of aquatic plants and fern spores have been excluded from the pollen sums because of their origin from local sources. For the authentic identification of sub-fossil palynomorphs in the sediments, the reference pollen slides available at BSIP Herbarium as well as the pollen photographs in the published literature (Nayar, 1990; Chauhan and Bera, 1990) were consulted. The recovered pollen taxa categorized as trees, shrubs, herbs, fern spores, algal remains and drifted are arranged in the same manner in the pollen spectra and pollen diagram.

MODERN POLLEN RAIN-VEGETATION RELATIONSHIP

For the proper appraisal of pollen deposition pattern vis-à-vis the modern vegetation from the study site, 6 surface samples (S-1 to S-6) were analysed (Fig.2). This comparative database generated on pollen rain-vegetation relationship has been taken as a modern analogue for proper assessment of the pollen sequence from the sedimentary bed in terms of past vegetation and climate.

The pollen assemblage obtained from mixed tropical deciduous teak forest portrays the dominance of non-arboreals (herbs) over arboreals (trees and shrubs). Amongst the tree taxa, *Madhuca indica* (8.81-36%) is recorded constantly in high frequencies. *Grewia* (0.49-3.99%) and *Acacia* (0.49-4.40%) too are present consistently in low to moderate frequencies. Sapotaceae (5.11-8.47%) are met with in high values, though in a few samples. The other tree taxa such as *Tectona grandis* (0.68-1.34%), *Aegle marmelos* (<0.5-1.22%), *Symplocos* (<0.5-1.73%) and *Lannea coromandelica* (0.13-0.51%) are recovered sporadically in low frequencies, whereas *Shorea robusta*, *Haldina cordifolia*, *Lagerstroemia parviflora*, *Mitragyna parvifolia*, *Ailanthus excelsa*, *Butea monosperma*, *Terminalia*, *Schrebera*, *Delonix regia* and *Bombax ceiba* (<0.5% each) are retrieved occasionally. The shrubby elements, *Caesalpinia* (1-3%) and Fabaceae (1.23-3.85%) are met with in moderate frequencies compared to *Rungia* (0.5%), *Triumfetta*, *Dendrophthoe*, *Ricinus* and *Ziziphus* (<0.5% each), which are rare.

The ground flora is marked by the consistently high frequencies of Poaceae (12.13-29.46%). Tubuliflorae (1.79-19.55%), *Evolvulus alsinoides* (4.26-9.97%), Lamiaceae (0.98-8.67%), Caryophyllaceae (3.27-7.67%), Chenopodiaceae/ Amaranthaceae (Cheno/Am) (1.79-4.67%), *Borreria* (0.55-3.28%), Malvaceae (<0.5-3%) and *Xanthium* (0.98-2%) are also consistent in moderate values. Cerealia pollen (<0.5-0.68%) is recorded intermittently in very low frequencies. However, *Justicia* (0.50-10.48%) is recorded from moderate to high values. Interestingly, its pollen is present in bunches of 100 in sample S-4 and 30 in sample S-5. *Ranunculus*, *Tribulus alatus*, *Alternanthera*, Convolvulaceae (1% each), *Cannabis sativa*, *Solanum* and Brassicaceae (<0.5% each) are scanty. Cyperaceae (3.68-6.33%) are recorded in high frequencies, whereas the rest of the marshy taxa viz., *Polygonum plebeium* (1.96-3.03%), *Pimpinella* (0.41-1.54%) and *Polygala glomerata* (<0.5%) are encountered infrequently in low to moderate frequencies. The aquatic elements such as *Typha* (0.41-1%), *Lemna* and *Nymphoides* (<0.5% each) are meagre. Fern trilete spores (0.77-17.13%) are retrieved consistently in high values, whereas lycopods (<0.5-1.79%) is present sporadically. The Himalayan elements such as *Cedrus* (0.50-1%), *Abies* and *Pinus* (<0.5% each) are feebly present. Algal spores such as zygospores of *Zygnema* (1-10.78%) exhibits high values consistently, while *Spirogyra* (0.34-0.57%) are recorded irregularly in low values. *Pediastrum* (0.19%) is present only in sample S-6. Fungal spores

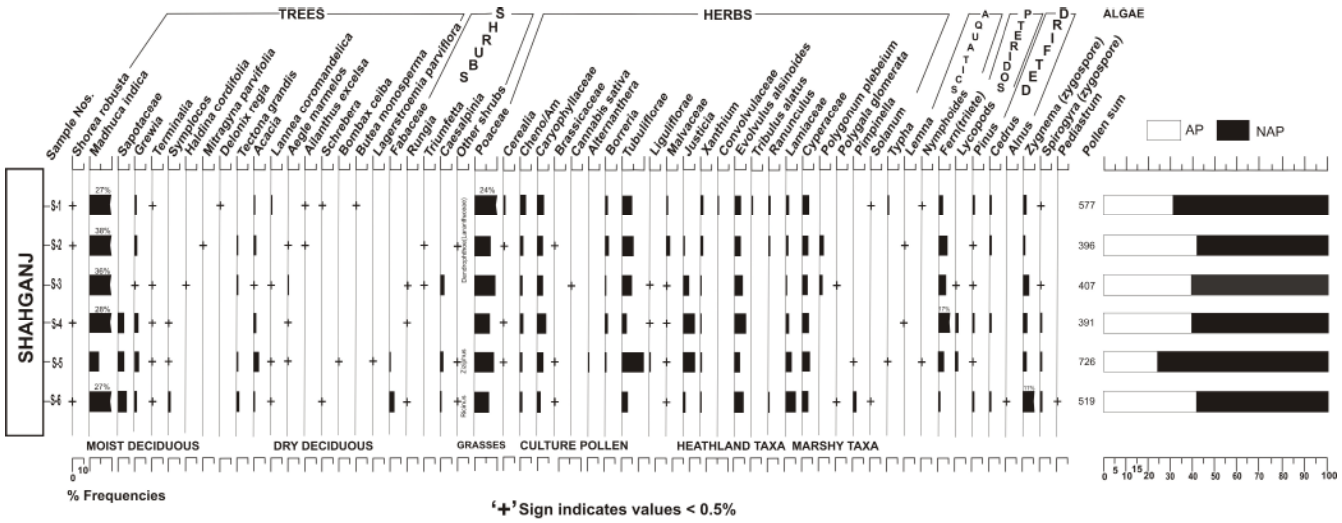

Fig. 2. Modern pollen spectra from Shahganj, Kishanpur, Sehore District.

viz., *Glomus*, *Nigrospora*, *Curvularia*, *Diplodia*, *Cookeina* and Microthyriaceae are present in fluctuating frequencies.

The pollen rain composition, thus, has revealed the dominance of non-arboreals and relatively low frequencies of arboreals, except *Madhuca indica*, which has been steadily encountered in high frequencies (5-38%) with an av. of 26.83% pollen of the total pollen rain. The better representation of *Madhuca indica* pollen could be inferred to its frequent presence in the open area and outskirt of the forest as well as good preservation of its pollen in the sediments. *Grewia*, *Acacia* and Sapotaceae are also somewhat better represented. Interestingly, *Tectona grandis*-a dominant forest constituent is lowly recovered with av. 1% pollen in the sediments, despite its frequent presence along the roadside and margin of cultivated field. Similarly, *Butea monosperma* occurring usually in the adjoining open area is also lowly represented. The other tree taxa viz., *Terminalia*, *Mitragyna parvifolia*, *Delonix regia*, *Schrebera*, *Ailanthus excelsa*, *Lannea coromandelica*, *Adina cordifolia*, etc. are recovered scarsely with average 9.5% pollen of the total pollen rain. The irregular representation of most of the tree taxa, despite their good presence in the forest floristics could be attributed to their low pollen productivity since they exhibit a strong tendency of entomophily (Chauhan, 1994, 2008; Chauhan and Quamar, 2013; Quamar and Chauhan, 2007, 2009, 2013a, 2013b; Quamar and Bera, 2014b, c; 2015a, b). The presence of non-arboreals such as grasses, Tubuliflorae, Cheno/Am, Caryophyllaceae, *Evolvulus alsinoides*, *Justicia*, *Lamiaceae*, etc. in the pollen rain corresponds to some extent with their composition in the ground flora. The retrieval of Cerealia and other culture pollen taxa viz., Cheno/Am, Caryophyllaceae, Brassicaceae, *Alternanthera* and *Cannabis sativa* in variable frequencies demonstrates the nearness of cultivated land and human habitation to the study area. The moderate presence of sedges and scarce record of other marshy elements such as *Polygala glomerata*, *P. plebeium*, *Pimpinella* and *Solanum* reflect the low marshy cover around the study area. Ferns and their allies flourish occasionally in the restricted damp and shady situations as well indicated by their scanty record. The encounter of pollen of *Pinus*, *Cedrus* and *Alnus* in moderate to low frequencies point to their exclusive wind transport from the Himalaya as there is no watercourse leading to central India from the said region.

DESCRIPTION OF POLLEN DIAGRAM

For the better understanding of the sequential changes in the palaeofloristics and contemporaneous climatic events in a chronological order in the region, the pollen diagram (Fig.3) has been divided into three distinct pollen zones, based on the fluctuating trend of the prominent arboreals and non-arboreals. These pollen zones are prefixed with the initials 'KJ' after the name of the investigation site and are numbered (KJ-I, KJ-II & KJ-III) from bottom to top and are described as below:

***Pollen Zone KJ-I (125-95cm)*: *Madhuca indica-Acacia*-Sapotaceae-*Terminalia*-Poaceae-Tubuliflorae-Cyperaceae-Ferns assemblage**

This pollen zone encompassing a time span of 3350 to 2250 yr BP demonstrates the dominance of non-arboreals over arboreal taxa. Among the arboreals, the prominent taxa-*Madhuca indica* (3.12-9%) followed by *Acacia* (1.49-5.80%) are encountered consistently in moderate to high frequencies, whereas *Terminalia* (0.41-3.51%), *Grewia* (0.37-2.07%), Anacardiaceae (0.27-1.68%), *Tectona grandis* (0.74-1.09%), Sapotaceae (1.09-1.61%), *Emblica officinalis*, *Aegle marmelos* and *Holoptelea* (0.26-1.19% each) are recorded infrequently in moderate to low values. The others viz., *Diospyros* (0.41-0.78%), *Butea monosperma* (0.40-0.70%), and Meliaceae (0.72% in one sample KJ-24 only), *Syzygium*, *Symplocos*, *Lagerstroemia parviflora*, Anacardiaceae, *Bombax ceiba*, *Lannea coromandelica* (<0.5% each) are represented in extremely low frequencies.

Among the shrubby elements, Fabaceae (0.82-4.10%) are recorded in good frequencies, whereas Acanthaceae (0.72%),

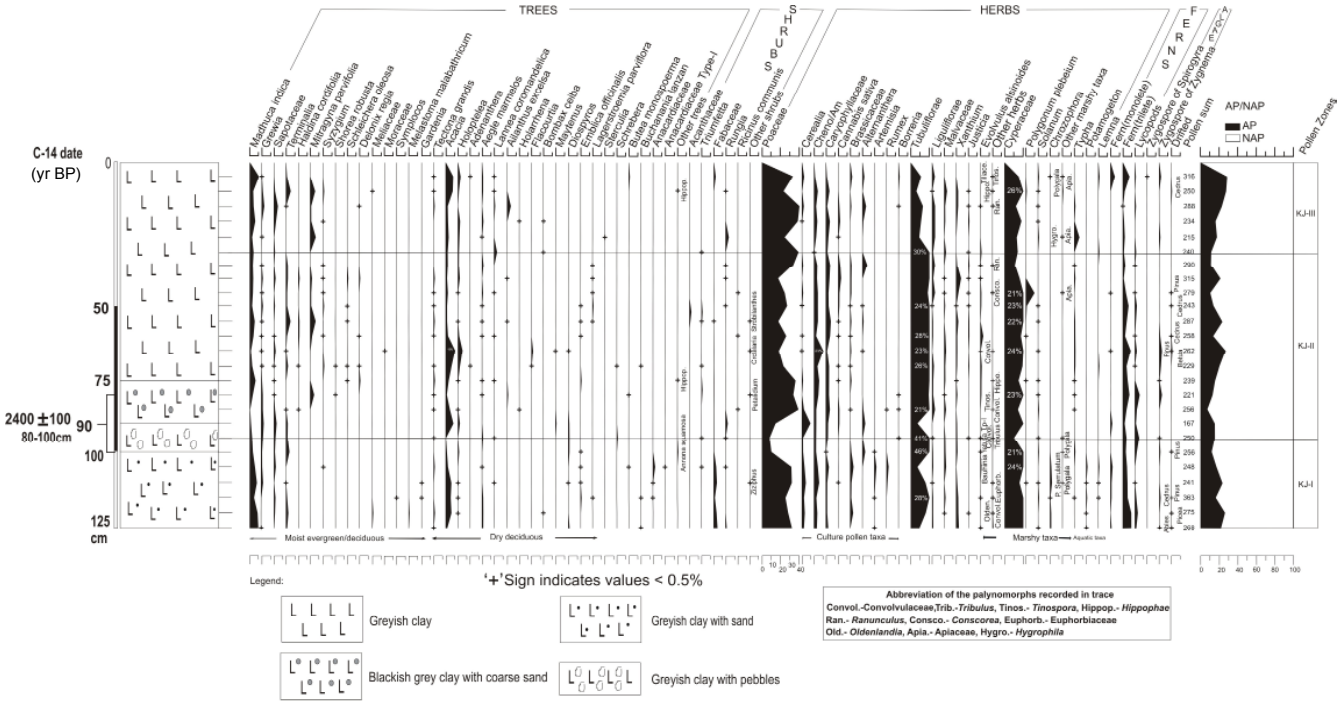

Fig. 3. Pollen diagram from Kachhia Jhora, Sehore District.

Rungia and *Melastoma malabathricum* (0.40-0.74% each), *Triumfetta* and *Ziziphus* (<0.5% each) are scarce.

The herbaceaous vegetation is represented by high frequencies of Tubuliflorae (7.20-46.09%) followed by Poaceae (9.76-33.53%). Cheno/Am (1.56-5.39%), Brassicaceae (0.54-3.20%), Caryophyllaceae (0.39-2.80%), Cerealia (0.78-2.54%) and *Xanthium* (0.82-2.61%) are recorded in moderate values. *Alternanthera* (2.73%) is encountered in moderate value in sample KJ-20 only. Others viz., Liguliflorae (0.41-1.19%), Malvaceae (0.36-1.60%), Convolvulaceae and *Evolvulus alsinoides* (0.27-0.80% each), *Justicia*, *Oldenlandia*, *Chrozophora* (0.27-1.65%) and Euphorbiaceae (<0.5% each) are feebly present. Cyperaceae (15.76-24.25%) are encountered steadily in high values, whereas *Solanum* (0.37-0.41%, as well as bunch of 100 pollen in one sample KJ-22 only), *Polygala* and *Polygonum plebeium* (<0.5% each) are scanty. The aquatic taxa, *Potamogeton* (0.36-1.20%), *Lemna* (0.27-0.80%) and *Typha* (0.41-0.78%) are occasional. Fern trilete spores (3.12-8.95%) are better represented in contrast to monolete spores (0.82-1.60%) and lycopods (0.41-2.54%). Algal remains- *Zygnema* zygospores (0.37-0.82%) are intermittently retrieved in low values. Drifted pollen of *Picea* and *Abies* (<0.5% each) are sporadic. Fungal spores such as *Nigrospora*, *Curvularia*, *Glomus*, *Diplodia Tetraploa*, Microthyriaceae, *Alternaria*, bi-celled ascospore and *Helminthosporium* have high to low frequencies, though sporadically.

***Pollen Zone KJ-II (95-35cm)*: *Acacia-Madhuca indica*-Tubuliflorae-Cyperaceae-Ferns assemblage**

This pollen zone with a solitary radiocarbon date of 2400±100 yr BP at 80-100cm depth and covering a time bracket of 2250 to 800 yr BP reveals again the dominance of non-arboreals. *Acacia* (0.78-13.35%), *Mitragyna parvifolia* (0.70-5.92%), *Madhuca indica* (0.59-5.85%), *Holoptelea* (0.34-4.85%) and *Terminalia* (0.39-4.52%) are the principal forest constituents as marked by their high frequencies, whereas Sapotaceae (0.38-2.99%), *Grewia* (0.34-2.07%), *Haldina cordifolia* (0.39-1.24%), *Aegle marmelos* (0.40-1.36%), *Tectona grandis* (0.35-1.09%) and *Syzygium* (0.31-0.87%) are also better represented in contrast to *Lagerstroemia parviflora*, *Lannea coromandelica*, *Buchanania lanzan* (<0.5% each), which are sporadic in moderate to low values. The other tree taxa such as *Schleichera oleosa* (0.34-0.93%), *Ailanthus excelsa* (0.31-0.90%), *Delonix regia*, *Flacourtia* and *Schrebera* (0.32-0.82% each) and *Shorea robusta* (<0.5%) appear for the first time. *Emblica officinalis* (0.34-0.82%), *Butea monosperma* (0.46-0.74%), *Hippophae*, *Maytenus*, *Diospyros*, *Holarrhena*, *Adenanthera* (<0.5% each) are stray. The shrubby taxa, *Rungia* and *Triumfetta* (0.34-1.23% each) are better represented as compared to Fabaceae, *Ricinus communis*, *Petalidium*, *Crotalaria* and *Strobilanthes* (<0.5% each). However, Acanthaceae (2.05%) have moderate value in one sample only.

Tubuliflorae (5.6-56%) as well as Poaceae (8-40.27%) are the dominant elements among the herbs in this pollen zone too. Cheno/Am (1.93-22.51%, also in bunch of 100 in one sample KJ-17 only), *Alternanthera* (0.38-5.17%), *Xanthium* (0.41-4.76%) and Caryophyllaceae (2-4.52%) are also recorded in high to moderate to low frequencies. Cerealia (0.38-8.98%) has comparatively high values, but encountered sporadically as compared to the preceding pollen zone. Liguliflorae (0.41-2.86%), *Evolvulus alsinoides* (0.31-2.71%), *Cannabis sativa* (0.34-2.53%), Malvaceae (0.31-1.56%), *Tribulus alatus* (1.16%) and *Justicia* (0.31-0.87%) have moderate to low values, however, *Rumex*, *Ranunculus*, *Conscorea* and *Tinospora* (<0.5% each) are trivial. Cyperaceae (10-41.31%) maintained its high frequencies despite its slightly reduced values compared to the preceding pollen zone. *Polygonum plebeium* (0.38-9.31%) has intermittently high value. Other marshy elements viz., *Solanum* (<1%) and *Polygala* (<0.5%) are occasional in contrast to the preceding pollen zone. Apiaceae (<0.5%) appears for the first time. *Typha* (0.34-1.24%) and *Lemna* (<1%) are rare. Fern trilete spores (0.93-7.23%) and lycopods (0.34-4.97%) have higher values than monolete spores (0.35-0.38%). Algal remains- *Zygnema* zygospores (0.93-2.67%) are recorded in moderate values. The sub-tropical and temperate elements viz., *Pinus*, *Cedrus* (<0.5% each) and *Betula* (0.76%) are sporadic. The fungal spores such as *Nigrospora*, *Glomus*, *Curvularia*, *Diplodia*, *Cookeina*, ascospores and Microthyriaceae are encountered in fluctuatingly high to moderate to low values.

***Pollen Zone KJ-III (35-0cm)*: *Madhuca indica-Acacia-Mitragyna parvifolia*-Sapotaceae-Poaceae-Tubuliflorae-Cyperaceae-*Typha*-Ferns assemblage**

This topmost pollen zone with the temporal range of 800 yr BP to Present depicts the dominance of non-arboreals (herbs) and relatively much reduced frequencies of arboreals. *Madhuca indica* (2.32-12.65%), *Acacia* (2.10-7.91%) and *Mitragyna parvifolia* (1.04-5.98%) are the major constituents among the trees. Sapotaceae (0.8-4.16%), *Terminalia* (0.34-4.8%) and *Lannea coromandelica* (0.31-3.28%) too have good frequencies, despite their infrequent presence. *Ailanthus excelsa* is present in good value in one sample only. *Holoptelea* (1.2-2.10%) and *Aegle marmelos* (0.46-1.26%) have moderate to low values. The other tree taxa viz., *Butea monosperma* (0.63%) as well as *Holarrhena*, Anacardiaceae, *Sterculia*, Meliaceae and *Delonix regia* (<0.5% each) are feebly present.

Among the shrubby elements, *Rungia* (0.4-3.25%) and Fabaceae (1.58%) are recorded sporadically in moderate values, whereas *Triumfetta* and *Ricinus communis* (<0.5% each) are rare. All these taxa decrease considerably in comparison to that witnessed in the preceding pollen zones.

Among the herbs, grasses (23.2-39.16%) and Tubuliflorae (5.6-29.58%) retain their high frequencies. However, Tubuliflorae decline in this pollen zone. Cheno/Am (0.41-4%), Caryophyllaceae (0.69-3.84%) and Liguliflorae (0.4-3.12%) are consistently retrieved in low to moderate values, whereas *Alternanthera* (0.84-3.8%), Malvaceae (0.69-3.2%), *Xanthium* (0.84-2.08%), *Borreria* (0.34-2.08%), Brassicaceae (0.69-1.89%), *Cannabis sativa* (0.46-1.70%) and *Evolvulus alsinoides* (0.34-1.23%) are met with occasionally in low to moderate values. Cerealia (0.42-2.21%) shows increasing trend. The other herbaceous taxa such as *Justicia* (0.34-0.84%), *Tinospora* (0.63%), *Chrozophora* and *Ranunculus* (0.34% each) are present inadequately. Among the marshy elements, Cyperaceae (11.80-26.8%) exhibits increasing trend, whereas Apiaceae (0.31-1.2%), *Polygala* (0.12%), *Solanum* (0.34-0.93%) and *Polygonum plebeium* (0.8%) become more sporadic than in the previous zone. *Hygrophila* (0.46%) is the new addition in this pollen zone. Trilete fern spores (0.34-7.27%) are better represented than monolete spores (4.43%) and lycopods (0.69-1.23%), which are sporadically represented in low to moderate values. Algal remains- zygospores of *Zygnema* (1.39-1.89%) and *Spirogyra* (0.31%) are in low values. *Cedrus* (0.8%) is the only Himalayan element. The fungal spores such as *Nigrospora*,

Glomus, *Curvularia*, *Diplodia*, *Cookeina*, Microthyriaceae and *Alternaria* are recorded in high to low values.

DISCUSSION

The pollen data obtained from the investigation of 1.25m deep sediment core from Kachia Jhora, Sehore District has provided some dependable information concerning the temporal and spatial change in vegetation in response to climate change in the southwestern Madhya Pradesh since the last 3300 years. The emerged out pollen sequence has demonstrated that between 3350 and 2250 yr BP (KJ-I), open mixed tropical deciduous forest largely encompassing *Madhuca indica*, *Acacia*, *Terminalia*, Sapotaceae, *Grewia*, *Aegle marmelos*, *Tectona grandis*, *Diospyros*, etc. occurred in the region. The other deciduous trees such as *Emblica officinalis*, Anacardiaceae, *Gardenia*, *Symplocos*, *Syzygium*, *Holoptelea*, *Annona squamosa*, *Lagerstroemia parviflora*, *Flacourtia*, etc., together with thickets of Fabaceae as well as *Rungia*, Acanthaceae and *Ziziphus* were sparsely distributed in the forests. By comparing the overall vegetation composition with the modern analogue as described elsewhere (in the section- Modern pollen rain-vegetation relationship), it could be deduced that a warm and less humid climate prevailed (during this phase) in the region than today, which could be most probably ascribed to reduced monsoon precipitation. Almost similar observation has been made at Basaha Jheel, Central Ganga Plain, Unnao District, U.P. (Chauhan and Chatterjee, 2008), where open vegetation occupied the region under semi-humid climate around 3300 yr BP. The herbaceous flora on the forest floor was composed by Tubuliflorae, grasses, *Xanthium*, Liguliflorae and Malvaceae. The vicinity of the lake was under incipient cereal-based agriculture practice by the local populace as well as some other sort of human activities, which is substantiated by the consistent presence of Cerealia and other culture pollen taxa viz., Cheno/Am, Caryophyllaceae, Brassicaceae, *Alternanthera*, *Artemisia*, *Rumex* and *Cannabis sativa*. The retrieval of *Typha*- a semi-aquatic plant, *Potamogeton* and *Lemna* as well as *Zygnema* in fluctuatingly low values signals the existence of the lake. The lake was encircled by a wide swampy margin as portrayed by the preponderance of sedges (Cyperaceae) together with meagre presence of others viz., *Polygonum plebeium*, *P. serrulatum* *Solanum* and *Polygala*. Ferns and their allies inhabited luxuriantly in the moist and shady situations around the lake and in the adjoining forest stands. The record of pollen of *Pinus*, *Abies* and *Picea* is indicative for the Himalayan connection of wind circulation pattern, which facilitated their long distance transport from the Himalaya.

Subsequently, between 2250 and 800 yr BP (KJ-II) with the incursion of a large number of trees such as *Mitragyna parvifolia*, *Delonix regia*, *Schlriechera oleosa*, *Ailanthus excelsa*, *Shorea robusta*, *Haldina cordifolia*, *Adenanthera*, *Diospyros*, etc. and much frequent occurrence of *Madhuca indica*, *Terminalia*, *Acacia*, *Holoptelea*, *Lannea coromandelica*, *Holarrhena*, Sapotaceae, *Grewia*, etc. depict that the open mixed tropical deciduous forests transformed into dense and varied mixed tropical deciduous forests. However, *Butea monosperma*, *Schrebera*, *Maytenus*, Moraceae, *Hippophae* were scarce. This enrichment in the forest floristic demonstrates that the region enjoyed a warm and relatively more humid climate on account of intensification of southwest monsoon. This phase shows partial similarity with the second last phase of Jagmotha Swamp, Sidhi District, north-eastern M.P. (Chauhan, 2000), and Saapna Lake, Betul District (Chauhan and Quamar, 20012a) as well as the second phase of Deosila Swamp, Assam (Dixit and Bera, 2011), and the last phase of Amjhera Swamp, Hoshangabad district, south-western M.P. (Chauhan and Quamar, 2012b). As usual, the ground vegetation was dominated by grasses together with other prominent heathland taxa viz., Tubuliflorae, *Xanthium*, Liguliflorae, Malvaceae, etc. The agricultural practice might have continued in the region with relatively high pace as testified by the improvement in Cerealia pollen. Further, the enhancement in other culture pollen taxa such as Cheno/Am, Caryophyllaceae, *Cannabis sativa*, *Alternanthera* and *Rumex* (though decreased a bit) is suggestive of the escalating human impact in the region. The rising trend of sedges as well as other accompanying taxa viz., *Polygonum plebeium*, *Solanum* and Apiaceae reflects the expansion of marshy condition around the lake. The lake attained a wider stretch than before as is deciphered by the somewhat increased frequencies of *Typha*, *Lemna* and freshwater alga-*Zygnema*. Ferns and lycopods flourished well in damp and shady habitats in the lake milieu.

Since 800 yr BP to Present (KJ-III), the diminishing trend of most of the forest ingredients viz., *Acacia*, *Tectona grandis*, *Haldina cordifolia*, *Syzygium*, *Terminalia*, Sapotaceae, *Holoptelea*, *Lannea coromandelica* and *Delonix regia* as well as the overall reduction in a number of forest constituents in contrasts to that seen in the preceding phase elucidates that the mixed tropical deciduous forest got less diversified in floristic composition. However, *Madhuca indica*, *Mitragyna parvifolia*, *Aegle marmelos* and *Ailanthus excelsa* continued to be the major forest constituents more or less alike as in the preceding phase. The others, such as *Holarrhena*, *Bombax ceiba* (a savannah element) and *Hippophae* occurred sparingly in the forests together with shrubby elements namely *Rungia*, Fabaceae and *Triumfetta*. This dwindling of the forest composition in terms of diversity and density with the advent of this phase reveals that a warm and relatively moderate humid climate prevailed in the region, which could perhaps be the consequence of a reduction in southwest monsoon rainfall than witnessed in the preceding phase. This phase coincides partly with the last phase of Kachhar lake, Sehore District, south-western M.P. (Quamar and Chauhan, 2011). This is also supported by a concurrent expansion of grasses and better representation of other heathland herbs viz., Liguliflorae (Asteraceae), *Xanthium*, Malvaceae, etc., which invaded instantly the available open area. The agricultural practice continued in the region with more or less same intensity since Cerealia and concomitant cropland weeds viz., Chenopodiaceae/Amaranthaceae, Caryophyllaceae, *Alternanthera*, Brassicaceae, *Cannabis sativa*, etc. do not portray any marked change in their representation. The marshy condition around the lake has maintained its similar status as earlier because sedges and other marshy taxa such as *Solanum*, *Polygonum plebeium*, *Polygala* and Apiaceae do not exhibit any change. However, the lake shrank as portrayed by the scanty retrieval of aquatic elements - *Typha* and *Lemna* as well *Zygnema* - a fresh water alga.

CONCLUSIONS

The pollen record of a lacustrine sediment core from south-western Madhya Pradesh has provided significant insights concerning the shifts in vegetation and coeval climate as well as agrarian activities, its subsequent pace owing to the varying trends of southwest monsoon and lake-level changes since the last 3300 years (Fig. 4). Our main results are as follows:

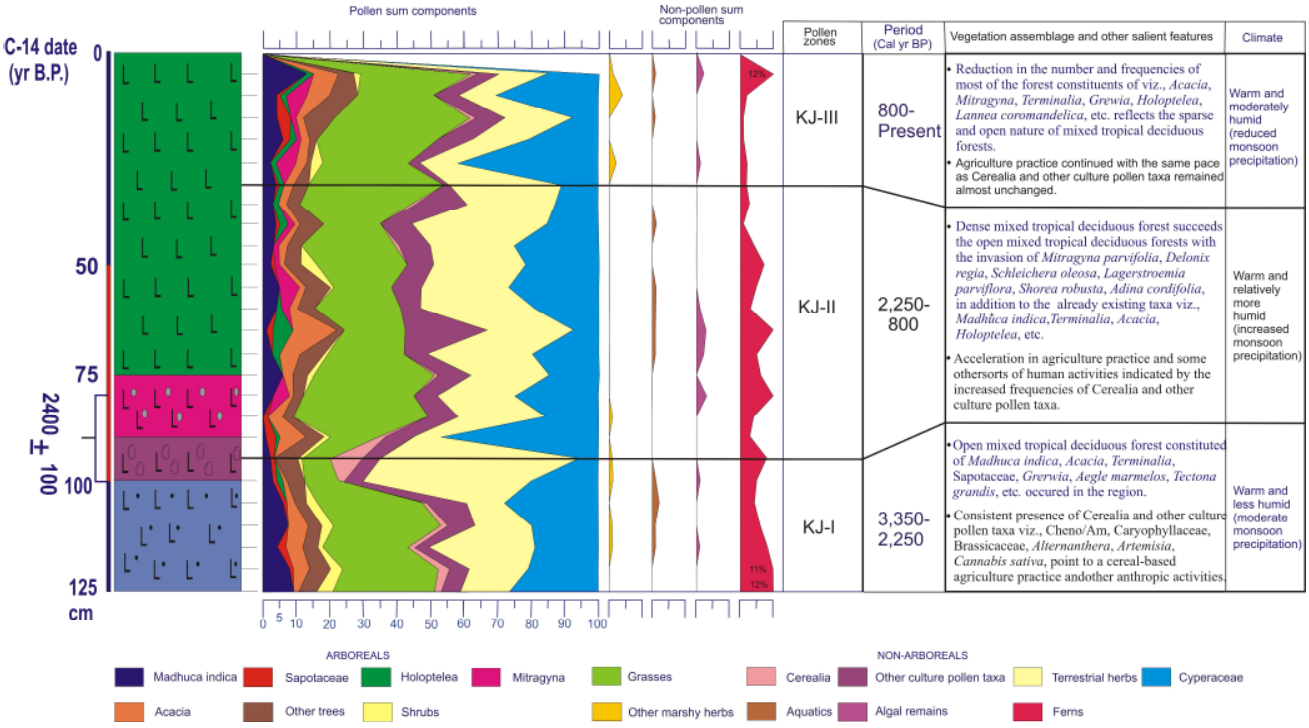

Fig. 4. Summary pollen diagram showing the salient features of the present investigation.

1. Between 3350 and 2250 yr BP, open mixed deciduous forests surrounding the lake existed under a warm and less humid climate than today, which could be indicative of reduced monsoon precipitation.
2. Between 2250 and 800 yr BP, the open mixed deciduous forests got dense and varied in the floristic composition with the invasion of a large number of forest ingredients in response to the onset of a regime of warm and relatively more humid climate with increased monsoon precipitation.
3. From 800 yr BP to Present, with the depletion of most of the tree constituents the forests again turned into open mixed deciduous type as a result of change in climate which becomes warm and moderately humid in contrast to that prevailed earlier.
4. Incipient cereal-based agricultural practice was present in the study area but its pace increased during the latter two phases.
5. Lake existed in the region which became wide in the latter phase owing to the increased monsoon precipitation. However, it got shrunk in the last phase because of reduced monsoonal rainfall.

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