Late Holocene vegetation, climate change and human impact in southwestern Madhya Pradesh, India

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ABSTRACT

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Pollen analysis of a 2 m deep sediment profile from the dried Kachhar Lake, Sehore District, has demonstrated that between 2050 and 1610 yr BP, open *Acacia*-scrub forest constituted of *Acacia* cf. *nilotica*, *Grewia*, *Mitragyna*, Sapotaceae flourished in the region under relatively warm and humid climate with moderate monsoon precipitation, than that prevails today. The retrieval of fragmentary charcoals implies the repeated forest fire incidences. The presence of Cerealia and ruderal plant taxa, viz. *Cannabis sativa*, Cheno/Am, Caryophyllaceae, etc. suggests the agricultural practices in the region. Between 1610 and 600 yr BP, *Acacia*-scrub forest turned profuse with expansion of *Acacia* cf. *nilotica* and other arboreals, viz. *Shorea robusta*, *Terminalia*, *Grewia* and *Madhuca indica* in response to more-humid climate with the onset of increased monsoon precipitation. Agriculture practice continued with same intensity as before. Since 600 yr BP onwards, the climate changed to less-humid as indicated by decline in *Acacia*-scrub forest. The decline in Cerealia reflects the low pace of agriculture practice.

Key-words—Late Holocene, Vegetation, Climate, Pollen analysis, Southwestern Madhya Pradesh.

भारत में दक्षिण पश्चिम मध्य प्रदेश की अंतिम होलोसीन वनस्पति, जलवायु परिवर्तन एवं मानवीय प्रभाव

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सारांश

जिला सेहोर की मौजूदा सूखी हुई कछार झील से प्राप्त 2 मी. गहरी परिच्छेदिका के पराग विश्लेषण ने दर्शाया है कि 2050 और 1610 वर्ष पूर्व के मध्य, साधारण मानसून अवक्षेपण सहित कोष्ण व आर्द्र जलवायु की सापेक्षतया के अंतर्गत क्षेत्र में *एकेशिया* के तुलनीय *निलोटिका, ग्रेविया, मित्रगायना,* सेपोटेसी के संघटित खुले एकेशिया-झाड़ी वन फल-फूल रहे थे जो कि आज प्रवृत्त है। खंडित लकड़ी के कोयले की पुनः प्राप्ति बारंबार वन अग्नि घटनाएं दूषित करती है। अनाज व कूड़ावासी पौधा टैक्सा अर्थात *भाँग,* कीनो, कैरियोफिलेसी इत्यादि की मौजूदगी क्षेत्र में खेती-बारी सुझाते हैं। 1610 व 600 वर्ष पूर्व के बीच, बढ़ते मानसून अवक्षेपण की शुरूआत के साथ अति-आर्द्र जलवायु की अनुक्रिया में *एकेशिया* जाति *निलोटिका* व अन्य वृक्षीय अर्थात *शोरिया रोबस्टा, टर्मिनेलिया ग्रेविया* और *मधुका इंडिका* के फैलाव के साथ *एकेशिया*-कुंज वन प्रचुर हो गया। खेती-बारी पहले जैसी तीव्रता की तरह होती रही। 600 वर्ष पूर्व से, जैसा कि ऐकेशिया-कुंज वन में ह्वास से इंगित है जलवायु अल्प-आर्द्र में तब्दील हो गई अनाज में अवनति खेती-बारी की अल्प प्रगति प्रतिबिंबित करती है।

संकेत-शब्द—अंतिम होलोसीन, वनस्पति, जलवायु, पराग विश्लेषण, दक्षिण-पश्चिमी मध्य प्रदेश।

INTRODUCTION

The Quaternary palaeovegetational and palaeoclimatic data from central India have so far been generated from eastern Madhya Pradesh comprising Sidhi and Shahdol districts only through the pollen analytical investigation of sedimentary deposits. These studies have furnished some cardinal facts concerning mainly the vegetation succession in response to climatic variability at larger intervals during the Holocene from the eastern region (Chauhan, 1995, 2000; Yadav *et al*., 2004) where much diversified tropical deciduous sal forests occupy most of the landscape. However, the information on the short-term climatic variability and its impact on the forest resource, particularly during the last 2 millennia have not yet received ample attention, barring a few reports from the eastern part of Madhya Pradesh (Chauhan, 2002, 2004, 2005; Chauhan & Quamar, 2010). In the present communication, an attempt has been made to bring out short-term climatic variability, vegetation shifts and pace of agriculture practice during the last two millennia in southwestern Madhya Pradesh through the pollen analytical studies of a series of samples at close intervals from a 2 m deep sediment profile from the catchment of the Narmada River in Sehore District.

The site Kachhar Lake stands about 1.5 km southeast of Kishanpur Village and 10 km east of Budhani between 77°40' Long. & 22°52'25" Lat. in Sehore District (Fig. 1). It lies in a deep gorge along the left bank of a perennial stream locally known as Ghatwala Nala. The Narmada River flowing about 500 m in the east has a wider stretch and hence most of the area here gets inundated during the rainy season. Topographically, the entire area is flood plain of the Narmada River and characterized by undulating and flat land surface. Geologically, this catchment area of the Narmada falls under Ramnagar Formation (Khan, 1992), which comprises the sediments that are being deposited in this flood plain. Most of the area in the ambience of Kachhar is under extensive cultivation of traditional crops. The moderate mountain range with altitudinal range of 500 m to 600 m, running from north to
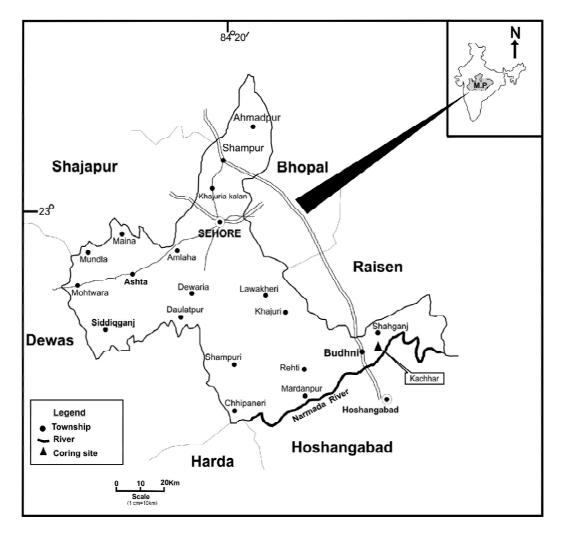

Fig. 1—Map showing the investigation site in Sehore District.

west adjacent to the investigation site, is marked by gentle slopes and supports luxuriant tropical deciduous teak (*Tectona grandis*) forest.

Climate of Sehore District, in general, is humid and is largely influenced by southwest monsoon. The summer season is marked by high temperature with average annual minimum and maximum of 24°C and 32°C respectively. However, temperature reaches a maximum of 43°C to 47°C during the extreme hot months of May and June. Winter season from November to January is marked by cold climate with average minimum and maximum temperatures of 7°C and 17°C respectively. However, the temperature goes down as low as 1°C in the extreme cold months of December and January. The average annual rainfall of the area is approximately 1200 mm.

The vegetation of the region is characterized by the dominance of tropical deciduous teak (*Tectona grandis*) forests (Champion & Seth, 1968). The other frequent associates of teak are *Diospyros melanoxylon*, *Buchanania lanzan*, *Emblica officinalis*, *Terminalia arjuna*, *T. bellerica*, *Adina cordifolia*, *Feronia lemonia*, *Mitragyna parvifolia*, *Lagerstroemia parviflora,* etc. However, the rugged and dried flood-prone catchment of the Narmada has groves of *Acacia nilotica* dominated scrub forest interspersed with open land. Besides, *Butea monosperma* also occurs abundantly along the edge of the forest, ravines and rocky plateaus. Thickets of *Ziziphus mauritiana*, *Carissa opaca*, *Nyctanthes arbor-tristis*, *Adhatoda vasica*, etc. are also frequent in the scrub forest.

Grasses together with *Ageratum conyzoides*, *Blumea* spp., *Leucas aspera*, *Micromeria biflora*, *Mazus japonicus*, *Sida rhombifolia*, *Sonchus* spp., *Oxalis acetosella*, etc. are the common constituents of ground vegetation. Along the water courses, the marshy elements, viz. *Scirpus articulatus*, *Cyperus rotundus*, *Polygonum serrulatum*, *P. plebeium*, *Hydrocotyle sibthorpioides*, *Eriocaulon quinquangularis*, *Centanella* spp., *Hygrophila auriculata*, *Solanum xanthocarpum* grow abundantly. Ferns are locally common in shady depressions.

The usual trees of human habitation are *Madhuca indica*, *Butea monosperma*, *Melia azedarach*, *Bombax ceiba*, *Acacia nilotica*, *Ficus tinctoria* and *F. benghalensis*.

MATERIAL AND METHODS

A 2 m deep trench was dug out to collect sediment profile from the dried Kachhar Lake bed at Kishanpur. In all, 20 samples were collected at 10 cm intervals from this profile for pollen analysis along with 6 bulk samples at larger intervals for radiocarbon dating.

The sediment profile is largely constituted of clay with minor fractions of sand, pebbles and charcoal pieces at different depths. The uppermost lithounit is made up of greyish clay with sand and rootlets and forms the thickest zone. The following thin lithozone is composed of clayey sand with

occasional rootlets, whereas, underlying to this are the lithozones of greyish sandy clay and greyish sandy clay with charcoal pieces. The bottommost zone is full of pebbles with trivial amount of clay. The depth-wise lithostratigraphic details are given as below (Fig. 2).

Two radiocarbon ages, i.e. 1970 ± 90 yr BP (BS-2840) at 180-195 cm depth and 1650 ± 100 yr BP (BS-2839) at 125-140 cm depth have been determined for this sediment profile. These have been used to calibrate the sedimentation rates for the profile. For the lower part, the ages 1970 ± 90 yr BP (180-195 cm) and 1650 ± 100 yr BP (125-140 cm), have been used to calibrate the sedimentation rate, which is 1 cm /5.8 years. For the upper part assuming the surface as modern and taking the age 1650 ± 100 yr BP (125-140 cm), the sedimentation rate is 1cm/13 years. These sedimentation rates have been used to extrapolate the ages of 2050 yr BP at 200 cm depth, 1610 yr BP at 125 cm depth and 625 yr BP at 50 cm depth to facilitate the chronological delineation of vegetation succession and climatic variability in the region during the last 2 millennia.

Standard technique of acetolysis (Erdtman, 1943) using 10% aqueous KOH solution, 40% HF solution and acetolysing mixture (9:1, acetic anhydride and concentrated sulphuric acid) was followed to segregate the pollen and spores from the sediments. Samples for microscopic examination were prepared in 50% glycerin solution.

All the samples analyzed were found to be rich in pollen/ spore contents. The pollen sums vary from 200 to 400 depending upon pollen productivity of the samples (Pl. 1). The pollen of aquatic plants and fern spores have been excluded from the pollen sums because of their local origin. The recovered pollen taxa have been categorized as trees, shrubs, herbs, ferns, algae, drifted and fungi and are arranged in the same manner in the pollen diagram.

POLLEN ANALYSIS

For the better understanding of the succession of vegetation and climate change, the pollen diagram (Fig. 3) is divided into three distinct pollen zones, based on the prominent arboreals and non-arboreals pollen recovered in the sediments. These are prefixed with initials 'KL' after the name of study site and are numbered from bottom to top.

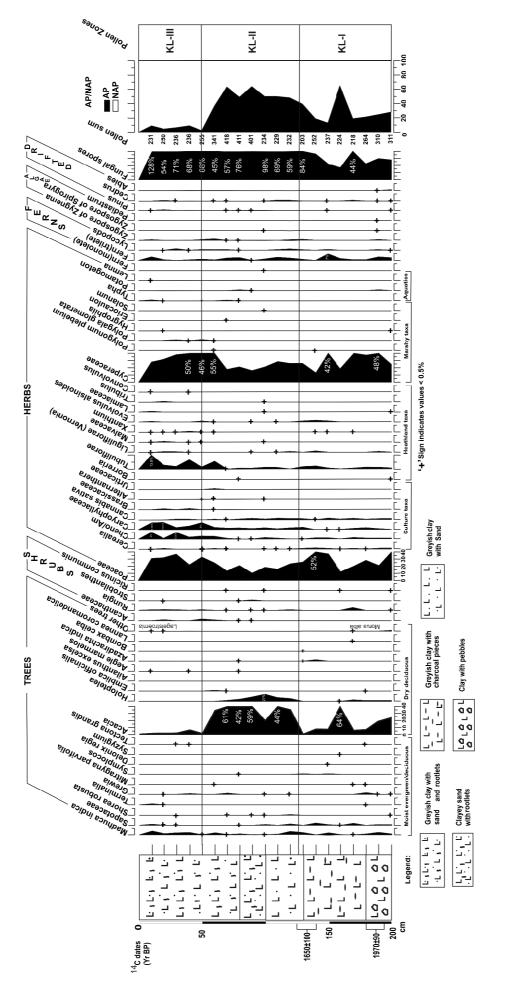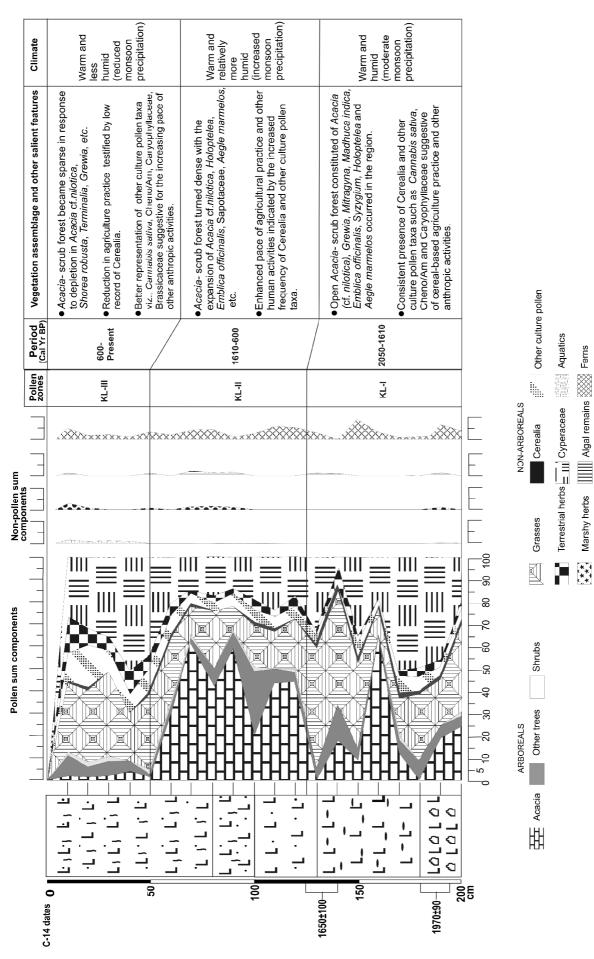| Depth (in cm)	Lithology
0-80	Greyish clay with sand and rootlets
80-100	Clayey sand with rootlets
100-130	Greyish clay with sand
130-180	Greyish clay with charcoal pieces
180-195	Greyish clay with frequent charcoal
195-200	Clay with pebbles

Fig. 2—Depth-wise lithostratigraphic details.

Fig. 3—Pollen diagram from Kachhar Lake, Sehore District.

Fig. 4—Composite pollen diagram showing the salient features of investigation.

Pollen Zone KL-I (200-125 cm): *Acacia-Grewia-***Sapotaceae-** *Mitragyna parvifolia-Holoptelea-Rungia-***Poaceae-** *Caryophyllaceae-Cheno/Am-Cerealia-Tubuliflorae-***Cyperaceae-Ferns Assemblage**

This pollen zone ^{14}C dated to 1970 ± 90 yr BP (180-195 cm) and 1650 ± 100 yr BP (125-140 cm) with a time interval of 2050 to 1610 yr BP shows the dominance of non-arboreals over arboreals. Among the trees, *Acacia* cf. *nilotica* (8.43-64.28%) is consistently recorded in high values. *Madhuca indica* (0.83-2.95%) and *Grewia* (0.32-4.16%) are recovered moderately, whereas Sapotaceae, *Holoptelea*, Moraceae, *Azadirachta indica*, *Lannea coromandelica* (0.49-1.72% each) are retrieved sporadically. Others, viz. *Tectona grandis* (< 1%), *Shorea robusta*, *Syzygium*, *Delonix regia, Mitragyna* and *Bombax ceiba* (< 0.5% each) together with shrubs, viz. *Rungia* (0.32-3.29%) and *Ricinus* (0.5%) are meagre.

Poaceae (12-51.72%), Tubuliflorae (0.84-10.34%), Caryophyllaceae (0.42-4.31%), Cheno/Am, *Cannabis sativa* (2.5% each) and Cerealia (1.72%) are the major non-arboreals. Liguliflorae and *Evolvulus alsinoides* (0.84-1.72% each) are better represented than *Solanum*, Lamiaceae, *Xanthium* and *Borreria* (< 1% each). Marshy element, Cyperaceae (13.79-50.54%) is met with in high frequencies, whereas *Hygrophila* (< 0.5%) is scanty. *Potamogeton* (0.64%) represents the aquatic vegetation. Fern spores (trilete 0.83-6.75%) are frequent. Lycopods (0.32-1.26%) are sporadic. Algal remains (*Zygnema*, *Spirogyra* and *Pediastrum*) are occasional. The Himalayan elements-*Cedrus* (0.32-1.09%), *Abies* and *Pinus* (< 1% each) are recorded scarcely.

Pollen Zone KL-II (125-50 cm): *Acacia-Holoptelea-***Poaceae-Caryophyllaceae-***Tubuliflorae-Cannabis sativa-Cheno/Am-***Cyperaceae-Ferns Assemblage**

This pollen zone encompassing a time bracket of 1610 to 600 yr BP brings out the much enhancement in *Acacia* cf.

nilotica (20.08-61.24%) followed by *Holoptelea* (0.71-27.35%) than in the Pollen Zone KL-I. *Madhuca indica* (0.42-2.63%) and Sapotaceae (0.24-1.64%) remain almost static as before. *Grewia* (043-1.45%), *Emblica officinalis* (1%), *Azadirachta indica*, *Symplocos* and *Mitragyna* (< 0.5% each) decline in this zone. *Shorea robusta*, *Aegle marmelos* and *Ailanthus excelsa* (< 0.5% each) and shrubby taxa-Acanthaceae and *Strobilanthes* (1% each) turn up in low values. However, *Rungia* and *Ricinus* (< 0.5% each) are encountered lowly.
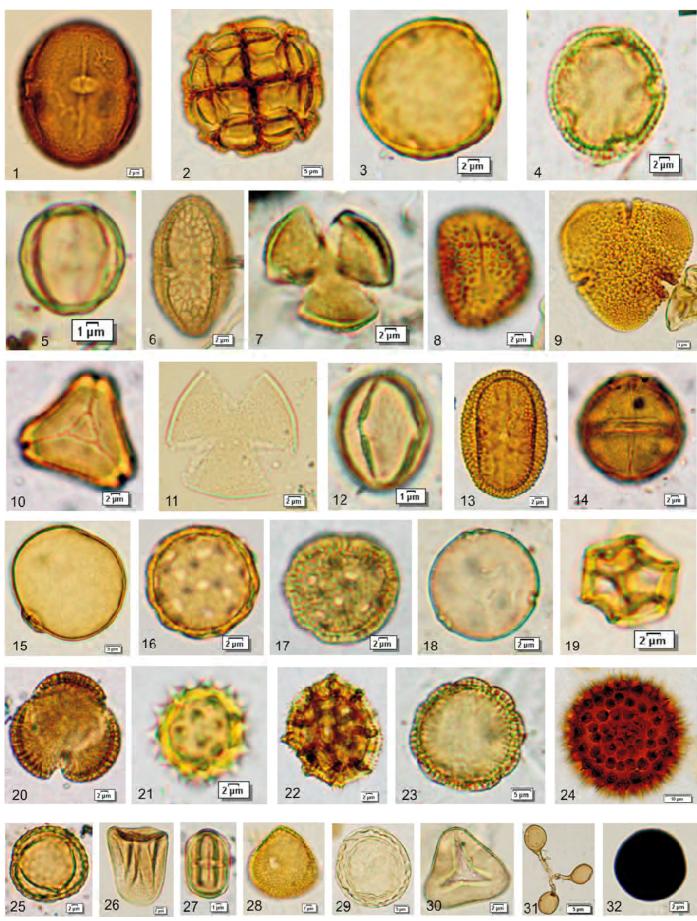
Poaceae (10.47-24.92%) declines considerably. Tubuliflorae (0.47-5.86%), Caryophyllaceae and Cheno/Am (0.24-3.51% each) remain almost same but improve in the upper part. *Cannabis sativa* (0.47-2.24%) portrays consistent presence as seen in the Pollen Zone KL-I. Liguliflorae, *Evolvulus alsinoides*, Lamiaceae, *Borreria* and *Xanthium* are infrequent. Cerealia (< 1%) has relatively lower frequencies. Urticaceae (0.58%), *Alternanthera*, Brassicaceae, *Tribulus* and Malvaceae (< 0.5% each) appear for the first time. Marshy elements, Cyperaceae (16.45-54.54%) declines, except a spurt at the top, whereas *Polygonum plebeium*, *Eriocaulon* and *Solanum* are rare. *Potamogeton* (0.48-1.45%) shows intermittently low values. *Typha* (0.24-0.95%) appears meagrely. Fern spores (trilete 0.48-4.36%) are steady, though in slightly reduced values, while monolete (< 0.5%) is present in one sample only. Lycopods and *Zygnema* (0.47-1.75% each) improve, whereas *Spirogyra* is extremely low. *Cedrus* and *Pinus* (< 1% each) are recovered feebly. Fungal spores, viz. *Glomus*, *Nigrospora*, *Diplodia*, *Curvularia*, *Tetraploa*, *Cookeina*, Microthyriaceae, *Alternaria*, etc. are met with in variable frequencies.

Pollen Zone KL-III (50-0 cm): *Madhuca indica-Acacia-***Poaceae-Caryophyllaceae-***Cheno/Am-Tubuliflorae-***Cyperaceae-Ferns Assemblage**

This topmost pollen zone with the temporal range of 600 yr BP to Present depicts the dominance of non-arboreals and

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PLATE 1 →

1. *Madhuca indica*
2. *Acacia*
3. *Holoptelea*
4. *Emblica officinalis*
5. *Terminalia*
6. *Grewia*
7. *Tectona grandis*
8. *Aegle marmelos*
9. *Bombax ceiba*
10. *Syzygium*
11. *Shorea robusta*
12. *Lannea coromandelica*
13. *Rungia*
14. *Ricinus communis*
15. Poaceae
16. Cheno/Am

17. Caryophyllaceae
18. *Cannabis sativa*
19. *Alternanthera*
20. *Brassica campestris*
21. Tubuliflorae
22. Liguliflorae
23. *Borreria*
24. Malvaceae
25. *Xanthium*
26. Cyperaceae
27. *Polygonum plebeium*
28. *Typha*
29. *Zygnema* zygospore
30. Fern trilete
31. *Glomus*
32. *Nigrospora*

PLATE 1

poor presence of arboreals. *Madhuca indica* (0.39-5.19%) exhibits increased values. *Acacia* cf. *nilotica* (0.78-3.38%) declines severely and attains the lowest value towards the termination of this zone. Sapotaceae and *Grewia* (0.4-0.84% each) also have reduced values. *Terminalia* (0.4-0.86%) and *Lagerstroemia* (< 0.5%) appear sporadically in the latter half. *Shorea robusta*, *Tectona grandis* and *Aegle marmelos* (< 0.5% each) are infrequent. The shrubby taxa, viz. Acanthaceae (0.8-1.56%) and *Rungia* (0.78-1.2%) denote rising trend. *Strobilanthes* (< 0.5%) is stray.

Poaceae (22.03-37.71%) depicts a rising trend with the onset of this zone. Cerealia (0.39-1.2%) remains sporadic as before. Caryophyllaceae (2.96-16.4%), Tubuliflorae (3.31-13.85%) and Cheno/Am (1.2-6.35%) show increasing trend with high values. *Xanthium*, Liguliflorae, Brassicaceae (0.8-1.27% each), Malvaceae, Lamiaceae (1% each), *Cannabis sativa* and *Evolvulus alsinoides* (< 1% each) are recorded sporadically, whereas *Convolvulus*, *Tribulus* and *Alternanthera* are stray. Cyperaceae (28.13-49.57%) has much improved values, but declines in the upper half. *Hygrophila* and *Polygala glomerata* (< 0.5% each) are scanty. *Typha* (0.39-1.29%) and *Lemna* (0.4%) are sporadic. Fern spores (trilete 0.42-5.19%) and Lycopods (0.4-1.69%) do not exhibit any change. *Zygnema, Pinus* and *Cedrus* (< 1% each) are rare. Fungal spores such as *Glomus*, *Nigrospora*, *Curvularia*, *Tetraploa*, *Diplodia*, Microthyriaceae, *Cookeina*, etc. remain almost unchanged.

DISCUSSION AND CONCLUSIONS

Pollen analytical investigation of a series of samples at close intervals from a 2 m thick section exposed along the left bank of ancient Kachhar Lake Basin has elucidated some cardinal facts pertaining to the short-term climatic variability and consequential vegetation changes as well as impact of anthropogenic activities in this extensively stretched catchment on the right bank of the Narmada River in southwestern Madhya Pradesh during the last two millennia or so (Fig. 4). The pollen sequence generated through the investigation of this dried lake bed has been divided into three distinct vegetation and climatic phases, taking into account the fluctuating trend of some prominent tropical deciduous trees as well as the herbaceous elements. The emerged vegetation pattern has divulged that between 2050 and 1610 yr BP, i.e. 100 BC to 350 AD (Pollen Zone KL-1), most of the flood-prone catchment in the immediate environs of the Narmada River Basin was occupied by an open *Acacia*-scrub forest, which was dominated by *Acacia* cf. *nilotica*, a common invader of the dry river-bed as seen today. However, the moist-loving trees, viz. *Grewia*, *Mitragyna* and members of Sapotaceae also occurred intermittently in association of *Acacia* cf. *nilotica* in the forest. A few other trees such as *Madhuca indica*, *Emblica officinalis*, *Syzygium*, *Delonix*, *Holoptelea* and *Aegle marmelos* grew very sparingly in the region. On the whole, if the floristic composition is seen in the present perspectives, it could be deduced that a relatively warm and humid climate prevailed in the region in response to moderate monsoon precipitation during this phase. The possible reason for the low forest cover with poor diversity during this phase could be the outcome of recurrent flood episodes in the area contiguous to the Narmada River, which restrained the proper regeneration and establishment of dense and varied tropical deciduous forests as seen today on the elevated plateau area, barely at a distance of 2 km from the investigation site. The ground flora by this time was largely constituted of grasses together with heathland taxa such as Asteraceae (Tubuliflorae & Liguliflorae), *Evolvulus alsinoides*, etc. The frequent documentation of Cerealia along with ruderal plants such as *Cannabis sativa*, members of Chenopodiaceae/ Amaranthaceae and Caryophyllaceae in good numbers signifies that the vicinity of the lake basin was under cereal-based agricultural practice as well as some other sorts of anthropogenic activities. The presence of fragmentary charcoals in the lithocolumn at the depth corresponding to this phase implies the repeated fire incidences in the neighbouring forests from where charcoals were drifted and ultimately got trapped in the sedimentary bed. Most of the area in the close surrounding of the lake remained intermittently highly water-logged during the course of sediment accumulation as evidenced from the much better representation of marshy vegetation exclusively dominated by sedges (Cyperaceae). Ferns flourished well in the moist and shady habitats in the proximity of the lake. Between 1610 and 600 yr BP, i.e. 350 AD to 1350 AD (Pollen Zone KL-II), the *Acacia*-scrub forest turned luxuriant as clearly indicated by the much expansion of *Acacia* cf. *nilotica* as compared to the preceding phase. Among the other arboreals, *Holoptelea* also thrived well, probably on the elevated area together with sparsely distributed trees of *Emblica officinalis*, Sapotaceae, *Aegle marmelos*, *Grewia* and thickets of *Rungia*, *Strobilanthes* and members of Acanthaceae. The overall proliferation of *Acacia*-scrub forest certainly took place as a result of steadily increasing monsoon precipitation and consequently a more-humid climate prevailed in the region compared to that prevailing during the preceding phase. In addition, during this period the course of the Narmada River might have changed and the region got abandoned, which paved the way for the invasion and much proliferation of *Acacia* cf. *nilotica,* a primary colonizer of dry river bed as very clearly witnessed by its gregarious presence today. The expansion of *Acacia* cf. *nilotica* dominated forest is also well corroborated by a concurrent and sharp reduction of grasses. The cereal-based agricultural practice continued with more or less same intensity as before since there is not any apparent alteration in the Cerealia and other culture pollen taxa. Since 600 yr BP, i.e. 1350 AD onwards (Pollen Zone KL-III), the climate turned relatively less-humid as evidently marked by an abrupt depletion in

Acacia cf. *nilotica* and most of the other arboreals such as *Shorea robusta*, *Terminalia*, *Grewia*, etc. Hence, it can be surmised that by this time the forest became sparser than witnessed in the preceding phases. However, the consistent presence of *Madhuca indica* with an increasing trend denotes that this important constituent of modern forest in the region, would have been conserved by the local populace due to its multifaceted utility for food, fodder, fuel and low grade timber. The meagre presence of Cerealia reflects that the area contiguous to the investigation site was under low intensity agricultural practice, most likely due to inundation from time to time. However, there was an escalation in other kinds of human activities as inferred from the better representation of culture pollen taxa such as *Cannabis sativa*, members of Chenopodiaceae/Amaranthaceae, Caryophyllaceae, Brassicaceae, etc. throughout this phase. The region was also under the impact of pastoral activity, particularly in the form of grazing as indicated by the substantial increase in Asteraceae (Tubuliflorae), because the members of this family are rarely preferred by goats and cattle as they are not palatable.

Thus, from the pollen proxy data it could be deduced that between 2050 and 1610 yr BP, i.e. 100 BC to 350 AD the catchment of the Narmada River was occupied by open *Acacia*-scrub forest under relatively warm and humid climate with moderate monsoon precipitation. The retrieval of fragmentary charcoals implies the recurrent forest fire incidences in the region. Between 1610 and 600 yr BP, i.e. 350 AD to 1350 AD, *Acacia*-scrub forest became profuse with the advent of a more-humid climate owing to increased monsoon precipitation. Since 600 yr BP, i.e. 1350 AD to Present, the climate turned less-humid as a result of reduced monsoon precipitation, which is depicted by severe decline in *Acacia*-scrub forest. Agriculture prosperity has been registered in most of the part of sequence, except for a decline since 1350 AD due to low monsoon precipitation.

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