Mid-Holocene vegetation vis-à-vis climate change in southwestern Madhya Pradesh, India

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Pollen analysis of a 1.75 m deep sediment core from Amjhera Swamp, Hoshangabad district shows that between 6000 and 5409 years BP, this region of southwestern Madhya Pradesh supported open mixed deciduous forests comprising *Lannea coromandelica, Terminalia, Madhuca indica, Grewia, Schleichera oleosa, Syzygium*, etc. under a warm and relatively less humid climate compared to today due to reduced monsoon precipitation. Between 5409 and 4011 years BP, the open mixed deciduous forests transformed into dense diversified mixed moist deciduous forests as a result of expansion of existing moist elements and better representation of *Aegle marmelos* and *Emblica officinalis* in response to initiation of a warm and relatively more humid climate, attributable to increased monsoon precipitation. Partially this phase of favourable climate coincides with the Period of Climatic Optimum. Around 4011 to 2178 years BP, the mixed moist deciduous forests became sparse and less varied owing to the onset of a warm and relatively less humid climate on account of weakening of monsoon. This is evidenced from the abrupt reduction in the prominent forest elements, viz. *M. indica, Terminalia, Grewia, S. oleosa*, etc. Since 2178 years BP to the Present, dense mixed moist deciduous forests got established again, which is manifested by the spurt in *M. indica, Terminalia, Grewia, S. oleosa, Syzygium, Haldina cordifolia*, etc. reflecting a warm and relatively more humid climate and arrival of the more active southwest monsoon.

Keywords: Climate change, deep sediment core, pollen analysis, swamp, vegetation.

THE Quaternary palaeovegetation and palaeoclimate information from Madhya Pradesh (MP), possessing about 24–26% forest resource of the country, has so far been generated from the northeastern[1–5], southeastern[6,7] and the central regions[8] through the pollen analytical study of lake and swamp deposits. These studies have provided some cardinal facts concerning the vegetation succession and climatic changes in a definite time-frame during the Holocene. However, the southwestern region with diversified teak (*Tectona grandis*) and mixed deciduous forests has not yet been given adequate attention on this aspect, except for a maiden report from Kachhar Lake, Sehore district[9], deducing short-term climatic variability and consequential vegetation shifts during the Late Holocene. Hence, we attempt to generate a database pertaining to vegetation scenarios and coeval climatic oscillations in the perspective of the fluctuating trend of southwest monsoon during the Mid-Holocene through the pollen analysis of a 1.75 m thick sediment core from Amjhera Swamp, Hoshangabad district, MP. Efforts have also been made to deduce the inception and latter pace of agrarian practice in the region, which is solely governed by fluctuating trend of the southwest monsoon.

Amjhera Swamp lies about 23 and 31 km southeast of Itarsi and Hoshangabad townships respectively, between 77°50′E long. and 22°30′25″N lat. amidst dense mixed tropical deciduous forest in Itarsi Forest Range (Figure 1). The swamp proper and its immediate vicinity are almost flat with an elevation of 780 ft amsl. However, the surrounding high plateaus and hillocks with gentle slopes attain elevations of 1500–2000 ft amsl. The swamp measures 300 m long and 150 m broad at its widest. It is perennial and mainly fed by subterranean as well as rainwater. The swamp is highly waterlogged at the centre; however, it gets shallower in the broader peripheral region. The area contiguous to the swamp is under cultivation of paddy and other conventional crops by the Gond tribals inhabiting therein. Physiographically, most of the area adjoining the study site is bumpy with deep gorges. The soil over the swamp and encircling cultivated area is blackish sticky clay with fine sand, whereas it is sandy clay in rest of the region. However, at certain places black cotton soil is found in pockets.

The area enjoys seasonal climatic fluctuations, which are largely influenced by the southwest monsoon. The mean average minimum and maximum winter temperatures are 11.7°C and 17°C respectively. However, during the extreme cold month of January the temperature descends to 1°C. The average annual minimum and

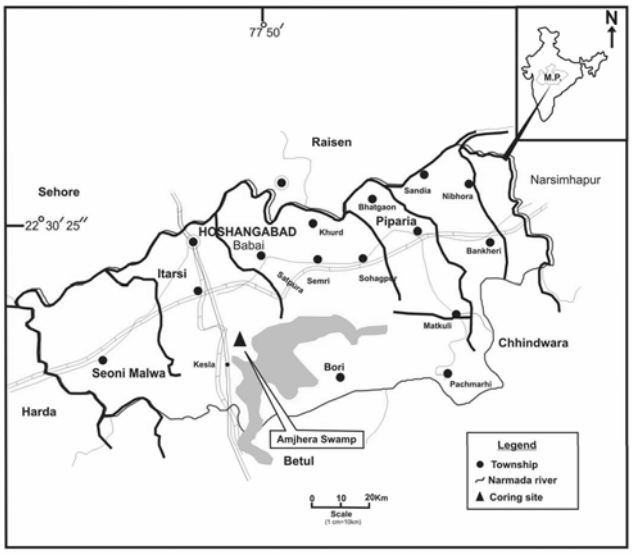

Figure 1. Map showing the study site at Amjhera, Hoshangabad district, Madhya Pradesh.

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maximum summer temperatures are 19.8°C and 32.8°C respectively. The temperature, nevertheless, shoots up to 42.1°C in the hottest month of May. The average annual rainfall is approximately 1225.9 mm. About 92.8% of the annual rainfall occurs during the monsoon period[10]. In general, the region is characterized by a warm and humid climate.

The tropical mixed deciduous forests around the swamp and the adjoining hillock at Amjhera are diversified, with teak (*Tectona grandis*) being a prominent constituent[11]. In addition, *Haldina cordifolia*, *Lagerstroemia parviflora*, *Mitragyna parvifolia*, *Buchanania lanzan*, *Terminalia tomentosa*, *Anogeissus latifolia*, *Schleichera oleosa*, *Wrightia tinctoria*, *Bauhinia retusa*, *B. racemosa*, *Aegle marmelos*, *Emblica officinalis*, *Chloroxylon sweitenia* and *Syzygium cumini* are also frequent. The shrubs in the forest include *Ziziphus mauritiana*, *Melastoma malabathricum*, *Woodfordia fruticosa* and *Strobilanthes angustifrons*. Around the habitation trees such as *Melia azadarachta*, *Ficus benghalensis* and *Acacia nilotica* together with thickets of *Ricinus communis*, *Adhatoda vasica* and *Carissa opaca* are common.

The terrestrial herbs close to the swamp largely comprise grasses, *Sida rhombifolia*, *Oxalis acetocella*, *Leucas aspera* and *Ageratum conizoides*. However, reed-swamp grasses, *Phragmites vulgaris* and *Typha latifolia* grow amply over the swamp. *Hydrocotyle sibthorpioides*, *Hygrophila auriculata*, *Polygonum plebeium*, *Rotala rotundifolia*, *Ammania baccifera*, *Cyperus rotundus* and *Scirpus triangulatus* are the other frequent wetland plants in the less waterlogged part of the swamp. Aquatic elements such as *Lemna paucicostata*, *Potamogeton nodosus* and *Nymphoides cristata* also grow profusely in ditches and water-accumulated areas over the swamp. The common pteridophytic taxa inhabiting moist and shady places in the forests are *Adiantum philippense*, *Dryopteris prolifera*, *Ceratopteris thelictroides*, *Selaginella lepidophylla* and *Lycopodium clavatum*.

A 1.75 m thick sediment core was collected from the Amjhera Swamp, using Hiller's peat auger. In all, 35 samples were taken at an interval of 5 cm each from the core for pollen analysis. In addition, four bulk samples were also picked up from the core at broader intervals for radiocarbon dating.

Six distinct lithozones are discernible in the sediment core, based on the changing sediment texture at different depths. The top lithozone, beneath the water column of 5 cm is composed of blackish sticky clay with rootlets and other plant debris of the vegetation growing over the swamp. This is followed by blackish sticky clay with sand zone, devoiding visible plant remains. Underlying this is the blackish sticky clay zone, which rests over the thickest blackish sticky clay with sand zone. Subsequent lithozone is made up of sandy clay and this overlies the bottommost stratum, constituted of sand with low fraction of clay (Table 1).

Four absolute radiocarbon ages were determined at different depths for this core (Table 2). The calibrated sedimentation rates from radiocarbon dates are not uniform owing to variation in the sediment composition throughout the core. The sedimentation rate between 85 and 140 cm depth has been calibrated to 21 years/1 cm, using two radiocarbon ages, i.e. 5199 ± 239 cal. years BP at 140–150 cm depth and 4103 ± 145 cal. years BP at 85–100 cm depth from the lower half. For the upper part of the core the sedimentation rate has been calibrated 37 years/1 cm, taking into account the radiocarbon age of 2271 ± 122 cal. years BP at 35–50 cm depth and assuming the surface modern. These two sedimentation rates have facilitated to extrapolate and interpolate more ages, i.e. 6000 years BP at 175 cm depth, 5409 years BP at 155 cm depth, 4011 years BP at 87.5 cm depth and 2178 years BP at 42.5 cm depth in order to delineate the temporal changes in vegetation pattern and contemporaneous climatic events in the region.

The standard technique of acetolysis using 10% aqueous KOH solution, 40% HF and acetolysing mixture (9 : 1 ratio of acetic anhydride and concentrated sulphuric acid) was followed for the extraction of pollen/spores from the sediments[12]. The samples were prepared in 50% glycerin solution for microscopic examination. The pollen sums varied from 271 to 1074, depending upon pollen productivity of the samples. These exclude the pollen of aquatic plants and spores of cryptogams (ferns, algae and fungi) due to their origin from local sources. The percentage frequencies of the recovered taxa have been calculated in terms of the total land-plant pollen. The recovered pollen taxa (Table 3) categorized as trees, shrubs, herbs, fern spores, algal remains and drifted (Figure 2) are arranged in the same manner in the pollen diagram.

The pollen diagram (Figure 3) constructed from Amjhera Swamp has been divided into four distinct pollen

Table 1. Lithological details of the sediment core

Depth (cm)	Lithology
0–25	Blackish sticky clay with rootlets and plant debris
25–50	Blackish sticky clay with sand
50–75	Blackish sticky clay
75–120	Blackish sticky clay with sand
120–140	Sandy clay
140–175	Clayey sand

Table 2. Radiocarbon dates for the sediment core

Depth (cm)	Laboratory ref. no.	Radiocarbon age (years BP)	Calibrated age (cal. years BP)
15–25	BS-2968	1120 ± 100	1120 ± 100
35–50	BS-2883	2260 ± 100	2271 ± 122
85–100	BS-2884	3730 ± 100	4103 ± 145
140–150	BS-2881	4540 ± 180	5199 ± 239

Table 3. Plant taxa recovered from the sediment core

Arboreals		Non-arboreals (herbs)	Others
Trees Moist elements (average annual rainfall 1200–1600 mm): *Madhuca indica*, *Syzygium*, *Terminalia*, *Lagerstroemia parviflora*, *Shorea robusta*, *Mitragyna parvifolia*, *Haldina cordifolia*, *Schleichera oleosa*, *Grewia*, *Symplocos*, *Bauhinia* Dry elements (average annual 900–1200 mm): *Lannea coromandelica*, *Aegle marmelos*, *Emblica officinalis*, *Holoptelea*, *Diospyros*, *Schrebera*, *Acacia*, *Bombax ceiba*, *Ehretia laevis*	Shrubs *Strobilanthes*, Fabaceae, *Peristrophe*, *Ricinus*, Acanthaceae (cf. *Rungia*), *Petalidium*, *Lepidagathis*, *Helicteres*, *Truimfetta*, *Cadaba*, *Dendrophthoe*	Culture pollen taxa Cerealia, Chenopodiaceae/Amaranthaceae (Cheno/Am), Caryophyllaceae, *Artemisia*, Brassicaceae, *Cannabis sativa*, *Alternanthera* Heathland taxa Poaceae, Asteraceae (Tubuliflorae, Liguliflorae), *Xanthium*, *Convolvulus*, *Evolvulus*, *Pedalium*, *Borreria*, Ranunculaceae, *Chrozophora*, *Justicia* Wetland taxa Cyperaceae (sedges), *Hygrophila*, *Polygonum plebeium*, *Eriocaulon* Aquatic taxa *Typha*, *Potamogeton*, *Lemna*, *Nymphoides*	Ferns Ferns producing monolete and trilete spores, *Ceratopteris* Algal remains *Zygnema*, *Spirogyra* Fungal remains *Glomus*, *Cookeina*, *Nigrospora*, *Diplodia*, *Curvularia*, Microthyriaceae, *Tetraploa* Drifted *Alnus*, *Cedrus*

zones, taking into consideration the fluctuating trend of some prominent arboreals and non-arboreal taxa. These pollen zones have been prefixed with the initials 'AJ' (AJ-I, AJ-II, AJ-III and AJ-IV) after the name of the study site and are described as follows.

Pollen zone AJ-I (175–155 cm) encompassing a timespan of 6000 to 5409 years BP reveals the dominance of arboreals (trees and shrubs) over non-arboreals (herbs). The tree taxa, viz. *Lannea coromandelica* (4.48–29.4%), *M. indica* (6.7–18.4%), *Terminalia* (7.4–15.3%), *Grewia* (2.8–7.3%) and *S. oleosa* (0.49–5.12%) are recorded consistently in high values, though in a fluctuating manner. Others such as *Syzygium* (0.2–12%), *L. parviflora* (0.5–1.28%), *Maytenus* (0.5–2.3%), *A. marmelos* (0.72–2.88%) and *E. officinalis* (0.92–2.88% each) are in moderate to low frequencies, whereas *Acacia*, *Bombax ceiba*, *H. cordifolia*, *M. parvifolia* and *Butea* are sporadic.

The shrubby element, Acanthaceae (cf. *Rungia*) (3.2–7.2%) denotes much higher frequencies compared to *Strobilanthes*, Fabaceae, *Dendrophthoe*, *Petalidium* and *Peristrophe* (0.5–1% each), which are met with sporadically.

Among the non-arboreals, Poaceae (13.2–29.5%) has much high values followed by Cerealia (1.2–12.6%), Tubuliflorae (2.96–9.8%) and Chenopodiaceae/Amaranthaceae (Cheno/Am 0.5–2%), which are recorded consistently in moderate values. Other terrestrial herbs, viz. Liguliflorae (1%), *Xanthium*, Caryophyllaceae, *Pedalium* and Convolvulaceae (< 0.5% each) are in trace amounts. The marshy taxon, Cyperaceae (sedges 5.7–96%) is recovered excessively, while *Hygrophila* (0.3–1.8%) is recorded constantly in low values. The aquatic elements, viz. *Potamogeton* (2.25–18.8%), *Nymphoides* (1.6–5.7%), *Typha* (0.24–5.44%) and *Lemna* (1.28–5.44%) are retrieved steadily in appreciable values. Aquatic fern *Ceratopteris* (10.24–12.31%) is much better represented compared to trilete spores (1.15–4.48%). *Spirogyra* (2%) is the lone representative of algae. Fungal spores, viz. *Glomus*, *Nigrospora* (5–10% each) and *Cookeina* (2–6%) are in good numbers. The presence of *Alnus* (0.5%) pollen denotes its exclusive wind transportation from the Himalaya.

Pollen zone AJ-II (155–87.5 cm) with two radiocarbon ages of 5199 ± 239 cal. years BP at 140–150 cm depth and 4103 ± 145 cal. years BP at 85–100 cm depth in the lower and upper halves respectively, and encompassing the temporal interval of 5409 to 4011 years BP reveals a substantial improvement in the major forest constituents, viz. *Terminalia* (10.49–45.5%), *L. coromandelica* (2.2–32.4%) and *M. indica* (7.4–11%) than in the pollen zone AJ-I. *S. oleosa* (0.8–14%), *Grewia* (2.62–8%), *E. officinalis* (1–6.9%) and *A. marmelos* (1–2.9%) also show a consistently rising trend. *Syzygium*, *B. ceiba* (0.5–1.9% each) and *Acacia* (0.15–1%) are somewhat better represented, whereas *L. parviflora*, *M. parvifolia*, *H. cordifolia* and *Maytenus* are infrequent. *Shorea robusta*, *Bauhinia*, *Holoptelea* and *Ehretia laevis* (0.5–1% each) turn up sporadically for the first time.

The shrubs, viz. Acanthaceae (cf. *Rungia*) (3.2–11.3%) and *Petalidium* (0.20–5.59%) maintain increasing trend in this zone too. *Strobilanthes* (0.59–1.16%) and *Peristrophe* (0.20–1.32%) are almost static as earlier. Others such as *Derris* (0.21–1.63%), *Lepidagathis* (0.22–1%), *Triumfetta* and *Cadaba* (< 0.5% each) appear scantily in this zone.

Among the non-arboreals, Poaceae (4.4–17.2%) after a sharp decline in the beginning exhibits an increasing trend; however, it has relatively lower frequencies than in the pollen zone AJ-I. Tubuliflorae (0.87–4.2%) is met with steadily in reduced frequencies, whereas Cheno/Am (0.18–4.6%) shows fluctuatingly increased frequencies. Liguliflorae, Ranunculaceae (0.2–1% each), Brassicaceae,

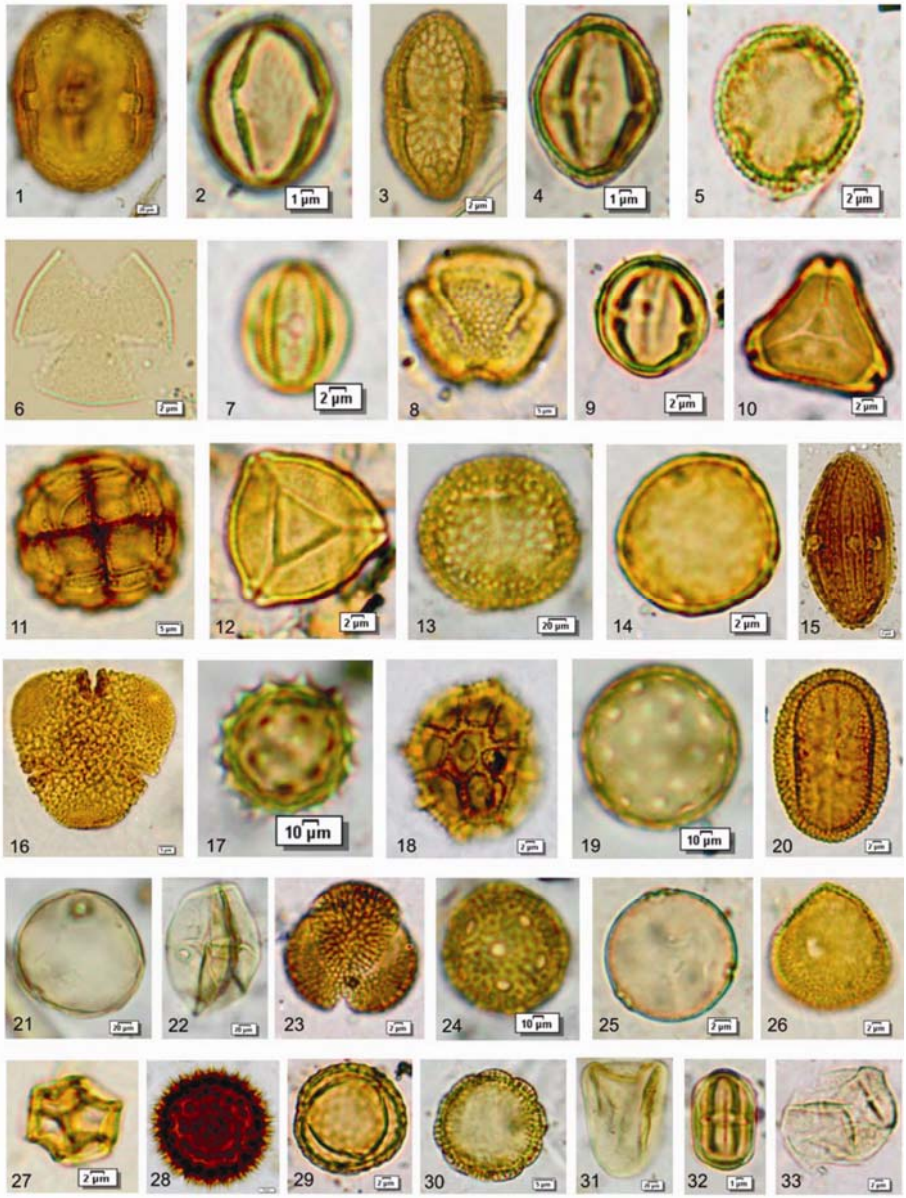

Figure 2. (1) *Madhuca indica*, (2) *Lannea coromandelica*, (3) *Grewia*, (4) *Lagerstroemia parviflora*, (5) *Emblica officinalis*, (6) *Shorea robusta*, (7) *Terminalia*, (8) *Mitragyna parvifolia*, (9) *Haldina cordifolia*, (10) *Syzygium*, (11) *Acacia*, (12) *Schleichera oleosa*, (13) *Aegle marmelos*, (14) *Holoptelea*, (15) *Strobilanthes*, (16) *Bombax ceiba*, (17) Asteraceae (Tubuliflorae), (18) Asteraceae (Liguliflorae), (19) Chenopodiaceae/Amaranthaceae, (20) Acanthaceae (cf. *Rungia*), (21) Poaceae, (22) Cerealia, (23) Brassicaceae, (24) Caryophyllaceae, (25) *Cannabis sativa*, (26) *Typha*, (27) *Alternanthera*, (28) Malvaceae, (29) *Xanthium*, (30) *Borreria*, (31) Cyperaceae, (32) *Polygonum plebeium* and (33) *Potamogeton*.

Xanthium and Caryophyllaceae (< 0.5% each) are scarce. *Artemisia*, *Alternanthera*, *Cannabis sativa* and *Evolvulus alsinoides* (< 0.5% each) are recorded for the first time. However, Cerealia (0.91–2.57%) portrays an increasing trend after an abrupt decline in the beginning. Cyperaceae (8.43–70%) is retrieved with much fluctuating values. *Hygrophila* (0.5–1.1%) is almost the same as before. Among the aquatic plants, *Typha* (0.11–1%) declines considerably, whereas *Lemna* (0.45–3.72%), *Potamogeton* (0.43–2.6%) and *Nymphoides* (0.19–3.3%) are recorded moderately. Trilete fern spores (0.91–5%) and *Ceratopteris* (10–12%) do not show any marked change. Stray pollen of *Cedrus* (0.5%) is also encountered. Algal remains, *Spirogyra* zygospores (0.5–5%) have improved values, while *Zygnema* (< 0.5%) is sporadic. Fungal spores comprising *Glomus*, *Nigrospora* and *Cookeina* are preponderant.

Pollen zone AJ-III (87.5–42.5 cm) with solitary radiocarbon age of 2271 ± 122 cal. years BP at 35–50 cm depth and covering a time bracket of 4011 to 2178 years BP demonstrates an overall depletion in arboreals. *M. indica* (1.4–7%) portrays much reduced values in the beginning, but improves slightly thereafter. Likewise, *Terminalia* (44.9–7.02%) and *L. coromandelica* (30–2.5%) also

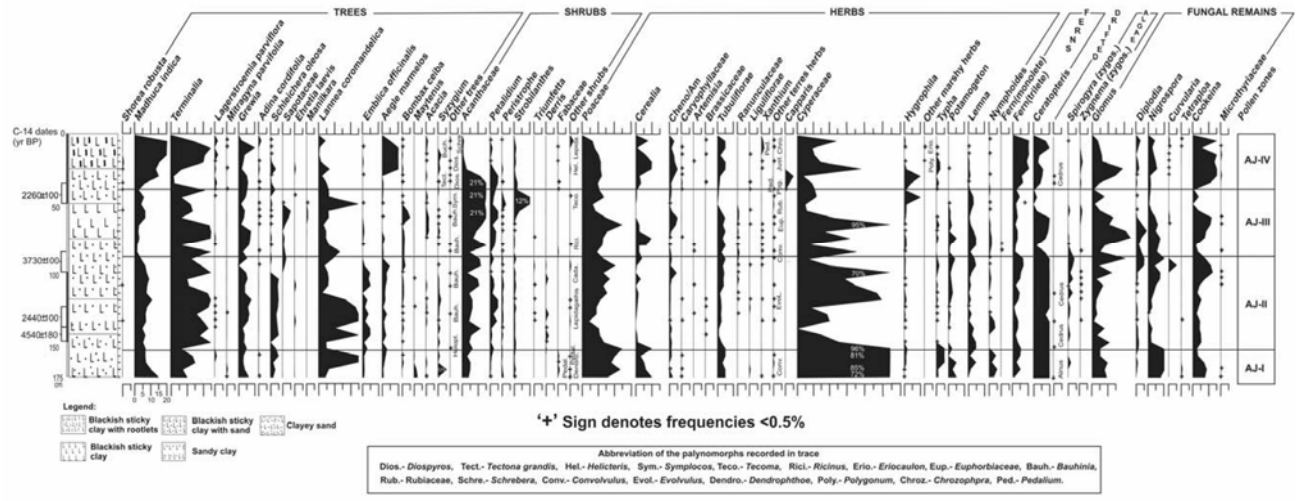

Figure 3. Pollen diagram from Amjhera Swamp, Hoshangabad district.

decline; however, they attain maximum values in the upper half. *Grewia* (1.4–7.7%) remains static, whereas *S. oleosa* (0.25–2.8%), *Acacia* (0.15–1.92%), *E. officinalis* (0.19–1%), *A. marmelos* (0.7–1.63%) and *Syzygium* (0.12–1.25%) become more sporadic. *B. ceiba* (0.25–4.94%), Sapotaceae (0.2–7.8%) and *Acacia* (0.1–1.92%) show enhanced values. *Manilkara* (0.2–1%), *L. parviflora*, *Shorea robusta*, *Bauhinia*, *H. cordifolia* and *M. parvifolia* (0.5% each) are meagre.

Acanthaceae (cf. *Rungia*) (4.6–20.7%) reveals an abrupt increase with the maximum value among the shrubs. Similarly, *Petalidium* (1.8–11.7%) and *Peristrophe* (0.2–2.6%) show a rising trend. *Strobilanthes* (0.24–12%) has fluctuatingly much increased frequencies in the upper part only. The new entrants, viz. Fabaceae (0.22–0.7%), *Ricinus* and *Tecoma* (< 0.5% each) are sporadic.

Poaceae (6.7–25.9%), in general, depicts a declining trend, except attaining high values in the middle. Cerealia (0.48–9.5%) too shows much improvement in the lower half, but dwindles sharply later. Cheno/Am (0.2–4%), Tubuliflorae (0.4–4.95%) and Ranunculaceae (0.24–1.26%) demonstrate a slight rise. *Artemisia*, Caryophyllaceae, Liguliflorae and *Xanthium* (< 0.5%) are scanty. Cyperaceae (5–94.8%) retains high frequencies, though in a deviating trend. *Hygrophila* (0.14–14.36%) is met with constantly in low values in the lower part, but increases drastically towards the termination of this pollen zone. The aquatic element *Lemna* (1.04–6.4%) exhibits increasing trend, whereas *Potamogeton* (0.1–9.89%), *Nymphoides* (0–6.4%) and *Typha* (0–1.6%) after a short rise, show a decreasing trend in the upper half. Fern spores trilete (1.4–4.3%) and *Ceratopteris* (3–10%) have somewhat reduced values. Algal remains decline sharply. Fungal spores, viz. *Glomus*, *Nigrospora* and *Cookeina* are in high frequencies than before.

Pollen zone AJ-IV (42.5–0 cm) with solitary radiocarbon age of 1120 ± 100 cal. years BP at 15–25 cm depth, covering the time-bracket of 2178 years BP to the Present is marked by much improvement in the prominent forest constituents, viz. *M. indica* (13.2–35.8%), *Terminalia* (1.7–30.6%), *A. marmelos* (0.2–18.62%) and *Grewia* (1.9–16%) in contrast to the preceding zone. *L. parviflora* (0.22–1.82%), *Syzygium* (0.14–1.87%), *S. oleosa* (0.25–3.4%) and *H. cordifolia* (0–1.6%) are slightly better represented than before. However, *L. coromandelica* (0.5–7.04%) is consistently present in reduced values. *Acacia* (0.22–1%), *B. ceiba* (0–1%), *Diospyros*, *E. laevis*, *Schrebera* and *M. parvifolia* are scanty.

Among the shrubs, Acanthaceae (20.7–1%) declines sharply in the upper half; however, *Petalidium* and *Strobilanthes* also show much reduced values compared to the preceding pollen zone. Others such as *Lepidagathis* (1.68%), Fabaceae, *Peristrophe* and *Helicteres isora* (0.5% each) are trivial.

Poaceae (6.4–12.25%) depicts constantly increasing trend. Cerealia pollen (1–16.2%) shoots up in this zone. Cheno/Am (1.4–7.7%) and Tubuliflorae (1.44–9.9%) have relatively lower frequencies than in pollen zone AJ-III. *Xanthium* (0.22–1.68%) exhibits slightly improvement, whereas Brassicaceae, Caryophyllaceae, *Artemisia* and Liguliflorae are intermittent. Cyperaceae (3.7–32.5%) is recorded in fluctuatingly high frequencies. *Hygrophila* (0.28–7.5%) after a short rise, decreases considerably later on. *Polygonum plebeium* and *Eriocaulon* are occasional. *Typha* (0.17–2.2%), *Lemna* (0.14–1.5%), *Potamogeton* and *Nymphoides* (0.5% each) are retrieved in lower frequencies compared to the preceding pollen zone. The drifted pollen of *Cedrus* (0.5%) is stray. Fern spores trilete (5.5–10.3%) and *Ceratopteris* (2.8–9.9%) are recorded in variably increased values. Algal and fungal spores are met with in deviating high values.

The pollen analytical study of 1.75 m deep sediment core from Amjhera Swamp, has provided important inferences pertaining to the temporal vegetation shifts in

response to climatic alterations and the impact of human activities this region of southwestern Madhya Pradesh has come across since prior to the Mid-Holocene. The pollen sequence generated has demonstrated that between the time interval of 6000 and 5409 years BP (pollen zone AJ-I), the landscape supported open mixed moist tropical deciduous forests largely constituted of *L. coromandelica* along with *Terminalia*, *M. indica*, *Grewia*, *S. oleosa*, *Syzygium* and *Aegle marmelos* as the major constituents, though they were sparsely distributed. Other deciduous trees such as *L. parviflora*, *M. parvifolia*, *H. cordifolia*, *Acacia*, *B. ceiba* and *E. officinalis* also occurred scantily together with a few thickets of Acanthaceae (cf. *Rungia*), *Petalidium*, *Peristrophe* and *Strobilanthes* in open areas interspersing the forest stands. From the emerging vegetation scenario, it could be inferred that since prior to the Mid-Holocene a warm and relatively less humid climate prevailed in the region than today, most likely due to reduced monsoon precipitation. The herbaceous flora on the forest floor as usual was dominated by grasses and members of Asteraceae with scarce presence of *Xanthium*. The area encircling the swamp was under some kind of cereal-based agricultural practice to a wider extent by the tribals dwelling therein. This is clearly manifested by the steady presence of Cerealia and concomitant cropland weeds belonging to Cheno/Am and Caryophyllaceae. The swamp was quite wider in dimension and it was abundantly overgrown by sedges and semi-aquatic herb *Typha*, as evidenced from their exceptionally high frequencies. Further, the preponderance of aquatic taxa, viz. *Potamogeton*, *Lemna* and *Nymphoides*, aquatic fern *Ceratopteris* as well as *Glomus* (fungus) is suggestive that the swamp was highly waterlogged with scattered ditches and ponds. Ferns also flourished luxuriantly in moist and shady niches around the swamp and in the adjoining forests.

Between 5409 and 4011 years BP (pollen zone AJ-II), the open mixed moist deciduous forests were succeeded by the diversified and dense mixed moist tropical deciduous forests as a consequence of the expansion of the prominent moist elements such as *Terminalia*, *L. coromandelica*, *M. indica*, *Grewia* and *S. oleosa* coupled with some improvement in dry forest elements, viz. *E. officinalis*, *A. marmelos* and *B. ceiba* as well as sporadic immigration of *S. robusta*, *Holoptelea* and *E. laevis* in the forest floristic. The thickets of Acanthaceae (cf. *Rungia*), *Petalidium* and *Peristrophe* also became more frequent in the forests. Simultaneously, with the expansion of the forests, the grasses declined considerably, most likely owing to shrinking of open space for their propagation on the forest floor. Thus, on the whole, the increased diversity and density of the mixed tropical deciduous forests reflect that the region experienced a warm and relatively more humid climate in response to increased precipitation with the intensification of SW monsoon. An identical forest floristic inferring equivalent climate has also been recorded from the southeastern region for almost the same time interval[6]. This phase of favourable climate falls partially within the time-bracket of the Period of Climatic Optimum, which has been recorded[13] globally between 7000 and 4000 years BP. The agrarian activities might have continued in the outskirts of the forests with high intensity; however, they were not so intense in the immediate vicinity of the swamp, probably due to inundation and extension of the swamp since Cerealia pollen are scarce. Moreover, the slight increase in the concomitant cropland weeds, namely Cheno/Am, Caryophyllaceae and Brassicaceae substantiates the rising human activities in the region. The swamp attained a wider stretch with deep perpetual hydrological status, hence luxuriantly overgrown by wetland plants, viz. sedges and *Hygrophila*. The aquatic elements such as *Lemna* and *Potamogeton* along with freshwater algae, *Spirogyra* and *Zygnema* also thrived well in the water-accumulating bodies over the swamp.

Around 4011 to 2178 years BP (pollen zone AJ-III), the mixed deciduous forests became much sparse and less diversified in floristic composition than witnessed prior to the preceding phase of open mixed tropical deciduous forests with the abrupt reduction in the moist forest constituents, *M. indica* in particular, as well as the other associates, viz. *Terminalia*, *L. coromandelica*, *Grewia*, *S. oleosa*, Sapotaceae, *E. officinalis* and *A. marmelos*. This diminution in the forests is also corroborated by a concurrent incursion of *B. ceiba* and *Acacia*, which are the common trees of savannah today in the region. The open nature of the forests paved the way for the further spreading out of the heathland shrubs, viz. Acanthaceae (cf. *Rungia*), *Petalidium* and *Strobilanthes*. Such a drastic depletion in the forests implies that a warm and relatively less humid climate prevailed in the region under the influence of a weak SW monsoon. This deterioration of climate is also validated by an overall decline of ferns, especially *Ceratopteris*. In addition, the dwindling of sedges and aquatic flora indicates that the swamp also got smaller because of adverse climatic conditions. However, the agricultural practice in the immediate domain of the swamp got accelerated, probably with the availability of more space for reclamation. This is confirmed by the improvement of Cerealia and the concomitant cropland weeds.

Since 2178 years BP to the Present (pollen zone AJ-IV), the dense and diversified mixed moist tropical deciduous forests got established again in the region. This is clearly elucidated by expansion in the major forest ingredients, viz. *M. indica*, *Terminalia*, *Grewia* and *A. marmelos* right from the beginning of this phase. Other forest associates such as *S. oleosa*, *Syzygium*, *L. parviflora*, *S. robusta* and *H. cordifolia* also became more frequent, contrary to the dry elements such as *Acacia* and *B. ceiba*, which became insignificant. From this proliferation of the forests it is surmised that a warm and rela-

tively more humid climate equivalent to the present day prevailed in the region with the advent of an active SW monsoon. The arrival of much favourable climatic condition during the last two millennia or so could have been the aftermath of invigoration of SW monsoon. The appreciable increase in Cerealia and other culture pollen taxa signifies the further augmentation in the cereal-based agriculture practice in the region on the whole as well as in the area contiguous to the swamp. Although the monsoon precipitation was good, the swamp assumed a smaller stretch, which is evident from the reduction in wetland and aquatic taxa. This change in the status of the swamp might have occurred on account of reclamation of its wider and less waterlogged peripheral area by the tribals in order to cope with the food security of the escalating human population in the region during the recent past.

Thus, the pollen proxy database retrieved through the study of a 1.75 m deep sediment core from the Amjhera Swamp has documented the changing vegetation scenarios and contemporaneous climatic episodes in southwestern Madhya Pradesh in a definite time-frame since prior to the Mid-Holocene. The pollen sequence generated has demonstrated that this region supported the open mixed tropical deciduous forests during the time-brackets of 6000 to 5409 years BP and 4011 to 2178 years BP under a warm and less humid climate in response to reduced monsoon precipitation. These time-intervals of adverse climate were found to alternate with the warm and more humid climatic regimes between 5409 and 4011 years BP as well as 2178 years BP to the Present, which could be ascribed to increased monsoon precipitation as well indicated by the establishment of diversified and dense tropical deciduous forests. The region was under the cereal-based agricultural practice right from the beginning of the sequence, i.e. since 6000 years BP; however, it has got accelerated during the last 2 millennia or so due to prevalence of more active SW monsoon. Further investigation of potential swamp and lake deposits from other regions of central India, using a concerted approach involving pollen, geochemical and isotope data is needed. This could significantly facilitate the simulation of precise trend of SW monsoon and its influence on the natural resource in central India during the Quaternary Period as well as in divulging the major climatic events from the Indian subcontinent in global perspective.

1. Chauhan, M. S., Origin and history of tropical deciduous Sal (*Shorea robusta* Gaertn.) forests in Madhya Pradesh, India. *Palaeobotanist*, 1995, **43**, 89–101.
2. Chauhan, M. S., Pollen evidence of Late-Quaternary vegetation and climatic changes in northeastern Madhya Pradesh. *Palaeobotanist*, 2000, **49**, 491–500.
3. Chauhan, M. S., Late-Holocene vegetation and climatic changes in Eastern Madhya Pradesh. *Gondwana Geol. Mag.*, 2004, **19**, 165–175.
4. Chauhan, M. S., Pollen record of vegetation and climatic changes in northeastern Madhya Pradesh during last 1,600 years. *Trop. Ecol.*, 2005, **46**, 265–271.
5. Yadav, D. N., Chauhan, M. S. and Sarin, M. M., Geochemical and pollen records from northeastern Madhya Pradesh: an appraisal of Late-Quaternary vegetation and climate change. *J. Geol. Soc. India*, 2004, **68**, 95–102.
6. Chauhan, M. S., Holocene vegetation and climatic changes in southeastern Madhya Pradesh, India. *Curr. Sci.*, 2002, **83**, 1444–1445.
7. Chauhan, M. S. and Quamar, M. F., Vegetation and climate change in southeastern Madhya Pradesh during Late Holocene, based on pollen evidence. *J. Geol. Soc. India*, 2010, **76**, 143–150.
8. Shaw, J., Sutcliffe, J., Lloyd-Smith, L., Schwenninger, J., Chauhan, M. S., Mishra, O. P. and Harwey, C., Ancient irrigation and Buddhist history in Central India: optically stimulated luminescence dates and pollen sequences from Sanchi dams. *Asian Perspect.*, 2007, **46**, 166–201.
9. Quamar, M. F. and Chauhan, M. S., Late Holocene vegetation, climate change and human impact in southwestern Madhya Pradesh, India. *Palaeobotanist*, 2011, **60**, 281–289.
10. *Hoshangabad District at a Glance*, District Groundwater Information Booklet, Hoshangabad District, Madhya Pradesh, Ministry of Water Resources, Central Ground Water Board, Northern Central Region, Government of India, 2009, pp. 6–19; http://cgwb.govt.in/District_profile/MP/Hoshangabad
11. Champion, H. G. and Seth, S. K., *A Revised Survey of Forest Types of India*, Government of India Press, New Delhi, 1968.
12. Erdtman, G., *An Introduction to Pollen Analysis*, Chronica Botanica Co, Mass., USA, 1943.
13. Benarde, M. A., *Global Warming*, John Wiley and Sons, New York, USA, 1992.

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New human fossils and associated findings from the Central Narmada Valley, India

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Explorations in the Central Narmada Valley have yielded a partial hominin femur and a humerus from a new locality, Netankheri located 3 km upstream from the previous hominin locality, Hathnora. The femur was recovered from the same Middle Pleistocene stratigraphic level that yielded calvarium at Hathnora and shares robust mosaic morphology of

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