Two natural dyes were extracted from sour and sweet pomegranate grown in Iran. Natural dyes are an environmental-friendly and low-cost source as sensitizer for DSSCs. The spectrophotometric properties of the natural dyes in solution and on TiO_2 substrate were examined. According to the results, sour and sweet pomegranate extracts showed absorption maxima in solution at 511 and 529 nm respectively. The absorption maxima of both natural dyes separately applied on TiO_2 films gave bathochromic shifts compared to the corresponding dye spectra in solutions. Finally, the natural extract dyes were utilized in constructed DSSCs and their photovoltaic behaviours were assessed. A solar energy to electricity conversion efficiency of 0.73%, 1.57% and 0.91% was achieved for sour pomegranate, sweet pomegranate and mixed extract respectively. The mixed extract has a conversion efficiency close to the average value of those sensitized with sour pomegranate and sweet pomegranate extracts. From these experimental results and discussion, it can be seen that sweet pomegranate extract presents the best photosensitized effect in DSSCs, which is due to the better interaction between the carbonyl and hydroxyl groups of anthocyanin on sweet pomegranate extract and the TiO_2 substrate in DSSCs.

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Received 10 January 2015; revised accepted 2 June 2015

Vegetation and climatic variability in southeastern Madhya Pradesh, India since Mid-Holocene, based on pollen records

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Pollen analysis of 1.75 m deep sediment core from Tula-Jalda (Amarkantak) in Anuppur district, Madhya Pradesh unravels that around 4500–3600 cal years BP, this region supported open mixed tropical deciduous forests comprising chiefly *Madhuca indica* followed by *Terminalia*, *Mitragyna parvifolia*, *Haldina cordifolia*, *Emblica officinalis* and *Acacia*, under a warm and relatively less humid climate. The retrieval of Cerealia and other cultural plants, viz. *Artemisia*, Cheno/Am and Caryophyllaceae signifies that the region was under cereal-based agricultural practice. The open mixed deciduous forests got enriched and dense around 3600–2761 cal years BP with the expansion of trees that already existed coupled with invasion of *Symplocos*, *Diospyros*, *Lannea coromandelica* and *Radermachera* with the inception of a warm and moderately humid climate in response to increased monsoon precipitation. Around 2761–2200 cal years BP, much expansion of the forests took place owing to

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initiation of a warm and more humid climate, attributed to intensification of the southwest (SW) monsoon. The modern Sal (*Shorea robusta*) forests were established around 2200 cal years BP, as clearly deciphered by the steady presence of *S. robusta* along with close allies such as *M. indica*, *Terminalia*, *H. cordifolia*, *E. officinalis*, etc. This change in the vegetation scenario implies that a warm and relatively more humid climate prevailed with timely arrival of the more active SW monsoon.

Keywords: Climate, pollen analysis, sediment core, vegetation.

QUATERNARY palaeoclimatic studies from the tropical regions of India have hitherto been carried out chiefly from the south Indian Nilgiri mountains, where most of the landscape abounds with vivid tropical evergreen forests, popularly known Shola forests[1–5] and forests in the Eastern Ghats[6]. These studies have brought out important data grid concerning the succession of forests and contemporary climatic changes as well as impact of human activities in the above regions since the Late Pleistocene. Similar studies pursued from the coastal regions have deduced the status of mangrove vegetation and sea-level changes in chronological sequence, in the context of fluctuating trend of the southwest (SW) monsoon during the Late Quaternary[7–9]. Pollen studies conducted on some lakes of Rajasthan desert have provided insights pertaining to the origin of the desert, vegetation and climate change and formation of inland basins due to monsoon variability since the Early Holocene[10]. However, central India with diversified tropical deciduous forests, constituting about 28% forest cover of the country, has not yet been given much attention in order to reconstruct their antiquity, temporal and spatial distribution as well as climatic variability they have witnessed during the Quaternary. Some sketchy information is available from eastern Madhya Pradesh (MP)[11–18] on this aspect during the Holocene on broader and shorter timescales through pollen analytical studies of lake and swamp deposits. Besides, some pollen-based studies have also been executed from central[19] and southwestern MP[20,21] deciphering the changing vegetation scenarios in these regions since the Mid-Holocene. In the present communication, we extend such studies to other areas in southeastern MP to delineate the vegetation shifts, climate change and impact of anthropogenic activities through meticulous pollen analysis of 1.75 m deep sediment core from Tula-Jalda in Anuppur district.

The study site, Tula-Jalda swamp is situated 2 km northwest of Amarkantak town and 100 km southeast of Sohagpur in Anuppur district (long. 81°46′N; lat. 22°41′E) at approximately 1000 m altitude (Figure 1). The swamp is perennial and spreads over a length of 100 m along the right bank of Narmada River and measures about 20 m in width. It is highly waterlogged and overgrown with reed-swamp grasses, *Phragmites karka* and *Typha latifolia* (elephant grass), a semi-aquatic tall herb. A natural spring is the source of perpetual water supply to the swamp. Locally, the landscape is marked by flat plain and deep gorge formed due to a stream; however, the southern and northern sides are occupied by bouldery flat-topped hillocks with gentle slopes. The swamp stands in the open area and is encircled with Sal (*Shorea robusta*) forests in ca. 100 m radii all around from the centre. Most of the area around the swamp is densely inhabited by the Gond and Bega tribes, who are pursuing agriculture.

The area is characterized by seasonal climatic variability with mean annual temperature range 21–31°C. The mean summer temperature during April to June is between 31°C and 33°C, with the highest record of 42°C in the extreme hot month of June. The mean winter temperature ranges between 16.3°C and 21°C. The temperature

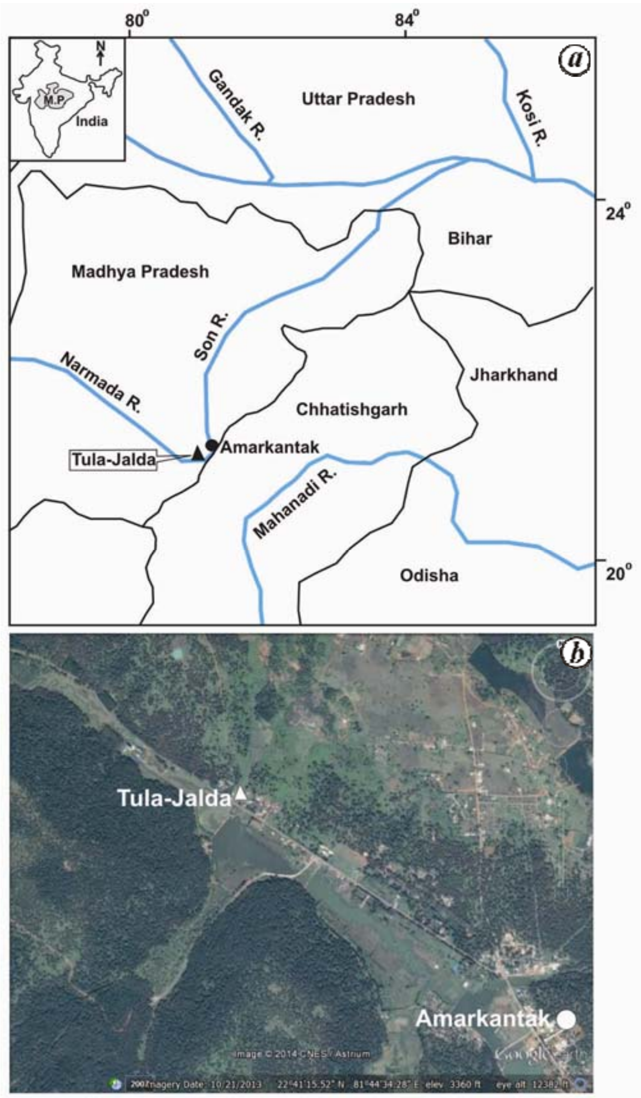

Figure 1. Location map (***a***) and *Google* image (***b***) showing the study site, forest cover and tribe habitation.

descends up to 1°C during the extreme cold months of December and January. Rainfall occurs largely from SW monsoon[22]. The rainy season commences in mid-June and continues till mid-September. About 70% rainfall occurs during this period. The average annual rainfall is approximately 1900 mm for the nearest township, Amarkantak. In general, the region enjoys a warm and humid climate.

The vegetation in the ambience of the swamp and as a whole in the region is characterized by the presence of luxuriant moist tropical deciduous forests with *S. robusta* (Sal) as a dominant constituent[23]. *Hadina cordifolia*, *Terminalia chebula*, *Mallotus philippensis*, *Mitragyna parvifolia*, *Buchanania lanzan*, *Lagerstroemia parviflora*, *Syzygium cumini*, *Anogeissus latifolia*, *Sterculia urens*, *Emblica officinalis* and *Ougenia oogeinensis* are also the principal components of these forests. Interestingly, *Madhuca indica*, *Diospyros melanoxylon* and *Butea monosperma* are entirely absent in these forests. *Acacia nilotica* and *Aegle marmelos* occur frequently in the dry river beds. The shrubby vegetation in the forests includes *Ziziphus mauritiana*, *Carissa opaca*, *Woodfordia fruticosa*, *Strobilanthes angustifron*s and *Indigofera gerardiana*. However, along the stream and on the river banks *Melastoma malabathricum*, *Osbekia* sp. and *Grewia tilifolia* occur frequently. *Bauhinia vahlii*, *Dioscorea hispida*, *Celastrus paniculata* and *Cuscuta reflexa* are the common climbers on a number of trees.

The herb vegetation on the forest floor as usual is dominated by grasses, viz. *Heteropogon contortus*, *Imperata cylindrica*, *Isachine globosa*, *Themeda triandra*, *Thysanolaena maxima*, *Eragrostiella nardoies* and *Cynodon dactylon*. However, *Desmodium dichotomum*, *Moghania* spp., *Urena lobata*, *Xanthium strumarium*, *Ageratum conyzoides*, *Plectranthus mollis*, *Sida rhombifolia*, *Euphorbia hirta*, *E. thymifolia*, *Crotararia juncea*, *Leucas aspera*, *Pogostemon benghalensis*, *Achyranthes aspera*, *Justicia simplex*, *Chenopodium spinosus*, *Oxalis acetocella*, *Leea* spp., *Stellaria media*, *Mazus japonicas* and *Micromeria biflora* are also common. Marshy plants comprising largely *Cyperus rotundifolia*, *Scirpus auriculatus*, *Polygonum plebeium*, *P. serrulatum*, *Eriocaulon quinquangularis*, *Rotala rotundifolia* and *Ammania baccifera* are abundant along the banks of rivers, streams, ponds and ditches. The meagre aquatic vegetation is found only in ditches, or where the flow of stream is slow, i.e. on the abrupt curves of stream and rivers. The important plant species include *Vallisneria spiralis*, *Potamogeton javanicus*, *Myriophyllum intermedium*, *Typha latifolia*, *Eriocaulon ritcheanum*, *Limnophlia indicum*, *Lemna polyrrhiza* and *Nymphoides cristatum*.

The materials for the present study include surface samples (moss pollsters) as well as core samples. Six surface samples were picked up at approximately 100 m intervals from the Sal forest adjacent to the swamp to study modern pollen–vegetation relationship. After a detailed survey of the swamp, a 1.75 m deep sediment core was collected from the western flank using Hiller's peat auger. In all, 22 samples consisting of 10 from the organic-rich upper part of the core (0–50 cm) at 5 cm interval and 12 from rest of the core (50–175 cm) at 10 cm interval were subjected to pollen analysis as the sediment in this part was composed of organic-deficient coarse sand with minor fraction of clay. In addition, four bulk samples were also taken from this core for radiocarbon dating at broader intervals, where there was a distinct change in the sediment texture.

The sediment composition of the core exhibits five clear-cut lithounits. The uppermost unit is made up of blackish clay with rich organic matter and rootlets followed by blackish clay with organic matter, forming the largest lithounit. The underlying unit is constituted of greyish clay with minor fraction of organic matter and this overlies the yellowish clay with coarse sand unit. The bottommost lithounit is made up of brownish–grey coarse clayey sand. Table 1 provides the lithological details. Four radiocarbon ages have been determined for this sediment core (Table 2).

The above radiocarbon ages at different depths have been used for the calculation of sedimentation rates. For the lower horizon, the ages 4219 cal years BP at 155–170 cm depth and 2728 cal years BP at 85–100 cm depth have been taken into account for the calculation of sedimentation rate, which is 21.5 year/cm. For the upper horizon with uniform sediment composition, the radiocarbon ages 2291 cal years BP at 45–60 cm depth and 1995 cal years BP at 20–30 cm depth were used and the sedimentation rate for this part is 11 year/cm. These sedimentation rates have facilitated interpolation and extrapolation of four more dates, i.e. 4500 cal years BP at 175 cm depth; 3600 cal years BP at 135 cm depth; 2761 cal years BP at 90 cm depth and 2200 cal years BP at 35 cm depth in order to delineate the temporal vegetation shifts and

Table 1. Lithology of the sediment core

Depth (cm)	Lithology
0–30	Blackish clay with rich organic matter and rootlets
30–110	Blackish clay with organic matter
110–140	Greyish clay with minor fraction of organic matter
140–150	Yellowish clay with traces of coarse sand
150–175	Brownish–greyish clayey coarse sand

Table 2. Radiocarbon dates of the core

Depth (cm)	Lab ref. no.	^{14}C ages years BP	Calibrated ages years BP
20–30	BS-2732	2050 ± 80	1995
45–60	BS-2728	2180 ± 70	2291
85–100	BS-2729	2540 ± 80	2728
155–170	BS-2726	3800 ± 100	4219

contemporary climate changes in the region since Mid-Holocene.

Samples were treated with 10% aqueous KOH and 40% HF solutions in order to deflocculate the pollen and spores from the bulk sediments and to dissolve the silica content of the samples respectively. Thereafter, the standard procedure of acetolysis using acetolysing mixture (9 : 1, acetic anhydride and concentrated sulphuric acid) was followed[24]. Finally, the samples were prepared in 50% glycerin solution for microscopic examination.

All the surface and core samples analysed were productive in pollen/spore content. The pollen sums range from 202 to 364, which exclude the pollen of aquatic plants and ferns due to their origin from the local sources. Further, the pollen of Cyperaceae (sedges) have also been excluded from the pollen sums due to their over-representation in the samples. The percentage frequencies of the recovered pollen taxa were calculated from the pollen sums for their representation in the pollen diagram. The pollen of the non-pollen sum components comprising Cyperaceae, aquatic plants and fern spores have also been calculated from the pollen sums for their representation in the pollen spectra and pollen diagram. The precise identification of the retrieved pollen and spores (Figure 2) has been carried out by consulting the reference pollen slides available at BSIP Herbarium as well as the pollen photographs and descriptions in the published literature[25,26]. The plant taxa categorized (Table 3) as trees, shrubs, herbs, ferns and drifted are arranged in the same sequence in the pollen spectra and pollen diagram.

To understand the modern pollen deposition pattern and extent of representation of extant vegetation/plant taxa in the pollen rain in relation to their factual presence in the region, six surface samples were analysed from the forest adjoining the study site (Figure 3). The pollen rain composition reveals the dominance of the non-arboreals (herbs) and comparatively low frequencies of arboreals (trees and shrubs). Among the trees, *Madhuca indica* (5–15%) is recovered in greater abundance compared to *S. robusta* (1–8%), *Syzygium* (2–5%), *Lagerstroemia* (1–3%) and *Terminalia* (1–5%), which are also recorded consistently. *E. officinalis*, *Schleichera oleosa*, *Bauhinia*, *Diospyros* and *H. cordifolia* (0.5–4% each) are sporadic with moderate to low frequencies, whereas *Grewia*, *Holoptelea*, *Acacia*, *Dodonaea*, *B. monosperma* and *B. lanzan* (1% each) are scanty. The shrubby elements, Fabaceae (2–8%) are steadily present. The rest, such as *Strobilanthes* (1–2%), Acanthaceae and *Ricinus communis* (1% each) are rare.

Poaceae (grasses, 30–42.5%) and Tubuliflorae (8–45%) depict their consistent presence in much higher frequencies among the non-arboreals. Chenopodiaceae/Amaranthaceae (Cheno/Am 1–7%), *X. strumarium* (0.5–5%), *Artemisia* (1–3%), Lamiaceae (1%) and Liguliflorae (1–5%) also show good frequency, despite their sporadic presence. Malvaceae, *Chrozophora* and Caryophyllaceae (1% each) are occasional. Cyperaceae (2–5%) is recovered consistently with fluctuating frequencies, whereas *Solanum* (< 0.5–1.5%) is scanty. The aquatic element, *Potamogeton* (1%) is encountered in one sample only. Fern spores (monolete 5–52.8% and trilete 54–58%) are abundant. The pollen of subtropical and temperate elements, viz. *Pinus* (< 0.5–1%) and *Cedrus* (1.5%) are met with only rarely.

Thus, the pollen assemblage obtained, in general, reveals the dominance of non-arboreals (herbs) and low frequencies of arboreals (trees and shrubs). Among the trees, *S. robusta* (Sal), constituting about 60% of the total forest flora, is recorded with an average 6% pollen only, irrespective of it being a high pollen producer[27]. The under-representation of Sal could be inferred due to poor preservation of its pollen in the sediments. The other associates of Sal, viz. *M. indica*, *Holoptelea* and Sapotaceae, despite their consistent presence, are also recovered in low frequencies. Rest of the trees, viz. *E. officinalis*, *Terminalia*, *S. urens*, *S. oleosa*, *Acacia*, *Lagerstroemia*, *H. cordifolia*, etc. occurring in good proportion in the forest are extremely sporadic with low frequencies. This irregular representation of all these taxa could be attributed to their low pollen productivity, since they exhibit a strong tendency for entomogamy. The partial preservation of their pollen in the sediments cannot be ruled out. The rest of the trees, besides *S. robusta*, constitute a fraction of average 22.6% of the pollen rain. Collectively, average 28.6% tree pollen represent the modern Sal-dominated forest in the area as well as existing climatic conditions in the region. Studies conducted on the Sal-dominated tropical deciduous forests from the northeastern part of MP[28,29] have also demonstrated identical representation of various forest components and other plant groups in the modern pollen rain. Similar observations have also been made regarding the ambiguous interplay of the tropical trees in the pollen rain from equivalent floristic provinces in Western Uganda[30].

The pollen diagram constructed from Tula-Jalda has been divided into three distinct pollen zones, based on the representation of prominent trees and non-arboreals (Figure 4). These pollen zones are prefixed with the initials ‘TJ’ after the name of investigation site Tula-Jalda and are numbered from bottom to top (TJ-I, TJ-II, TJ-III and TJ-IV) and are described below.

Pollen zone TJ-I (175–135 cm) with a solitary radiocarbon date of 3800 ± 100 years BP and encompassing a time bracket of 4500–3600 cal years BP shows excessively high values of non-arboreals (herbs) and a relatively reduced frequency and sporadic presence of arboreals (trees and shrubs). *M. indica* (2.04–5.45%) is consistently recorded in good frequencies followed by *Terminalia* (1.47–1.8%) and *M. parvifolia* (0.9–1%) in moderate values, whereas *E. officinalis* (1.36%), *S. robusta* (1.41%), *Flacourtia indica* (0.81%) and *Lagerstroemia* (0.68%) are scarce. The shrubby elements, viz. *Grewia*

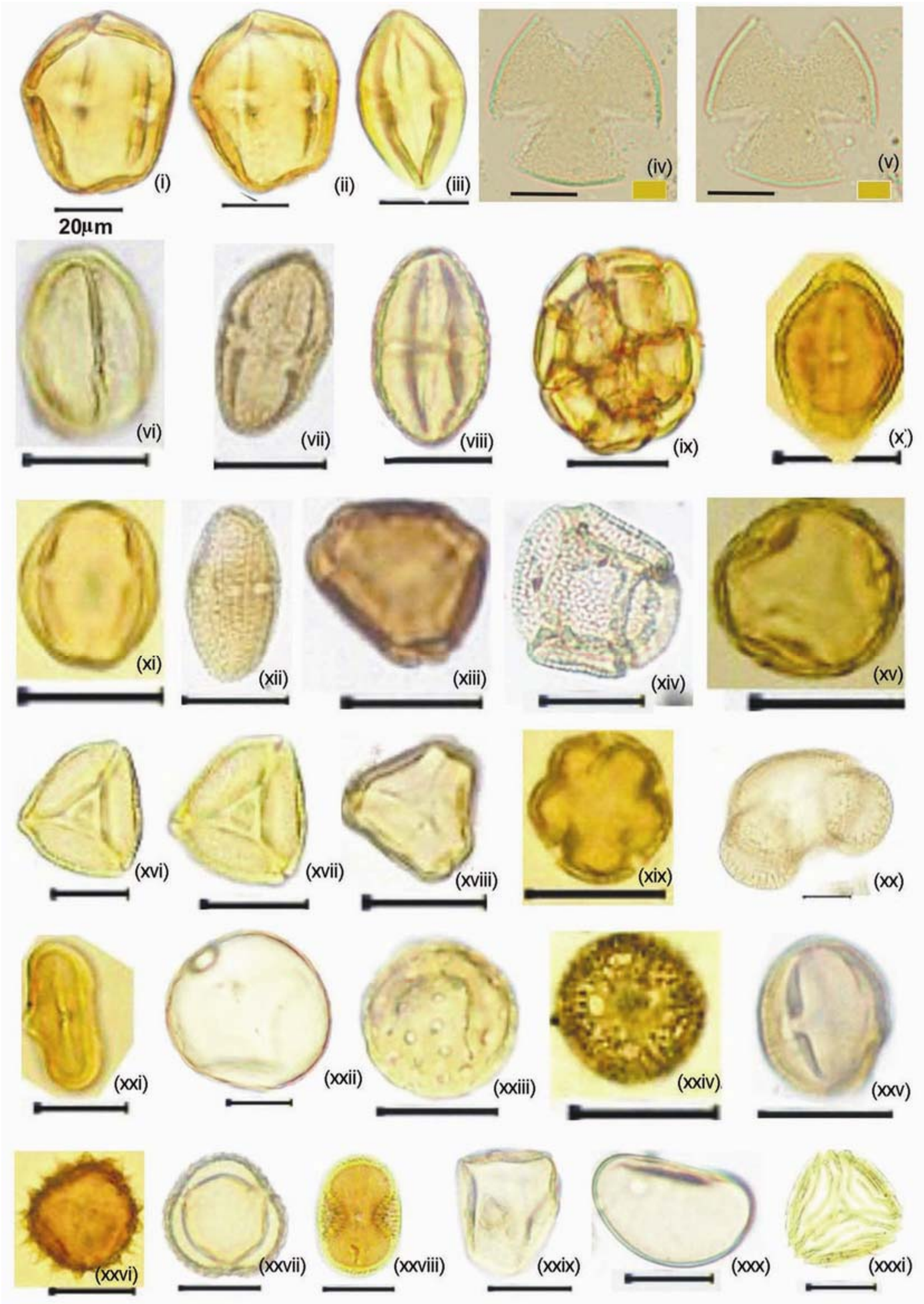

Figure 2. (i) and (ii), *Madhuca indica*; (iii), *Diospyros*; (iv) and (v) *Shorea robusta*; (vi), *Lannea coromandelica*; (vii) *Grewia*; (viii), *Buchanania lanzan*; (ix), *Acacia*; (x), *Lagerstroemia*; (xi), *Terminalia*; (xii), *Strobilanthes*; (xiii), *Symplocos*; (xiv), *Radermachera*; (xv), *Trewia*; (xvi), (xvii), *Schleichera oleosa*; (xviii), *Syzygium*; (xix), *Emblica officinalis*; (xx), *Pinus*; (xxi), Apiaceae; (xxii), Poaceae; (xxiii), Cheno/Am; (xxiv), Caryophyllaceae; (xxv), *Artemisia*; (xxvi), Tubuliflorae; (xxvii), *Xanthium*; (xxviii), *Justicia*; (xxix), Cyperaceae; (xxx), Fern (monolete); (xxxi), Fern (Trilete)-*Ceratopteris*.

(1.81–4.09%), Fabaceae (3.4–8.82%) and Acanthaceae (1.63–1.81%) have good frequencies compared to *Combretum* (0.81%), which is scanty.

Among the non-arboreals, Poaceae (48.5–63%) is consistently more abundant. Likewise, *Artemisia* (4.09–11.7%), Tubuliflorae (0.68–8.82%), Liguliflorae

Table 3. Plant taxa recovered in the sediment core

Arboreals		Non-arboreals	Others
Trees	Shrubs	Cultural taxa:	Ferns:
Moist deciduous elements: (average annual rainfall 1200–1600 mm) *Shorea robusta*, *Madhuca indica*, *Lagerstroemia*, *Mitrgyna parvifolia*, *Radermachera*, *Buchanania lanzan*, *Terminalia*, *Syzygium*, *Symplocos*, *Haldina cordifolia*, Sapotaceae, Meliaceae.	*Ricinus communis*, *Grewia*, *Lepidagathis*, *Strobilanthes*, Rutaceae, Fabaceae, Acanthaceae.	Cerealia, *Cannabis sativa*, Brassicaceae, *Artemisia*, Chenopodiaceae/amaranthaceae, Caryophyllaceae.	Ferns producing monolete spores and producing trilete spores.
Dry deciduous elements: (average annual rainfall 900–1200 mm) *Holoptelea*, *Acacia*, *Aegle marmelos*, *Trewia*, *Emblica officinalis*, *Schleichera oleosa*, *Lannea coromandelica*, *Flacourtia indica*, *Diospyros*, *Bombax ceiba*.		Heathland taxa: Poaceae (grasses), Asteraceae (Tubuliflorae & Liguliflorae), *Xanthium strumarium*, *Justicia*, Lamiaceae, *Evolvulus*, *Borreria*, *Convolvulus*, *Chrozophora*, Rubiaceae.	Drifted: *Pinus*, *Cedrus*.
		Wetland taxa: Cyperaceae (sedges), *Polygonum serrulatum*, *Polygala*, *Solanum*, *Hygrophila*, *Eriocaulon*, Liliaceae.	
		Aquatic taxa: *Typha*, *Trapa*, *Potamogeton*, *Myriophyllum*.	

(2.94–10.8%), Cheno/Am (0.68–2.94%) have frequent presence. Cerealia (1.63%), Caryophyllaceae (4.08%), *Justicia* (1.8%), Brassicaceae (0.68%) and *Convolvulus* and *Evolvulus* (0.68–1% each) are sporadic. The marshy element, Cyperaceae (sedges 61–161%) is preponderant followed by *P. serrulatum* (0.81–7.48%) and *Hygrophila* (0.91–3.4%) with moderate values. The aquatic element, *Potamogeton* (1.47–2.7%) is steadily present in moderate values. Fern spores (monolete 5.45–12.9% and trilete 62.7–136%) are abundant.

Pollen zone TJ-II (135–90 cm) with ^{14}C age of 2540 ± 80 years BP and covering the time zone 3600–2761 cal years BP exhibits considerable increase in trees compared to the preceding zone. *M. indica* (1.92–5.8%) and *Terminalia* (1.28–1.86%) remain the same as before, whereas *M. parvifolia* (1.28%), *H. cordifolia* ((0.67–0.98%), *E. officinalis* (0.68–2.8%) and Sapotaceae (1.34%) are extremely sporadic. *Lagerstroemia* (0.67–1.28%), *Acacia* (0.98–1.86%), *Diospyros* (0.64–0.96%), *Holoptelea* (3.23%), *Symplocos* and Meliaceae (0.67–0.98%) turn up with moderate to low values. The shrubby elements, viz. *Grewia* (2.8–5.76%) and Fabaceae (0.67–5.6%) have steadily good frequencies, whereas *Strobilanthes* (0.93–1.8%) is recorded for the first time.

The ground vegetation is still dominated by Poaceae (35.2–53.2%), though with slightly reduced values. Tubuliflorae (2.8–5.8%), *Artemisia* (0.98–7.05%), Cheno/Am (0.67–5.8%) and Liguliflorae (2.8–5.12%) are recorded constantly. Caryophyllaceae (0.93–2.68%) has sporadically moderate values. *Evolvulus* (2.56%), *Justicia* (1.28%), Brassicaceae (2%) and Lamiaceae and *Chrozophora* (0.67% each) are occasional. Cyperaceae (14.7–104%) and *Hygrophila* (0.98–14.7%) retain consistently high frequencies. *P. serrulatum* (1.92%) and Liliaceae (0.67%) are noticed in one sample each. The aquatic element, *Potamogeton* (2.94–16%) portrays enhanced values. *Myriophyllum* (0.67%) appears feebly in this zone. Fern spores (monolete 1.96–12.8% and Trilete 37–214%) become frequent. The Himalayan elements, *Pinus* (1.28%) and *Cedrus* (0.64%) are trivial.

Pollen zone TJ-III (90–35 cm) with a radiocarbon age of 2180 ± 70 years BP and encompssing a time interval of 2761–2200 cal years BP documents a reduced number of trees. *M. indica* (1.8–3.6%), *Symplocos* (1.42–2.7%) and *Lagerstroemia* (2.1–3.03%) are better represented with increased values. *Terminalia* (1.83–2.1%), *Holoptelea* (0.52–1.5%), *M. parvifolia* (2.7%) and Sapotaceae (2.75–3.75%) are sporadic. *Radermachera* (0.71–4.18%), *A. marmelos* (1.42%), *L. coromandelica* (0.71–1.8%), *Diospyros* (7.8%) and Meliaceae (0.91–1.5%) also appear sporadically. Fabaceae (3.13–5.71%), *Grewia* (2.7–6.8%) and *Strobilanthes* (0.91–2.81%) are the prominent shrubs. Rutaceae (1.83%), Acanthaceae (0.52–2.7%) and *Lepidagathis* (0.75%) are infrequent.

Among the non-arboreals, Poaceae (40.6–50.4%), Cheno/Am (1.04–9%), *Artemisia* (1.8–6.19%) and Tubuliflorae (1.83–6.81%) are also recovered consistently as earlier. Caryophyllaceae (0.75–2.7%), Brassicaceae (2.14–3.13%), *Justicia* (0.52–1.42%) and Liguliflorae (2.1–2.75%) are sporadic with fluctuating values. *Cannabis sativa* (1.8%), Lamiaceae (0.75%) and *Chrozophora* (0.52%) are trivial. The marshy taxon, Cyperaceae (26.9–163%) exhibits deviatingly high frequencies together with *Hygrophila* (2.27–7.28%) in moderate values.

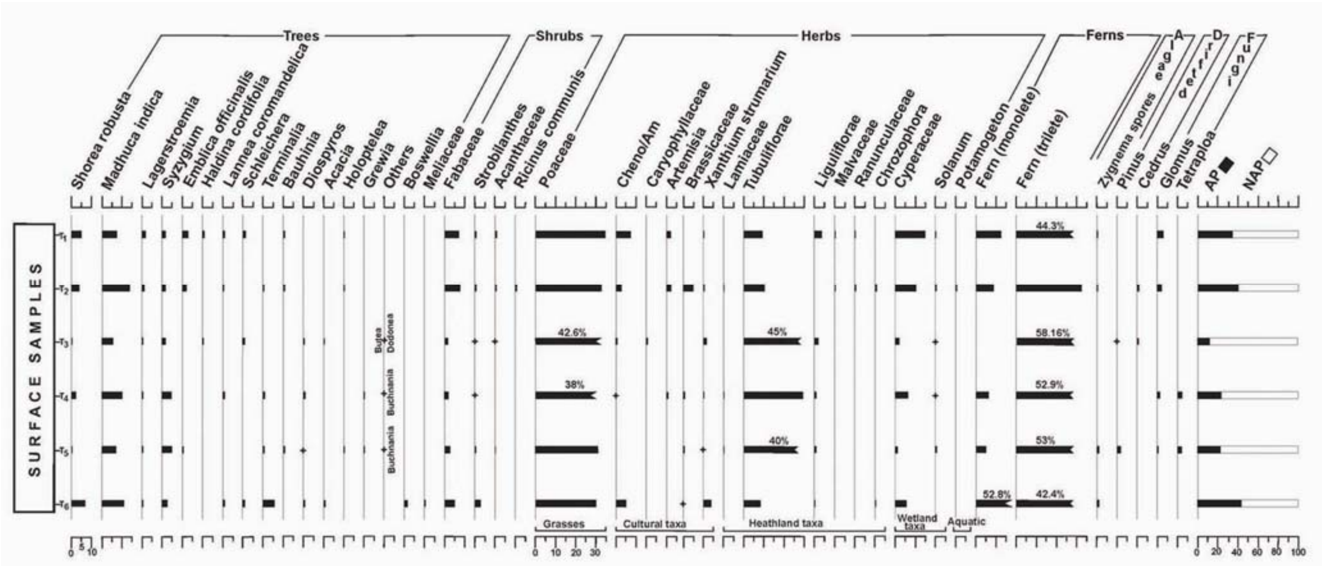

Figure 3. Pollen spectra from Tula-Jalda, Anuppur district, Madhya Pradesh.

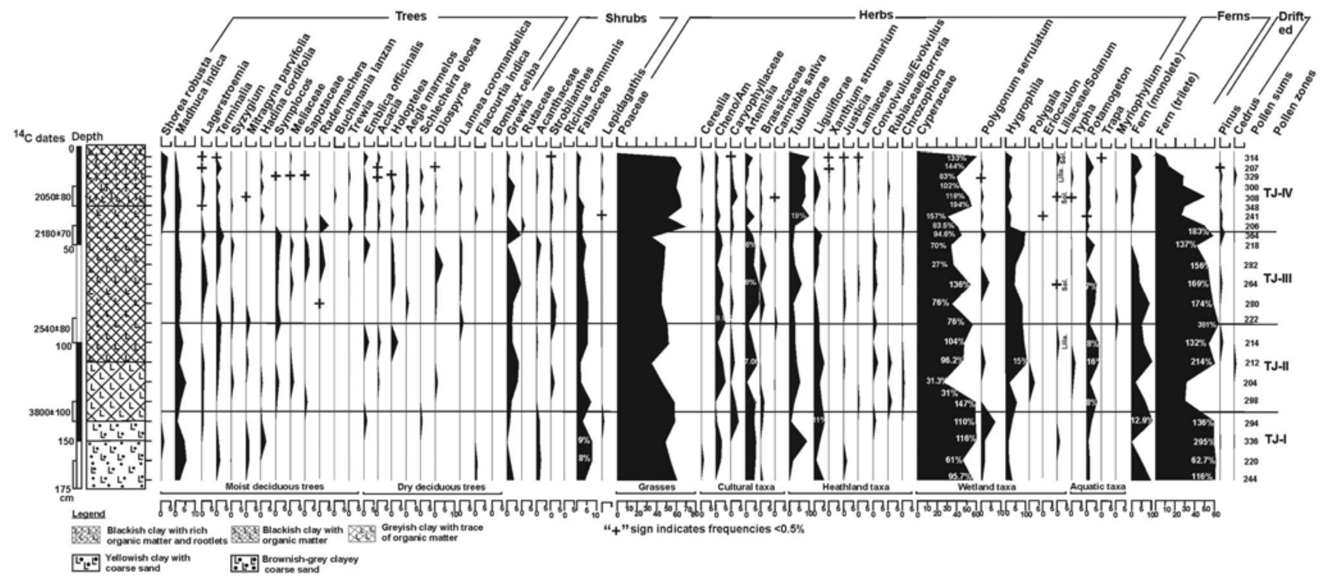

Figure 4. Pollen diagram from Tula-Jalda.

Liliaceae (1.8%) and *P. serrulatum* (2.27%) are retrieved in one sample each. The aquatic element, *Potamogeton* (1.8–6.8%) shows improvement and *Typha* (1.4%) is scanty. Fern spores (monolete 3.6–9.06% and trilete 8.26–3.87%) decline in this zone. *Pinus* (0.52%) is scarce.

Pollen zone TJ-IV (35–0 cm) with solitary ^{14}C age of 2050 ± 80 years BP and covering the temporal range of 2200 cal years BP to the present depicts reappearance of *S. robusta* (2–4%) with constantly enhanced values. *M. indica* (3.25–5.74%) is also invariably in good numbers as before. *E. officinalis* (0.5–1.88%), *A. marmelos* (0.96–1.72%) and *Acacia* (0.30–1.88%) are better represented, whereas *Terminalia* (0.314–2.5%) and *Lagerstroemia* (0.30–3.8%) are retrieved slowly. *L. coromandelica* (1.33%), *Symplocos* (0.30–4.25%), *Holoptelea* (0.30–1.27%), *Syzygium* (0.57%), *Diospyros* (1.14%), Meliaceae (0.30–0.62%) and *M. parvifolia* (0.32%) become more sporadic. *S. oleosa* (0.9–1.14%), *Bombax ceiba* (0.64%) and *Buchanania lanzan* (0.32%) turn up meagerly. *Radermachera* (7.07%) spurts are in early part only. *H. cordifolia* (0.41–0.96%) reappears after a lapse in the previous zone. The shrubs, viz. *Grewia* (0.6–7.07%), Fabaceae (0.9–3.44%) and *Strobilanthes* (0.31–1.44%) are present appreciably. *Lepidagathis* (0.41–0.66%), *Acalypha* (0.90%), Rutaceae (0.6–2%) and *Trewia* (1.50%) are stray.

Poaceae (29.3–69.5%) followed by Tubuliflorae (2.5–13.18%), Liguliflorae (1.5–4.3%) and Caryophyllaceae

(0.31–3.56%) reveal a rising trend. Cheno/Am (0.57–2.72%) and *Artemisia* (0.5–4.45%) decline slightly, while Brassicaceae (0.5–0.9%), *C. sativa* (0.32–0.54%), Lamiaceae (0.48–0.66%) and *Justicia* (0.48–0.66%) are scanty. Cerealia (0.66–1.44%) reappears together with *X. strumarium* (0.3–0.48%) and *Borreria* (0.66%). The marshy element, Cyperaceae (83.3–146%) shows high frequencies along with *Hygrophila* (1.14–9.24%) and *P. serrulatum* (0.30–2.72%) with some improvement. Liliaceae (0.3–0.96%) and *Eriocaulon* (0.41%) are extremely sporadic. *Potamogeton* (0.41–3.86%) is recorded with slightly reduced abundance. *Typha* (0.32–1.25%) reveals improvement, whereas *Trapa* (0.31%) appears scarcely. Fern spores (monolete 0.57–4.83% and trilete 9–53.7%) decline in this zone. *Pinus* (0.48–1.65%) and *Cedrus* (0.57%) are intermittent.

Pollen analytical investigation of a 1.75 m deep sediment core from Tula-Jalda swamp lying close to human habitation, has revealed significant information concerning the vegetation shifts, contemporaneous climatic variability and impact of human activity in southeastern MP since the last 4500 years. The pollen sequence has demonstrated that the hillocks adjacent to the swamp supported open mixed tropical deciduous forests around 4500 to 3600 cal years BP (pollen zone TJ-I), which comprised largely *M. indica* accompanied by *Terminalia*, *M. parvifolia* and *H. cordifolia* with stray presence of *E. officinalis*, *Lagerstroemia*, *F. indica* and members of Sapotaceae. Interestingly, *S. robusta*, a dominant constituent of modern tropical deciduous Sal forests in the region, was a trivial associate of the open mixed forests around 3950 cal years BP, as marked by its sporadic occurrence. However, the undergrowths, viz. *Grewia*, Fabaceae and Acanthaceae flourished substantially in the forests. The observed vegetation composition suggests that the region was under a warm and relatively less humid climate than today. At that time the southwestern region also supported mixed deciduous forests under an equivalent climatic condition[21]. Similarly, the Rajasthan desert also witnessed 50 cm more rainfall than today around 5000–3000 years BP, though with an entirely different vegetation set-up[10]. This phase of favourable climate falls partially within the time bracket of Period of Climatic Optimum[31]. The ground flora was largely composed of grasses (Poaceae) together with heathland elements of Asteraceae. The retrieval of Cerealia and ruderal plants, viz. *Artemisia*, Cheno/Am and Caryophyllaceae implies a low-paced incipient agrarian practice and other sorts of human activities in the region. Further, the significantly high frequencies of Asteraceae imply that the region was under intensive pastoral activities as the plants of this family are unpalatable to cattle and goats and hence have more pollen in the sediments[30]. The swamp was quite big in expanse and abundantly overgrown with wetland taxa, viz. sedges and *P. serrulatum*. There were small ditches and ponds interspersed over the swamp as evidenced from the feeble record of aquatic element, *Potamogeton*. The moist and shady niches in and round the swamp were preponderantly inhabited by ferns and their allies, as well marked by their frequent record.

The open mixed tropical deciduous forests continued to thrive in the region; however, they were varied and dense in composition around 3600–2761 cal years BP (pollen zone TJ-II), as well documented by the expansion of *M. indica*, *Lagerstroemia*, *Terminalia*, *E. officinalis* as well as incursion of a few more other forest constituents, viz. *Acacia*, *Symplocos*, *Diospyros*, *L. coromandelica*, Meliaceae, etc. in appreciable numbers accompanied by *Syzygium* in relatively reduced frequencies. The undergrowth remained static in composition as in the preceding phase; however, it got enriched as manifested by consistent presence of *Grewia*, Fabaceae and invasion of *Strobilanthes* and Acanthaceae. In general, it could be presumed that the increase in the floristic variability occurred in response to initiation of a warm and moderately humid climate on account of increased monsoon precipitation. An equivalent vegetation scenario and climatic condition also prevailed in northeastern MP[12] about 200 km away from the present site during almost the same time interval. Similarly, the forest groves became varied and dense in the Central Ganga Plain around 3200 years BP owing to congenial climatic condition[32,33]. Further, the rising trend of sedges and other wetland elements, *P. serrulatum* and *Hygrophila* reflects that the swamp had a wider stretch than earlier. The abundance of ferns also corroborates the favourable climatic condition during this phase. The record of pollen of *Pinus* and *Cedrus* in the sediments elucidates their exclusive wind transportation from the Himalayan region, because there is no water course from the Himalaya to central India. Their presence also suggests the Himalayan connection of regional wind circulation pattern.

Between 2761 and 2200 cal years BP (pollen zone TJ-III), open mixed tropical deciduous forests transformed into mixed tropical deciduous forests as evidenced from the maximum expansion of most of the moist forest constituents such as *M. indica*, *Terminalia*, *Lagerstroemia*, *Symplocos*, Meliaceae, etc. as well as spurt in *Radermachera* in the beginning of this phase. The dry forest elements such as *A. marmelos* and *Holoptelea* also immigrated in the forest flora, though sparingly, in addition to much increase in *Diospyros* in the latter part of this phase. During this period of enrichment of the forests, grasses declined, probably as a consequence of depletion of open space on the forest floor, inhibiting their proliferation. From this diversification and expansion of the forests, it can be inferred that the region experienced intensified SW monsoon, depicting the prevalence of a warm and more humid climate than earlier. A similar climatic and vegetation set-up has also been recorded at Padauna swamp lying about 20 km east of the present site[17].

The modern Sal-dominated tropical deciduous forests came into existence around 2200 cal years BP (pollen zone TJ-IV) as elucidated by the reappearance and consistent improvement of *S. robusta*. The close allies of *S. robusta* such as *M. indica*, *Terminalia*, *H. cordifolia*, *E. officinalis*, *Acacia*, *S. oleosa*, *Holoptelea* and *A. marmelos* also became prominent than before. This significant change in the vegetation scenario occurred as a consequence of the timely arrival of more active SW monsoon coinciding with seed-shedding, a crucial factor for the regeneration and expansion of Sal in northern and southern MP[34], as its seeds are viable for one week time only after shedding from the parent plant. The region has come across a warm and relatively more humid climatic condition during this period. However, the earliest evidence of formation of Sal-dominated forest has been recorded around 2800 cal years BP at Padauna[17] Swamp located about 20 km east of the present site, probably due to setting of the required climatic condition in this region about 600 years earlier. It is noticeable that northeastern MP, the modern Sal-dominated tropical deciduous forests, were established around 1600 cal years BP at Jarbokho[15] and around 1100 cal years BP at Jagmotha in Sidhi district in northern MP[12], i.e. about 600 and 1100 years later respectively, compared to the present investigation site. This temporal and spatial variability concerning the establishment of Sal forests might have occurred due to delayed advent of strong SW monsoon in northern MP. Interestingly, the encounter of Cerealia with increased values deciphers the augmentation in cereal-based agricultural practice most likely to sustain the escalating human population during the last 2200 years in the region. In addition, the pastoral and other human activities became more intense during the last two millennia as evidenced from substantial rise in the Asteraceae and ruderal plants respectively.

Prior to analysis of the sediment core from Tula-Jaida, the study of pollen rain was conducted through the investigation of surface samples from its vicinity in order to understand on pollen rain-vegetation relationship in the region. This comparative database generated has served as modern analogue for the appraisal of pollen sequence of the past in terms of vegetation and climate change in the region. It has been observed that only average 28% tree pollen represent the modern Sal dominated tropical deciduous forests. Further, Sal constituting approximately 60% fraction of the forest cover, is represented by average 6% pollen only in the surface sediments out of the total tree pollen. This under-representation of Sal and deviating trends of trees in general in the pollen sequence was taken into consideration while inferring the changing vegetation scenarios and concurrent climatic episodes since the Mid-Holocene. In addition, sedges (Cyperaceae) and ferns were neglected from the pollen sums owing to their over-representation, which include terrestrial plant pollen only. However, their fluctuating trends have been used to decipher the status of the swamp as well as microclimatic variability, which are also affected by the deviating trend of the SW monsoon. Thus, the pollen records deduce that this region supported open mixed tropical deciduous forests around 4500–3600 cal years BP under a warm and relatively less humid climate than today, probably due to weak SW monsoon. Between 3600 and 2761 cal years BP, the open mixed deciduous forests got enriched with the invasion of more trees on account of onset of a warm and moderately humid climate, attributable to active SW monsoon. Later on, around 2761–2200 cal years BP, the forests became diversified and profuse as a consequence of immigration of more trees and expansion of those already existing. This significant change in the forest floristic suggests that a warm and relatively more humid climate prevailed in the region in response to the more active SW monsoon. The modern climax tropical deciduous Sal forests were established around 2200 cal years BP and continue till today with the timely advent of the more active SW monsoon, a decisive factor for the regeneration Sal. The low-paced agrarian practice was initiated around 4500 cal years BP in the region. However, it intensified from 2200 cal years BP probably due to extension of cultivated land in order to cope with the food security of the increasing human population coupled with the prevalence of more favourable climatic condition in the region.

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ACKNOWLEDGEMENTS. I thank the Director, Birbal Sahni Institute of Palaeobotany (BSIP), Lucknow for providing the necessary facilities to carry out this work, and to Dr C. M. Nautiyal (Geochronology Lab, BSIP) for radiocarbon dating of the core samples.

Received 13 August 2014; revised accepted 12 May 2015

A perspective of alkaline Lonar Lake, Maharashtra, India with reference to its hydrochemistry

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The inland Lonar Lake, encompassing a circular area of about 1 sq. km is situated in Buldhana district, Maharashtra state, India. The lake is part of the Lonar crater believed to have formed due to meteoric impact. It is third largest natural salt-water lake in the world. The lake water is not only saline, but also highly alkaline. In recent years, it is believed that the alkalinity and salinity of the lake water is being diluted with increased lake water level due to external inputs like seepage of water into the lake from nearby surface reservoirs. Studies on hydrochemical and isotopic signatures of lake water, and also lake water levels were carried out for one year to understand the lake dynamics. The generated data were compared with those available in the literature. This comparison showed that the water level and hydrochemistry of lake water are controlled by the local rainfall and evaporation, and that there are no other external water inputs to the lake.

Keywords: Alkaline lake, hydrochemistry, Lonar Crater, stable isotopes.

LONAR Lake located at 19°58′34.2″N lat. and 76°30′29.4″E long. is a near circular unique feature (Figure 1 *a*) located in Buldhana district, Maharashtra, India. The shallow, alkaline and saline lake is part of the Lonar crater in

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