10. Crawford, A. R., Reconnaissance Rb–Sr dating of Precambrian rocks of southern Peninsular India. *J. Geol. Sci. India*, 1969, **10**, 117–166.
11. Emerson, D. H., Embleton, B. J. J. and Clark, D., The Flemington intrusion field N.S.W.: Petrophysical and petrological notes: Symposium on Applied Magnetics Interpretation. *Bull. Aust. Soc. Explor. Geophys.*, 1979, **12**(**X**)**1**, 99.
12. Mutton, A. J. and Shaw, R. D., Physical property measurements as an aid to magnetic interpretation: Symposium on Applied Magnetics Interpretation. *Bull. Aust. Soc. Explor. Geophys.*, 1979, **X**, 99.
13. Rudman, A. J. and Blakely, R. F., A geophysical study of a basement anomaly in India. *Geophysics*, 1965, **30**, 740–761.
14. Subramanyam, C. and Verma, R. K., Gravity interpretation of the Dharwar greenstone – gnesis – granite terrain in the southern Indian shield and its geological implications. *Tectonophysics*, 1982, **84**, 225–245.
15. Vijaya Raghava, M. S., Jawahar, G. and Sherbakova, T. V., An ultrasonic profiling investigation on some fresh and weathered granites of Hyderabad, India. *Geophys. Prospect.*, 1977, **25**, 768–779.
16. Balakrishna, S., Venkatanarayana, B. and Gogte, B. S., Some studies on granites along Mysore–Hyderabad traverse. *Bull. NGRI*, 1971, **9**, 67–86.
17. Balakrishna, S. and Raghava Rao, M., Pink and grey granties Hyderabad. *Curr. Sci.*, 1961, **30**, 264.
18. Bhimashankaram, V. L. S., Murali Manohar Rao and Murty, B. V. S., Design and development of direct reading density balance. *J. Instrum. Soc. India*, 1975, **5**, 16–19.
19. Fedensky, V. V., *Exploration Geophysics*, Nedra, Moscow (in Russian), 1967, p. 672.
20. Balakrishna, S. and Ramana, Y. V., Laboratory and field velocity measurements in granites. *J. Ind. Geophys. Union*, 1964, **4**, 45–56.
21. Balakrishna, S., Christopher, G. and Vijaya Raghava, M. S., Magnetic susceptibilities of Hyderabad granites. *Bull. NGRI*, 1963, **1**, 41–47.
22. Ramadass, G. and Venkata Chary, M., Integrates geophysical investigations for groundwater targeting in the Osmania University Campus, Hyderabad, AP. *J. Indian Acad. Geosci.*, 1992, **35**, 19–30.
23. Janardan Rao, Y. and Sitaramayya, S., Petrochemistry of the granitic rocks of the Ghatkeasr area, Hyderabad, AP. *Indian Minerologist*, 1971, **12**, 40–50.
24. Gnaneshwar, P. and Sitaramayya, S., Petrochemistry and origin of Archean granitic rocks of Hyderabad. *Indian J. Geol.*, 1998, **70**, 249–264.
25. Gnaneshwar, P., Pandu Ranga Reddy, I., Jettaiah, P. and Bala Kotaiah, G., Mineralogical characteristics of alterations in the pink (porphyritic) granits of Hyderabad, AP, India. *J. Indian Acad. Geosci.*, 2005, **48**, 79–84.
26. Vijaya Raghava, M. S. and Narasimha Rao, R. L., Some physical properties of weathered granites deduced from ultrasonic profiling data. *Riv. Ital. Geofis.*, 1977, **IV**, 259–262.
27. Ramadass, G., Ramaprasada Rao, I. B., Himabindu, D. and Srinivasulu, N., Pseudo-surface-velocities (densities) and pseudodepth-densities (velocities) along selected profiles in the Dharwar craton, India. *Curr. Sci.*, 2002, **82**, 197–202.
28. Varaprasada Rao, S. M. and Bhimashankaram, V. L. S., Geophysical investigations for barites at Gopalpur, Khammam district, AP, India. *J. Geol. Soc. India*, 1982, **23**, 32–38.
29. Daniel, *Applied Non-parametric Statistics*, Houghton-Miff Co., Boston, 1978, pp. 276–278.
30. Kendall, S. M. and Stuart, A., *The Advanced Theory of Statistics*, Charles Griffin and Co. Ltd., 1967, vol. 2.


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# Pollen proxy records of Holocene vegetation and climate change from Mansar Lake, Jammu region, India

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**Pollen analysis of a 30 m deep sediment core from Mansar Lake has revealed that around 9000–8000 yrs BP, the mixed chirpine–oak forests dominated by *Pinus* cf. *roxburghii* (chirpine) existed in the Jammu region under a cool and dry climate. Later, they were succeeded by mixed oak–chirpine forests between 8000 and 7000 yrs BP with the expansion of oak (*Quercus* cf. *incana*) and other broad-leaved taxa in response to initiation of a warm and humid climate. Between 7000 and 3000 yrs BP, the cool and dry climate prevailed again as inferred by the reduction in broad-leaved taxa and a simultaneous improvement in the conifers, especially *Pinus* cf. *roxburghii*. However, a brief spell of pluvial activity is witnessed between 5500 and 4250 yrs BP, as envisaged by the presence of sandy deposits. Around 3000 to 750 yrs BP, expansion of oak and most of the broad-leaved taxa suggests the prevalence of a warm and more humid climate. From 750 yrs BP to the Present the climate deteriorated, as reflected by the replacement of mixed oak–chirpine forests by mixed chirpine–oak forests in the region. There has been an acceleration of human activities during the last millennium as indicated by the record of culture pollen taxa.**

**Keywords:** Climate change, Holocene, pollen proxy, vegetation.

EXTENSIVE Quaternary palaeoclimatic studies have been carried out in various sectors of the Himalaya such as Kumaon[1,2], Garhwal[3–5], Himachal Pradesh[6–9], Ladakh[10] and Kashmir[11–13], based on pollen evidence retrieved from the lacustrine sediments. However, the Jammu region, abounded with a number of natural lakes and sedimentary deposits, has not yet received attention to understand the antiquity of the flora and climatic changes this region has experienced during the Quaternary period. The present communication brings out some interesting facts concerning the vegetation scenario as well as the climatic fluctuations and the impact of anthropogenic activities in the region during the Holocene through the pollen analytical investigation of a 30 m deep sediment core from the Mansar Lake.

Mansar, a freshwater lake in the Lower Siwalik belt, is situated about 60 km east of Jammu city between 75°8′52″ E long. and 32°41′28″ lat., at an elevation of 665 m amsl

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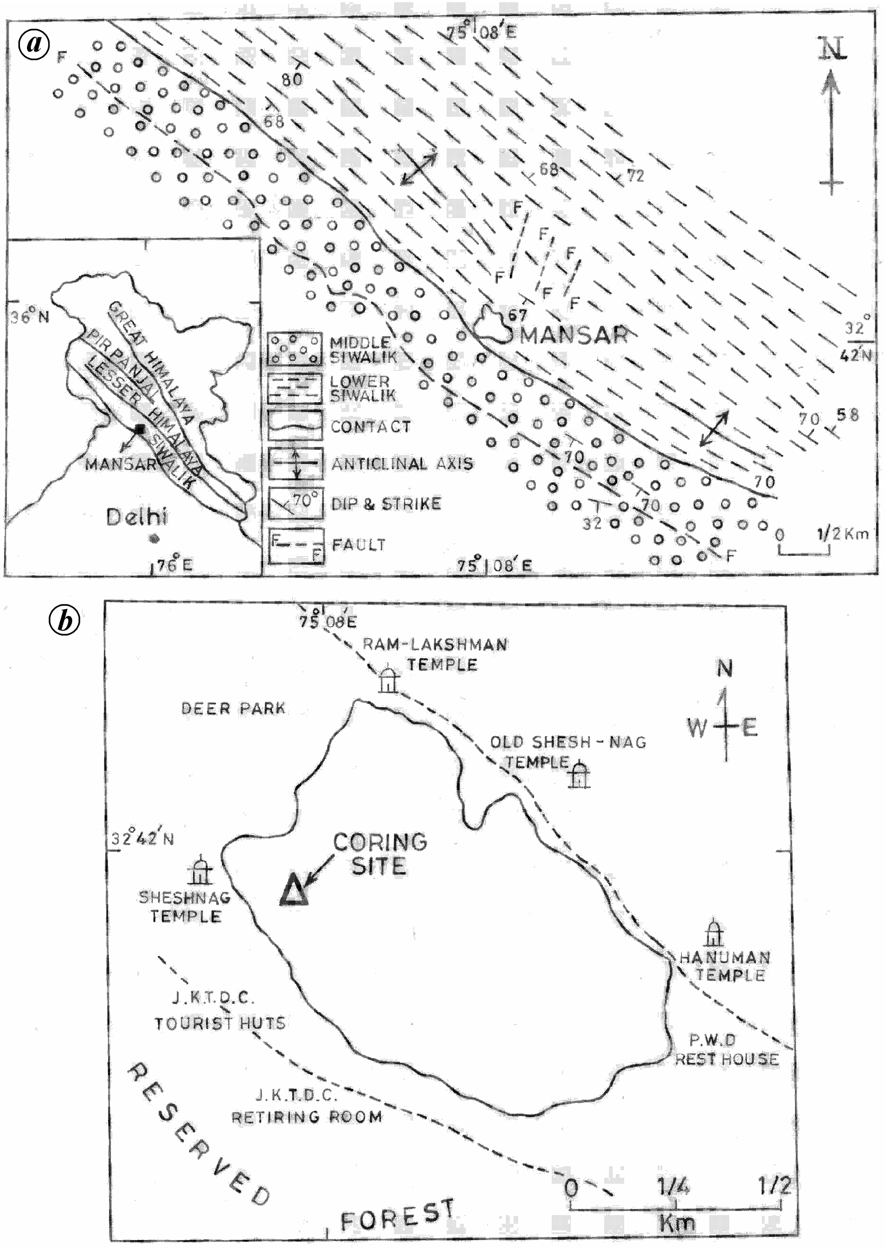


**Figure 1.** ***a***, Map showing geological setting of Mansar Lake area. ***b***, Configuration of Mansar Lake and coring site (after Das *et al.*[14]).

(Figure 1). It measures approximately 1015 m in length and 40 m at its broadest and covers an area of 649 $m^2$, with maximum depth of 35 m. Mansar is a Holocene monomictic, oligotropic and one of the oldest lakes in the outer Himalayan subtropical belt. It is a non-drainage type of lake fed by rainwater, catchment run-off and subterranean springs[14].

Geologically, Mansar Lake lies on the anticlinal axis of a major anticlinorium of the folded Lower Siwalik Formation, which consists of sandstone, siltstone and shale. The presence of alternating Lower Siwalik sandstone, siltstone and shale in the catchment implies that the basin subsided intermittently during the accumulation of Siwalik sediments[15].

The Jammu region is largely characterized by the presence of chirpine and oak forests. Chirpine (*Pinus roxburghii*) forests occur thickly on the sunny hill slopes around the lake and they are almost devoid of any undergrowth. However, the oak forests dominated by *Quercus incana* are seen in the vicinity of the Mansar Lake site, particularly in moist and damp valleys. The common associates of oak in these forests are *Rhododendron* sp., *Alnus nitida*, *Salix* sp., *Mallotus philippensis*, *Lyonia ovalifolia*, *Cinnamomum tamala*, etc. In addition, *Dodonea viscosa*, *Prinsepia utilis* and *Pyrus malus* also occur, though scantily. *Rosa moschata*, *Rubus lesiocarpus*, *R. ellipticus*, *Viburnum cotinifolium*, *Zanthoxylum alatum*, *Crataegus crenulata* and *Myrsine africana* are frequent shrubs of oak forests. The rich, herbaceous complex on the forest floor comprises chiefly *Saxifraga*, *Bergenia ligulata*, *Viola biflora*, *Ranunculus arvensis*, *Anemone* sp., *Cotoneaster bacillaris, Mazus japonicus* and *Micromeria biflora.* Aquatic elements such as *Typha*, *Lemna* and *Potamogeton* thrive well in the lake with shallow water as well as along the banks of streams and rivulets.

A 30 m deep sediment core was bore-holed below the water column of 5 m following auger and rotatory method from the western flank of the lake for pollen analytical investigation. In all 120 samples were picked up for pollen analysis at variable intervals depending upon the sediment composition of the core. Besides, six bulk samples were also collected from the core for radiocarbon dating at larger intervals.

The sediment composition of the core exhibits the presence of sand, silt and clay in variable fractions. The depthwise lithostratigraphical details of the core are given in Table 1.

Six absolute radiocarbon dates determined for this sediment core are given in Table 2.

The sedimentation rates as calibrated from radiocarbon dates are not uniform owing to variation in the sediment composition throughout the core. They have been calibrated to 1 m/500 yrs at 29.12–26.45 m depth, 1 m/300 yrs at 26.45–24.56 m depth, 1 m/229 yrs at 24.46–21.8 m depth and 1 m/250 yrs at 21.84–13.44 m depth. These sedimentation rates have enabled us to extrapolate more dates, i.e. 9000 yrs BP (29.6 m), 8000 yrs BP (27.6 m), 7000 yrs BP (24 m), 5500 yrs BP (21.6 m), 4250 yrs BP (16.4 m), 3000 yrs BP (13 m) and 750 yrs BP (7.7 m) for precise delineation of the temporal changes in vegetation pattern and climate in the region.

**Table 1.** Depthwise lithostratigraphical details of the core

| Depth (m) | Lithology |
|---|---|
| 0–5 | Water column |
| 5–7.70 | Silty clay to clayey silt mixed with organic decomposed vegetation |
| 7.70–13.0 | Clayey silt mixed with mica and few decomposed wood particles |
| 13.0–16.6 | Clayey silt mixed with fine particles of mica and a few decomposed wood particles |
| 16.6–21.6 | Silty sand mixed with very fine particles of mica |
| 21.6–29.6 | Clayey silt mixed with very fine particles of mica |
| 29.6–30 | Silty sand mixed with very fine particles of mica |

**Table 2.** Absolute radiocarbon dates for the sediment core

| Laboratory ref. nos | Depth (m) | $^{14}C$ Date (yrs BP) |
|---|---|---|
| BS-1814 | 11.28–11.60 | 1690 ± 120 |
| BS-1843 | 13.28–13.6 | 2670 ± 100 |
| BS-1813 | 21.64–21.96 | 4690 ± 120 |
| BS-1812 | 24.28–24.64 | 6630 ± 90 |
| BS-1810 | 26.26–26.64 | 7230 ± 90 |
| BS-1793 | 28.96–29.28 | 8560 ± 130 |

For the extraction of pollen/spores from the core samples, the conventional technique of acetolysis[16], using 10% aqueous KOH solution, 40% HF and acetolysing mixture (9 : 1 acetic anhydride and conc. sulphuric acid) was followed. The pollen sums for the samples analysed, varied from 150 to 200, depending upon their pollen potential. The percentage frequencies of the retrieved pollen were calculated from the sums, which exclude the pollen/spores of aquatic plants and ferns due to their origin from local provenance. The recovered pollen taxa categorized as trees, shrubs, herbs and ferns were arranged in the same sequence in pollen diagram.

The pollen diagram constructed (Figure 2) for Mansar Lake has been broadly divided into five distinct pollen zones, based on fluctuations in the frequencies of some prominent arboreal and non-arboreal taxa, and numbered from bottom to top of the sequence. The pollen zones have been prefixed with the initials 'ML' after the name of the investigated site, i.e. Mansar Lake and are described below.

Pollen Zone ML-I (29.6–27.6 m) with a solitary radio carbon date, i.e. 8560 ± 130 yrs BP and encompassing the time-span between 9000 and 8000 yrs BP brings out the dominance of arboreals over non-arboreals. Among the arboreals, *Pinus* cf. *roxburghii* (50%) was recorded with much higher values followed by *Quercus* cf. *incana* (20–25%) and *Ulmus* (2–9%), the major broad-leaved taxa. The temperate conifers, *Larix* (2%) along with *Cedrus*, *Betula* (2% each) and *Abies* (1%) were recorded in low values. *Juglans* and *Alnus* (1–2% each) and other broad-leaved associates of oak, viz. Myrtaceae, *Mallotus* and *Dodonea* (>1% each) were met with meagrely. The shrubby elements such as Rosaceae, *Oldenlandia* and Oleaceae (2–3% each) were consistent with low frequencies. Poaceae (20–57%) followed by *Artemisia* (6%), Cheno/Am (4%) and Urticaceae (2%) were also recorded in good frequencies. Other terrestrial constituents such as Rubiaceae, Caryophyllaceae and Euphorbiaceae (1% each) were extremely sporadic. The marshy element, Cyperaceae (1–3%) together with aquatics, *Typha* (1–5%) and *Potamogeton* (2%) and freshwater alga, *Botryococcus* (3%) were recorded in good numbers. Fern spores (monolete and trilete, 2–3% each) were encountered consistently in this zone.

Pollen Zone ML-II (27.6–24 m) with $^{14}C$ date of 7230 ± 90 yrs BP covering the time interval of 8000 to 7000 yrs BP, was characterized by dominance of *Quercus* cf. *incana* (10–40%), followed by *Pinus* cf. *roxburghii* (7–44%). The temperate taxa, viz. *Alnus*, *Betula* (2% each), *Carpinus* and *Corylus* (1% each) had increased values. *Abies*, *Cedrus* (2% each) and *Larix* (1%) were represented in the upper half only. *Ephedra* (2%) appeared for the first time. Among the broad-leaved taxa, *Ulmus* (1–3%) was better represented compared to

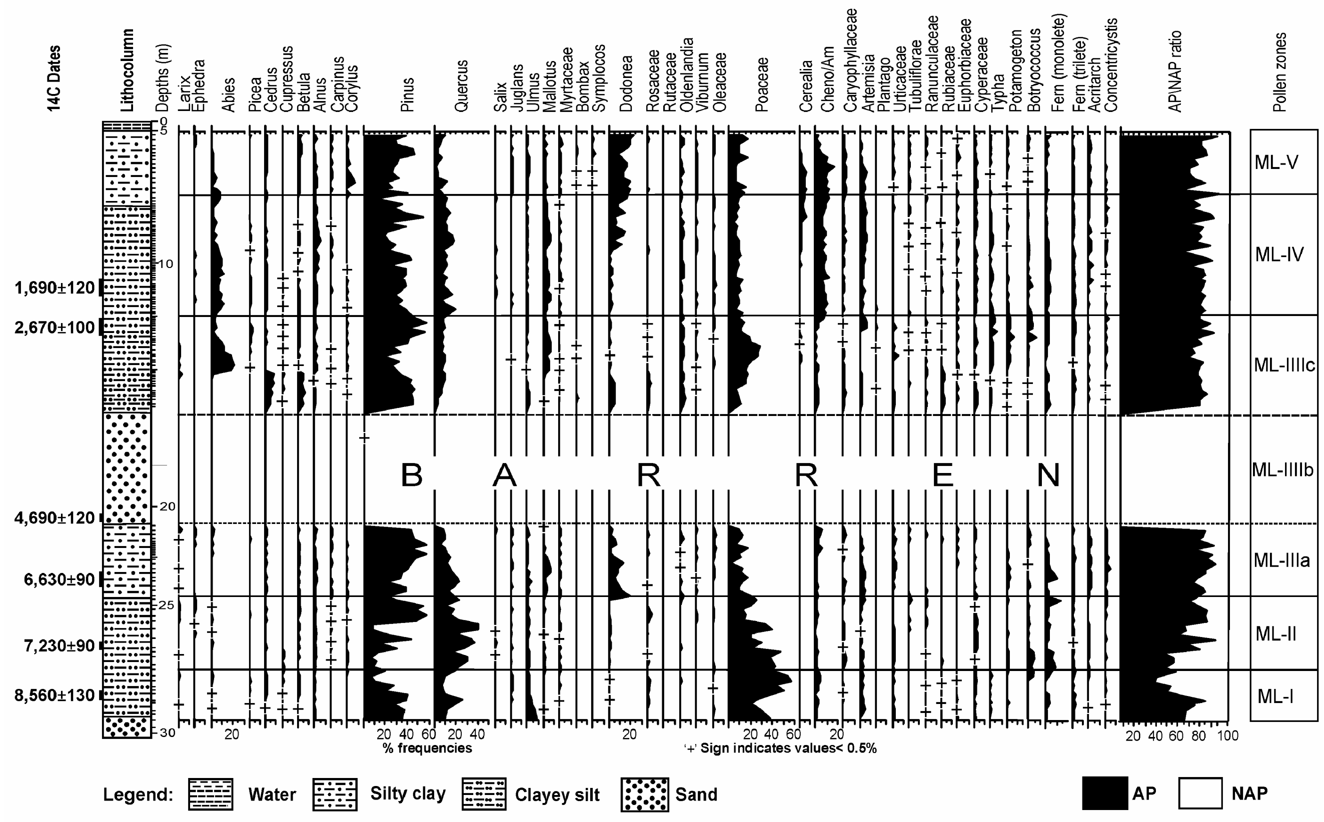


**Figure 2.** Pollen diagram from Mansar Lake, Jammu.

*Dodonea*, *Mallotus*, Myrtaceae, *Salix* (2% each) and *Juglans* (1%). Shrubby element such as *Oldenlandia* (1%) was consistently present, whereas Rosaceae (4%) and Oleaceae (2%) respectively, were met with in the upper and lower parts of this zone. Among the non-arboreal elements, Poaceae (42–22%) showed a gradual declining trend. Urticaceae (3%) and Caryophyllaceae (2%) were met with in increased frequencies, whereas *Artemisia* (1%) declined considerably. Ranunculaceae (3%) and Tubuliflorae (1%) were extremely sporadic. Cyperaceae (3%) did not exhibit significant change. *Potamogeton* (3–10%) and *Botryococcus* (4%) had comparatively higher frequencies than the preceding zone. Fern spores (monolete 3% and trilete 2%) remained static as before.

Pollen Zone ML-III (24–13 m) was further divided into three subzones (ML-IIIa, ML-IIIb and ML-IIIc), based on minor but significant changes in the vegetation pattern as described below.

Pollen Subzone ML-IIIa (24–21.6 m), covering a time-period from 7000 to 5500 yrs BP, was marked by the rising trend of *Pinus* cf. *roxburghii* (19–57%); however, *Quercus* cf. *incana* (5–25%) declined suddenly. *Alnus* and *Carpinus* (2% each) had a slight increase in their values. Other conifers, *Larix* (4%), *Abies* (3%) and *Cedrus* (1%) were recovered with increased frequencies, whereas *Ephedra* (1%) was present only in the upper part. The broad-leaved taxa such as *Mallotus* (4%), *Carpinus*, *Corylus*, *Betula*, *Ulmus* (2% each), *Juglans* and Myrtaceae (1% each) had more or less continuous curves. *Dodonea* (2.1–11.8%) showed increased values. *Salix* (2%) was present scantily. Shrubby elements such as *Oldenlandia*, Oleaceae (3% each), Rosaceae (2%) and *Viburnum* (1%) were sporadically present. The non-arboreal element Poaceae (2–20%) declined sharply in this zone, whereas *Artemisia* (1–6%), Urticaceae (4%), Caryophyllaceae (3%), Cheno/Am (5%) and Ranunculaceae (1–2%) had slightly increased values in contrast to the previous zone. Marshy element, Cyperaceae (4%) declined compared to the previous zone. Fern spores (monolete 8% and trilete 3%) were recorded in decreasing trend. The aquatic *Potamogeton* (3%) and freshwater alga, *Botryococcus* (1–2%) were encountered in the upper half only.

Pollen Subzone ML-IIIb (21.6–16.4 m), dating from 5500 to 4250 yrs BP was almost palynologically barren, except for stray occurrence of Poaceae and *Pinus* pollen.

Pollen Subzone ML-IIIc (16.4–13 m) with the time range of 4250 to 3000 yrs BP portrayed an increase in *Pinus* cf. *roxburghii* (12–42%), *Quercus* cf. *incana* (3–10%), *Larix* (2–3%) and *Abies* (3–18%). Other higher-altitude conifers such as *Picea* (2–3%), *Cedrus* (0.5–8%) and *Cupressus* (0.41–2%) along with the broad-leaved taxa, viz. *Betula* (0.5–7%), *Alnus* (3%), *Carpinus* and *Corylus* (1% each), exhibited more or less continuous curves as before. On the other hand, *Ulmus* (0.17–3%), *Juglans*, *Bombax* (1% each), *Dodonea* (6%), *Mallotus* (0.5–6%), Myrtaceae and *Juglans* (<0.5% each) were marked by reduced frequencies than in Pollen Subzone ML-IIIa. Shrubby elements such as *Oldenlandia* (1.8–4.4%), Oleaceae, Rosaceae (0.5–3% each) and *Viburnum* (1%) remained static. The non-arboreals such as Poaceae (6–27%) after an increase in the beginning, declined in the upper half, whereas Rubiaceae (0.6–4%), Cheno/Am (0.81–3.2%), *Artemisia,* Urticaceae (2% each), Carypohyllaceae, Ranunculaceae (1–2% each) and Tubuliflorae (1%) did not show any change. Cerealia pollen (>1%) was recorded for the first time. Cyperaceae (4%) had increased value, whereas aquatic taxa, viz. *Typha* (0.41–5%), *Potamogeton* (0.41–6%) and a freshwater alga, *Botryococcus* (7%) were recorded with rising trend. Fern spores (monolete and trilete 4% each) formed more or less continuous curves.

Pollen Zone ML-IV (13–7.7 m) with a time bracket of 3000 to 750 yrs BP, began with the increase in *Quercus* cf. *incana* (6–23%) and a corresponding sudden decline in *Pinus* cf. *roxburghii* (18–42%). *Corylus* (2%) reduced further and became sporadic. *Alnus* (1–3.5%) and *Abies* (2.11%) showed consistently improved values. *Betula* (0.5–2%), *Cedrus*, *Cupressus*, *Carpinus* and *Picea* (1% each) were represented by slightly decreased values and disappeared in the upper part. *Dodonea* (1–14%) was encountered with enhanced frequencies in the upper half. *Oldenlandia* (1–3%), *Ulmus* and Myrtaceae (1% each) remained unchanged. *Viburnum* and Oleaceae (1–3% each) showed a slight increase in their values. The non-arboreal elements chiefly represented by Poaceae (5–14%), Cheno/Am (1%) and *Artemisia* (2%) were recovered in low values. Cerealia (5%) pollen was seen almost from the beginning of the pollen zone and demonstrated higher frequency in the upper half. The other non-arboreals were marked by the sporadic presence of Ranunculaceae (3%), Caryophyllaceae (2%), *Plantago*, Urticaceae, Tubuliflorae and Rubiaceae (1% each). Fern spores (monolete and trilete 3% each) maintained more or less the same frequency as seen in the previous pollen zone. The aquatic vegetation was largely represented by colonies of *Botryococcus*, whose curve showed an ascending trend, attaining a maximum value of about 8%. *Potamogeton* (3%) formed a low and irregular curve, whereas *Typha* (3%) was consistent.

Pollen Zone ML-V (7.7–5 m) with time interval from 750 yrs BP to the Present, was characterized by somewhat improved frequencies of temperate elements such as *Corylus* (1–7%), followed by *Betula* (1–4%) and *Cedrus* (2%). *Pinus* cf. *roxburghii* exhibited almost the same values as in the previous zone. *Quercus* (2–11%), *Abies* and *Alnus* (1–3% each) also showed a slight decrease. The other trees and shrubby elements represented either in short curves or sporadically were *Picea* (1–2%), *Ephedra* (1–2%), *Cupressus* (1%), *Bombax* (0.36–6%) and *Symplocos* (0.4–3%). The curves for Poaceae (6–19%) followed by Cheno/Am (1–12%), *Artemisia* (1–7%) and Cerealia pollen (1–6%) increased considerably. Caryophyllaceae (1–3%), Urticaceae, Tubuliflorae, Ranunculaceae, Rubiaceae and Euphorbiaceae (1% each) were sporadically present. Cyperaceae (1–4%) improved, whereas aquatic elements, viz. *Typha*, *Potamogeton* and *Botryococcus* (2% each) declined sharply. Fern spores (monolete 2% and trilete1%) had reduced values.

The Quaternary palynological studies conducted on a 30 m deep sedimentary profile from Mansar Lake located in the subtropical belt of Jammu, has provided some interesting inferences concerning vegetation shifts, climate variability, lake-level fluctuations and human settlement in the region since the early Holocene. The available pollen sequence has demonstrated that around 9000–8000 yrs BP (Pollen Zone ML-I) this region had either mixed chirpine–oak forests or chirpine (*Pinus* cf. *roxburghii*) and oak (*Quercus* cf. *incana*) forests growing side by side in dry sunny hill slopes and moist shady depressions respectively, in the proximity of the lake site and adjoining areas. *Pinus* occurred luxuriantly as indicated by its exceedingly high frequencies, in contrast to other arboreal forest constituents. Among the broadleaved elements, *Quercus* cf. *incana* was important. However, the associates of oak such as *Mallotus* and *Juglans* were also frequent in these forests, whereas *Salix* and *Bombax malabaricum* coupled with a few shrubby elements of Rutaceae, Rosaceae and Oleaceae occurred meagrely in certain open forest patches. The overall vegetation mosaic suggests that a cool and dry climate prevailed in the region during this period. The ground vegetation was abundantly composed of grasses. A good proportion of cultural pollen taxa, viz. Cheno/Am, Caryophyllaceae, *Artemisia* and Urticaceae indicate that the region was under some sort of human activity. The lake margin was profusely overgrown with sedges, whereas ferns and their allies thrived well in moist and shady conditions contiguous to the lake site. The intermittent encounter of pollen of aquatic elements, viz. *Typha* and *Potamogeton* reveals that the lake was smaller in expanse, probably owing to reduced monsoon precipitation during this period.

Subsequently, around 8000–7000 yrs BP (Pollen Zone ML-II) the mixed chirpine–oak forests were succeeded by mixed oak–chirpine forests as well as manifested by the expansion of *Quercus* cf. *incana* and a coeval decline in *Pinus* cf. *roxburghii*, with the onset of a warm and humid climatic regime in response to increased monsoon precipitation. *Quercus* cf. *incana* along with *Ulmus*, Myrtaceae and *Mallotus* were the close constituents of the oak–broad-leaved forests. *Dodonea*, an inhabitant in humid conditions, also immigrated for the first time to these forests during the latter part of this phase, though sporadically. This significant alteration in the vegetation composition with the inception of warm and humid climate is also well substantiated by the improvement in the temperate broad-leaved elements, such as *Alnus*, *Corylus* and *Betula* in particular. *Larix*[17], which is presently confined to the Eastern Himalaya, also flourished well under the impact of the prevailing congenial climatic conditions, as deciphered by more frequent record of its pollen at this level in the pollen sequence. Furthermore, a relative increase in herbaceous taxa, viz. Cheno/Am, Caryophyllaceae, *Artemisia*, Tubuliflorae and Ranunculaceae in addition to grasses (Poaceae) depicts that the ground flora also grew abundantly on the forest floor as well as along the terrestrial lake margins. The improvement in sedges (Cyperaceae) and better representation of aquatics such as *Typha*, *Potamogeton* and freshwater alga, *Botryococcus* denotes that the lake attained a larger dimension with a wide swampy margin. Pteridophytes, especially ferns also thrived well in the vicinity of the lake on account of the prevailing damp and moist conditions.

Around 7000–5500 yrs BP (Pollen Subzone ML-IIIa), the mixed oak–broad-leaved–chirpine forests were succeeded by mixed chirpine–oak–broad-leaved forests, as deduced from the expansion of *Pinus* cf. *roxburghii* and a corresponding sharp depletion in *Quercus* cf. *incana*, with the beginning of this phase. Likewise, the other broad-leaved thermophillous constituents of oak forests such as *Juglans*, *Mallotus* and Myrtaceae also dwindled and were poorly represented as before. *Dodonea* also tend to become scanty, despite its consistent occurrence. Most of the shrubby components did not exhibit any noticeable change, except Oleaceae, which showed a marginal improvement in its occurrence. On the whole, vegetation composition in general depicts that cool and dry climatic conditions with deteriorating trend prevailed in the region due to reduction in monsoon precipitation. The declining trend of sedges together with aquatic element *Potamogeton* and complete disappearance of *Typha* demonstrate the lowering of lake level on account of the prevalence of harsh climatic condition, which is attributed to further decrease in the monsoon precipitation during this period. Chronologically, this phase coincides with the Period Climatic Optimum, which has been witnessed globally between 7000 and 4500 yrs BP[18] However, the reverse climatic trend witnessed in the pollen sequence during this time bracket could be ascribed to the regional climatic variability.

The phase covering the time-span of 5500–4250 yrs BP (Pollen Subzone ML-IIIb) is characterized by the stray presence of grass and *Pinus* pollen. Hence, no palaeovegetational inferences could be drawn for this phase. However, the presence of sandy layer at 21.8–6.4 m depth in the lithocolumn suggests that the sediments might have been deposited in a pluvial environment.

Around 4250–3000 yrs BP (Pollen Subzone ML-IIIc), further depletion of *Quercus* cf. *incana*, *Dodonea*, except for *Mallotus*, which expands in the latter part of this phase, and contemporary enhancement in *Pinus* cf. *roxburghii* together with grasses (Poaceae), imply the commencement of cool and dry climatic conditions. This adverse climatic condition turned more detrimental for the proliferation of broad-leaved oak forests. The invasion of *Bombax malabaricum*, an ingredient of tree-savannah, also supports the open nature of forests by this time, which is probably ascribed to deterioration in the climate. Furthermore, the improvement in most of the other temperate taxa, such as *Abies*, *Picea*, *Cedrus*, *Betula*, *Carpinus*, *Corylus* and a contrary reduction in *Larix* suggests downward shifting of temperate forests under the influence of harsh climatic regime. However, the selective felling of *Quercus* cannot be denied. Interestingly, the first encounter of Cerealia pollen and somewhat better representation of other cultural pollen taxa such as Cheno/Am, Urticaceae, *Artemisia* and Caryophyllaceae during this phase suggests the commencement of cereal-based agricultural practice in the region. The extermination of *Larix* from the Jammu region of northwestern Himalaya since 3500 yrs BP onwards, as evident from the absence of its pollen in the latter half of this phase, might have occurred as a consequence of adverse climate in the region.

Between 3000 and 750 yrs BP (Pollen Zone ML-IV), the climate most likely turned warm and moist as seen from the steady improvement in *Quercus* cf. *incana*, *Mallotus*, *Ulmus*, *Juglans*, *Dodonea*, etc. and substantial decline in *Pinus* cf. *roxburghii* during this period. The change in the vegetation assemblage suggests the replacement of mixed chirpine–oak–broad-leaved forests by mixed oak–broad-leaved–chirpine forests owing to the amelioration in climate, which became relatively more humid than witnessed in the earlier phase (Pollen Zone ML-II). The lake attained a wider dimension in response to increased precipitation during this phase, which could probably be attributed to the prevalence of the active southwest monsoon, as indicated by the better representation of aquatic elements such as *Typha* along with improvement in the freshwater alga, *Botryococcus* and sedges. Intensive agricultural practice in the vicinity of the lake site is evidenced by the significant increase and consistent occurrence of Cerealia along with other culture pollen taxa such as Cheno/Am, *Artemisia*, Urticaceae and Caryophyllaceae. The Medieval Warm Period[19], which has been recorded from various parts of the world between AD 740 and 1150, coincides with the latter half of this climatic phase.

Since 750 yrs BP (Pollen Zone ML-V) onwards, a shift in the vegetation pattern was again witnessed, i.e. the mixed oak–chirpine forests were succeeded by mixed chirpine–oak forests as well demonstrated by the steep reduction in *Quercus* cf. *incana* together with Myrtaceae and *Mallotus*, and disappearance of *Salix* with the inception of this phase. The shrubby vegetation comprising *Oldenlandia*, Oleaceae and *Viburnum* also become scanty, as marked

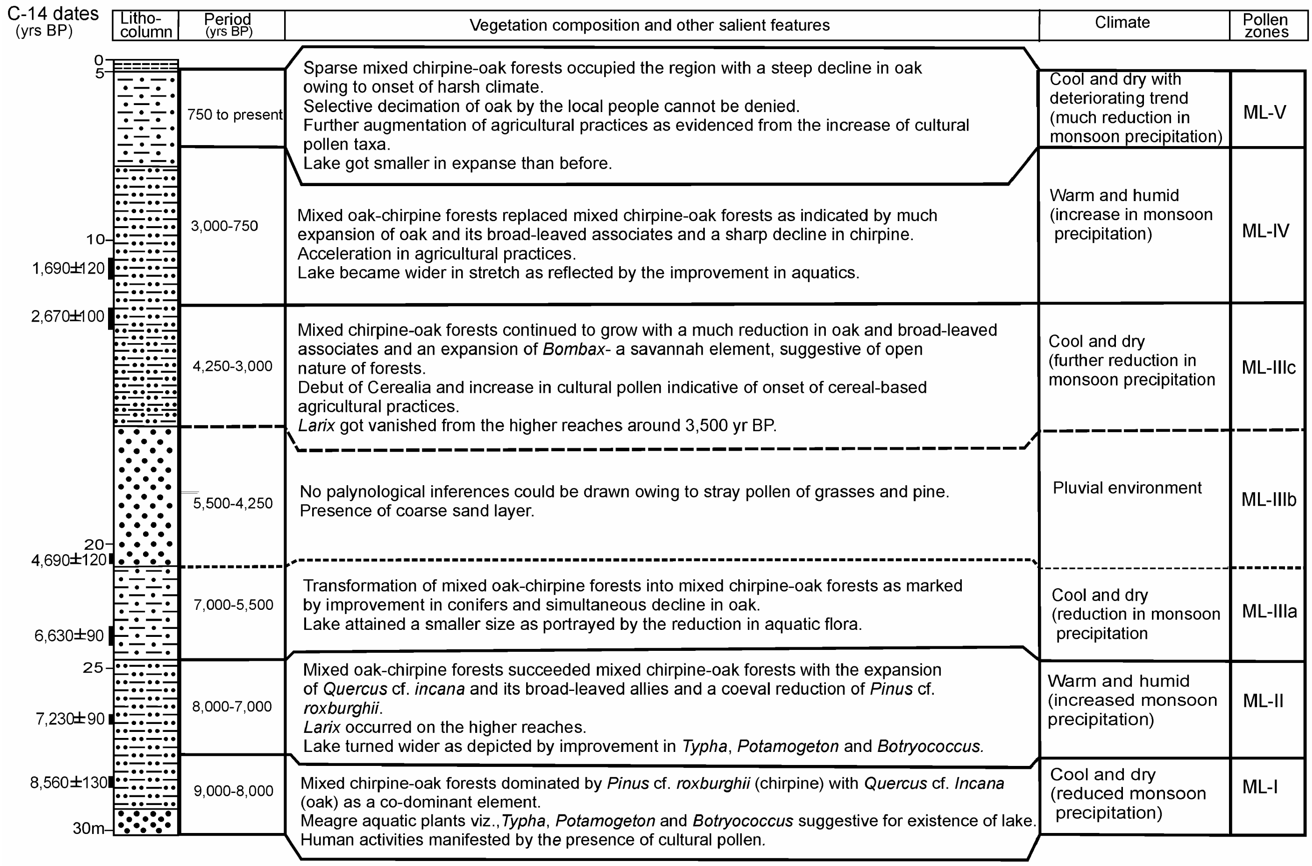


**Figure 3.** Palaeovegetation and palaeoclimatic inferences from Mansar Lake profile.

by the reduced frequencies of its constituents. *Juglans* and *Ulmus* remained scarce, as before. However, *Pinus* cf. *roxburghii* remained dominant as reflected by its much higher frequencies during this phase. This change in the vegetation scenario noticeable by the re-establishment of chirpine–oak forests occurred as a consequence of deterioration of climate, which turned cool and dry. This alteration in the vegetation scenario and contemporary climatic condition continues today, as is well supported by the good representation of *Cedrus*, *Betula*, *Alnus*, *Carpinus*, *Corylus* and *Ephedra*, deciphering thereby the downward shifting of the temperate belt on account of the prevailing unfavourable climatic condition. The latter part of this phase corresponds to the Little Ice Age[20] event, which is well known at global level between the time-periods of AD 1550 and 1850. Acceleration in agricultural practices as clearly manifested by the better representation of Cerealia and other culture pollen taxa, Cheno/Am, *Artemisia*, etc. also occurred during this phase in order to sustain the increasing human population in the region.

Thus, the pollen proxy records obtained through the investigation of sediment core from Mansar Lake have deciphered the changing vegetation scenarios and contemporary climatic events in the Jammu region since early Holocene (Figure 3). The study has divulged four cool and dry climatic events dated 9000–8000 yrs BP; 7000 to 5500 yrs BP; 4250–3000 yrs BP, and 750 yrs BP to the Present, as reflected by the presence of mixed chirpine–oak forests. The lake had a smaller dimension during these time intervals as deduced from the low aquatics pollen. The two alternating warm and humid phases dated 8000–7000 yrs BP, and 3000–750 yrs BP are well marked by the existence of mixed oak–chirpine forests in the region. The lake attained wider spreads during these phases as inferred by the better representation of aquatic flora. However, the presence of sandy layer at the level dated 5500–4250 yrs BP, suggests that the region also experienced an episode of pluvial environment. Furthermore, the area was under some sort of human activities since 9000 yrs BP. However, the cereal-based agricultural practice commenced around 4250 yrs BP and since then it has continued with accelerating pace to cope with the increasing human population in the region.


1. Vishnu-Mittre, Gupta, H. P. and Robert, R. D., Studies of post glacial vegetational history of Kumaon Himalaya. *Curr. Sci.*, 1967, **16**, 69–94.
2. Chauhan, M. S. and Sharma, C., Pollen analysis of mid-Holocene sediments from Kumaon Himalaya. *Geol. Surv. India, Spl. Publ.*, 1996, **21**, 257–269.

3. Bhattacharyya, A. and Chauhan, M. S., Vegetational and climatic changes during recent past around Tipra Bank Glacier, Garhwal Himalaya. *Curr. Sci.*, 1997, **72**, 408–412.
4. Chauhan, M. S., Sharma, C. and Rajagopalan, G., Vegetation and climate during Late-Holocene in Garhwal Himalaya. *Palaeobotanist*, 1997, **46**, 211–216.
5. Sharma, C., Chauhan, M. S. and Rajagopalan, G., Vegetation and climate in Garhwal Himalaya during last 4000 years. *Palaeobotanist*, 2000, **49**, 501–507.
6. Chauhan, M. S., Mazari, R. K. and Rajagopalan, G., Vegetation and climate in upper Spiti region, Himachal Pradesh during late Holocene. *Curr. Sci.*, 2000, **79**, 373–377.
7. Sharma, C. and Chauhan, M. S., Studies in Late-Quaternary vegetational history in Himachal Pradesh-4. Rewalsar Lake-II. *Pollen Spores*, 1988, **30**, 395–408.
8. Bhattacharyya, A., Vegetation and climate during post glacial period in the vicinity of Rohtang Pass, Great Himalaya Range. *Pollen Spores*, 1988, **30**, 417–427.
9. Chauhan, M. S., Late Holocene vegetation and climate in the alpine belt of Himachal Pradesh. *Curr. Sci.*, 2006, **91**, 1572–1578.
10. Bhattacharrya, A., Vegetation and climate during the last 30,000 years in Ladakh. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 1989, **73**, 25–38.
11. Vishnu-Mittre and Sharma, B. D., Studies of post glacial vegetational history from the Kashmir Valley-1. Haigam Lake. *Palaeobotanist*, 1966, **15**, 185–212.
12. Sharma, C. and Gupta, H. P., Palynostratigraphy and palaeoenvironment: Krachipathra, lower Karewa, Kashmir. *Curr. Trend Geol.*, 1985, **6**, 91–95.
13. Gupta, H. P., Sharma, C., Dodia, R., Mandavia, C. and Vora, A. B., A palynological interpretation of climatic changes in Kashmir (India) during the last 3 million years. In *The Evolution of the East Asian Environment* (ed. Whyte, R. O.), Centre of Asian Studies, University of Hong Kong, 1984, pp. 553–568.
14. Das, B. K., Al-Mikhlafi, A. S. and Kaur, P., Geochemistry of Mansar Lake sediments, Jammu, India: Implication for source-area weathering, provenance, and tectonic setting. *J. Asian Earth Sci.*, 2006, **26**, 649–668.
15. Tandon, S. K., Heavy minerals and quartz axial ratios as provenance indicators in the Siwalik sediments around Ramnagar, Kumaun Himalaya. *Himalayan Geol.*, **2**, 206–221.
16. Erdtman, G., *An Introduction to Pollen Analysis*, Waltham Mass., USA, 1943.
17. Sharma, C. and Gupta, H. P., Past and present distribution of *Larix griffithiana* Hort. Ex. Carr. in the Indian subcontinent as evidenced by palynology. *Zfa. Archaol. Berlin*, 1984, **18**, 239–246.
18. Benarde, M. A., *Global Warming*, John Wiley, New York, 1992.
19. Lamb, H. H., *Climate: Past, Present and Future*, Methuen, London, 1977.
20. Berger, A., *Climatic Variations and Variability: Facts and Theories*, D. Reidel, Dordecht, 1981.

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