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Vegetation Dynamics and Hydro-Climatic Changes during the Middle Holocene from the Central Himalaya, India

Mohammad Firoze Quamar [1,2,*], Anoop K. Singh [3], Lalit M. Joshi [4], Bahadur S. Kotlia [4], Dhruv Sen Singh [3], Corina Anca Simion [5], Tiberiu Sava [5] and Nagendra Prasad [1,2]

1 Birbal Sahni Institute of Palaeosciences, Lucknow 226007, India
2 Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India
3 Department of Geology, University of Lucknow, Lucknow 226007, India
4 Department of Geology, Kumaun University, Nainital 263001, India
5 Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering, 077125 Măgurele, Romania
* Correspondence: mohdfiroze_quamar@gmail.com or quamar_bot@yahoo.co.in

Abstract: Understanding the spatiotemporal monsoonal variability during the Holocene helps in understanding the rise and fall of many civilizations. In this study, a 2.65 m high palaeo lake sedimentary profile from the Kumaun Lesser Himalaya, Uttarakhand State, India was pollen analysed to reconstruct the variability in the monsoonal precipitation during the Middle Holocene. The study revealed that between ~7522 and 7216 cal yr BP, conifers dominated mixed broad-leaved forests occurred around the landscape of the study area, indicating a less cold and dry climate with decreased monsoon precipitation. Broad-leaved taxa during this phase show increased values considerably, indicating amelioration in climatic condition, which could be, in global perspective, broadly falling within the time-interval of the Holocene Climate Optimum (HCO; 7000–4000 BP). Between ~7216 and 6526 cal yr BP, dense conifers-dominated mixed broad-leaved forests transformed the conifers-dominated broad-leaved forests around the study area under a cold and drier climate with further reduction in monsoon precipitation. Subsequently, between ~6526 and 5987 cal yr BP, conifers-dominated broad-leaved forests continued to grow, but with lesser frequencies, around the study area under a comparatively less cold and dry climate with reduced monsoon precipitation. Finally, between ~5987 and 5817 cal yr BP, the frequencies of conifers-dominated broad-leaved forests further decreased around the landscape of the study area under a comparatively lesser cold and dry climate, probably indicating decreased monsoonal precipitation. Hence, the present study mainly showed the dominance of conifers forests around the study area between ~7522 and 7216 cal yr BP, ~7216 and 6526 cal yr BP, ~6526 and 5987 cal yr BP and between ~5987 and 5817 cal yr BP; however, broad-leaved forests also demonstrated increasing tendency between ~7522 and 7216 cal yr BP in the milieu of cold and dry climates. Moreover, the study also revealed that a lake was formed around 7522 cal yr BP along the Kulur River, a tributary of Saryu River around the study area and existed until 5817 cal yr BP.

Keywords: vegetation dynamics; climate change; monsoon; Middle Holocene; HCO; Kumaun Lesser Himalaya; India

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1. Introduction

The Indian Summer Monsoon (ISM) plays a pivotal role in the global hydrological cycle. The ISM is the seasonal reversal in wind direction, resulting into intense rainfall during the summer [1,2]. It affects about 60% of the global population [3], as it provides vital precipitation (>80% of the annual precipitation in the Indian sub-continent) for agriculture [4,5]. Thus, understanding of the ISM rainfall variability during the Holocene is necessary for understanding the present climate, as well as for prediction of future climate [6–13]. The changes in climate during this epoch have significant impacts on landscape, vegetation, and climate worldwide. Moreover, understanding the vegetation history and hydro-climatic changes is necessary to understand the vegetation succession and to predict future terrestrial ecosystem dynamics and biodiversity changes in an area in a particular time frame, especially during the Holocene. With regards to the human development and establishment of centers of civilizations, the Holocene is also important. The rise and fall of many civilizations took place owing to the gradual or abrupt climate changes during the Holocene. Evidence of various societal crumpling during the last 6000 years also exist on local and regional scales. Such societal collapses could be owing to the abrupt shifts to drier and/or colder climatic systems [14–20].

Various studies have been carried out on the palaeovegetation and palaeoclimatic reconstruction from the Western Himalaya, India, based on pollen, megafloral remains and geochemicals [21–37]. However, pollen (and/or geochemistry)-based palaeovegetation and palaeoclimate study from the Kumaun region of the Central Himalaya is wanting, except [9–11,38–42]. Therefore, with the prime object of understanding the vegetation response to the ISM rainfall variability during the Middle Holocene from the Kumaun region, Uttarakhand State (Central Himalaya), India, the present study was carried out. The records of the ISM during the Middle Holocene (8.2–4.2 kyr BP) are asynchronous [43] owing to the different responses of the two branches of the ISM (the Bay of Bengal: BoB and the Arabian Sea: AS branches). Additionally, changes in the moisture source and latitudinal migration of the Inter Tropical Convergence Zone (ITCZ) play an important role [43,44]. Meanwhile, the abrupt ISM weakening at 8.2 kyr BP could be due to the large influx of the freshwater into the Labrador Sea from the melting of the Laurentide Ice Sheet (LIS), resulting into a decrease in the Atlantic Meridional Overturning Circulation (AMOC) [45,46]. Increased solar insolation and associated enhanced evaporation in the oceans, as well as the northward movement of the ITCZ drives the strengthening of the ISM during the Early Holocene [44]. However, the stronger phase of El-Niño and a shift of the Indian Ocean Dipole to a strong negative state could be causing the ISM weakening during the Late Holocene [47,48]. Furthermore, regional and global contextualization, made in the present study, will help understand the evolution of the ISM-influenced climate and vegetation.

2. Regional Settings

2.1. Study Area and Geology

The study area (29°47′02.7″ N; 79°58′13.6″ E, elevation: 1213 m a.s.l.) is situated in the Kumaun Lesser Himalaya, Uttarakhand State, India (Figure 1a). Many palaeo lake profiles from 0.5 to 2.75 m are scattered in this area. These profiles support the existence and possible extension of a palaeolake along Kulur River, a tributary of Saryu River (Figure 1b). This sector of Himalaya is also crisscrossed by boundary, as well as subsidiary thrusts/faults [49–53], wherein the metasedimentary and crystalline rocks are folded and faulted owing to the intense deformation [54]. Thus, the area is made up by the rocks of various groups and formations of Lesser Himalaya, such as dolomite, slates, limestones, quartzite, etc. The deposition of various formations of rocks represents a single cycle of tidal flat sedimentation during the Riphean Period [55]. The highly deformed quartzite and meta-sedimentaries of above formations, as well as ongoing tectonic activity increased the susceptibility of the area to the major landslide activity in the basin too, responsible for damming of river and formed a plaeolake [13,36,38,56–58].

2.2. Vegetation and Climate

Sub-tropical broad-leaved hill forests, Sub-tropical pine forests, Sub-tropical dry evergreen forests and Himalayan dry temperate forests constitute the vegetation of the study area [59,60].

Cold, humid winter-type climate (Dfc) is found in and around the study area [61]. The very climate is characterised by a short humid summer and cold humid winter of longer duration. The winter temperature is around 10 °C and the summer temperature is <18 °C. Additionally, the study area is influenced by the Indian Summer Monsoon (ISM).

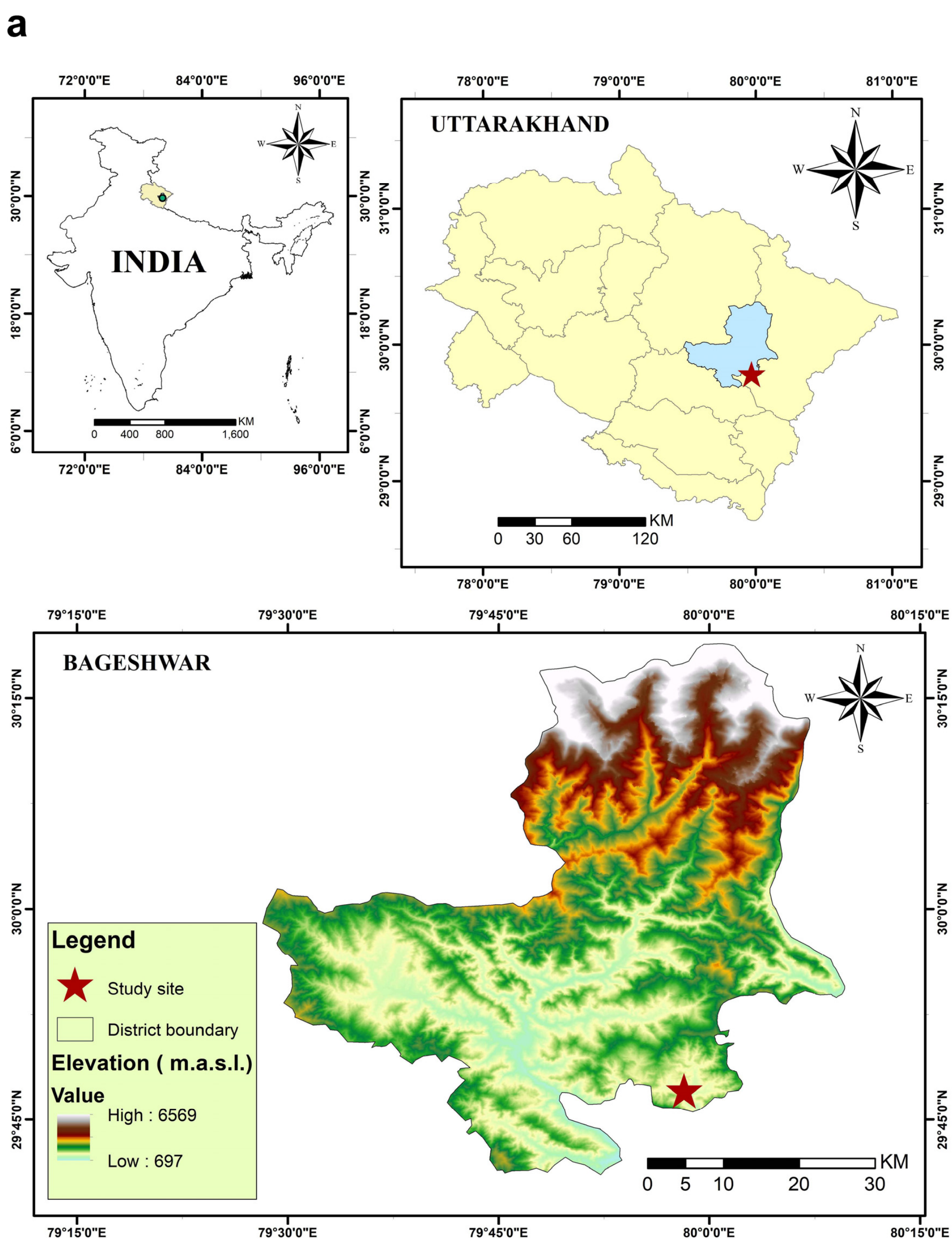

Figure 1. *Cont.*

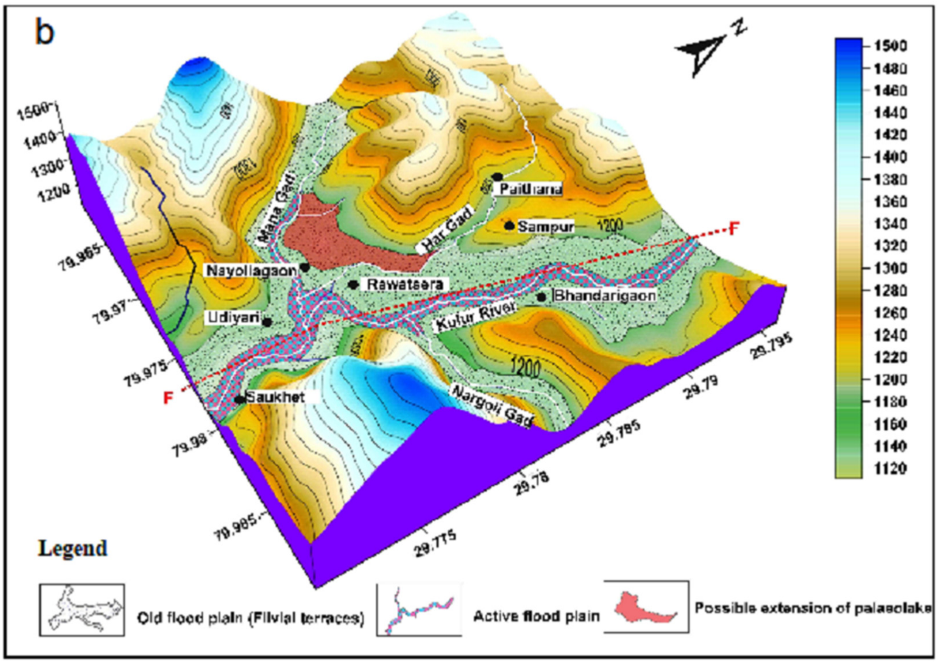

Figure 1. (**a**) Shuttle radar topographic mission (SRTM) digital elevation map (DEM) of the Kumaun region, Uttarakhand State, India, showing the study site. Geographic map of India showing Uttarakhand State (inset left); Geographic map of Uttarakhand State showing Kumaun region (couloured) (inset right). Source of Figure 1a: The Figure 1a is created using ArcGIS 10.3. (**b**) DEM image showing the RSP and its possible extension along the Kulur River, a tributary of Saryu River, in Kumaun Lesser Himalaya, India.

3. Materials and Methods

3.1. Filed Work and Sampling

A 2.65 m high palaeo lake sedimentary profile was dug out from the Rawatserapalaeolake in Kumaun Lesser Himalaya (Figure 2). The litholog comprises 18 cm thick matrix supported gravely sand with clastic material as a basal unit, which is underlain by 5 cm thick mud deposit with oxidized rock fragments. It is overlain by the deposition of 5 cm thick unoriented debris material, which is followed by 120 cm thick mud deposit with oxidized rock fragments with a sharp contact. This mud unit is overlain by 3 cm thin layer of unoriented debris material, which is followed by 15 cm thick mud deposit. After this alternate layers of clastic material (20 cm, 12 cm, and 5 cm), there were muddy deposits (6 cm, 5 cm). These alternate layers are overlain by the 30 cm thick mud deposit with a 3 cm thick unoriented debris material. The top most 18 cm thick unit is unoriented debris material. The sub samples were collected at 3 cm interval. In this organic sediments were found and collected at a height of 24 cm, 138 cm, 236 cm for AMS dating. In addition, three calibrated AMS ^{14}C dates were calculated from this trench at 24 cm (7.508 $\pm$ 0.050 Ka BP) 138 cm (6.955 $\pm$ 0.063 Ka BP) and 236 cm (6.077 $\pm$ 0.050 Ka BP) heights from bottom, respectively (Table 1). The age-depth model has been shown in Figure 3.

3.2. Protocol for Sample Processing

Palynomorphs are extracted from the sediment samples following the Erdtman's method [62]. The samples were first treated with 10% potassium hydroxide (KOH) to remove the humus. 40% hudrofluoric acid (HF) treatment was thereafter given in order to remove silica. Acetolysis was finally done to remove the cellulose [62]. 50% glycerine solution is used to make the solution homogeneous for microscopic examination. In order to avoid any bacterial and/or fungal contamination, phenol (a few drops) were added in the solution.

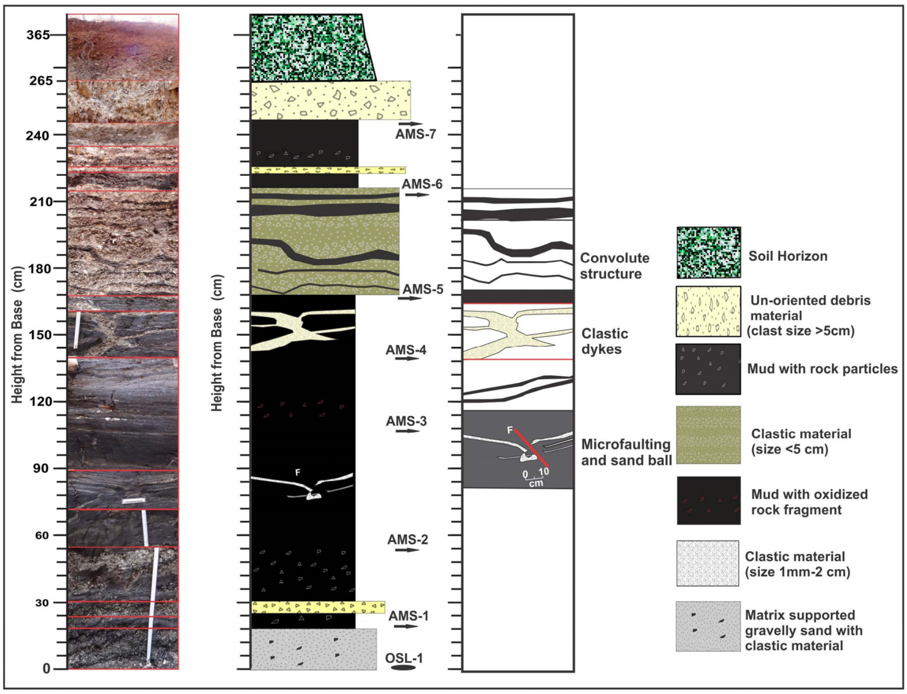

Figure 2. Litholog of the RSP sedimentary profile.

Table 1. AMS ^{14}C dates of the RSP sediment profile.

S. No.	Sample Code	Height from Base (cm)	Age (Ka BP)
1	RSPA1	24	7.508 ± 0.050
2	RSPA4	138	6.955 ± 0.063
3	RSPA7	236	6.077 ± 0.050

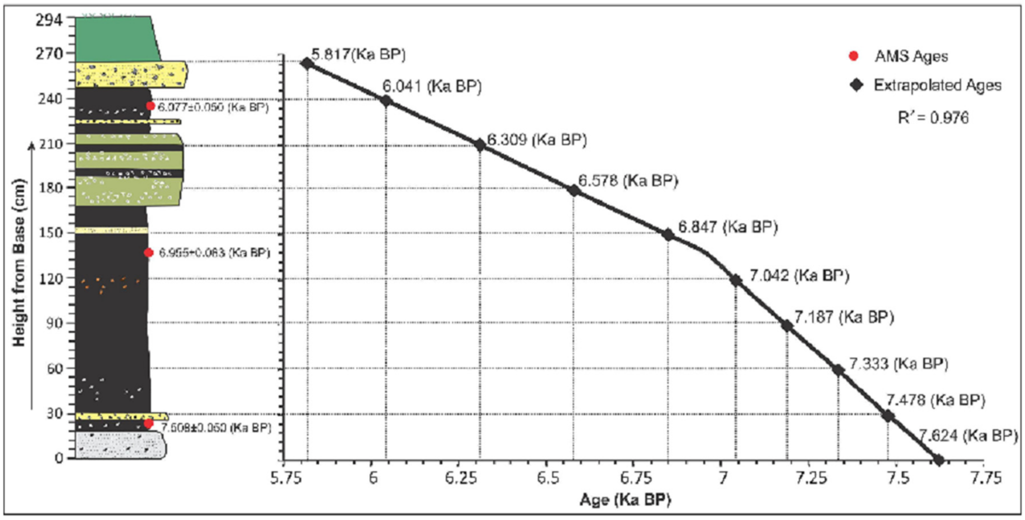

Figure 3. Age-depth model of the RSP sedimentary profile.

3.3. Microscopy and Construction of Pollen Diagram

The counting of pollen and spore was completed under Olympus BX50 light microscope with attached DP 26 software for photography. The identification of pollen and spores (Figures 4–6—plates 1–3) was made by using the pollen photographs in published records [34,63–67]. The relevant reference pollen slides held at the Birbal Sahni Institute of Palaeosciences (BSIP) Herbarium, Lucknow also assisted in identification. More than 300 terrestrial pollen grains were counted per sample (Supplementary File S1). TILIA software was used to construct the pollen diagram (Figure 7) [68,69].

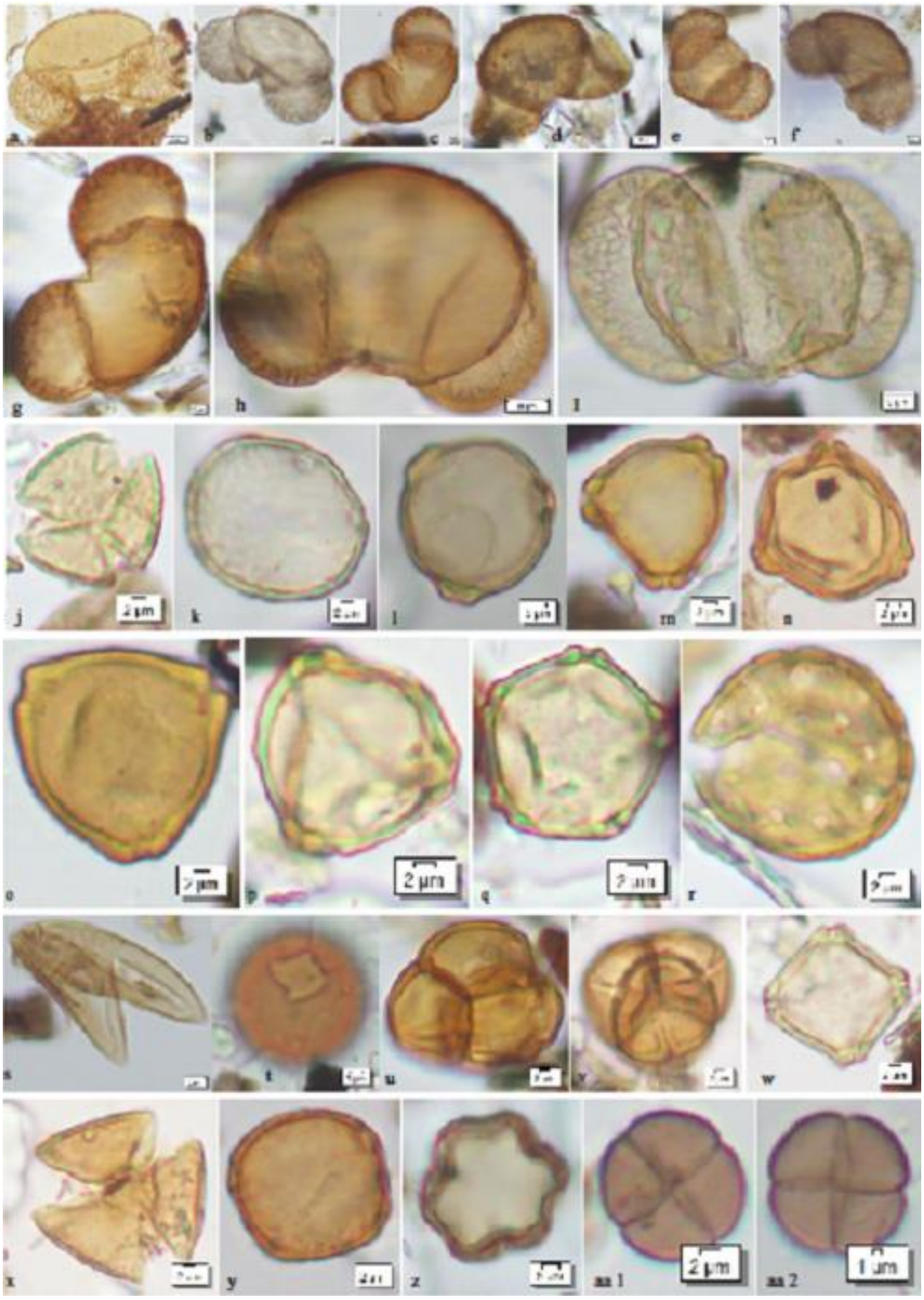

Figure 4. Plate 1. Key palynomorphs recovered from the RSP sedimentary profile samples. **Explanation of Figure 4_plate 1.** (**a**–**c**). *Pinus*, (**d**–**f**). *Cedrus*, (**g**). *Abies*, (**h**). *Picea*, (**i**). *Podocarpus*, (**j**). *Quercus*, (**k**). *Ulmus*, (**l**,**p**). *Betula*, (**m**,**n**). *Carpinus*, (**o**). *Corylus*, (**q**,**w**). *Alnus*, (**r**). ***Juglans***, (**s**,**t**). *Juniperus*, (**u**,**v**). *Rhododendron*, (**x**). Ranunculaceae, (**y**). *Holoptelea*, (**z**). *Terminalia* spp., (**aa 1**,**aa 2**). Mimosaceae.

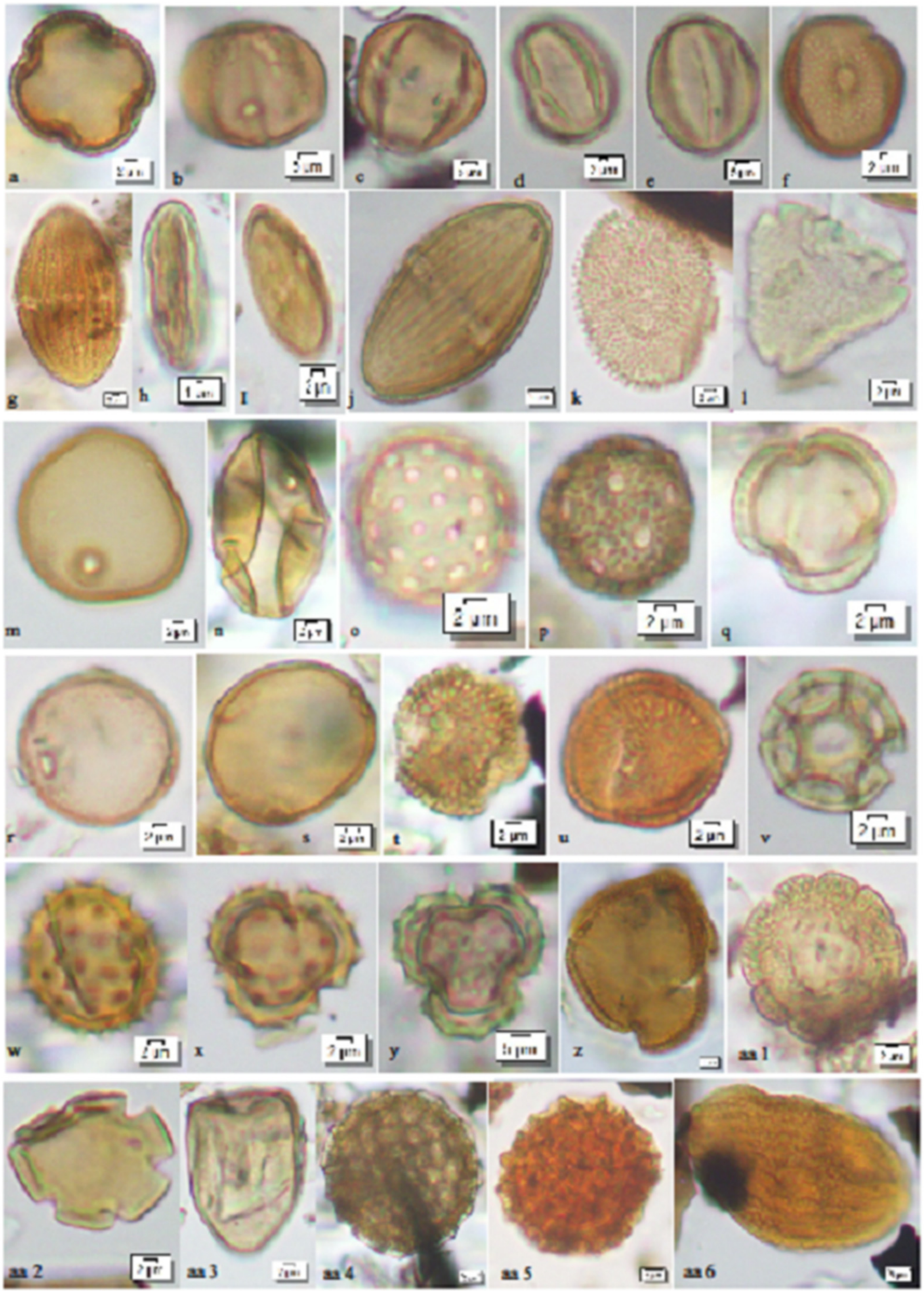

Figure 5. Plate 2. Key palynomorphs recovered from the RSP sedimentary profile samples. **Explanation of Figure 5_plate 2.** (**a**). *Emblica officinalis*, (**b**). *Aegle marmelos*, (**c**–**e**). Sapotaceae, (**f**). *Grewia*, (**g**–**j**,**aa 6**). *Strobilanthes*, (**f**,**k**). *Croton*, (**l**). *Ziziphus*, (**m**). Poaceae, (**n**). Cerealia, (**o**). Amaranthaceae, (**p**). Caryophyllaceae, (**q**). *Artemisia*, (**r**,**s**). *Cannabis sativa*, (**t**,**u**). Brassicaceae, (**v**). *Alternanthera*, (**w**–**y**). Asteroideae (Tubuliflorae), (**z**). *Evolvulus alsinoides*, (**aa 1**). *Borreria* sp., (**aa 2**). *Pedalium murex*, (**aa 3**). Cyperaceae, (**aa 4**,**aa 5**). Cichorioideae (Liguliflorae).

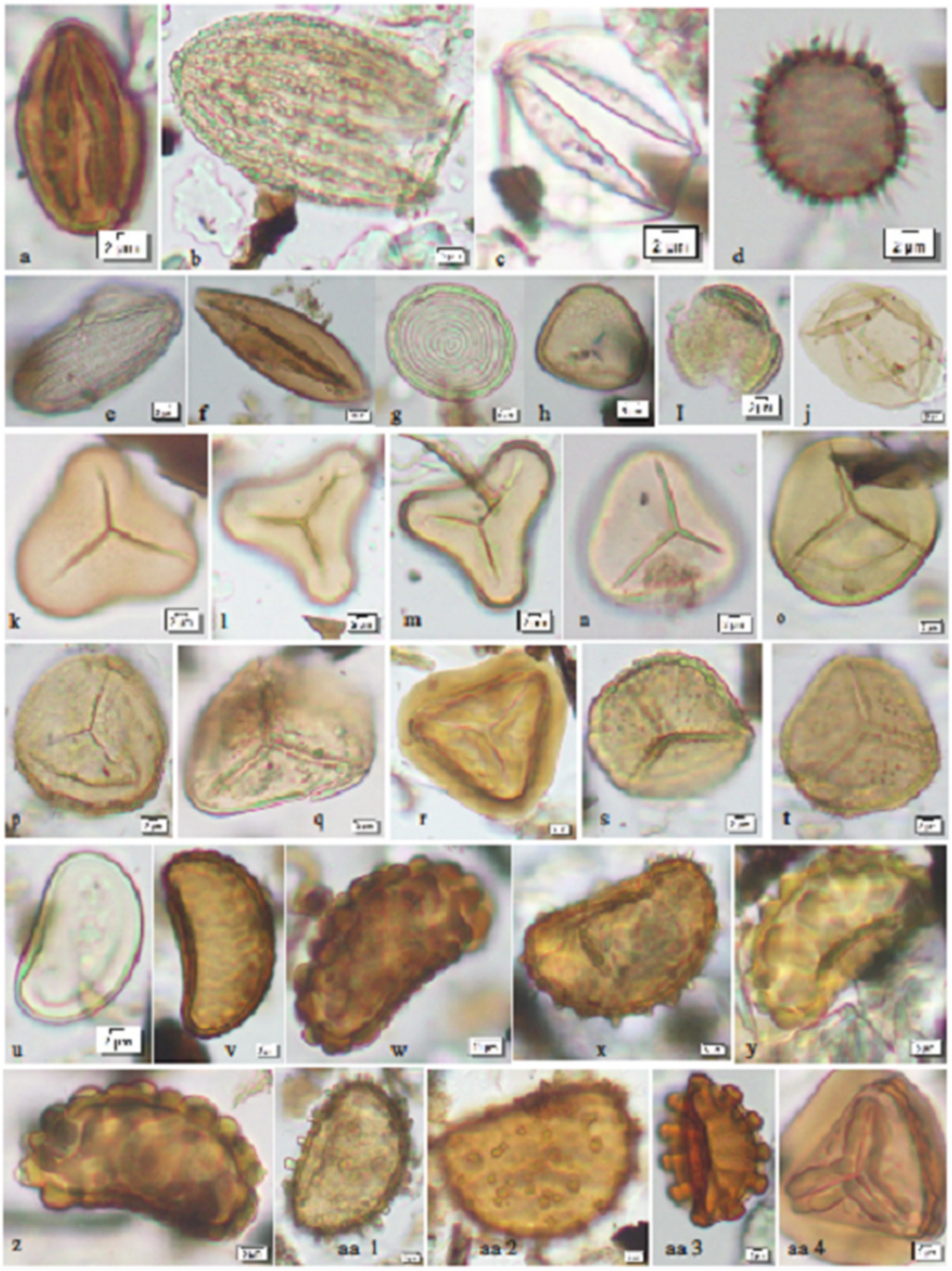

Figure 6. plate 3. Key palynomorphs recovered from the RSP sedimentary profile samples. **Explanation of Figure 6_plate 3.** (**a**). *Aesculus*, (**b**,**e**). *Strobilanthes*, (**c**). *Zygnema* (Zygospore), (**d**). *Lemna*, (**f**). *Spirogya* (Zygospore), (**g**). *Pseudoschizaea*, (**h**). *Typha*, (**i**). undentified, (**j**). *Potamogeton*, (**k**–**r**). Trilete fern spore type I, (**s**,**t**,**w**). Trilete fern spore type II, (**u**,**v**). Monolete fern spore type I, (**x**–**z**,**aa 1**–**aa 4**). Monolete fern spore type II.

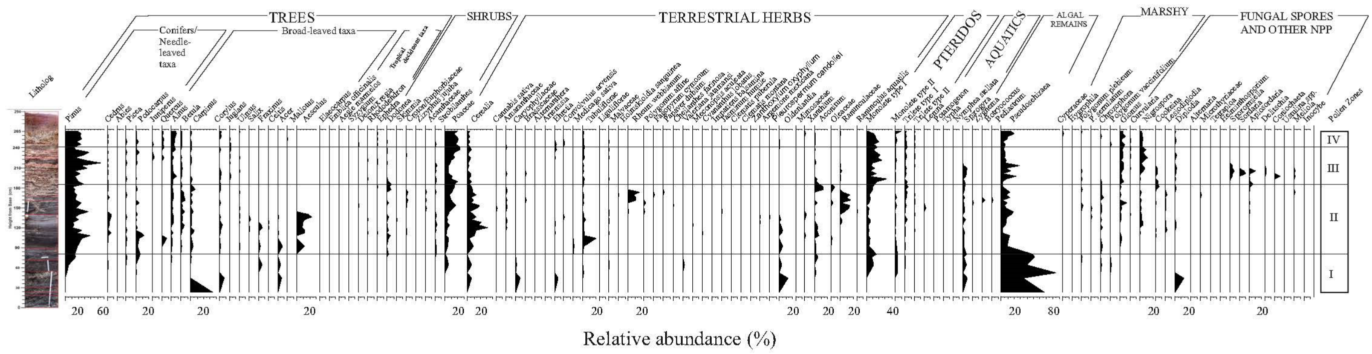

Figure 7. Graphic representation of the recovered palynomorphs, comprising the tree taxa (conifers, broad-leaved taxa and tropical deciduous taxa), shrubs, as well as the pteridophytic taxa, aquatic taxa, algal remains, marshy taxa, as well as fungal spores and other non-pollen palynomorphs (NPPs), from the RSP sedimentary profile.

4. Results

The pollen diagram (Figure 7) has been divided into four distinct pollen zones (RSP–I, RSP–II, RSP–III and RSP–IV), based on the changes in the frequencies of prominent arboreal and non-arboreal taxa in order to study the vegetation dynamics and coeval climate (change) around the study area. These pollen zones are named after the name of the site of investigation, Rawatsera Palaeolake (RSP) and are discussed below:

Pollen Zone RSP–I (21–84 cm; ~7522–7216 cal yr BP). This pollen zone, falling in the time interval of ~7522 and 7216 cal yr BP, showed the higher frequencies of arboreals, especially conifers and comparatively lower values of the non-arboreal taxa. The pollen assemblages suggest conifers-dominated mixed broad-leaved forests around the landscape of the study area. *Pinus* sp. (average value of ~14% pollen), among the conifers (average value of ~44.43%), have been recorded in high frequencies. Broad-leaved taxa (average value of ~10.49% pollen) have increased values. The shrubby taxa also show decreased values (average 4.44% pollen) in this pollen zone. Poaceae, among the herbs, are recorded in high frequencies (average ~9% pollen). Cerealia and other cultural pollen taxa have lesser values (average 3% pollen and average 2.25% pollen, respectively. The terrestrial herbaceous taxa (average ~4.51% pollen) have also been recorded in lesser frequencies. Pteridophytic spores, including the trilete and monolete fern spores, have high values (average ~25.46% spores). Marshy and aquatic taxa show decreased values (average 1.33% and 0.08% pollen, respectively). Algal spores are represented in high values (average 81.24% spores). The fungal spores have average ~3% spores, showing lesser values.

Pollen Zone RSP–II (84–186 cm; ~7216–6526 cal yr BP). The pollen assemblage of this pollen zone having the time interval of ~7516 and 6526 cal yr BP has revealed that dense conifers-dominated mixed broad-leaved forests present around the study area. *Pinus* sp. (average ~19% pollen), among the conifers (average ~61% pollen), has been recorded in high values compared to the preceding pollen zone. Broad-leaved taxa (average ~10% pollen) show comparatively lesser values. The frequency of the shrubby taxa shows highest values (average ~6% pollen) in the pollen assemblage. Poaceae value increased (average ~10% pollen) comparatively so as the case with Cerealia (average 8% pollen) and other cultural pollen taxa (average 3% pollen). Additionally, the terrestrial herbaceous taxa show increased value (average ~8% pollen). Trilete and monolete fern spores are also encountered in high values (average ~46% spores). Marshy and aquatic taxa increased comparatively (average values of ~3% and 1%, respectively). Algal spores (average 40% spores) increased and have been encountered in comparative high values. The fungal spores (average ~7% spores) increased comparatively.

Pollen Zone RSP–III (186–246 cm; ~6526–5987 cal yr BP). This pollen zone showing the temporal range of ~7158–6793 cal yr BP has indicated that the conifers-dominated broad-leaved forests continued to exist around the study area. *Pinus* sp. (average sum of ~28%

pollen), among the conifers (average sum of 41% pollen), increased comparatively; however, the conifers, in totality, decreased comparatively. The contribution of broad-leaved taxa is ~2% pollen (average sum) in the pollen assemblage, however. The contribution of shrubs is low (average 1.85% pollen) in the pollen assemblage. Poaceae (average sum of ~8% pollen) have decreased compared to the preceding pollen zones. Similar is the case with Cerealia and other cultural pollen taxa (average sum of ~2.3% and 0.65% pollen, respectively). The terrestrial herbaceous taxa have lesser values (average value of <1% pollen). Pteridophytic spores, such as trilete and monolete fern spores have contributed with average values of 34.49% spores to the pollen assemblage. Marshy and aquatic taxa contributed with <1% pollen in the pollen assemblage. Algal spores show increased values (average ~20% spores) compared to the preceding pollen zone. The fungal spores (average ~9% spores) increased comparatively.

Pollen Zone RSP–IV (246–265 cm; ~5987–5817 cal yr BP). The pollen assemblage of this topmost pollen zone has shown that conifers dominated broad-leaved forests existed around the study area. *Pinus* sp. (average ~22% pollen), among the conifers (average sum of ~37% pollen), is recorded in high frequencies, but their values decreased comparatively in the pollen assemblages. Broad-leaved taxa (average sum of 4.47% pollen) show increased values compared to the preceding pollen zone. Shrubs have low values (average sum of 2% pollen) in the pollen assemblages. Poaceae show comparative high values (average sum of 19% pollen), along with Cerealia (average sum of 3% pollen) and other cultural pollen taxa (average value of ~1% pollen) in the pollen assemblage. Terrestrial herbs have an average of ~1% pollen in the pollen assemblage. Pteridophytic spores comprising trilete and monolete fern spores have an average sum of ~39.13% spores in the pollen assemblage. Marshy (average sum of ~1% pollen) and aquatic taxa (average sum of ~0.19% pollen) are encountered meagerly. Algal spores (average sum; 15% spores) are recorded in high values. Fungal spores and other NPP have been recorded moderately (average sum of ~5.38% spores).

The upper ~30 cm (265–294 cm) could not be incorporated in the present study as the samples failed to yield any palynomorphs (pollen and spores) owing to the presence of sandy soil layers. Similarly, from 0 to 20 cm of the studied profile, owing to the presence of matrix supported gravelly sand with clastic material, were not included in the present study.

5. Discussion

5.1. Reconstruction of Vegetation Dynamics and Hydro-Climate Changes during the Middle Holocene

Palynological studies conducted on a 2.65-m high palaeo lake sediment profile from RSP suggested the Middle Holocene vegetation history and coeval climatic changes around the study area in Central Himalaya, India. The pollen assemblages have demonstrated that between the time interval of ~7522 and 7216 cal yr BP (Pollen Zone RSP–I), conifers-dominated mixed broad-leaved forests existed around the landscape of the study area under a less cold and dry climate, possibly indicating a reduced monsoon precipitation. The broad-leaved forest elements, such as *Quercus*, *Carpinus*, *Corylus*, *Ulmus*, *Fraxinus*, and *Acer* noticeably increased (average sum of 10.49% pollen) during this phase, compared to the other phases. These increased values of the broad-leaved taxa demonstrate some sort of amelioration in climate (resulting into the increase of broad-leaved taxa), which could be well correlated with the period of the Holocene Climate Optimum (HCO) or Holocene Thermal Maximum (HTM) (7000–4000 BP) [70].This phase is also correlated with the second phase of the Surinsar Lake (SL–II, ~ 7700–6125 yr BP), Jammu [33]. Poaceae, Cerealia, Asteroideae and *Ehretia*, as well as Caryophyllaceae, *Oldenlandia*, *Aconitum*, Oleaceae and Ranunculaceae are the chief herbaceous vegetation around the study area in this zone. Monolete fern spores grow locally around the study area in the region. Zygospores of *Spirogyra* and *Pseudoschizaea* sp., and *Polygonum* spp. and *Chrozophora* indicate that the lake assumed a smaller dimension with decreased marshy margin during this phase around the study area as is indicated by the decreased values of aquatic taxa, marshy taxa and algal remains. Between ~7216 and 6526 cal yr BP (Pollen Zone RSP–II), with the comparative expansion of the existing conifers, such as *Pinus* sp., *Cedrus* sp. *Podocarpus* sp., as well as the broad-leaved forest elements, such as *Alnus* sp., *Betula* sp., *Carpinus* sp. and *Corylus* sp. and appearance of *Fraxinus* sp., *Celtis* sp., *Salix* sp., *Ulmus* sp., *Aesculus* sp. and *Dodonea* sp. and under a regime of a comparatively more cold and drier climate and further reduction in monsoonprecipitation, dense conifers-dominated mixed broad-leaved forests occupied the landscape of the study area. This phase broadly correlated with the Mansar Lake (ML–III, ~7000–3000 yr BP), Jammu (Western Himalaya), India [32]. Poaceae, Cerealia, Asteroideae and *Ehretia*, as well as Amaranthaceae, *Cannabis sativa*, *Oldenlandia*, Brassicaceae, Cichorioideae (Liguliflorae), Malvaceae, *Aconitum* and Ranunculaceae are the main herbaceous vegetation in this zone. Monolete and trilete fern spores grow locally around the study area in the moist and shady places in the region. *Lemna*, as well as zygospores of *Spirogyra* and *Pseudoschizaea* sp., and *Polygonum* spp. and *Chrozophora* indicate that the lake level shrunk, compared to the preceding phase, with decreased marshy margin around the study area during this phase. Subsequently between ~6526 and 5987 cal yr BP (Pollen Zone RSP–III), the conifers, such as *Pinus* sp., *Cedrus* sp., and *Podocarpus* sp. continued to grow with comparative lesser values along with the broad-leaved taxa, such as *Alnus* sp., *Betula* sp., *Carpinus* sp., *Corylus* sp., and *Juglans* sp. The changing vegetation assemblages with respect to the preceding pollen zone suggest that the conifers-dominated broad-leaved forests continued to grow around the study area under a less cold and dry climate and reduced monsoon precipitation. Grasses (Poaceae), Cerealia, and Asteroideae, as well as Amaranthaceae, *Cannabis sativa*, Caryophyllaceae, Brassicaceae, Cichorioideae (Liguliflorae), Malvaceae, *Rheum webbianum*, *Aconitum*, Oleaceae and Ranunculaceae constitute the herbaceous vegetation in this zone. Pteridophytic spores, such as monolete and trilete fern spores thrived well in the moist and shady places of the study area in the region. *Lemna*, *Typha*, as well as zygospores of *Spirogyra* and *Zygnema*, *Botryococcus*, *Pediastrum* and *Pseudoschizaea* sp., and sedges (Cyperaceae), *Polygonum* spp. and *Chrozophora* indicate a widened water body (lake) with increased marshy margin around the study area during this phase. Finally, between ~5987 and 5817 cal yr BP (Pollen Zone RSP–IV), the climate further deteriorated as is manifested by a shift in the vegetation pattern around the study area. The conifers-dominated broad-leaved forests, comprising of the dominance of *Pinus* sp., *Cedrus* sp., and *Podocarpus* sp. (conifers) and presence of comparatively lesser number of broad-leaved taxa such as *Alnus* sp., *Quercus* sp., *Betula* sp., *Juglans* and *Corylus* sp. (broad-leaved taxa) occurred around the landscape of the study area under a comparative less cold and dry climate with reduced monsoon precipitation. The herbaceous vegetation was chiefly composed of grasses (Poaceae), Cerealia (cereal Poaceae), Asteroideae (Tubuliflorae) and *Ehretia*. The presence of pteridophytic taxa, such as monolete and trilete fern spores, indicates their local presence in humid condition around the study area. The presence of aquatic taxa, such as *Lemna*, as well as freshwater algae, especially *Pseudoschizaea* sp., and sedges (Cyperaceae), *Polygonum* spp. is suggestive of the existence of a water body (lake) with marshy margin around the study area during this phase.

The presence of sandy soil deposits for the upper ~30 cm depth (between 265–294 cm depth in the lithocolumn) is suggestive of a pluvial environment. Concurrently, with no significant pollen and spores except a few *Pinus* sp. and Poaceae pollen, no palaeovegetation and coeval palaeoclimate could be suggested. Moreover, similar situation could be suggested for the samples between 0–20 cm depth of the litholog of the studied palaeo lake around the study area.

5.2. Regional Correlation and Global Contextualization of the HCO

The Holocene Climate Optimum (HCO), falling between 7000 and 4000 cal yr BP [70], has been recorded from the diverse areas of the Indian sub-continent, such as from the temperate belt of Kashmir [71], the alpine belt of Marhi in Himachal Pradesh (~8000–3500 yr BP) [72], Dhakuri peat bog (~6000–4500 cal yr BP) [73], Tso Kar lake in Ladakh (~6.9–4.8 ka BP) [74], Chandra peat bog, Lahaul, Northwestern Himalaya

(~6732–3337 cal yr BP) [75], Gharana Wetland, Jammu (~5296–2776 cal yr BP) [34]. This HCO was also recorded from the tropical region of central India, such as from the Hoshangabad District, Madhya Pradesh [76,77], the Anuppur District, Madhya Pradesh [78], the Koriya District, Chhattisgarh [79], the Mahasamund District, Chhattisgarh [80–82].

For the HCO, various names were proposed by different workers [80] and also the HCO is asynchronous, probably owing to the varied timing and magnitude of the HCO at global lavel [83].The HCO was a relatively warm climatic phase between 11 and 5 ka BP and is commonly linked with the orbitally forced summer insolation maximum [83–87]. Other forcings and feedbacks, in addition to the remnant Laurentide Ice sheet (LIS) also affect the HCO [87,88].The HCO is delayed by 1000–2000 years at mid-to-high latitudes of the Northern Hemisphere owing to the cooling effect of the LIS compared to the orbitally forced insolation maximum, particularly in northeast North America, the North Atlantic, Western Europe and a zonal band across Eurasia [83,89,90]. A rather steady timing of the HCO across the globe was also suggested, however [91]. Moreover, larger differences could exist for diverse seasons, specified the seasonal nature of the orbital forcing [91].

6. Conclusions

Reconstruction of vegetation history and hydro-climate changes during the Middle Holocene from the Kumaun region of Central Himalaya, India shows that varying degrees of the dominance of conifers forests existed around the study area between ~7522 and 7216 cal yr BP, ~7216 and 6526 cal yr BP, ~6526 and 5987 cal yr BP and between ~5987 and 5817 cal yr BP. However, broad-leaved forests also existed around the study area, but showed the recessive nature. The broad-leaved forests, moreover, demonstrated their increased values during ~7522–7216 cal yr BP, which indicate amelioration in climatic condition in the existing cold and dry climate. The ameliorating climate between ~7522 and 7216 cal yr BP falls broadly within the time interval of the asynchronous Holocene Climate Optimum (7000–4000 BP). The study also revealed that a lake was formed at the study site around 7522 cal yr BP along the Kulur River, a tributary of Saryu River, and existed until 5817 cal yr BP.

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