Tropical Ecology **52**(1): 69-77, 2011 ISSN 0564-3295
© International Society for Tropical Ecology
www.tropecol.com

Climate change and vegetation succession in Lalitpur area, Uttar Pradesh (India) during late holocene

ANJUM FAROOQUI* & B. SEKHAR

Birbal Sahni Institute of Palaeobotany, 53, University Road, Lucknow 226 007

Abstract: The palynological study was carried out in three sediment cores one each from centripetal perennial lakes in Talbehat (depth 1.0 m; 25° 0' 10" N and 78° 26' 20" E), Madaura (depth 0.8 m; 24° 22' 35" N and 78° 48' 9" E) and Dhaura (depth 1.2 m; 24° 17' 40" N and 78° 51' 8" E) flanked at three corners of the Lalitpur district, Uttar Pradesh, in order to understand the climate and vegetation pattern during late holocene. Three pollen zones could be identified indicating the succession of vegetation from Moist Deciduous Forest (~4000 yrs BP) to Mixed Deciduous Forest (~2000 yrs BP) and finally to Dry Deciduous Forest since ~1400 yrs. BP. Dominance of *Shorea, Hopea* in the beginning of late holocene along with other moisture loving tree taxa and their decline since ~1400 yrs BP indicate an increase in aridity/weakened monsoon. However, the diversification of vegetation since the last millenium in the study area is unlike the reduction in tree taxa recorded during the same period from the fertile Gangetic plain. This difference is attributed to (1) gradual nutrient enrichment and accumulation of *in-situ* undisturbed soil cover in time, retaining more soil moisture during monsoons, and (2) slow pace of agricultural development due to rugged, undulating terrain resulting into lower anthropogenic pressure compared to the Gangetic plain.

Resumen: Este estudio palinológico fue llevado a cabo en tres núcleos de sedimento, cada uno proveniente de un lago perenne centrípeto en Talbehat (profundidad 1.0 m; 25° 0' 10" N y 78° 26' 20" E), Madaura (profundidad 0.8 m; 24° 22' 35" N y 78° 48' 9" E) y Dhaura (profundidad 1.2 m; 24° 17'40"N y 78° 51' 8" E) que flanquean en tres esquinas el distrito Lalitpur, Uttar Pradesh, con el fin de entender el patrón climático y vegetacional durante el Holoceno Tardío. Fue posible identificar tres zonas polínicas que indican la sucesión de la vegetación, de bosque húmedo caducifolio (~4000 años AP) a bosque mixto deciduo (~2000 años AP) y finalmente a bosque seco deciduo desde hace ~1400 años AP. La dominancia de *Shorea* y *Hopea* al inicio del Holoceno Tardío, junto con otros taxones mesofíticos, y su decremento desde ~1400 años AP indican un incremento en la aridez y un monzón debilitado. Sin embargo, la diversificación de la vegetación desde el último milenio en el área de estudio es diferente de la reducción de taxones arbóreos registrada durante el mismo periodo en la fértil planicie del Ganges. Esta diferencia es atribuida a (1) el gradual enriquecimiento de nutrientes y la acumulación de una cubierta no perturbada de suelo *in situ* a través del tiempo, reteniendo más humedad del suelo durante los monzones, y (2) el ritmo lento de desarrollo agrícola debido al terreno abrupto y ondulado, lo cual produjo una presión antropogénica menos intensa en comparación con la que ha ocurrido en la planicie Gangética.

Resumo: A fim de compreender o padrão do clima e da vegetação durante Holoceno tardio realizou-se o estudo polínico em três núcleos de sedimento,sendo um de cada um de lagos perenes em Talbehat (profundidade de 1,0 m, 25° 0' 10" N e 78° 26' 20" E), Madaura (profundidade de 0,8 m; 24° 22' 35" N e 78° 48' 9" E) e Dhaura (profundidade 1,2 m; 24° 17' 40" N e 78° 51'8" E) que flanqueiam os três cantos dodistrito de Lalitpur, Uttar Pradesh. Três zonas de

* *Corresponding Author*; e-mail: afarooqui_2000@yahoo.com

pólen puderam ser identificadas, indicando a sucessão da vegetação da Floresta Decídua Húmida (~4000 anos BP), a Floresta DecíduaMista (~ 2000 anos BP) e, finalmente, a Floresta Decídua Seca ~1400 anos BP. A dominância da *Shorea, Hopea* no início do Holoceno Tardio, juntamente com outros taxa arbóreas de zonas húmidas, e o seu declínio desde ~1400 anos BP indicam um aumento da aridez/enfraquecimento da monção. No entanto, a diversificação da vegetação desde o último milénio no área de estudo é diferente da redução dos taxa arbóreos registados durante o mesmo período naplanícieférтil do Ganges. Esta diferença é atribuída ao (1) enriquecimento gradual de nutrientes e acumulação in-situda cobertura não disturbada do solo e *que retém* nele mais humidade durante as monções, e (2) o ritmo lento do desenvolvimento da agricultura, devido ao terreno acidentado e ondulado, de que resultou uma menor pressão antrópica em comparação com a planície do Ganges.

Key words: Climate, India, late holocene, lake sediment, succession, Uttar Pradesh, vegetation.

Introduction

Plant species have traditionally evolved to adapt to the climate changes during geological timescales. The type of vegetation and its distribution largely depends on the environmental factors such as temperature, rainfall, humidity/ aridity, geomorphology, etc. The vegetation reconstruction through palynology from natural archives such as lake sediment provides the data on plant succession which allows us to infer climate and vegetation changes that have occurred through the geological time period. Uttar Pradesh (U.P.) constitutes the north-western and central part of India comprising a vast central fertile Gangetic plain with flat topography broken by numerous ponds, lakes and rivers in the centre.

Several lakes present in the central Ganga plain were formed during the early holocene ~8300 yrs BP (Agarawal *et al.* 1992; Sharma *et al.* 2004; Singh 1996), as a result of river channel abandonment due to change in base level and tectonic activity. Information on palaeovegetation pattern from Gangetic plain and adjoining areas in Uttar Pradesh reveal agriculture practice since ~7500 yrs BP that enhanced during late holocene (Chauhan *et al.* 2005). However, the humid climate and comparatively strengthened monsoon between ~3000 to ~2000 yrs BP gradually became less humid and finally, since the last millenium, the arboreal tree taxa declined drastically (Chauhan *et al.* 2004; Gupta 1978; Saxena *et al.* 2006; Sharma *et al.* 2001; Sharma *et al.* 2004). The Gangetic plain is marked by increased anthropogenic activity particularly during late holocene period leading to enormous deteriorating changes in the landscape, vegetation and hydrological conditions (Singh 2005). The increased aridity in climate enhanced by the anthropogenic activity in this region since ~2000 yrs BP resulted into increased alkalinity in the soil and decline in forest cover (Chauhan *et al.* 2004). Climate induced changes in vegetation from Madhya Pradesh (eastern and southern part of central India) are discussed at large by Chauhan (2002, 2005), attributing the changes to similar climatic fluctuations. However, palaeovegetational and palaeoclimatic studies are inadequate from the southern part of Uttar Pradesh which primarily falls in the central India and comprises semi-arid dry deciduous forest cover with low area of arable land due to undulating terrain and thin soil cover. Lalitpur district of Uttar Pradesh (U.P.) is a transitional zone between western thorn forest and eastern moist deciduous forest. The objective of the study here is to unravel the trend in vegetational changes in response to climate change with special reference to areas of comparatively low historical agricultural expanse and higher forest cover compared to the central Gangetic plain.

Study area

The Lalitpur district falls in the Bundelkhand region forming the southern fringe of U.P. (Fig.1) demarcated by the Vindhyan hills and plateau. It falls under semi-arid climatic zone characterised by rugged undulating terrain, scanty water resources and low soil cover with granitic outcrops. The area with poor soil cover and uncertain rainfall has limited agricultural development (CSE 1999; Singh

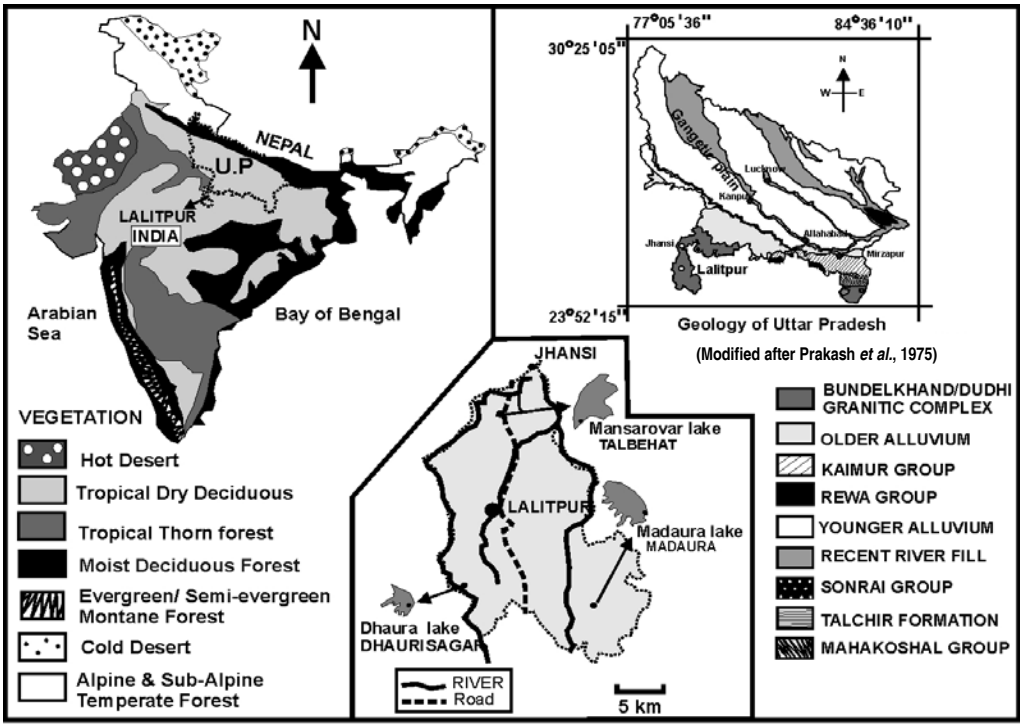

Fig. 1. Location of study sites in Lalitpur area of Uttar Pradesh (U.P.), India.

1989). The forest cover of Uttar Pradesh accounts for about 5.71 per cent of the total 240,928 km² geographic area. Lalitpur district has 11.07 per cent forest cover within its 5039 km² of geographic area.

The undulating topography has an elevation ranging from 350 to 650 m above mean sea level. Average rainfall per year is 800-900 mm but most is lost to runoff due to low and coarse soil cover. The number of rainy days in the region ranges from 48 - 75 days annually. Dry months in a year range from 3 to 7. The highest temperature is 48 °C in summers. Numerous streams and rivers flow through valleys that are generally charged during monsoons. The Betwa River forms the northern and western boundary of the district, and most of the district lies within its watershed. The Jamni River, a tributary of the Betwa, forms the eastern boundary. The Dhasan River forms the district's southeastern boundary, and the southeastern portion of the district lies within its watershed. The soil type is porous, yellowish to reddish, thin soil cover ranging from 0.1 to 3.0 m. The area is Bundelkhand Gneissic Complex (Prakash *et al.* 1975) which is scoured by numerous drainage channels, and stretch north beyond the town of Lalitpur gradually becomes more rocky. Low red hills of granitoid rock with long ridges run from south-west to north-west. The nutrient and sediment load in the watershed through surrounding hard rock is comparatively low and coarse.

Present vegetation

Vindhyan highlands are located in between the Indo-Gangetic plains and the Narmada valley, and have natural vegetation of tropical dry deciduous forests (Champion & Seth 1968). Variability in edaphic and geomorphological conditions here bring about significant difference in the forest types. Depending on the soil cover and availability of soil moisture, the rocky terrain mainly supports scrubby thorn vegetation and tropical dry deciduous forest. The scrubby vegetation, in general, is composed of *Barleria cristata* L.*, Bridelia retusa* Spreng.*, Carissa spinarum* L.*, Diospyros melanoxylon* Roxb.*, Gymnosporia montana* (Roth) Benth., *Ipomoea carnea* Jace. (along streams), *Lantana camara* L., and herbaceous taxa of Asteraceae and Euphorbiaceae families. The major tree taxa of the tropical deciduous forest consist of *Acacia nilotica* (L) Delile*, Acacia leucophloea* (Roxb.) Willd.*, Aegle*

marmelos (CORREA), *Alangium salvifolium* (L.F.) WANG., *Annona squamosa* L., *Anogeissus latifolia* (Roxb. ex DC.) Wall. ex Guill. & Perr., *Areca catechu* L., *Bauhinia racemosa* Lam., *Buchanania lanzan* Spreng., *Butea monosperma* (Lam.) Taubert, *Casearia tomentosa* Roxb., *Dalbergia sisso* Roxb., *Phyllanthus emblica* L., *Hardwickia binata* Roxb. and *Lagerstroemia parviflora* Roxb., *Madhuca indica* J. F. Gmel., *Mangifera indica* L., *Mimosa himalayana* Gamble, *Tamarindus indica* L., *Woodfordia fruticosa* Kurz, *Xeromphis spinosa* (Thunb.) Keay., *Ziziphus mauritiana* Lam., etc. The present vegetation cover and plant communities in the region are reported by Farooqui (1992), Raghubanshi *et al.* (1991) and Raghubanshi & Tripathi (2009).

Materials and methods

The palynological study was carried out in three sediment cores one each from centripetally drained perennial lakes in Talbehat (1.0 m), Madaura (0.8 m) and Dhaura (1.2 m) flanked at three corners of the Lalitpur district, Uttar Pradesh (Fig.1). The precise locations of the sampling sites are: Talbehat 25° 0' 10" N and 78° 26' 20" E, Madaura 24° 22' 35" N and 78° 48' 9" E and Dhaura 24° 17' 40" N and 78° 51' 8" E. The sediment core was obtained by manually operated Hiller's peat auger and sub-sampled at 5 cm interval before bringing to laboratory for palynological study. The colour of the soil is according to Munsell Colour codes. The soil texture on the basis of percentage of sand in the sediment was analysed following density method (USDA 1992). For palynological study the samples were subjected to wet digestion firstly by KOH (potassium hydroxide) and subsequently to hydrofluoric acid (HF), glacial and anhydrous acetic acid following standard method (Erdtman 1943). The sediment being coarser were not rich in pollen/spores which restricted the counting to a maximum of 200 pollen in each sub-sample and the percentage occurrence of the diverse pollen taxa allowed us to identify four climatic phases (I, IIa, IIb and III). The calibrated radiocarbon dates have been obtained from Radiocarbon laboratory, Birbal Sahni (BS) Institute of Palaeobotany, Lucknow.

Results

Lithology (Table 1)

The Mansarovar Lake in Talbehat covers an area of about 2 km^2. The main rock type around the lake constitutes coarse grained Pegmatite, Quartz veins, basic rocks (Dolerite), Apelite and coarse grained Porphyritic granite. The soil derived from the weathering of the surrounding rock type is reddish brown in colour due to high percentage of oxidised iron. A 100 cm sediment core retrieved from the periphery of the lake shows three types of lithology. The 80 - 100 cm bottom sediment above the basement rock is reddish brown (2.5 YR ¾ to R ¾) and comprises loamy sand (76 % coarse sand). The sediment from 40 - 80 cm is rusty brown (7.5 YR 4/8 to 7.5 YR 5/8) and fine sandy loam (58 % fine sand). The upper 40 cm sediment is blackish brown (7.5 YR 2/2) loam (43 % fine sand).

The Madaura Lake in Madaura covers an area of about 1.5 km^2. The 80 cm sediment core could be retrieved from the periphery of the lake beyond which strikes the ultramafic rock. The main lithounits observed here are Dolerite dykes, Quartz veins and Pegmatite, coarse to medium Diorite, Peridotite and Talc actinolite schist. Predominantly, most of the area is covered by black cotton soil. The entire sediment column is blackish to very dark brown (7.5 YR 2/2) sandy loam (62 % sand).

The Dhaura Lake in Dhaurisagar covers an area of about 1.0 km^2. The two major stratigraphic units are Sonrai Carbonate Formation and Solda Iron Formation. The soil cover in the area is an amalgamation of grey and red coloured soil. The red colour is due to the weathering of iron formation. A 120 cm sediment core was retrieved from the periphery of the lake and the bottom sediment i.e., 100 - 120 cm is brownish (7.5 YR 4/8 to 7.5 YR 5/8) fine sandy loam (56 % sand) with lenses of coarser reddish sand and blackish peaty organic matter. The 40 - 100 cm sediment core is blackish to dark brown (7.5 YR 2/2), loam (49 % sand) that slightly changes to more silty texture in the top 0 - 40 cm sediment.

Chronology (Table 1)

Five calibrated Radiocarbon dates (^{14}C) were obtained following Stuiver *et al.* (1998). Four dates are from Talbehat and Dhaura and one from Madaura lake. The deepest 115 - 120 cm sediment from Dhaura dates back to 3865 ± 100 yrs BP and at 75 to 80 cm it is 2745 ± 100 yrs BP. Sediment in Talbehat lake from 95 - 100 cm dates back to 4090 ± 200 yrs BP and at 35 - 40 cm to 1410 ± 120 yrs BP. The bottom sediment from Madaura Lake dates back to 2350 ± 150 yrs BP. Thus, the three

Table 1. Lithology, radiocarbon dates and vegetation from three lakes in Lalitpur, U.P..

Depth (cm)	Study site			Vegetational succession
	Mansarovar lake, Talbehat	Madaura lake, Madaura	Dhaura lake, Dhaurisagar	
0-40	loam	sandy loam	blackish loam	Dry Mixed Deciduous Teak Forest (Phase III): *Acacia, Annona, Anogeissus, Bauhinia, Bombax, Boswellia, Bridelia, Butea, Carissa, Cassia, Cocculus, Combretum Diospyros, Elaeodendron, Eucalyptus, Flacourtia, Grewia, Gymnosporea, Helectris, Ipomoea, Lagerstroemia,* Lythraceae*, Madhuca, Mitragyna,* Myrtaceae, *Nyctanthus,* Fabaceae*, Schleichera, Syzigium, Tectona, Terminalia, Woodfordia, Xeromphis, Zizyphus*
35-40	1410 ± 120 yrs BP (BS-2491)	sandy loam		
40-80	sandy loam	sandy loam	blackish to dark brown loam	Dry Sal Forest (Phase IIb): *Acacia, Boswellia, Buchanania,, Casearia, Cassia, Dalbergia, Diospyros, Elaeodendron, Hopea, Lagerstroemia,* Lamiaceae*, Lannea, Madhuca, Mitragyna,* Myrtaceae, Fabaceae*, Schleichera, Shorea, Syzigium, Terminalia*
75-80	–	2350 ± 150 yrs BP (BS-1713)	2745 ± 100 yrs BP (BS-1994)	Mixed deciduous and Moist Sal Forest (Phase IIa): *Anogeissus, Bombax, Boswellia, Buchanania, Butea, Casearia, Cassia, Croton, Diospyros, Gardenia, Garuga, Lagerstroemia, Madhuca, Mitragyna, Schleichera, Shorea, Sterculia, Terminalia,*
80-100	loamy sand	–	–	
95-100	4090 ± 200 yrs BP (BS-1992)	–	–	Moist Sal Forest (Phase I): *Anogeissus,* Asteraceae *Bombax, Boswellia, Buchanania, Casearia, Cassia, Croton, Dalbergia, Diospyros, Hopea, Lagerstroemia, Lannea, Mitragyna, Randia, Schleichera, Shorea, Terminalia*
100-120	–	–	sandy loam with lenses of coarser reddish sand and blackish peaty organic matter	
115-120	–	–	3865 ± 100 (BS-2492)	

cores from Lalitpur district provide an age period of sediment deposition since the beginning of late holocene.

Net rate of sedimentation (Fig. 2)

The net rate of sedimentation was calculated on the basis of radiocarbon dates and the depth of the sediment. In the Talbehat lake the net rate of sedimentation in upper 40 cm sediment is 0.028 cm yr^{-1} while the remaining deeper sediment was deposited at a slower rate of 0.022 cm yr^{-1}. In Madaura the total sediment of 80 cm was deposited at the net rate of 0.034 cm yr^{-1}. In Dhaura Lake the net rate of sedimentation in 0 - 80 cm is 0.029 cm yr^{-1} and from 80 - 120 cm it is 0.036 cm yr^{-1}. It is obvious that the deeper sediment in the core was deposited at a comparatively faster rate in Madaura and Dhaura Lake suggesting increased precipitation that led to more sediment runoff

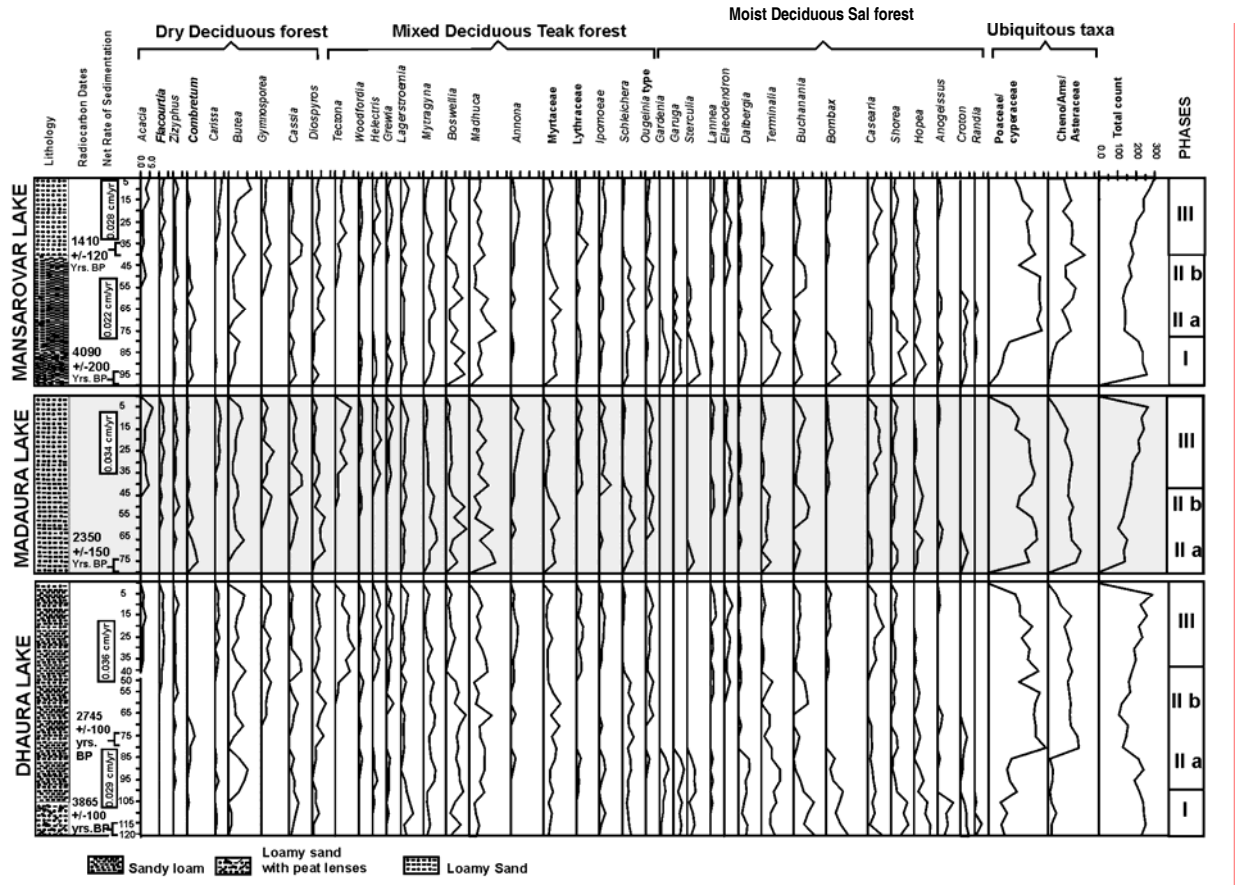

Fig. 2. Palynological spectrum of three core samples from lakes in Dhaurisagar, Madaura and Talbehat, Lalitpur, U.P..

which is characterized by coarser sand percentage and lenses of peaty organic matter. An average net rate of sedimentation in the upper sediment in all the three cores is 0.029 cm yr^{-1} suggesting a comparatively low rate of sediment supply perhaps due to reduced precipitation.

Palynology

On the basis of palynological succession, primarily three phases (I to III) were identified (Fig. 2). Phase II is the transitional phase and is sub-divided into IIa and IIb.

Phase I (4090 to 3865 yrs BP) Moist Deciduous Forest

The palynological spectrum in this phase mainly comprises elements typical to Moist Deciduous Forest and includes ~70 per cent of pollen taxa dominated by *Anogeissus,* Asteraceae*, Bombax, Buchanania, Casearia, Cassia, Croton, Diospyros, Hopea, Lagerstroemia, Randia, Shorea, Terminalia.* Out of this, *Shorea* (Sal) & *Hopea* constitute 8 and 6 per cent respectively. The remaining 30 per cent comprises elements of mixed Dry Deciduous Forest and shows dominance of pollen taxa like *Boswellia, Dalbergia, Lannea, Mitragyna* and *Schleichera.*

Phase IIa (3865 to 2350 yrs BP) Mixed Moist Deciduous Forest

This phase is dominated by about 80 per cent of Mixed Moist Deciduous Forest elements and include pollen taxa like *Anogeissus, Bombax, Boswellia, Buchanania*, *Butea, Diospyros,* Fabaceae*, Gardenia, Garuga, Madhuca, Mitragyna, Schleichera, Sterculia* and *Terminalia.* The remaining 20 per cent comprises pollen taxa like *Anogeissus, Butea, Casearia, Cassia, Croton, Diospyros, Lagerstroemia* and *Shorea.*

Phase IIb (2350 to 1410 yrs BP) Mixed Dry Deciduous Forest

This phase exhibits dominance of 60 per cent of Dry Deciduous Forest elements and include pollen taxa like *Acacia, Boswellia, Buchanania,*

Dalbergia, Diospyros, Elaeodendron, Lannea, Madhuca, Mitragyna, Myrtaceae*, Schleichera, Shorea, Terminalia.* The remaining 40 per cent included pollen taxa like *Anogeissus, Casearia, Cassia, Croton, Hopea* and *Lagerstroemia.*

Phase III (Since 1410 yrs BP) Dry Deciduous Forest

The palynological spectrum in this phase comprises 45 per cent of Dry Deciduous Forest taxa like *Acacia, Butea, Carissa, Cassia*, *Combretum, Diospyros, Flacourtia, Gymnosporea* and *Zizyphus*. Another 35 per cent comprises dominance of pollen taxa like *Anogeissus, Boswellia, Grewia, Helectris, Lagerstroemia, Madhuca, Mytragyna, Nyctanthus, Tectona* (Teak) and *Woodfordia*. The remaining 20 per cent includes *Annona, Bauhinia, Bombax, Bridelia, Butea*, *Cocculus, Elaeodendron*, Fabaceae, *Ipomoea,* Lythraceae, Myrtaceae, *Schleichera*, *Terminalia* and *Xeromphis*.

Discussion

An important determinant of the present day distribution of communities in the dry tropical forest is soil texture (Jha & Singh 1990). The plant communities identified in the Vindhyan region (Raghubanshi *et al.* 1991) are: (1) *Tectona-Acacia* (2) *Lagerstroemia-Terminalia* (3) *Lagerstroemia-Acacia-Lannea* (4) *Shorea-Buchanania* (5) *Tectona-Holarrhena* (6) *Acacia-Terminalia* (7) *Anogeissus-Holarrhena* (8) *Adina-Lannea* (9) *Terminalia-Shorea* (10) *Shorea* community, and (11*) Hardwickia-Acacia*. Of the identified communities, *Lagerstroemia–Acacia–Lannea* community is the most prevalent followed by *Acacia–Terminalia* community. Presently, the common plant species in the region are *Anogeissus latifolia, Boswellia serrata. Diospyros melanoxylon, Hardwickia binata, Lagerstroemia parviflora, Lannea coromandelica, Tectona grandis* and *Terminalia* spp.

The monsoonal and other weather conditions in India are variable. The Dry Deciduous forests and Scrubs grow in areas where the rainfall is between 50 cm and 100 cm. These are found in Central Deccan plateau, south-east of Rajasthan, Punjab, Haryana and parts of Uttar Pradesh and Madhya Pradesh which experience seven to eight months of dry period in the annual cycle and receive rainfall during June to September each year by south-west monsoon. Practically, until now, inadequate information exists on Holocene climate and temporal vegetation succession in the Vindhyan highlands. Our palynological study reveals the existence of Moist Deciduous Forest comprising Sal (*Shorea* and *Hopea* species) in the beginning of late holocene but later these species declined from the study area and the forest was replaced by dry deciduous Teak (*Tectona*) forest since the last millennium. This suggests that the climate ~4000 to 1400 yrs BP, in the study area, was relatively moist having fewer dry months in the annual cycle than now. A gradual colonization by Teak (*Tectona grandis*) forest during the last millennium indicates dry and semi-arid climatic conditions characterised by relatively low rainfall and increased number of dry months (Champion & Seth 1968; Pal *et al.* 2009). The length of the dry season (month yr^{-1}) according to the bioclimatic maps prepared from climate data at the 71 pollen sampling sites have been studied from southern India (Pascal 1982). Thus, the climate of the Lalitpur district as evident through palynological data since ~4000 yrs BP was sub-humid moist in Phase-I (4 - 6 months yr^{-1} dry period) to semi-arid/ sub-humid dry in Phase IIa and IIb (5-7 months yr^{-1} dry period) and finally became semi-arid in Phase III (7-9 months yr^{-1} of dry period). Heterogeneous sediment constituting coarser loamy sand embedded with occasional lenses of peaty organic matter reflects a stronger monsoon in the beginning of late holocene (~4000 yrs BP). The sandy loam or blackish loamy texture during the later part of late holocene shows the maturity status of the soil cover in the near vicinity due to high per cent of clay. The clay particles are flexible and plastic because of their lattice-like design and have large surface area which is chemically reactive to attract and hold positively charged nutrient ions readily available to plant roots (Hiller 2003). This feature allows the clayey soils to absorb water and other substances into their structure. Therefore, such type of soil in the undulating rocky non-arable terrain with low soil cover and low agricultural expanse allowed water and nutrient retention in phase - III which supported the diversification of the Dry Deciduous vegetation despite the gradual increase in aridity and weakening of monsoon since late holocene. As a result, about 35 pollen taxa were recorded during the last millennium as compared to about 17 taxa recorded during ~4000 to 2340 yrs BP in the study area.

Archaeological investigations along many important sites in the southern, central and western parts of the Indo-Gangetic Plain suggest considerable progress from incipient agricultural activities to well developed agricultural practices over a span of the last 10,000 years (Sharma *et al.* 1980 and Williams *et al.* 2006). Increased anthropogenic activity in the highly fertile central Gange-

tic plain led to enormous deteriorating changes in the landscape, vegetation and hydrological conditions (Singh 2005). Abandoned human habitation in the Gangetic plain and increased alkalinity in the soil has been recorded since ~2200 yrs. BP which enhanced since 1800 yrs BP. resulting into a decline of arboreal pollen taxa which indicates a gradual weakening of monsoon since late holocene (Chauhan *et al*. 2004). Other reports of increased aridity influencing vegetation cover during late holocene from the Gangetic plain have been reported by Sharma *et al*. (2004) and Saxena *et al*. (2006). In the contemporary eastern side of central India (Madhya Pradesh - M.P), Moist and Dry Tropical Deciduous sal forests occur today (Champion & Seth 1968) but palynological study reveals the dominance of Moist Deciduous Forest during the beginning of late holocene (4600-1800 yrs BP) that gradually changed to Mixed Dry Deciduous sal forest (Chauhan 2002, 2005). This transition is attributed to increased aridity. Thus, the beginning period of late holocene signifies the prominence of south-west monsoon or the reduced number of dry months in the entire central part of India which supported moisture loving sal (*Shorea*, *Hopea*) forest. Similar type of vegetation continue to exist today in the eastern MP characterized by higher rainfall but a reduction in *Shorea robusta* (Sal) and expansion of *Bombax malabaricum* was recorded between 850-400 yrs BP (Chauhan 2005; Chauhan *et al*. 2004) suggesting increased aridity enhanced by anthropogenic activity. In the eastern margin of the Thar Desert, Rajasthan a saline lake existed between 6,000 and 1300 yrs BP and finally the present-day semiarid conditions set in since 1,200 yrs BP (Achyuthan *et al*. 2007). The lake sediment profiles and the vegetational changes recorded from southern India (Bera & Farooqui 2000; Farooqui 2008) also correlate well with records from other parts of the Indian subcontinent indicating a climate shift towards increased aridity and reduced months of monsoon. In view of the above and other records from India (Meher-Homji & Gupta 1999) it is concluded that throughout the Indian sub-continent and in most parts of the world (Brooks 2006) the climate (increasing aridity) played an important role in vegetation succession and human adaptation during late holocene. However, in the present study, under similar climatic conditions the vegetational diversification took place at its own pace depending on edaphic conditions and less anthropogenic pressure (agricultural practices). The present day forest cover is comparatively more prominent in the southern parts of Uttar Pradesh, confined to Lalitpur, Mirzapur and Sonbhadra districts, and in the north, the 'Tarai region' (foothills of Siwaliks). Therefore, palynological study in such rugged terrains with thin soil cover and undulating topography accompanied by low anthropogenic activity (in terms of agricultural expanse) are best suited for palaeoclimate and paleoenvironmental interpretations. It is predicted that future increases in aridity may give way to teak/dry deciduous forest replacing the economically more important sal/ Moist Deciduous Forest from most parts of the Indian sub-continent. Thus, more high resolution palaeo-vegetational data are required from contemporary areas in order to establish the holocene climate fluctuation versus anthropogenic pressure responsible for regional vegetation changes through time and space.

Acknowledgments

Thanks are due to Director, Birbal Sahni Institute of Palaeobotany, for providing necessary facilities and Radiocarbon Laboratory for ^{14}C Dates of the sediments. Authors are grateful and thank the referees for their valuable suggestions which helped us to improve the manuscript.

References

Achyuthan, H., A. Kar & C. Eastoe. 2007. Late quaternary-holocene lake-level changes in the eastern margin of the Thar Desert, India. *Journal of Paleolimnology* **38**: 493-507.

Agarawal, A. K., M. H. Rizvi, I. B. Singh, A. Kumar & S. Chandra. 1992. Carbonate deposits in Ganga plain. pp.35-43. *In*: I.B. Singh (ed.) *Gangetic Plain: Terra Incognita*: Geology Department, Lucknow University.

Bera, S. K. & A. Farooqui. 2000. Mid-holocene vegetation and climate of South Indian Montane. *Journal of Palaeontological Society of India* **45**: 49-56.

Brooks, N. 2006. Cultural responses to aridity in the middle holocene and increased social complexity. *Quaternary International* **151**: 29-49.

Champion, H. G. & S. K. Seth. 1968. *A Revised Survey of the Forest Types of India*. Manager of Publications, Delhi, India.

Chauhan, M. S. 2002. Holocene vegetation and climatic changes in southeastern Madhya Pradesh, India. *Current Science* **83**: 1444-1445.

Chauhan, M. S. 2005. Pollen record of vegetation and climatic changes in north eastern Madhya Pradesh during last 1,600 years. *Tropical Ecology* **46**: 265-271.

Chauhan, M. S., A. K. Pokharia & I. B. Singh. 2005. Preliminary results on the palaeovegetation during holocene from Lahuradewa Lake, district Sant Kabir Nagar, Uttar Pradesh. *Pragdhara* **15**: 33-40.

Chauhan, M. S., C. Sharma, I. B. Singh & S. Sharma. 2004. Proxy records on late holocene vegetation and climate changes from Basaha Jheel, Central Ganga Plain. *Journal Palaeontogical Society of India* **49**: 27-34.

CSE (Centre for Science and the Environment). 1999. *The Citizen's Fifth Report: Part II. Statistical Database*. New Delhi.

Erdtman, G. 1943. *An Introduction to Pollen Analysis*. Waltham Mass.

Farooqui, A. 2008. The evolution of Pichavaram mangrove and its environment since middle holocene. *Journal Geological Society of India - IGCP- 464. Special Volume* **96**: 40-54.

Farooqui, A. 1992. A vegetational survey of some mineral exploration areas in Lalitpur, Uttar Pradesh, India. *Geophytology* **21**: 113-118.

Gupta, H. P. 1978. Holocene palynology of Kathauta Tal, Chinhat, Lucknow. *Geophytology* **21**: 191-194.

Hiller, S. 2003. Clay mineralogy. pp. 139-142. *In*: G.V. Middleton, M. J. Church, M. Coniglio, L. A. Hardie & F. J. Longstaffe (eds.) *Encyclopedia of Sediments and Sedimentary Rocks*. Kluwer Academic Publishers, Dordrecht.

Jha, C. S. & J. S. Singh. 1990. Composition and dynamics of dry tropical forest in relation to soil texture. *Journal of Vegetation Science* **1**: 609-614.

Meher-Homji, V. M. & H. P. Gupta. 1999. A critical appraisal of vegetation and climate changes during quaternary in the Indian Region. *Proceedings of Indian National Science Academy* **B65**: 205-244.

Pal, D. K., T. Bhattacharya, P. Srivastava, P. Chandran & S. K. Ray. 2009. Soils of the Indo-gangetic plains: their historical perspective and management. *Current Science* **96**: 1193-1202.

Pascal, J. P. 1982. Bioclimatics of the western ghats of India. *Institut Français de Pondichery: Travaux de la Section Scientifique et Technique*, **88**.

Prakash, R., P. Swarup & R. N. Srivastava. 1975. Geology and mineralisation in the southern parts of Bundelkhand U.P. Lalitpur district U.P.. *Journal Geological Society of India* **16**: 143-156.

Raghubanshi, A. S. & A. Tripathi. 2009. Effect of disturbance, habitat fragmentation and alien invasive plants on floral diversity in dry tropical forests of Vindhyan highland: a review. *Tropical Ecology* **50**: 57-69.

Raghubanshi, A. S., C. S. Jha, C.B. Pandey, L. Singh & J. S. Singh. 1991. Effects of forest conversion on vegetation and soil carbon and functional trait of resulting vegetation. pp. 723-749. *In*: Y. P. Abrol, P. N. Wattal, A. Gnanum, Govindji, D. R. Ort & A. H. Teramura (eds.) *Impact of Global Climate Changes on Photosynthesis and Plant Productivity*. Oxford and IBH Publishing Company, New Delhi.

Saxena, A., V. Prasad, I. B. Singh, M. S. Chauhan & R. Hasan. 2006. On the holocene record of phytoliths of wild and cultivated rice from Ganga plain: evidence for rice-based agriculture. *Current Science* **90**: 1547-1552.

Sharma, S., M. Joachimski, M. Sharma, H. J. Tobschall, I. B Singh, C. Sharma, M. S. Chauhan & G. Morgenroth. 2004. Late glacial and holocene environmental changes in Ganga plain, Northern India. *Quaternary Science Reviews* **23**: 145-159.

Sharma, C., M. S. Chauhan, S. Sharma, M. Sharma & I. B. Singh. 2001. Proxy record of holocene vegetation and climate change from Sanai Tal, Central Ganga Plain, Uttar Pradesh. National Symposium on Role of Ecological Science, Integrated Development and Related Social Issues. *Geological Survey of India, Special Publication* **65**: 199-202.

Sharma, G. R., V. D. Misra, D. Mandal, B. B. Misra & J. N. Pal. 1980. *Beginning of Agriculture*. Abinash Prakashan, Allahabad.

Singh, R. L. 1989. National Geographic Society of India. "Bundelkhand Region", India. pp. 597-622. *In*: R. L. Singh (ed.) *A Regional Geography*. UBS Publishers Distributors Ltd., New Delhi.

Singh, I. B.1996. Geological evolution of Ganga Plain-An overview. *Journal Palaeontological Society of India* **41**: 99-137.

Singh, I. B. 2005. Quaternary palaeoenvironments of the Ganga plain and anthropogenic activity. *Man and Environment* **30**: 1-35.

Stuiver, M., P. J. Reirner & T. F. Braziunas.1998. High-precision radiocarbon age calibration for terrestrial and marine samples. *Radiocarbon* **40**: 1127-1151.

U.S.D.A. (United States Department of Agriculture). 1992. *Soil Conservation Service, Soil Survey Laboratory Methods Manual*. Soil Survey Investigation Report 42 Washington, DC.

Williams, M. A. J., J. N. Pal, M. Jaiswal & A. K. Singhvi. 2006. River response to quaternary climatic fluctuations: evidence from the Son and Belan valleys, north-central India. *Quaternary Science Review* **25**: 2619-2631.