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Palynological study along the Triyuga River section from the Upper Siwalik sediment and its paleoclimatic implication

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ABSTRACT

The records of past vegetation and climate using palynological study from the Upper Siwalik sediment along the Triyuga River section, eastern Nepal discloses 117 taxa belonging to 36 families. Different palynomorphs from gymnosperm, angiosperm (dicotyledonous and monocotyledonous) and pteridophytes were identified some up to species level like *Abies*, *Picea*, *Pinus*, and *Tsuga, Justicia, Strobilanthes, Betula, Terminalia, Artemisia, Corylus*, *Quercus, Liquidambar, Fraxinus, Salix, Symplocos, Urtica, Typha, Cyathea, Lygodium, Ceratopteris* under light microscope. Some palynomorphs were identified up to their family level such as Anacardiaceae, Apocynaceae, Bombacaceae, Leguminosae, Malvaceae, Arecaceae, Liliaceae, and Poaceae. The palynomorphs from this section revealed diversity in vegetation with tropical-subtropical to lower temperate humid and warm climatical condition with plenty of precipitation throughout the time of deposition of the Upper Siwalik. Additionally, the Coexistence Approach (CoA) further highlighted this section experienced at the MAT 16.8-21.7°C, WMT 23.6-26.1°C, CMT 10.6-14.6°C, and MAP 1122-1682 mm, HMP 115-349 mm, LMP 19-73 mm, WMP 82-172 mm.

Keywords: Upper Siwalik, Palynomorph, Paleoclimate, Coexistence Approach (CoA)

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INTRODUCTION

Onward of the India-Asia collision there was uprising of the Himalaya orogeny and this phenomenon affected regional, Asian as well as global climatic parameters (Molnar et al., 2009). The Siwalik Group of sediment also known as younger Himalayas developed along the lower foothills of Nepal, India and Pakistan mostly influenced by the Asian monsoon system. The climatic and floristic diversity pattern changes in the Siwalik Group of Nepal Himalaya through plant remains analysis have been presented by various researchers (Lakhanpal and Awasthi, 1984; Awasthi and Lakhanpal, 1990; Prasad, 1990a; 1990b; Prasad et al., 2011; Prasad and Pandey, 2008; Srivastava et al., 2017; Adhikari et al., 2018; 2022). Palynological studies from the fluvial sediments of the Siwalik Group are found to be an excellent proxy for the paleo-vegetation and climate reconstruction (Sarkar, 1990; Hoorn et al., 2000; Paudayal, 2012; 2013a,b). Besides the numbers of past studies, there is not adequate dataset for the quantitative analysis of the paleo-environment through palynological investigation. The purpose of this study is reconstruction of paleoclimate on the basis of palynomorphs recorded from the Upper Siwalik sediments of the Triyuga River section, eastern Nepal (Fig. 1) using Coexistence Approach (CoA) described by Mosbrugger and Utescher (1997) and Utescher et al. (2014).

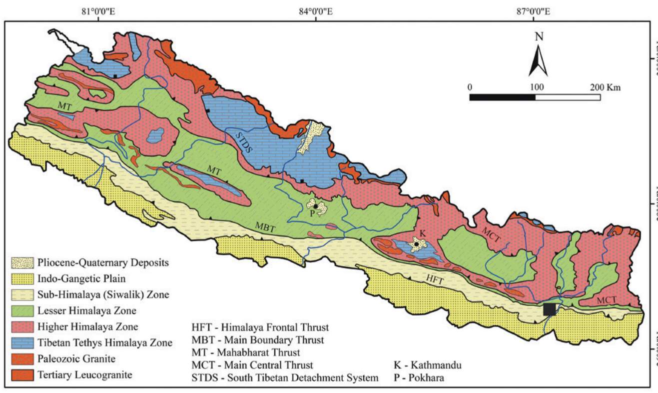

Fig. 1: Geology of the Nepal Himalaya (modified after Martin et al., 2005) including the Siwalik Group on the foothill of the Himalaya. Black rectangle indicates study area.

GEOLOGY OF STUDY AREA

The results of deformation and uplift of the Himalan belt huge pile (up to 6000 m thick) of synorogenic sediments of muds, silts, sands, and gravels have been deposited in foreland basin, south margin of the uprising Himalaya. These deposited sediments called as Siwalik Group, is bounded between the Lesser Himalaya and the Indo-Gangetic Plain in the north and south respectively (Gansser, 1964; Valdiya, 2002) (Fig. 1). The deposited sediments are overall coarsening upward while the individual beds are fining upward in sequence (Prakash et al., 1980; Nakayama and Ulak, 1999), and called as the Churia Group in Nepal (Tokuoka and Yoshida, 1984). The Central Churia Thrust (CCT) equivalent to the Sit Khola Thrust (SKT)

(Dhital et al., 1995) separates this single unit into northern and southern belt (Tokuoka et al., 1986). During the depositional time, the fluvial system changed from meandering to braided river system in the basin (Hisatomi and Tanaka, 1994; DeCelles et al., 1998; Nakayama and Ulak, 1999).

The past studies along the Triyuga River section in eastern Nepal has been mainly focused on stratigraphy, structure, petrography and geomorphological evolution (Hagen, 1969; Itihara et al., 1972; Pradhan et al., 2004; Dhital, 2015; Acharya et al., 2020). The southern part of the Triyuga River section consists the sediments of the Indo-Gangetic Plain while the northern parts were bounded by the Precambrian metasedimentary rocks of the Lesser Himalaya (Pradhan et al., 2004; Dhital, 2015; Acharya et al., 2020) (Fig. 2). The Siwalik Group can be conceded into three thrust belts between; the Main Frontal Thrust (MFT) and the Kamala Tawa Thrust (KTT), the Kamala Tawa Thrust (KTT) and the Marin Khola Thrust (MKT), and the Marin Khola Thrust (MKT) and the Main Boundary Thrust (MBT) respectively from the south to the north of the study area (Acharya et al., 2020) (Fig. 2).

The Siwalik Group in the Triyuga River section of central Nepal incorporate three litho-units: the Lower, Middle and Upper Siwalik (Fig. 2). The Lower Siwalik represents variegated (greenish grey, yellowish grey, purple, brownish grey) mudstone and greenish grey to grey siltstone interbedded with fine to medium-grained greenish grey sandstone. The sandstone beds are highly indurated and calcareous in nature. The medium to very coarse-grained, 'salt and pepper' sandstone and cross-bedded sandstone interbedded with finely laminated black mudstone and grey siltstone are present in the Middle Siwalik. Concretion, sand and mud balls are abundantly found in sandstone beds with profusely calcareous nature. The Upper Siwalik represents matrix to clast supported conglomerate with light grey mudstone, dark grey siltstone and fine-grained grey sandstone. The clasts of quartzite, sandstone, limestone, gneiss with the maximum clast size up to 20 cm are found in conglomerate of the section.

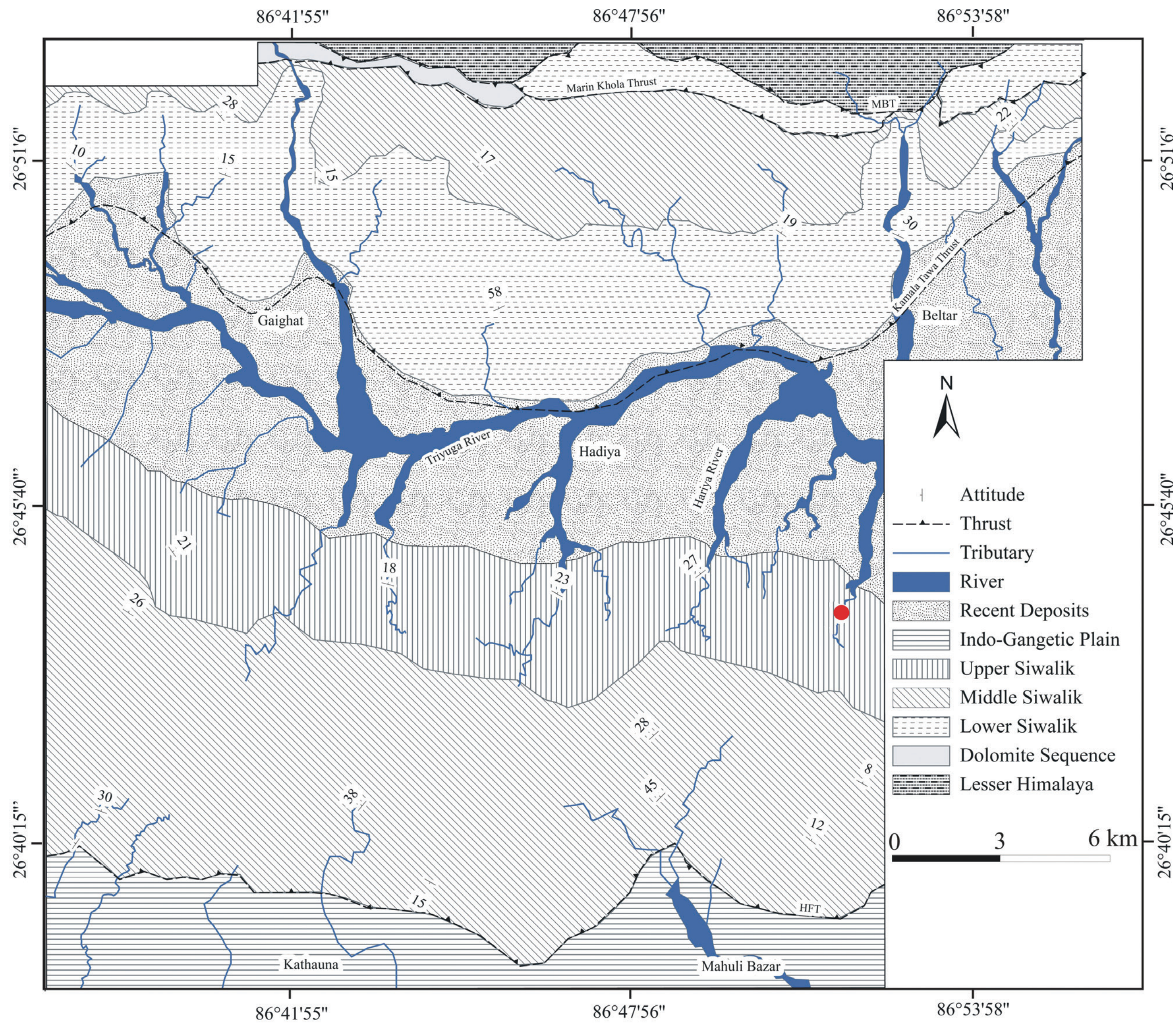

Fig. 2: Geological map of study area (modified after Acharya et al., 2020). Red circle indicates palynological sample locality.

MATERIALS AND METHODS

Palynological analysis

Seventeen palynological samples were collected from the different horizons of the Siwalik Group such as mudstone, siltstone, and fine-grained sandstone, exposed along the Triyuga River section (Fig. 3). Further, the collected samples were prepared following the techniques described by Ferguson et al. (2007) at the Central Department of Geology laboratory, Tribhuvan University, Kathmandu, Nepal. The collected samples from the field were cleaned to remove surface contamination by recent palynomorphs. About 200 gm of collected sample from each horizon was grained to make powder and treated with conc. Hydrochloric acid (HCl) to remove carbonates. The Hydrofluoric acid (HF) was added to the sample to remove silicates minerals followed by Acetolysis solution. The Acetolysis solution was made by 9:1 ratio of Acetic Anhydride $(CH_3CO)_2O$ and conc. Sulphuric acid (H_2SO_4). Before and after acetolysis treatment in each step, the samples were washed with water and glacial acetic acid. Finally, the organic matter was separated from inorganic remains using Heavy Liquid ($ZnCl_2$) with specific gravity 2.0. Thus, the obtained organic matter was mounted in glycerin and studied under OLYMPUS-BX43 light microscope under X10, X20, X40, X60 magnifications. The photographs were taken at X60 magnification by the means of OLYMPUS-DP73 camera attached with the microscope and with Cellsens Entry software. The palynomorphs were identified up to generic level and some to family level. The palynomorphs were identified and compared in the various published articles, literatures, manual and atlas (Krutzsch, 1963; Academia Sinica, 1982; Gupta and Sharma, 1986; Punt et al., 1994; Tissot et al., 1994; Fuhsiung et al., 1995; Beug, 2004; Hesse et al., 2009). Collected samples, residues and slides are kept in the archive at the museum of Central Department of Geology (CDG), Tribhuvan University, Kathmandu, Nepal.

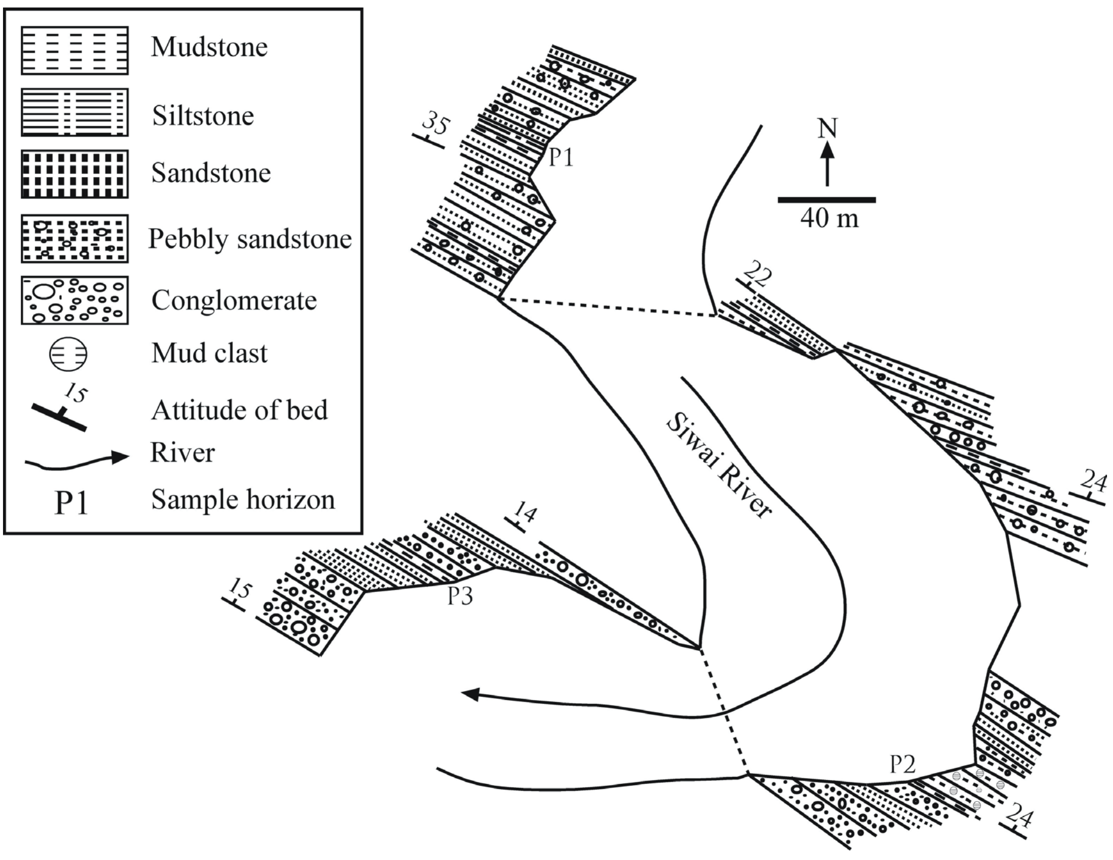

Fig. 3: Geological route map showing the sample horizon for palynological study.

Coexistence Approach (CoA) analysis

The Coexistence Approach (CoA) has been used widely for quantitative paleoclimate reconstruction in the Cenozoic (Mosbrugger and Utescher, 1997; Utescher et al., 2014). The CoA can be applied on any fossil assemblage of leaves, fruits, woods, seeds, flowers, and pollen. The CoA is based on the Nearest Living Relatives (NLRs) approach which assumes that plant fossils as a close affinity with their modern analogs and uses the climatic requirements of NLRs to infer the climatic conditions under which a fossil assemblage coexisted (Mosbrugger and Utescher, 1997; Utescher et al., 2014). The CoA requires only the presence or absence of fossil pollen taxa, regardless of their abundance and is thus independent of the sampling size and some taphonomic filtering (Mosbrugger and Utescher, 1997). However, a minimum of 10 fossil taxa where NLRs are known and climatically significant is required for reliable paleoclimate reconstruction (Mosbrugger and Utescher, 1997; Utescher et al., 2014). Although accuracy of the NLR approach decreases with an increasing age of Palaeoflora, may not always be the accuracy as using quantitative methods for reconstruction (Uhl, 2006).

Altogether Seven climatic parameters are reconstructed, i.e. mean annual temperature (MAT, °C), temperature of the coldest month (CMT, °C), temperature of the warmest month (WMT, °C), mean annual precipitation (MAP, mm), precipitation of the driest month (low month precipitation; LMP, mm), precipitation of the warmest month (WMP, mm), and mean precipitation of the wettest month (high month precipitation; HMP, mm) by using the PALEOFLORA database (Utescher and Mosbrugger, 2018). The PALAEOFLORA database and extraction of climate data of fossil NLRs are discussed detail by Utescher et al. (2014).

RESULTS

Palynofloral assemblage

Out of 17 palynological samples collected from the Upper Siwalik in the Triyuga River section only three samples contain palynomorphs. The mudstone (P2) bed revealed significant number of the palynomorphs, but siltstone (P1) and mudstone (P3) bed yielded plenty preservation of palynomorphs (Fig. 3). Altogether 117 species of palynomorphs belonging to 6 species of a single gymnosperm family, 55 species of 25 dicotyledonous families, 12 species of 4 monocotyledonous families, 35 species of 6 pteridophyte families, and 7 species of trilete spore were recorded. In the palynomorphs gymnosperm taxa were represented by Pinaceae (*Abies*, *Picea*, *Pinus* and *Tsuga*). The majority of palynomorphs identified from this section revealed angiosperms such as Acanthaceae (*Justicia*, *Strobilanthes*), Anacardiaceae, Apocynaceae, Betulaceae (*Betula*), Bombacaceae, Combretaceae (*Terminalia*), Compositae (*Artemisia*), Corylaceae (*Corylus*), Dipterocarpaceae, Fagaceae (*Quercus*), Hamamelidaceae (*Liquidambar* sp.), Leguminosae, Malvaceae, Oleaceae (*Fraxinus*), Salicaceae (*Salix*), Symplocaceae (*Symplocos*), Urticaceae (*Urtica*), Arecaceae, Liliaceae, Poaceae, Typhaceae (*Typha*). The pteridophyte spores belonging to Cyatheaceae (*Cyathea*), Lygodiaceae (*Lygodium*), Perkeriaceae (*Ceratopteris*), Polypodiaceae (*Polypodium*) and Pteridaceae (*Pteris*) are the most common palynomorphs recorded from this section. The complete lists of palynomorphs are presented in Table 1 and the microphotographs of all palynomorphs are presented in Plates I-V.

Table 1: List of plant taxa recovered from the Upper Siwalik in the Triyuga River section.

Division	Family	Species Name	No. of Species
Gymnosperm	Pinaceae	*Abies* sp.	2
		Picea sp.	1
		Pinus sp.	2
		Tsuga sp.	3
Dicotyledonous	Acanthaceae	*Justicia* sp.	3
		Strobilanthes sp.	5
		Acanthaceae gen. indet.	1
	Anacardiaceae	Anacardiaceae gen. indet.	2
	Apocynaceae	Apocynaceae gen. indet.	3
	Betulaceae	*Betula* sp.	1
	Bombacaceae	Bombacaceae gen. indet.	3
	Boraginaceae	Boraginaceae gen. indet.	1
	Brassicaceae	Brassicaceae gen. indet.	1
	Cannabaceae	Cannabaceae gen. indet.	1
	Combretaceae	*Terminalia* sp.	1
	Compositae	*Artemisia* sp.	3
		Compositae gen. indet.	3
	Convolvulaceae	Convolvulaceae gen. indet.	1
	Corylaceae	*Corylus* sp.	2
	Dipterocarpaceae	*Dipterocarpus* sp.	1
	Euphorbiaceae	Euphorbiaceae gen. indet.	1
	Fagaceae	*Quercus* sp.	3
	Hamamelidaceae	*Liquidambar* sp.	3
	Leguminosae	Leguminosae gen. indet.	2
	Malvaceae	Malvaceae gen. indet.	4
	Myrtaceae	Myrtaceae gen. indet.	1
	Oleaceae	*Fraxinus* sp.	2
	Onagraceae	Onagraceae gen. indet.	1
	Salicaceae	*Salix* sp.	3
	Symplocaceae	*Symplocos* sp.	1
	Ulmaceae	*Ulmus* sp.	1
	Urticaceae	*Urtica* sp.	2

Division	Family	Species Name	No. of Species
Monocotyledonous	Arecaceae	Arecaceae gen. indet.	5
	Liliaceae	Liliaceae gen. indet.	2
	Poaceae	Poaceae gen. indet.	4
	Typhaceae	*Typha* sp.	1
Pteridophytes	Cyatheaceae	*Cyathea* sp.	2
	Lygodiaceae	*Lygodium* sp.	9
	Parkeriaceae	*Ceratopteris* sp.	2
	Polypodiaceae	*Polypodium* sp.	4
	Pteridaceae	*Pteris* sp.	17
	Selaginellaceae	*Selaginella* sp.	1
	Other Trilete	Trilete gen. indet.	7

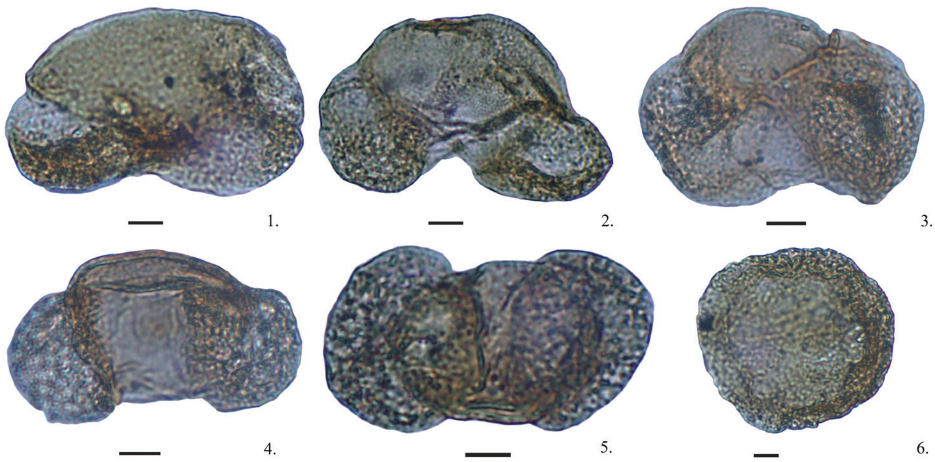

Plate I: Gymnosperm pollen. 1-2 *Abies* sp., 3. *Picea* sp., 4-5. *Pinus* sp., 6. *Tsuga* sp. (Scalebar = 10 µm).

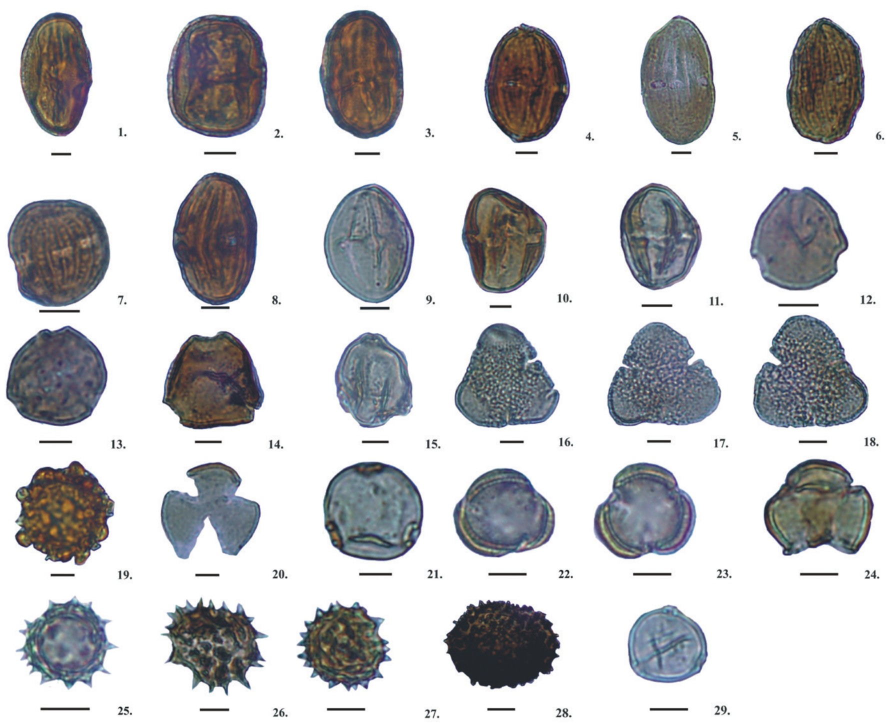

Plate II: Dicotyledonous Pollen. 1-3. *Justicia* sp., 4-8. *Strobilanthes* sp., 9. Acantheceae gen. indet., 10-11 Anacardiaceae gen. indet., 12. Apocynaceae gen. indet., 13-14. Apocynaceae gen. indet., 15. *Betula* sp., 16-18. Bombacaceae gen. indet., 19. Boraginaceae gen. indet., 20. Brassicaceae gen. indet., 21. Cannabaceae gen. indet., 21-24. *Artemisia* sp., 25-27. Compositae gen. indet., 28. Convolvulaceae gen. indet., 29. *Corylus* sp. (Scalebar = 10 µm).

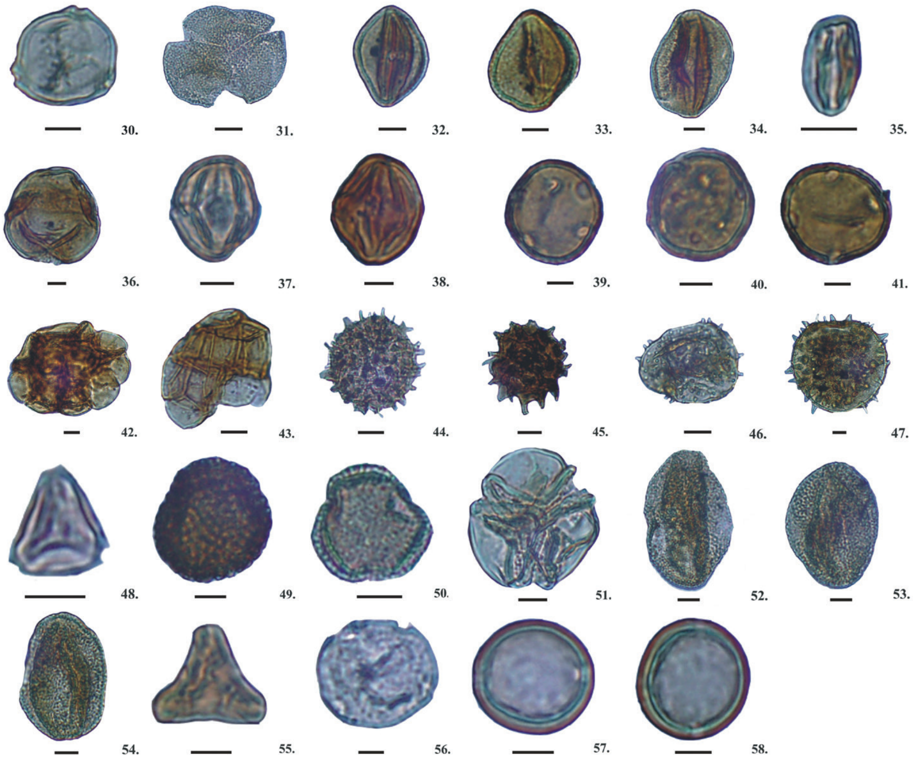

Plate III: Dicotyledonous Pollen. 30. *Corylus* sp., 31. *Dipterocarpus* sp., 32-34. Euphorbiaceae gen. indet., 35. *Castanopsis* sp., 36-38. *Quercus* sp., 39-41. *Liquidambar* sp., 42-43. Leguminosae gen. indet., 44-47. Malvaceae gen. indet., 48. Myrtaceae gen. indet. 49-50. *Fraxinus* sp. 51. Onagraceae gen. indet. 52-54. *Salix* sp. 55. *Symplocos* sp. 56-58. *Urtica* sp. (Scalebar = 10 µm).

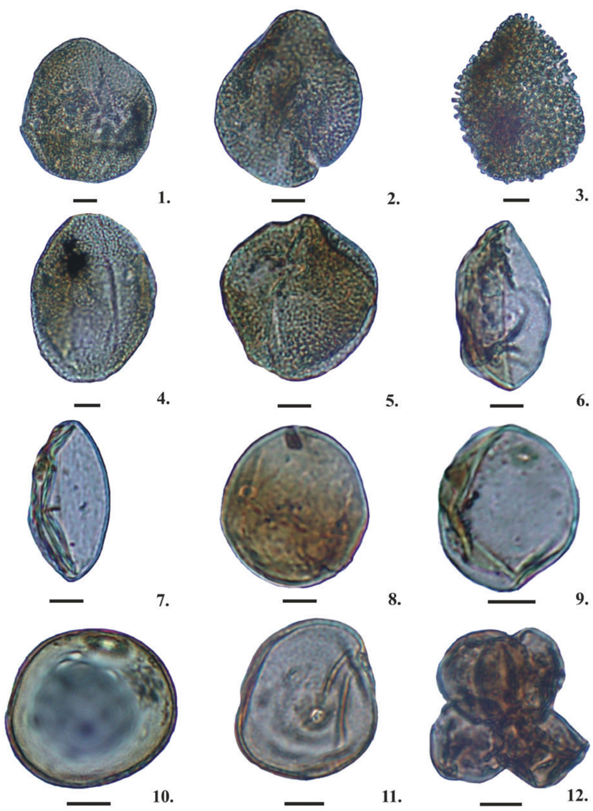

Plate IV: Monocotyledonous Pollen. 1-5. Arecaceae gen. indet., 6-7. Liliaceae gen. indet., 8-11. Poaceae gen indet., 12. *Typha* sp. (Scalebar = 10 µm).

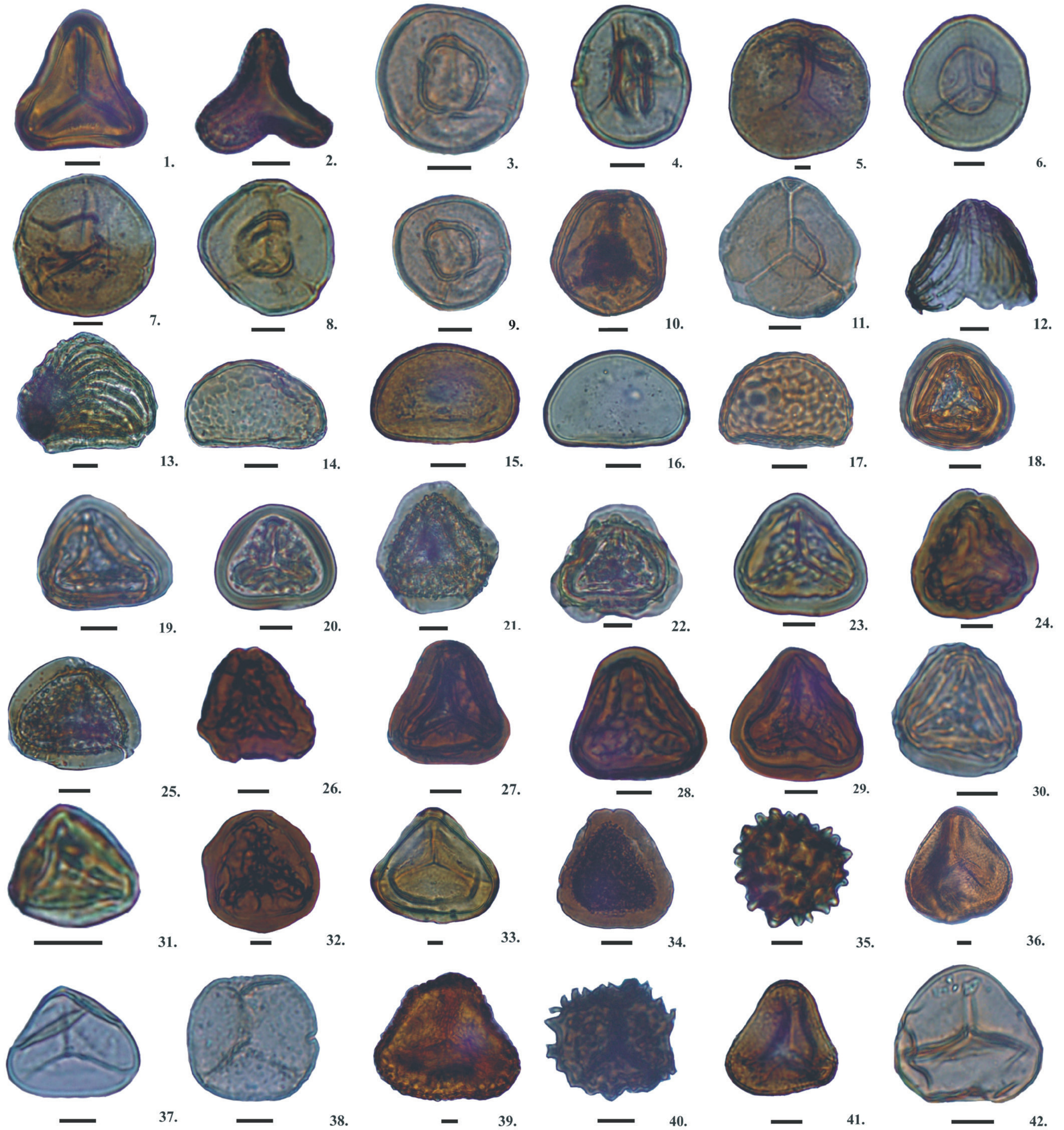

Plate V: Pteridophytes Spore. 1-2. *Cyathea* sp., 3-11. *Lygodium* sp., 12-13. *Ceratopteris* sp., 14-17. *Polypodium* sp., 18-34. *Pteris* sp., 35. *Selaginella* sp., 36-42. Trilete spore (Scalebar = 10 µm).

Temperature and precipitation reconstruction

The total of 16 NLRs taxa were used to reconstruct temperature and precipitation parameters quantitatively through CoA analysis for Triyuga section (Figs. 4, 5). The coexistence intervals (CIs) of the reconstructed temperature obtained from the palynomorphs are: 16.8-21.7 ºC for MAT (average ~19.3 ºC), 10.6-14.6 ºC for CMT (average ~12.6 ºC), and 23.6-26.1 ºC for WMT (average ~24.9 ºC) (Fig. 4). The CIs of the reconstructed precipitation are: 1122-1682 mm for MAP (average ~1402 mm), 19-73 mm for LMP (average ~46 mm), 115-349 mm for HMP (average ~232 mm), and 82-172 mm for WMP (average ~ 127 mm) (Fig. 5).

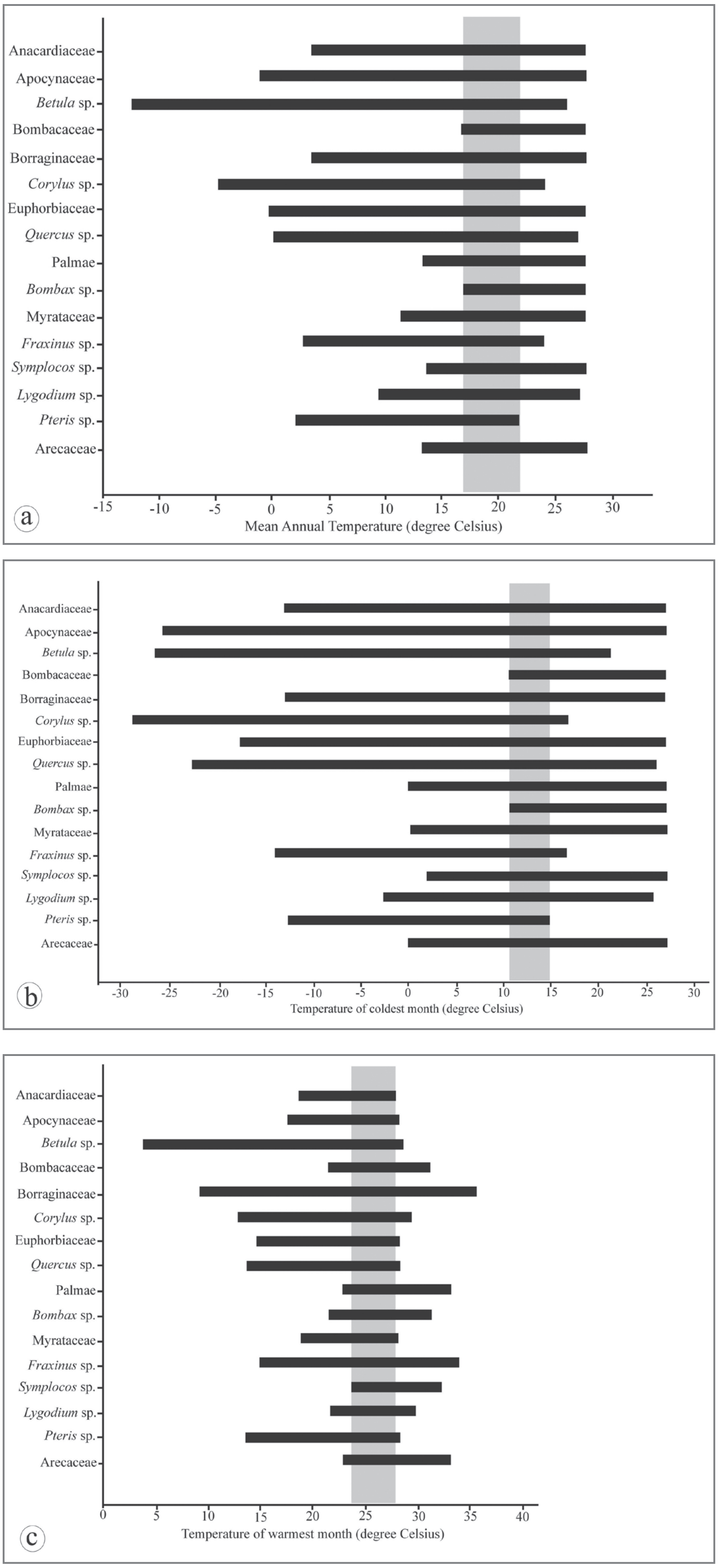

Fig. 4: Climatic ranges of the NLRs identified for the palynomorphs of the Upper Siwalik. Grey shaded areas: Coexistence Intervals (CIs). (a) Mean Annual Temperature (MAT), (b) Temperature of the Coldest Month (CMT), (c) Temperature of the Warmest Month (WMT).

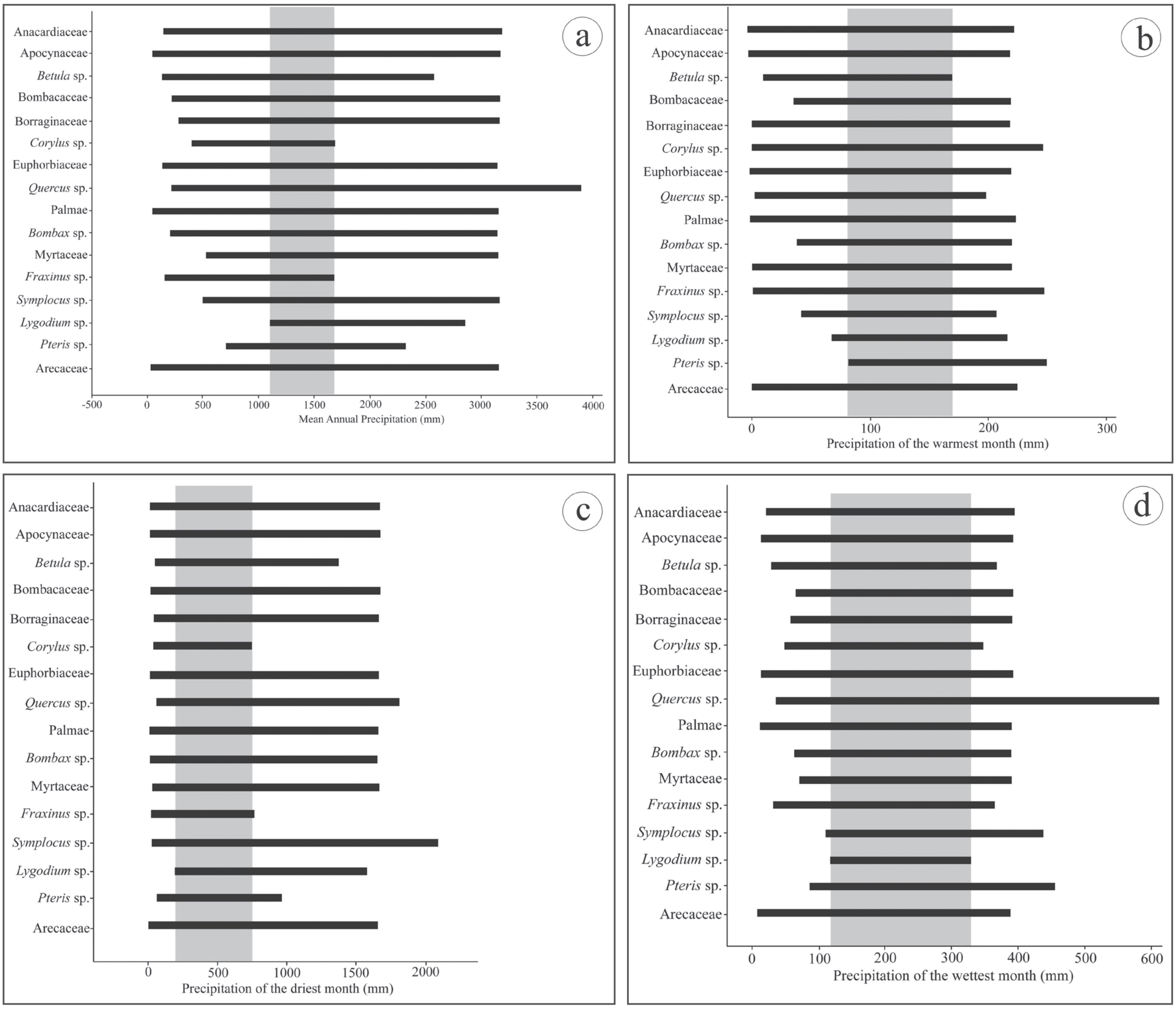

Fig. 5: Climatic ranges of the NLRs identified for the palynomorphs of the Upper Siwalik. Grey shaded areas: Coexistence Intervals (CIs). (a) Mean Annual Precipitation (MAP), (b) Precipitation of the Warmest Month (WMP), (c) Precipitation of the Driest Month (LMP), (d) Precipitation of the Wettest Month (HMP).

DISCUSSION AND CONCLUSION

Paleofloristic analysis and paleoenvironment

The palynological assemblages of the Upper Siwalik of the Triyuga River section are poor in preservation. The identification of the most of the palynomorphs was difficult as surface ornamentation and aperture arrangements were not clear as a result of the deformed and distorted condition. The palynofloral assemblage consists of 117 species under 36 family. Numerically, dicotyledonous (47%) were most abundant followed by pteridophytes (30%), monocotyledonous (10%), gymnosperms (7%) and other unidentified pteridophyte spores (6%) (Fig. 6a).

The majority of palynomorphs recovered from these sediments belong to flowering plant families belonging to Arecaceae, Anacardiaceae, Dipterocarpaceae, Euphorbiaceae, Juglandaceae, Liliaceae, Myrtaceae, Poaceae, Ulmaceae and Urticaceae together with fern plant families i.e. Cyatheaceae, Lygodiaceae, Polypodiaceae and Pteridaceae, which have affinities to plants growing in wet evergreen to semi-evergreen forests under tropical to subtropical climatic zone (GoN, 2009). In addition, the tropical to subtropical flora includes *Terminalia* sp., *Castanopsis* sp., Myrtaceae, *Symplocos* sp., Ulmaceae and Urticaceae. However, the Bombacaceae family is dominated in the tropical condition (Press et al., 2000). The occurrence of riverine vegetation such *Typha* sp., Liliaceae indicate the near water and wetland condition. Urticaceae are monoecious or dioecious herbs, rarely shrubs and trees and Boraginaceae are mostly herbs found in swampy area (Paudayal, 2012; 2013a,b). The *Dipterocarpus* sp. indicates the warm and humid climate with dry season of not more than 3-4 months (Srivastava et al., 2017). However, nowadays these species are not recorded in the entire flora of Nepal (Press et al., 2000). The increasing rate of dry seasons due to the uprising of the Himalaya (Valdiya, 2002) might be most possible reasons for its disappearance from the modern flora of Nepal. The pteridophytes spores like *Lygodium* sp. occurs in tropical to temperate forest within humid shady area while *Pteris* sp. occurs in shady moist and open dry area and mostly found in tropical and sub-tropical climate (Humagain and Paudayal, 2018). Spore of *Ceratopteris* sp. and other trilete spores are indicators of the warm and humid with tropical to sub-tropical climatic condition in the marshy swampy forests (Paudayal, 2012; 2013a,b).

The evergreen coniferous trees such as *Abies*, *Picea*, *Tsuga*, *Salix* spp. are found in temperate region and *Pinus* sp. grow in subtropical to temperate forest in Nepal (Press et al., 2000). The pollen of *Justicia* sp., *Strobilanthes* sp., Anacardiaceae, indicates the tropical to temperate climate and *Corylus* sp. found in temperate forest while *Quercus* sp. are mostly found in subtropical to temperate climate in Nepal. However, *Betula* sp. occurs in mixed forest of subtropical to alpine climatic condition (Press et al., 2000; GoN, 2009). The broad leaf trees *Betula* sp. indicates the subtropical to temperate climate in the shady slopes. The pollen of the Corylaceae and Hamamelidaceae taxa indicate the subtropical to temperate climatic forest. The Leguminosae, Malvaceae, and Oleaceae taxa represent prevalence of subtropical to lower temperate climate. The *Cyathea* sp. is typically found in tropical to temperate terrestrial forest with warm humid climate and along the stream side (Paudayal, 2012; 2013a,b).

The Palynological assemblage recovered from the Triyuga River section has affinities to plants growing in tropical, subtropical, temperate, cosmopolitan humid and warm environments. The ecological groups of Triyuga River section show dominance of tropical-subtropical plant remains over the temperate ones (Fig. 6b). It indicates the dominance of the tropical-subtropical forest has 79%, followed by subtropical-temperate forest of 12% and temperate forest of 10% (Fig. 6b). The ecological groups based on recovered palynomorphs along with incidence of trilete spore indicate a wet evergreen to semi-evergreen forest of tropical-subtropical warm and humid climate within a near marshy swampy ecological habitat. Based on the NLRs methodology, the reconstructed climate data derived from the Upper Siwalik of the Triyuga River section indicate a tropical climate having a MAT of 16.8-21.7ºC, WMT of 23.6-26.1ºC, CMT of 10.6-14.6ºC, (Fig. 4). The precipitation reconstruction data indicates MAP of 1122-1682 mm, HMP of 115-349 mm, LMP of 19-73 mm, WMP of 82-172 mm (Fig. 5), which is sufficient for the growth of tropical forest.

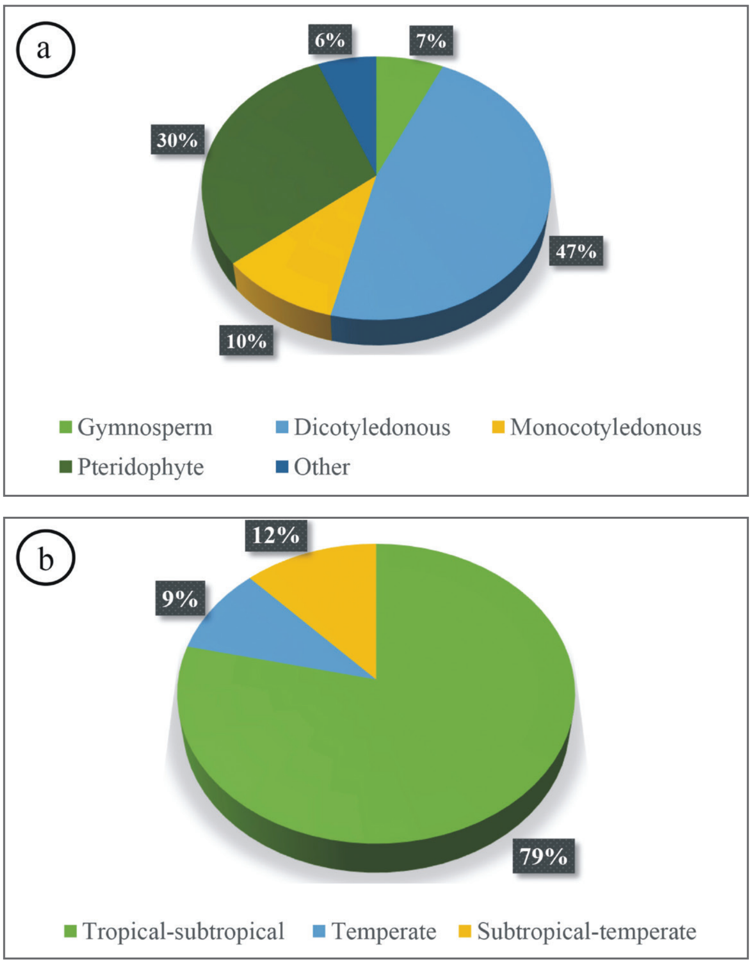

Fig. 6: (a) Floristic diversity in the Upper Siwalik of the Triyuga River section, (b) Paleoclimatic forest types in the Upper Siwalik of the Triyuga River palynomorphs assemblage.

Analyzing overall palynological assemblage of the Triyuga River section of the Upper Siwalik experienced the tropical-subtropical to lower temperate humid and warm climatical condition with plenty of precipitation during the deposition period. Present day temperature and precipitation in the Terai region indicate relatively dry climatic conditions then before (Adhikari et al., 2017).

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