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Plant Macrofossils from Churia Formation (Miocene) of Koilabas Area in the Himalayan Foot Hills of Western Nepal and their Palaeoclimatic Consideration

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Abstract Palaeobotanical study on the plant macrofossils from Lower and Middle Churia Formation (Miocene) of Koilabas area, western Nepal has revealed the presence of 116 species belonging to 83 genera of 33 angiospermous families. They are mainly based on leaf-impressions and a fruit and seed. The family Fabaceae is the most dominant family represented by 21 species in this assemblage followed by Annonaceae (10 species), Dipterocarpaceae, Sapindaceae and Anacardiaceae (6 species) and Combretaceae, Rubiaceae, and Moraceae (5 species). Fabaceae which appeared in Upper Paleocene became a major constituent of the evergreen forest during Miocene times all along the Himalayan foot hills. The predominance of evergreen and moist deciduous taxa in this fossil assemblage indicates the prevalence of tropical warm humid climate with plenty of rain fall during the Miocene. The present-day distribution of comparable modern species of all the fossils recovered from Koilabas area indicates that they are mostly known to occur in South east Asia, Indo-Malayan and North-east Indian regions, wherever favorable climatic conditions exist. Most of the taxa represented in the fossil assemblage do not occur in the Koilabas area or all along the Himalayan foot-hills of both India and Nepal. This obviously indicates that changes in the climate must have taken place after the deposition of Siwalik sediments in the Koilabas area. Study of the structural features of fossil leaf-impressions suggests that the Koilabas area in the Himalayan foot-hills of western Nepal enjoyed a tropical climate along with plenty of rainfall during the Miocene times. Coexistence /Nearest Living Relative (NLR) method further suggests that the area enjoyed a tropical climate with the Mean Annual Temperature (MAT) 23-30℃ and Mean Annual Precipitation (MAP) 2400 -3600 mm) during the Miocene.

Keywords: *plant macrofossils, Koilabas area, Himalayan foot hills, western Nepal. paleoclimate estimation, plant diversity, Miocene*

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1. Introduction

During the uplift of Himalaya, the Siwalik (Middle Miocene) has been considered as the most important as several significant changes took place in physiography and environment which ultimately changed the floral composition of foothills regions. The older forms, which could not adjust themselves to the new environment, gradually became disappeared and in their place new plants came into existence and flourished there. Most of the taxa migrated from South - east Asia to Indian sub-continent via Myanmar and vice versa after the establishment of land connection between India and South east Asia [1]. As the result many taxa, especially members of Dipterocarpaceae which were present during the Paleogene in south-east Asia appeared in the Indian sub-continent during Neogene.

The Sub-Himalaya Zone is also called as Churia Zone and is delimited on the south by the Main Frontal Thrust (MFT) and on the north by the Main Boundary Thrust (MBT). It consists basically of fluvial deposits of the Neogene age (23 to 1.6 million years old). This Zone extends all along the Himalaya forming the southernmost hill range with width of 8 to 50 km. The Lesser Himalayan rocks thrust southward over the rocks of Churia along the MBT. The general dip of beds of Churia has northward trend with varying angles and the overall strike is east-west. The Churia Zone has number of east-west running thrusts. The Churia sediment is characterized by alternate presence of sand stone and mud

stone facies, the later very often containing abundant plant fossils belonging to both Monocotyledonous and Dicotyledonous families [2-5].

The fossil localities in Koilabas area (27°42': 82°20') are situated in the Dang section of Churia Hills in western Nepal. Koilabas is a small town lies in Dang Deokhuri district of Lumbini Anchal of south western Nepal (Figure 1). The Churia sediments in the study area found running in a north-east direction and are well exposed along Koilabas-Lamhi road and Koilabas nala coming down from Dang Valley and running towards Terai region through Koilabas town. Churia sequence consists of several alternations of sandstone and mudstone beds of varying thickness. Middle and Upper Miocene age has been assigned to these Churia beds on the basis of lithology and vertebrate fauna [6].

In the last four decades a huge amount of plant fossils was collected from the Lower and Middle Churia sediments of different fossil localities, Serianaka, Darwaja, Chorkholi and Koilabas nala (Figure 3, Figure 4). The palaeobotanical study on these plant fossils, especially leaf impressions revealed the occurrence of 116 species of mostly dicotyledonous families [7-15,43,44,45]. The main objective of the present study on the fossil plants from Siwalik of Koilabas area is to reconstruct the fossil flora/ palaeovegetation and to throw light on the climatic changes during Churia succession over a life span of 20 Ma. They provide valuable database of fossil flora for the interpretation of sequential changes in floral composition of the areas in term of the changing climate. On the basis of all the available data the authors discussed in details the palaeoclimate and plant diversity of the area during Miocene period.

2. Geology of the Study Area

One of the most important episodes in the mountain building process during Middle Miocene is the formation of a long and narrow depression on the northern border of India. This depression became the site of deposition of massive alluvial detritus derived from the existing mountain and brought down by rain, rivers, and streams. This is known as Siwalik also called Churia sediments in Nepal. The area of present study falls in Dang section of Western Nepal Himalaya. The Siwalik Formation in Nepal Himalaya is often called Churia Group which lies south of the Main Boundary Thrust. This group is thin in Narayangarh and thickens in Nawalpur due to development of valley and again it is thin in Butwal and thickens maximum to Dang area where two valleys, Dang and Rapti Valleys developed (Figure 1).

The detailed lithology and stratigraphy of the Siwalik (Churia) Group of Nepal have been given by a number of geologists in India and abroad [6,16-22]. The Churia Group has often been classified into two formations: (i) Lower Churia Formation (Sandstone Facies), and (ii) Upper Churia Formation (Conglomerate Facies) [23,24,25]. However, a threefold lithostratigraphic classification of the formation in the western Nepal Himalaya has been suggested [18]. The Lower Churia Formation with an average thickness of about 1800 m is composed of fine-grained green chlorite, biotite muscovite calcareous well bedded indurate sandstones and siltstones (Figure 2).

Figure 1. Google map showing physiography and location of study area (Δ)

Figure 2 (a). Field photograph showing fossiliferous beds at Imlibasa in Koilabas area, western Nepal from where fossil material was collected. **(b).** Field photograph showing another fossiliferous exposure in Koilabas Nala, western Nepal containing well preserved leaf and fruit impressions

The sandstone is inter-bedded with green nodular withering clay and siltstone and yellow micaceous clay. Sometimes friable white to yellow medium grained arkosic pebbly sandstones inter-bedded with green to brown fine-grained sandstones are seen in the upper part of the formation. The gross composition of sandstone is 80% quartz, 10% muscovite, 5% biotite and black tourmaline and black minerals 5%. The rock generally shows simple current bedding.

The Upper Churia Formation consisting mainly of boulder pebble bed and loose micaceous sandstone is exposed in south of Lower Formation in Dang area, Trijuga area, and east of Dharan. They are graded and

cyclic in nature. The bottom part is composed of boulder beds. The boulders are rounded consisting mainly of quartzite cemented with clay.

The fossil localities in Koilabas area ($27^0$42': $82^0$20') are situated in the Dang section of Churia Hills in western Nepal. In this area, the Lower Churia Formation is observed from Koilabas to Darwaja containing fine grained sandstone beds with variegated clay and some pebbles (Figure 1, Figure 2). From Darwaja to Masot Khola the rocks are of Upper Formation. Above the Upper Formation again lies the Lower Formation in Garudbir pass which is found thrusted [16]. According to Chaudhuri's classification of three-fold division of Churia (Siwalik) Hills, this area from Koilabas to Darwaja falls in Lower Churia (Siwalik) Formation and beyond Darwaja to Chor Khola onward the rocks are supposed to be belonging to Middle Churia (Siwalik) Formation which is predominantly arenaceous in nature. The fossil locality, Serianaka is situated about 10 km. west of town, Koilabas at Indo-Nepal Border. The lower Churia sediments are well exposed in this area.

3. Materials and Methods

The present study is based on the plant macrofossils comprising mainly fossil leaves collected from Lower and Middle Churia sediments of Koilabas ($27^0$42': $82^0$20') and nearby area in Dang Deokhuri District of Lumbini Anchal, western Nepal (Figure 1). The fossil leaves (Figure 3 & Figure 4) were identified with their modern analogues at the Herbarium of Central National Herbarium, Sibpur, Howrah, West Bengal. The physiognomic features of fossil leaves such as leaf margin, nature of apex and base, and shape and size have been analyzed for deducing the climate of the area. The Climatic parameters i.e., Mean Annual Temperature (MAT) and Mean Annual Precipitation (MAP) of Koilabas area as well as those the area where modern analogues of the fossils are found today, have been obtained from published literature [26], Climatological table of Observation in India (1931-1960) and through internet (Climate and average weather in Philippines (weather-and-climate.com). For the estimation of palaeoclimate, Foliar physiognomic method and Nearest Living Relatives (NLR) method have been used.

4. Result and Discussion

4.1. Floral Analysis

Palaeobotanical study on the plant macrofossils from the Lower and Middle Churia sediments of Koilabas and nearby area in western Nepal enhanced our knowledge of the angiospermic flora during Miocene period. The present fossil assemblage consists of a variety of woody plants distributed amongst 116 species belonging to 83 genera of 33 angiospermous families (Table 1, Figure 5). They are mainly based on leaf-impressions and a fruit and seed. The fruit and seed show close affinity with the extant fabaceous genera *Pongamia* and *Entada* respectively. The fabaceous taxa show overall dominance consisting of about 21 taxa in the assemblage (Figure 3). The earlier fossil records also show their abundance from other localities in the Siwalik foot-hills of Uttar Pradesh, Himachal Pradesh, Bihar and West Bengal in India during Mio-Pliocene [27-32]. These fabaceous taxa have not been authentically recorded from the Paleogene sub-period of India and Nepal, which indicate that they might have entered later in the Indian sub-continent during Miocene Period, after the establishment of land connections from where they were flourishing. The genera like *Clinogyne, Uvaria Alstonia, Canthium, Paranephelium, Nauclea* and, *Artocarpus* in the present assemblage.

Figure 3. Phytogeographically important taxa recovered from Siwalik sediments of Koilabas area. (a) *Dipterocarpus siwalicus* Lakhanpal & Guleria, (b) *Sabia eopaniculata* Prasad (c) *Filicium koilabasensis* Prasad (d) *Mangifera someshwarica* Lakhanpal & Awasthi (e) *Euphoria nepalensis* Prasad (f) *Ficus retusoides* Prasad (g) *Morinda siwalika* Prasad (h) *Dalbergia siwalika* Prasad (i) *Cassia miosiamea* Prasad (j) *Anacolosa mioluzoniensis* Prasad (k) *Gaertnera siwalica* Prasad (l) *Ficus nepalensis* Prasad (m) *Terminalia koilabasensis* Prasad (n) *Euphoria nepalensis* Prasad

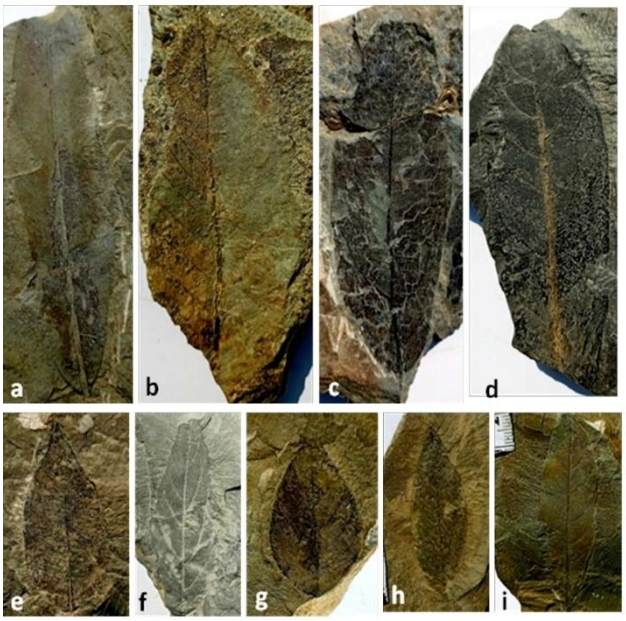

Figure 4. Evergreen to moist deciduous fossil taxa in the fossil flora of Koilabas area. (a)*Kayea kalagarhensis* Prasad (b) *Vitex siwalicus* Prasad (c) *Hopea mioglabra* Prasad (d) *Lagerstroemia siwalika* Prasad (e) *Cassia nepalensis* Prasad (f) *Diospyros koilabasensis* Prasad (g) *Millettia siwalica* Prasad (h) *Mesua tertiara* Lakhanpal (i) *Bouea koilabasensis* Prasad

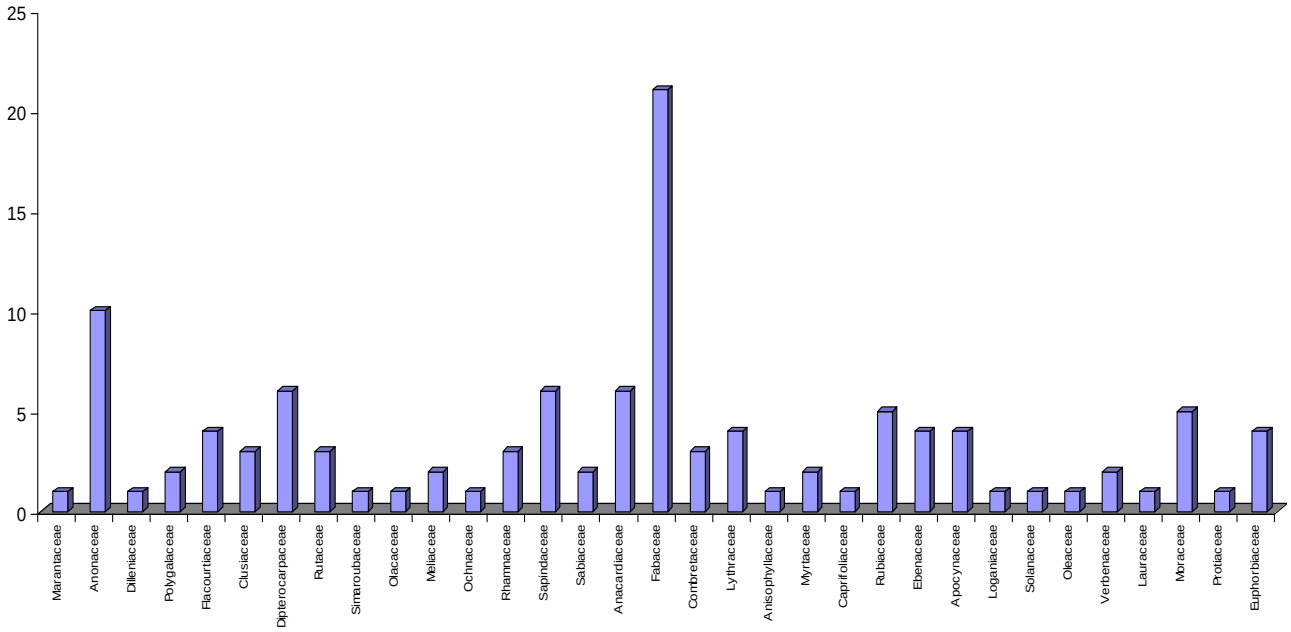

Figure 5. Diagram showing the frequency of fossil taxa in each family known from the Siwalik sediments of Koilabas area, western Nepal

The *Sabia*, *Cariesa*, *Anacolosa*, *Otophora* and *Tapiria* are described already from other fossil localities in the Himalayan foot hills while the genera like, *Qualea*, *Iodes*, *Ochna*, *Arytera*, *Canavalia* and *Alyxia* are new to Tertiary flora of India and Nepal. The present-day distribution of the modern equivalents of the fossil taxa known from Koilabas area indicates their wider distribution in different geographical regions all over India and other places. In India they are distributed mostly in north east and southern regions due to favorable climatic conditions. The fossil assemblage comprises more than 20 those taxa which are found to grow both in India and Malaya Peninsula. These are Donax *cunnaeformis*, *Dillenia indica*, *Securidaca inappendiculata*, *Mesua ferrea*, *Flacourtia catafracta*, *Dipterocarpus tuberculatus*, *Evodia fraxinifolia*, *Euphorea longana*, *Sabia paniculata*, *Sabia malabarica*, *Bouea burmanica*, *Mangifera indica*, *Swintonia schwenckii*, *Albizia lebbek*, *Pongamia glabra*, *Canavalia rosea*, *Cassia siamea*, *Dalbergia sericea*, *Morinda umbellata*, *Cinnamomum inuctum* and *Ficus glaberrima.* This indicates that there has been a fair exchange of taxa between the two sub-continents. A good number of taxa like, *Goniothalamus meboldii*, *Mitrephora macrophylla*, *Polyalthia sumatrana*, *Fissistigma elegans*, *Ryparosa kunstelri*, *Otophora fruticosa*, *Isoptera borneonsis*, *Shorea curtisii*, *Paranephelium xestophyllum*, *Terminalia angustifolia*, *Randia uncaria* and, *Nauclea subdita*, *Antedesma montanum*, restricted to the Malaysian region, have also been found in the present assemblage. Besides, few taxa, *Qualea densiflora*, *Arytera*, *oshaneiana* are also found to grow in the tropical regions of other countries like Africa, America, China and Sri Lanka, etc.

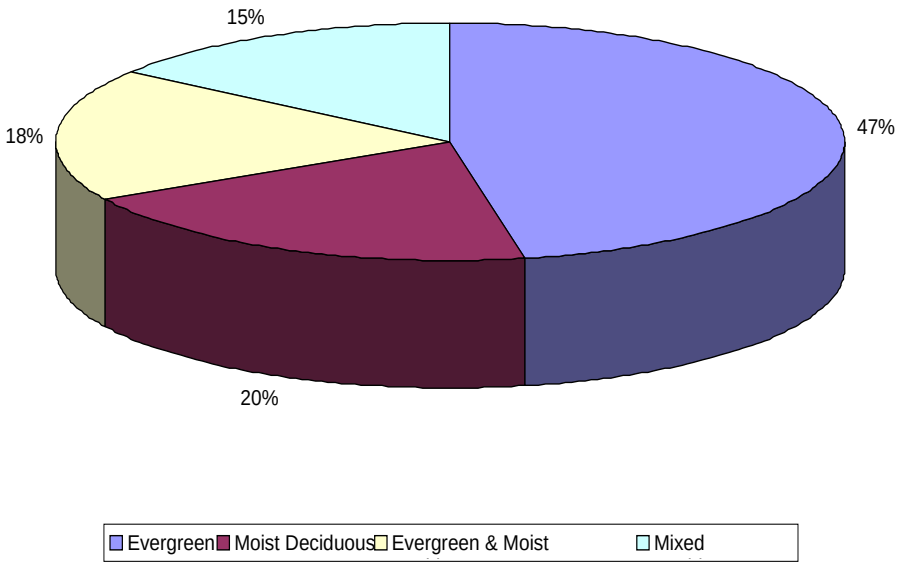

Figure 6. Diagrammatic representation of different types of Forest elements in the Siwalik flora of Koilabas area, western Nepal

Table 1. Present day distribution and forest types of comparable taxa of fossils recovered from the Churia (Miocene) sediments of Koilabas area, western Nepal

Fossil Taxa	Modern Equivalents	Distribution	Forest type
1	**2**	**3**	**4**
Marantaceae *Donax kasauliensis* Srivastava & Guleria; Prasad & Dwivedi, 2008	*D. cannaeformis* Lour.	Indo-Malayan region	Evergreen to Moist deciduous
Anonaceae *Miliusa miovelutina* Prasad *et al.*,1997	*M. velutina* H. f. & Th.	Sub-Himalayan tract, Myanmar	Moist deciduous
Miliusa siwalica Prasad *et al*, 1999	*M. thoretii* Finet & Gagnep.	India, China	Moist deciduous
Anona koilabasensis Prasad *et al.*,1999	*A. laurifolia* Linn.	Java	Evergreen
Goniothalmus siwalicus Prasad *et al.*,1997	*G. meboldii* Blume	Malaya	Evergreen
Mitrephora miocenica Prasad *et al.*, 1997	*M. macrophylla* Oliver	Malaya	Evergreen
Melodorum jarwaensis Tripathi *et al*, 2002	*M. bicolor* H. f. & Th.	N.E. India, Myanmar	Evergreen to Moist deciduous
Polyalthia palaeosumatrana Tripathi *et al.*, 2002	*P. sumatrana* Kurz	Sumatra, Borneo, Malaya	Evergreen to Moist deciduous
Fissistigma senii Lakhanpal	*F. wallichii* H. f. & Th.	N. E. India	Evergreen
Fissistigma mioelegans Prasad *et al.*, 1999	*F. elegans* H. f. & Th.	Malaya, Malacca	Evergreen
Uvaria siwalika Prasad	*U. hamiltonii* H. f. & Th.	N. E. India, Andaman, Myanmar	Evergreen to Moist deciduous
Dilleniaceae *Dillenia palaeoindica* Prasad & Prakash, 1984	*D. indica* Linn.	India, Myanmar	Moist evergreen
Polygalaceae *Securidaca miocenica* Prasad *et al.*, 1997	*S. inappendiculata* Has.k	N.E. India, Java	Evergreen to Moist deciduous
Qualea siwalica Prasad & Dwivedi, 2008	*Q. densiflora* Warm	Tropical America	Evergreen
Flacourtiaceae *Flacourtia seriaensis* Prasad *et al.*, 1997	*F. catafracta* Roxb.	N.E. India, Myanmar, Malaya	Moist deciduous
F. koilabasensis Prasad & Dwivedi, 2008	*F. montana* Grahm.	N. E. India, Myanmar, S. India	Evergreen to Moist deciduous
Ryparosa prekunstelri Prasad, 1990a	*R. kunstelri* King.	Malaya	Evergreen
Gynocardia mioodorata Prasad *et al.*, 1999	*G. odorata* R. Br.	N.E. India, Myanmar	Evergreen
Clusiaceae *Mesua tertiara* (Lakhanpal) Prasad, 1990a	*M. ferrea* Linn.	North east India, Myanmar, Malaya	Evergreen
Kayea kalagarhensis Prasad,1993	*K. floribunda* Wall.	North east India,Myanmar	Evergreen
Garcinia nepalensis Prasad *et al.*, 1999	*G. cowa* L.	N.E.India,Bangladesh, Myanmar	Evergreen
Dipterocarpaceae *Isoptera siwalica* Prasad *et al.*, 1999	*I. borneonsis* Br.	Java, Myanmar	Evergreen
Dipterocarpus siwalicus (Lakhanpal & Guleria) Prasad,1990b	*D. tuberculatus* Roxb.	North east India, Myanmar, South east Asia	Evergreen to Moist deciduous
D. koilabasensis Prasad *et al.*, 1999	*D. turbinatus* Gaertn.	N.E. India, Bangladesh, Myanmar	Evergreen
Hopea mioglabra Prasad, 1994	*H. glabra* W. & A.	South India	Evergreen
Shorea eutrapizifolia Prasad *et al.*, 1999	*S. trapizifolia* Thw.	Ceylon	Evergreen
S. miocurtisii Prasad & Dwivedi, 2008	*S. curtisii* Dyer	Malaya	Evergreen
Icacinaceac *Iodes koilabasensis* Prasad & Dwivedi, 2008	*I. ovalis* Kurz	North east India, Malaya, Myanmar	Evergreen to Moist deciduous

Fossil Taxa	Modern Equivalents	Distribution	Forest type
1	**2**	**3**	**4**
Ochnaceae *Ochna miowallichii* Prasad & Dwivedi, 2008	*O. wallichii* King	North east India, Andaman, Malaya, Myanmar	evergreen to Moist deciduous
Rutaceae *Evodia koilabasensis* Prasad, 1994e	*E. fraxinifolia* Hook. f.	North east India, Malaya, Nepal	Evergreen
Murraya khariensis (Lakhanpal & Guleria) Prasad, 1994	*M. paniculata* (Linn.) Jacq.	Sub Himalayan region, k Myanmar, Andaman, Australia Myanmar	Evergreen
Atlantia miocenica Prasad, 1994	*A. monophylla* Corr.	South and North India, Myanmar, Andaman	Evergreen
Simaroubaceae *Brucea darwajensis* Prasad *et al* 1999	*B. mollis* Wall.	N.E. India, Myanmar	Evergreen
Meliaceae *Chloroxylon palaeoswietenia* Prasad, 1990a	*C. swietenia* DC.	India, Sri Lanka	Mixed deciduous
Aglaia nepalensis Prasad *et al* 1999	*A. euryphylla* Koor. & Valeton	Java	Moist deciduous
Rhamnaceae *Berchemia nepalensis* Prasad & Dwivedi, 2007	*B. hamosa* Brongn.	Nepal, Wallich, Western. peninsula	Mixed deciduous
B. siwalica Tripathi *et al*, 2002	*B. floribunda* Wall.	N. E. India	Evergreen
Zizyphus miiocenica Prasad, 1994e	*Z. jujuba* Lam.	India, Myanmar	Evergreen to Moist deciduous
Sapindaceae *Filicium koilabasensis* Prasad, 1994	*F. decipience* Thw.	South India, Sri Lanka, Tropical Africa	Evergreen
Euphorea nepalensis Prasad, 1994	*E. longana* Lamk.	South and North India, Myanmar, Malaya	Evergreen
Otophora miocenica Prasad, 1994	*O. fruticosa* Blume.	Malaya	Evergreen
Nephelium palaeoglabrum Prasad *et al.,* 1997	*N. glabrum* Noronh.	Malaya	Evergreen.
Paranephelium seriaensis Prasad & Dwivedi, 2008	*P. xestophyllum* (Miq.) King	Malaya, Myanmar	Evergreen to Moist deciduous
Arytera seriaensis Prasad & Dwivedi, 2008	*A. oshaneiana* Radik.	Australia	Evergreen
Sabiaceae *Sabia eopaniculata* Prasad, 1994	*S. paniculata* Seem.	Sub-Himalayan region, Myanmar, Malaya	Evergreen
S. siwalica Dwivedi, et al., 2006a	*S. malabarica* Bedd.	N. E. India, Malaya	Evergreen
Anacardiaceae *Swintonia palaeoschwenckii* Prasad & Awasthi, 1996	*S. schwenckii* Teysn.	India, Myanmar, Malaya	Evergreen
Bouea koilabasensis Prasad, 1994	*B. burmanica* Griff.	South India, Andaman, Myanmar	Moist deciduous
B. premacrophylla Antal & Awasthi, 1993	*B. macrophylla* Griff.	Java, Borneo, Malaya	Evergreen to Moist deciduous
Tapiria chorkholiense Prasad, 1994	*T. hirsuta* Hook. f.	North east India, Nepal, Bhutan	Evergreen
Mangifera someshwarica (Lakhanpal & Awasthi) Prasad	*M. indica* Linn.	India Malaya	Evergreen to Moist deciduous
Dracantomelum seriaensis Prasad *et al*, 1997	*D. sylvestre* Blume	Borneo	Moist deciduous
Fabaceae *Pongamia kathgodamensis* Prasad	*P. glabra* Vent.	India, Sri Lanka, Malaya	Mixed deciduous
Albizia siwalica Prasad, 1990b	*A. lebbek* Gamble	North east India, Myanmar	Moist deciduous
Cassia nepalensis Prasad, 1990a	*C. siamea* Lam.	Central India	Moist deciduous
C. *miosiamea* Prasad, 1994	*C. hirsuta* Linn.	India, Myanmar, Malaya	Moist deciduous
C. *neosophora* Prasad, 1994	*C. sophora* Wall.	South east Asia	Moist deciduous
Dalbergia eucultrata Prasad *et al.*, 1999	*D. cultrata* L.	India, Myanmar	Mixed deciduous
D. miovolubilis Prasad *et al.*, 1997	*D. volubilis* Roxb.	India, Nepal	Mixed deciduous
D. miosericea Prasad, 1990b	*D. sericea* Boj.	Sub-Himalayan region, Madagascar	Moist deciduous
D. siwalika Prasad, 1994	*D. sissoo* Roxb.	Sub-Himalayan region	Moist deciduous
Millettia siwalica Prasad, 1990a	*M. ovalifolia* Kurz	Sub-Himalayan region, Myanmar	Evergreen
M. ovatus Tripathi *et al*, 2002	*M. pubinervis* Kurz	Myanmar	Evergreen to Moist Deciduous
M. palaeomanii Dwivedi, *et al.*, 2006a	*M. manii* Backer	Tropical Africa	Evergreen
Canavalia siwalica Dwivedi, *et al.*, 2006a	*C. rosea* DC.	Malaya, S. India	Evergreen to Moist deciduous
M. *imlibasensis* Prasad *et al* 1999	*M. brandisiana* Kurz	Myanmar	Moist deciduous
M. *koilabasensis* Prasad, 1990b	*M. macrostachya* Coll. & Hemsl.	Myanmar	Evergreen to Moist deciduous
M. miobrandisiana Prasad, 1994	*M. brandisiana* Kurz	Myanmar	Evergreen
Ormosia robustoides Prasad, 1990b	O. *robusta* Jacq.	Northeast India, Myanmar	Moist deciduous
Samanea siwalika Prasad, 1994	*S. saman* Merr.	Tropical Africa, America	Evergreen
Entada palaeoscandens (Awasthi & Prasad) Prasad, 1994	*E. scandens* Benth.	India, Myanmar	Mixed deciduous

Fossil Taxa	Modern Equivalents	Distribution	Forest type
1	**2**	**3**	**4**
Cynometra palaeoiripa Prasad *et al*, 1999	*C. iripa* Kotel.	India	Mixed deciduous
C. siwalika Awasthi & Prasad, 1996	*C. Polyandra* Roxb.	N. E. India, Malaya	Evergreen
Combretaceae *Anogeissus eosericea* Prasad & Prakash, 1984	*A. sericea* Brandis	Central India	Mixed deciduous
Clycopteris floribundoides Prasad, 1990a	*C. floribunda* Lam.	North east India, Myanmar, Western Peninsula	Mixed deciduous
Terminalia koilabasensis Prasad, 1990a	*T. angustifolia* Jacq.	Malaya	Evergreen
T. siwalica Prasad, 1990a	*T. pyrifolia* Kurz	Myanmar	Evergreen to Moist deciduous
T. panandhroensis (Lakhanpal & Guleria) Prasad, 1994	*T. tomentosa* W. A.	Sub-Himalayan region, Myanmar	Moist deciduous
Combretum sahnii (Antal & Awasthi) Prasad, 1994	*C. decandrum* Roxb.	Sub-Himalayan region, Bangladesh, Central India	Mixed deciduous
Lythraceae *Lagerstroemia siwalica* Prasad, 1994	*L. lanceolata* Wall.	Western Peninsula	Evergreen
L. mioparviflora Dwivedi, *et al*., 2006a	*L. parviflora* Roxb.	N. E. India, Myanmar	Evergreen to Moist deciduous
L. eomicrocarpa Dwivedi, *et al.*, 2006a	*L. microcarpa* Linn.	S. India, Myanmar, Australia	Evergreen to Moist deciduous
Woodfordia neofruticosa Prasad, 1994	*W. fruticosa* Kurz	Sub-Himalayan region, Tropical Africa, Peninsula	Mixed deciduous
Anisophylleaceae *Anisophyllea siwalica* Prasad & Awasthi,1996	*A. apetala* Scort.	Malaya	Evergreen
Myrtaceae *Syzygium miocenicum* Prasad & Prakash, 1984	*S. clavijlorum* Roxb.	North east India, Andaman, Myanmar	Evergreen to Moist deciduous
Syzygium miooccidentalis Prasad *et al*, 1999	*S. occidentalis* Bourd.	India	Moist deciduous
Caprifoliaceae *Lonicera mioquinquelocularis* Prasad, 1990a	*L. quinquelocularis* Hardw.	North west Himalaya, Nepal, India	Mixed deciduous
Rubiaceae *Canthium siwalica* Prasad & Dwivedi, 2007	*C. dydimum* Roxb.	India, Myanmar, Malaya	Evergreen
Randia miowallichii Prasad, 1990a	*R. wallichii* Hook. f.	North east India, Myanmar, Andaman	Evergreen
R. miouncaria Prasad & Dwivedi, 2007	*R.. uncaria* Elmer	Philippines	Evergreen
Morinda siwalica Prasad, 1994e	*M. umbellata* Linn.	South and North east India, Sri Lanka, Malaya	Evergreen
Nauclea seriaensis Prasad & Dwivedi, 2007	*N. subdita* (Miq.) Merr.	Malaya	Evergreen
Ebenaceae *Diospyros koilabasensis* Prasad, 1990a	*D. montana* Roxb.	India, Myanmar, Sub-Himalayan region	Mixed deciduous
D. pretoposia Prasad, 1990a	*D. toposia* Ham.	North east India, Bangladesh, Sri Lanka	Evergreen
D. darwajaensis Prasad *et al*., 1999	*D. dasyphyllea* Kurz.	Martaban	Evergreen
Apocynaceae *Tabernaemontana precoronaria* Prasad, 1990a	*T. coronaria* Willd	Sub-Himalayan region, Sri Lanka, Myanmar	Mixed deciduous
Carissa koilabasensis Prasad, 1994e	*C. paucinervia* A. De.	North east India, Myanmar	Evergreen
Alyxia koilabasensis Prasad & Dwivedi, 2007	*A. fasciculata* Benth.	N.E. India	Evergreen to Moist deciduous
Alstonia nepalensis Prasad & Dwivedi, 2007	*A. angustifolia* Wall.	Malacca, Myanmar, Malaya	Evergreen
Loganiaceae *Gaertnera siwalica* Prasad, 1990a	*G. bieleri* (D. Willd.) E. Petit	Tropical Africa	Evergreen
Solanaceae *Datura miocenica* Prasad, 1990a	*D. fastuosa* Linn.	India, Malaya, Tropical Africa	Mixed deciduous
Oleaceae *Anacolosa mioluzoniensis* Prasad, 1994e	*A. luzoniensis* Merr.	South east Asia	Evergreen
Verbenaceae *Vitex prenegundo* Prasad, 1990a	*V. negundo* Linn.	India, Sri Lanka, China	Mixed deciduous
V. siwalica Prasad, 1990a	*V. pubescens* Vahl.	India, Myanmar	Evergreen
Lauraceae *Cinnamomum mioinuctum* Prasad, 1990a	*C. inuctum* Meissn.	Myanmar, Malaya	Evergreen to Moist deciduous
Moraceae *Ficus precunia* (Lakhanpal) Prasad, 1990a	*F. cunia* Ham.	Sub-Himalayan region, Assam, Myanmar India, Malaya	Mixed deciduous
F. retusoides ad, 1990a	*F. retusa* Linn.	India, Malaya	Evergreen
F. nepalensis Prasad, 1990a	*F. . glaberrima* Blume	India and Malaya	Evergreen
F. eomysorensis Tripathi *et al*, 2002	*F. mysorensis* Heyn	N.E. India, Myanmar, Sri Lanka, Western. Ghats	Evergreen

Fossil Taxa	Modern Equivalents	Distribution	Forest type
1	**2**	**3**	**4**
Artocarpus nepalensis Prasad & Awasthi	*A. integrifolia* Linn.	N. E. India, Myanmar, Western Ghats	Evergreen
Protiaceae *Helicia eoerretica* Prasad *et al*, 1999	*H. erretica* Hook. f.	N.E. India, Myanmar Martaban	Evergreen
Euphorbiaceae *Phyllanthus koilabasensis* Prasad *et al*, 1999	*P collumnaris* Muell. - Arg.	Myanmar	Mixed deciduous
P. mioreticulatus Prasad *et al*, 1999	*P reticulatus* Poir.	India, Myanmar, Ceylon Malaya	Mixed deciduous
Antedesma siwalica Prasad *et al*, 1999	*A. montanum* Bl.	Malaya	Evergreen
A. miocenica Prasad & Dwivedi, 2007	*A. veluntinosum* Blume	Myanmar, Malaya	Evergreen

The present floral assemblage consists of 3 major types of elements: (1) Evergreen, (2) Evergreen and moist deciduous (3) Moist deciduous. (4) Mixed deciduous. Out of 116 taxa recorded from Koilabas area, 54 taxa are evergreen, 20 evergreen to moist deciduous, and 23 moist deciduous and 17 Mixed deciduous. Thus, the evergreen elements dominate the fossil flora of Koilabas area (Figure 6; Table 1) during Miocene in contrast to mixed deciduous vegetation occurring today in the area [33].

4.2. Palaeoclimate Estimation

Palaeoclimate estimation from fossil plants is one of the most important contributions of palaeobotanical studies. The present is the key to the past. The principal basis to any study of the past is the principle of 'Uniformity in the order of nature'. This principle implies on the physical and biological processes which like today's environment as well as vegetation must have been in the operation since past. Likewise, the type of weather variation and climatic conditions as observed today must also occur in the past. The best approach to the study of palaeoclimate or palaeoecology of a particular area is to compare the fossil floras with the modern vegetation and to know the existing climatic conditions. It is rather difficult to deduce the precise palaeoclimate/palaeoecology of an area prior to the Tertiary Period, because the modern vegetation is quite different from those of earlier periods. The study becomes more accurate as we go from Paleocene upward until the Pleistocene as the modern equivalents of the fossil forms still exist in the present-day vegetation and obviously the fossils could satisfactorily be compared and identified with the modern taxa.

Thus, the Tertiary fossil plants are supposed to be the reliable indicators of past climate especially those that are identified with modern taxa. The accuracy of interpretations based on them is inversely proportional to the geological ages of the deposits from which the fossils are collected. As the plant fossils for the present study have been collected from the Miocene sediments and the modern equivalents of these fossil forms still exist in the forests of different phytogeographical regions, it has, therefore become easier to deduce the palaeoclimate and palaeoecology of the Koilabas area in the Himalayan foot-hills of western Nepal during Miocene.

The other parameters for deducing palaeoclimate are the physiognomic characters of plant fossils. The presence of exclusively leaf-impressions in any floral assemblage plays a deciphering role in interpreting the palaeoclimate and palaeoecology. Further, this is an independent systematic relationship of the species and therefore, it is likely that the errors in interpretation are minimum. Thus, on the basis of plant mega fossils especially leaf-impressions, the interpretation regarding palaeoclimate can be drawn by two methods: (i) Nearest living relative method, i.e., from comparison of the leaf-impression with the extant taxa. (ii) Foliar physiognomy method, i.e., from study of the structural features of leaf-impressions.

4.2.1. Nearest Living Relative Method

This approach for interpreting past climate uses the climatic preferences of modern plants to interpret the past. The plant fossils collected from Koilabas area have been compared with their modern equivalents and it has been observed that a few of them still exist in the area. Therefore, it is easier to infer the palaeoclimate of the region during Miocene. It requires three bits of information: (i) a living relative for each fossil species (ii) the autecology of the living relatives of each fossil species and (iii) a modern association of species similar to the fossil flora. In the real sense, the modern analog community should be similar to the fossil assemblage in both species' composition and relative abundance of taxa. (iv) For each climate parameter analyzed, the climatic ranges under which maximum number of NLRs of individual fossil flora can Co-exist (Coexistence Interval), is determined. Thus, if coexistence interval of two comparable modern species of the fossils i.e., *Donnax cunnaeformis* Lour and *Miliusa velutina* H. f. & Th. is about 17°-30℃ and 17.5°-29℃ respectively, it means that the comparable fossil species *Donnax kasauliensis* and *Miliusa miovelutina* were presumably also surviving under a Mean Annual Temperature (MAT) between 17°-30℃ and 17.5°-29℃ respectively, indicating thereby, both species probably coexisted when Mean Annual Temperature (MAT) Co-existence interval was between 17℃ and 30℃. Likewise, Coexistence intervals or MAT of 29 similar looking living relatives (NLR) of fossils of Koilabas assemblage were obtained from Internet and through data from Indian Meteorological Department. The MAT value estimated by above method indicated MAT (Mean Annual Temperature) in the Himalayan foot hills of Koilabas area was 23.5-30℃ during Miocene (Middle and Upper) whereas the present-day MAT of Koilabas area (based on data of Department of Hydrology and Meteorology, Nepal) in the Himalayan foot hill zone is 23℃ (Figure 7a).

In a similar way, Coexistence intervals of Mean Annual Precipitation (MAP), of comparable extant species were obtained from Indian Meteorological Department through Internet which showed the MAP value for extant species ranging between 2400-3600 mm. It is therefore presumed,

that somewhat similar conditions of precipitation prevailed around the Koilabas area in the past (Figure 7b).

The fossil plants recovered so far from the Churia sediments of the Koilabas area comprise 116 elements which were compared with modern taxa (Table 1). The present habit and habitat of the recorded taxa show that they mostly occur in the tropical evergreen and moist deciduous forests of north east India, Bangladesh, Myanmar and Malaya and adjoining areas receiving higher [[25,26,34,35,36]; Table 1].

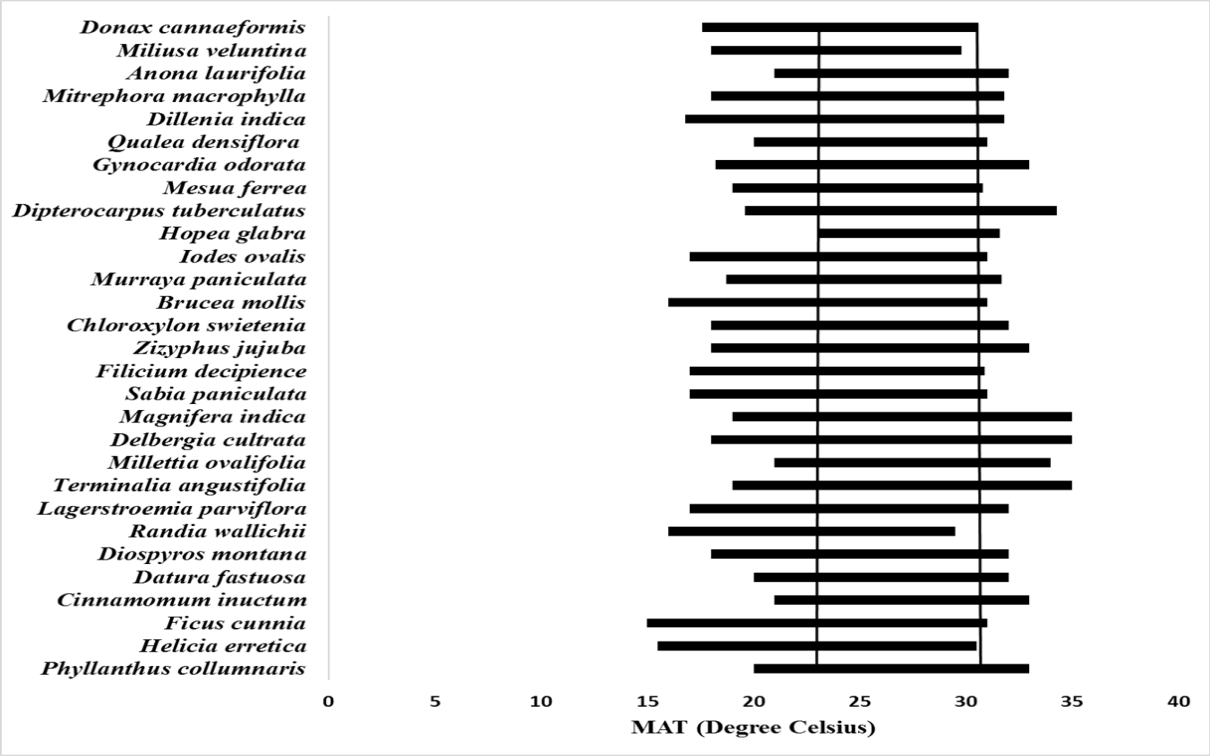

Figure 7a. Showing the coexistence intervals of climatic parameter Mean Annual Temperature (MAT), of modern relatives of recorded fossil species recorded from Koilabas area, western Nepal. The vertical line indicates the common range of MAT and horizontal line indicates the intervals of coexistence

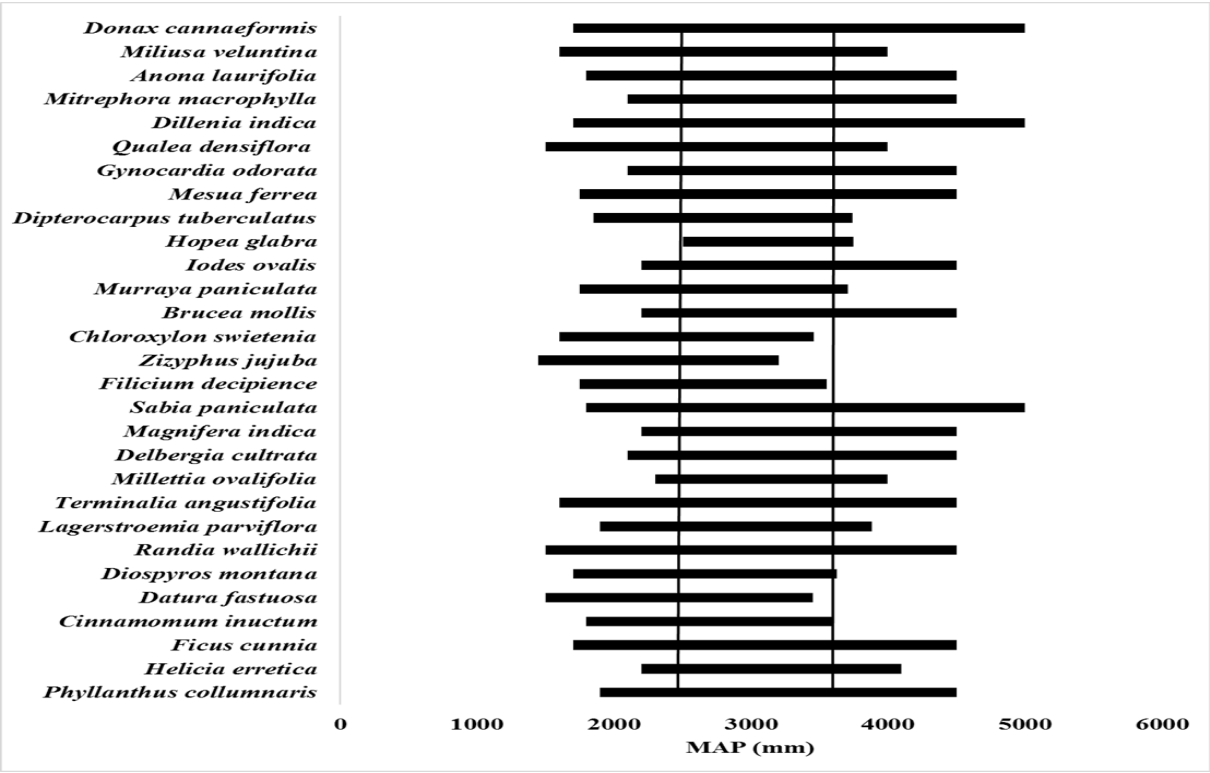

Figure 7b. Showing the coexistence intervals of climatic parameter Mean Annual Precipitation (MAP), of modern relatives of recorded fossil species from Koilabas area, western Nepal. The vertical line indicating the common range of MAP and horizontal line indicates the intervals of coexistence

Thus, it may be surmised that a warm and humid climate prevailed in the Koilabas area at the time of deposition in contrast to the present relatively dry climate. The predominance of evergreen elements in the assemblage (Figure 6) further indicates the prevalence of tropical (warm humid) climate with plenty of rainfall. Most of the taxa represented in the fossil assemblage do not occur in the Koilabas area or all along the Himalayan foot-hills of both India and Nepal (Table 1). This obviously indicates that changes in the climate must have taken place after the deposition of Siwalik sediments in the Koilabas area.

4.2.2. Foliar Physiognomy Method

Physiognomy uses morphological features to reflect some functional or physiological features of the plant. For example, thick, waxy, succulent leaves indicate arid environment in which plant must conserve water. Leaf physiognomy is particularly useful for deducing temperature and precipitation pattern because the leaf is instrumented in maintaining plant water and temperature balance.

The study of structural features of fossil angiospermous leaves such as size, venation, density, texture, margin, shape and tip, etc. has a great relationship with climate and thus provides more reliable results (Table 2). As this method is independent of the systematic relationship of the species, the errors in the interpretation of palaeoclimate are minimized as compared to the above nearest living relative method. The detailed physiognomic study of the fossil leaves recovered from the Siwalik sediments of Koilabas area, Nepal provides considerable data on climatic conditions prevailing at the time of sedimentation.

Table 2. Physiognomic characters of the fossil flora recovered from the Churia (Miocene) sediments of Koilabas area, western Nepal

PHYSIOGNOMIC CHARACTERS								
Fossil Taxa	**Average leaf size sq. cm**	**Leaf margin entire (E) non-entire (N)**	**Drip tips presence (P) absence (A) indistinct (-)**	**Nature of Petiole normal (N) indistinct (-) Swollen (S)**	**Leaf texture chartaceous (CH) coriaceous (CO)**	**Leaf base shape acute (A) obtuse (O) cuneate (C) cordate (CR) attenuate (AT) indistinct (-)**	**Leaf Organization Compound VS Simple**	**Venation pattern Close (C) Distant (D)**
1	2	3	4	5	6	7	8	9
Donax kasauliensis	46.8	E	-	-	CH	O	S	C
Anona koilabasensis	31.15	E	-	-	CH	O	S	C
Miliusa siwalica	42.75	E	-	-	CO	-	S	C
M. mioveluntina	63.00	E	-	-	CH	-	S	C
Melodorum jarwaensis	71.50	E	P	-	CH	-	S	C
Polyalthia palaeosumatrana	19.68	E	-	-	CH	-	S	C
Mitrephora miocenica	44.10	E	P	N	CH	O	S	C
Fissistigma senii	17.55	E	A	-	CH	A	S	C
F. mioelegans	17.48	E	P	-	CO	O	S	C
Goniothalmus siwalica	18.78	E	-	-	CH	A	S	C
Uvaria siwalica	44.00	E	-	-	CH	-	S	C
Dillenia palaeo indica	52.50	N	-	-	CH	-	S	C
Qualea siwalica	24.50	E	-	-	CH	-	S	C
Securidaca miocenica	24.00	E	-	-	CO	O	S	C
Ryparosa prekunstelri	61.92	E	-	N	CO	A	S	D
Gynocardia mioodorata	32.75	E	-	-	CO	A	S	D
Flacourtia koilabasensis	29.75	E	-	-	CH	-	S	C
F. seriaensis	7.60	N	-	-	CO	-	S	C
Mesua tertiara	10.00	E	P	N	CH	A	S	C
Kayea kalagarhensis	41.60	E	-	N	CO	A	S	C
Garcinia nepalensis	35.00	E	-	N	CO	A	S	C
Dipterocarpus siwalicus	128.00	E	P	N	CH	O, CR	S	D
D. koilabasensis	236.25	E	-	-	CO	-	S	C
Shorea eutrapizifolia	13.25	E			CO	A	S	C
S. miocurtisii	8.00	E	A	N	CH	A	S	C
Hopea mioglabra	28.44	E		-	CO	A	S	D
Isoptera siwalica	34.20	E	-	-	CH	O	S	D
Evodia koilabasensis	20.90	E		-	CH	O	C	C
Murraya khariense	07.30	E	A		CO	A	C	D
Atlantia miocenica	05.22	E			CH	A	C	C
Brucea darwajensis	08.27	E	P	N	CO	A	S	C
Iodes koilabasensis	12.25	E	A	-	CH	A, O	S	C, D
Chloroxylon palaeoswietenia	05.60	E	-	-	CH	A	C	C
Aglaia nepalensis	25.50	E		-	CH		C	C

PHYSIOGNOMIC CHARACTERS								
Fossil Taxa	**Average leaf size sq. cm**	**Leaf margin entire (E) non-entire (N)**	**Drip tips presence (P) absence (A) indistinct (-)**	**Nature of Petiole normal (N) indistinct (-) Swollen (S)**	**Leaf texture chartaceous (CH) coriaceous (CO)**	**Leaf base shape acute (A) obtuse (O) cuneate (C) cordate (CR) attenuate (AT) indistinct (-)**	**Leaf Organization Compound VS Simple**	**Venation pattern Close (C) Distant (D)**
1	2	3	4	5	6	7	8	9
Berchemia nepalensis	16.38	E	P	-	CH	C	S	C
B. siwalica	8.00	E	-	-	CH	A	S	C
Zizyphus miocenica	05.60	E		-	CH	O	S	D
Ochna miowallichii	24.84	E	P	-	CH	A	S	C
Filicium koilabasensis	26.25	E	P	N	CH	A	S	C
Euphorea nepalensis	27.00	E	P	-	CO	A	S	C
Nephelium palaeoglabrum	45.00	E	-	N	CH	A	S	C
Otophora miocenica	14.25	E	A	S	CO		S	D
Paranephelium seriaensis	27.00	E	-	-	CH	A	S	C
Arytera seriaensis	27.20	E	-	-	CH	C	S	C
Sabia eopaniculata	21.98	E	P	-	CH		S	C
S. siwalica	21.00	E	P	-	CH	A	S	C
Bouea koilabasensis	22.00	E	P	N	CO	A	S	D
B. premacrophylla	37.00	E	P	-	CH	A	S	C
Swintonia palaeoschwenckii	3.50	E	-	N	CH	O	S	C
Tapiria chorkholiense	11.25	E	-	-	CO	O	S	D
Mangifera someshwarica	28.40	E	P	N	CH	A	S	D
Dracantomelum seriaensis	33.15	E	-	-	CH	-	S	C
Albizia siwalica	07.50	E	A	N	CO	A	C	D
Casssia. nepalensis	10.08	E	P		CH	O	C	D’
C. m*iosiamea*	05.25	E	A	N	CH	O	C	C
C. *neosophora*	03.80	E	A	N	CH	O	C	C
Dalbergia miosericea	14.40	E	A	N	CH	A	C	.p
D. eucultrata	06.46	E	A	-	CH	A	C	C
D. siwalica	07.20	E	-	-	CH	O	C	C
D. miovolubilis	02.00	E	-	N	CH	A	C	C
Millettia. koilabasensis	28.40	E	P	-	CH	A	C	D
M. miobrandisiana	02.53	E	-	-	CH	O	C	D
M. imlibasensis	07.48	E	-	-	CH	O	C	C
M. palaeomanii	4.8	E	-	N	CO	O	C	C
M. ovatus	8.75	E	P	-	CH	O	C	C
Ormosia robustoidses	35.00	E	P	-	CH	O	C	C
Canavalia siwalica	3.52	E	A	N	CH	O	C	C
Cynometra iripa	02.80	E	A	N	CH	A	C	C
C. siwalika	56.00	E	P	-	CO	A	C	C
Samanea siwalica	02.00	E	-		CH	O	C	D
Anogeissus eosericea	10.75	E	-	N	CH	O	S	D
Calycopteris floribundoides	12.48	E	P	-	CO	O	S	D
Terminalia koilabasensis	11.20	E	P	-	CH	A	S	D
T. siwalica	35.60	E	P	N	CO	A	S	D
T. panandhroensis	57.60	E		N	CO	O	S	D
Combretum palaeodecandrum	15.75	E	P	-	CH	-	S	D
Lagerstroemia siwalica	42.00	E	-	-	CH	-	S	D
L. eomicrocarpa	9.45	E	P	-	CH	A	S	C
L. mioparvifolia	10.80	E	A	-	CH	A	S	C
Woodfordia neofruticosa	03.00	E	-	-	CO	CR	C	D
Anisophyllea siwalica	20.80	N	-	-	CH	O	S	C
Syzygium miocenicum	24.44	E	-	N	CH	C	S	C
S. *miooccidentalis*	08.00	E		N	CH	A	S	C
Lonicera mioquin quelocularis	08.75	E	-	-	CH	O	C	D
Randia miowallichii	13.80	E	-	N	CH	C	S	D
R. miouncaria	49.90	E	-	-	CH	C	S	C, D

PHYSIOGNOMIC CHARACTERS								
Fossil Taxa	**Average leaf size sq. cm**	**Leaf margin entire (E) non-entire (N)**	**Drip tips presence (P) absence (A) indistinct (-)**	**Nature of Petiole normal (N) indistinct (-) Swollen (S)**	**Leaf texture chartaceous (CH) coriaceous (CO)**	**Leaf base shape acute (A) obtuse (O) cuneate (C) cordate (CR) attenuate (AT) indistinct (-)**	**Leaf Organization Compound VS Simple**	**Venation pattern Close (C) Distant (D)**
1	2	3	4	5	6	7	8	9
Canthium siwalica	7.79	E	A	-	CH	-	S	C, D
Nauclea seriaensis	45.58	E	E	-	CH	O	S	C
Morinda siwalica	07.56	E	P	-	CH	-	S	C
Diospyros koilabasensis	09.00	E	-	-	CH	CR	S	D
D. darwajensis	55.90	E	-	-	CO	O	S	C
D. pretoposia	108.00	E		N	CO	O	S	D
D. tulsipurensis	32.42	E	A	-	CH	O	S	C
Tabernaemontana precoronaria	13.86	E	P	N	CH	C	S	D
Alyxia koilabasensis	4.16	E	-	-	CH	A	S	C
Alstonia nepalensis	17.50	E	-	N	CO	C	S	C
Carissa koilabasensis	05.60	E	A	-	CH	A	S	D
Gaertnera siwalica	12.00	E	-	-	CH	A	S	D
Datura miocenica	59.20	N	P	N	CH	A	S	C
Anacolosa mioluzoniensis	23.12	E	A	N	CO	A	S	D
Vitex prenegundo	20.90	E	P	N	CH	A	S	C
V. siwalica	31.50	E	-	-	CH	-	S	C
Cinnamomum mioinuctum	06.48	E	A	N	CH	C	S	D
Ficus precunia	20.25	E	-	-	CO	CR	S	D
F. retusoides	31.32	E	P	N	CH	A	S	C
F. nepalensis	28.00	E	-	-	CO	O	S	D
Helicia eoerretica	42.00	E	-	N	CH	A	S	C
Phyllanthus koilabasensis	08.93	E	A	N	CH	A	C	C
P. mioreticulatus	03.50	E	A	N	CH	A	C	C
Antedesma siwalica	47.15	E	-	-	CH	A	S	C
A. miocenica	33.60	E	-	-	CH	O	S	C
Artocarpus nepalensis	49.50	E	-	-	CO	A	S	C

The best indicator of climate appears to be the leaf margin, viz., entire versus non-entire. The approach to climate reconstruction is directly based on the work of Baily and Sinnot [37] who had found a robust relation between the margin and climate. Typical entire margined leaves of woody families like Anonaceae, Lauraceae, Ebenaceae, Clusiaceae, Sapotaceae, Dipterocarpaceae and Apocynaceae, etc. are practically absent from mesophytic cold temperate regions. On the contrary, non-entire leaved families as Betulaceae, Aceraceae, Platanaceae, etc. are absent from low land tropical areas. Nevertheless, the families like Malvaceae, Rosaceae, Ulmaceae, Fagaceae, Tiliaceae, Flacourtiaceae, Anacardiaceae and Fabaceae bear both types of leaf margins, i.e., entire and non-entire. According to Bailey et al. [37] the woody plants of tropical low lands possess entire margins, while in temperate they possess non-entire margins. Similarly, it has concluded that the tropical rain forests have the highest percentage of entire margined species.

This percentage decreases with decreasing temperature either with increasing altitude to the submontane and montane rain forests or with increasing latitude to the warm temperate forest [38]. This criterion, when applied to the fossil flora of the Koilabas area, reveals that all the species, except four taxa, i.e., *Dillenia palaeoindica, Flacourtia seriaensis, Datura miocenica* and *Anisophyllea siwalica*, have entire margin indicating a warm tropical climate (Table 2).

Leaf size and shape are selected by the climate and are strongly correlated with climatic variables. Accordingly, fossil dicotyledonous leaves are considered to be among the most reliable indicators of terrestrial palaeoclimate. It has been seen that leaf size distribution in any forest type is correlated with available moisture and it is found bigger in the understory elements of humid evergreen forests but decreases with low temperature or precipitation. Further, the percentage of species having large leaves should be highest on the piedmont somewhat higher on the mountain in order to correlate with precipitation [39]. It has also postulated that optimal size, as determined by the balance between transpiration rate and photosynthesis, should be greatest in the tropics, decreases in the subtropics and increases in the warm temperate forests [40].

The leaf size may be measured typically by 5 size classes, viz., leptophyll (up to 0.25 sq cm), nanophyll (0.25-2.25 sq cm), microphyll (2.25-20 sq cm), mesophyll (20-182 sq cm) and macrophyll (182-1640 sq cm) [39]. According to this classification the floral elements obtained from Koilabas area possess mainly microphyll and mesophyll type of leaves. Application of the above criterion to the Koilabas assemblage in which most of the

taxa possess optimal sized leaves (Table 2) again indicates that a tropical humid climate prevailed in the area during Middle Miocene.

The 'Drip tip', an extended leaf tip, is also another important physiognomic feature of angiospermous leaves and is generally seen in wet tropical forest elements [41]. The function of the drip tip is to hasten the run off of water from the leaf. It facilitates them to retard the growth of epiphytes. The deciduous leaves generally lack drip tip because of their short life span [46]. In the present assemblage about 30 taxa possess conspicuous drip tips. In some specimens the tips either got broken or indistinct due to bad preservation (Table 2). Thus, it also shows the prevalence of tropical humid climate around Koilabas area during Siwalik sedimentation.

There is other six physiognomic features that have been used as an aid in determining the past climate. 1. Organization– compound versus simple leaves 2. Venation pattern 3. Venation density 4. Leaf texture 5. Leaf base shape and 6. Leaf form. These characters are less useful than margin type, leaf size and drip tips and some of them are also difficult to analyze in the fossil material. The organization of leaves as simple or compound has been correlated with available moisture or precipitation. Dolph and Dilcher postulated that the percentage of simple leaves increases from piedmont to both mountain and coastal regions where precipitation is higher [42]. Since majority of elements (about 85 elements, Table 2) in the Siwalik flora of Koilabas area possesses simple leaves indubitably indicating higher precipitation during Middle Miocene. From the foregoing discussion it may be suggested that the Himalayan foot-hills near Koilabas in western Nepal enjoyed a tropical climate with plenty of rainfall during the Siwalik sedimentation. This is, however, contrary to the present-day climate of the area with reduced precipitation.

5. Conclusion

The plant fossil assemblage so far recovered from Miocene sediments of Koilabas and nearby area comprises 116 species belonging to 83 genera of 33 angiospermous families. The tropical evergreen elements dominate the fossil flora of Koilabas area, western Nepal during Miocene in contrast to tropical mixed deciduous elements occurring at present which indicates the prevalence of tropical warm humid climate with plenty of rain fall during the deposition of Siwalik sediments.

Fabaceae represented by 21 species is most dominant family in the Koilabas fossil assemblage (Figure 5) followed by Annonaceae (10 species), Dipterocarpaceae, Sapindaceae and Anacardiaceae (6 species). The family Fabaceae which appear in Upper Paleocene became a major component of the evergreen forest flourishing during Mio-Pliocene all along the Himalayan foot hills. The analysis of present-day distribution of all the 116 species recovered from the Churia sediments of Koilabas area, western Nepal indicate that they are mostly known to occur in South-east Asia, North-east India, Bangladesh, Myanmar and Malayan regions wherever favorable climatic conditions prevailed.

The Most of the taxa of the Koilabas fossil assemblage are locally extinct. This indicates that the climatic changes must have been taken place there after Miocene. The dominance of the fossil taxa having entire margined leaves in the fossil assemblage of Koilabas area is indicating the presence of tropical climate. The other feature like Drip tips, leaf size, leaf texture, nature of petiole and venation density etc. collectively also suggested tropical during Miocene times around Koilabas and nearby area.

The coexistence approach for paleoclimate reconstructions suggests that Koilabas area in the Himalayan foot hills of western Nepal enjoyed a tropical climate during the Lower and Middle Miocene with the value of MAT 23.5°-30℃ and MAP 2400-3600 mm.

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