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Palynological study of surface soil samples from the Kartala Forest Range of the Korba District, Chhattisgarh, central India: Modern pollen-rain/ vegetation relationship

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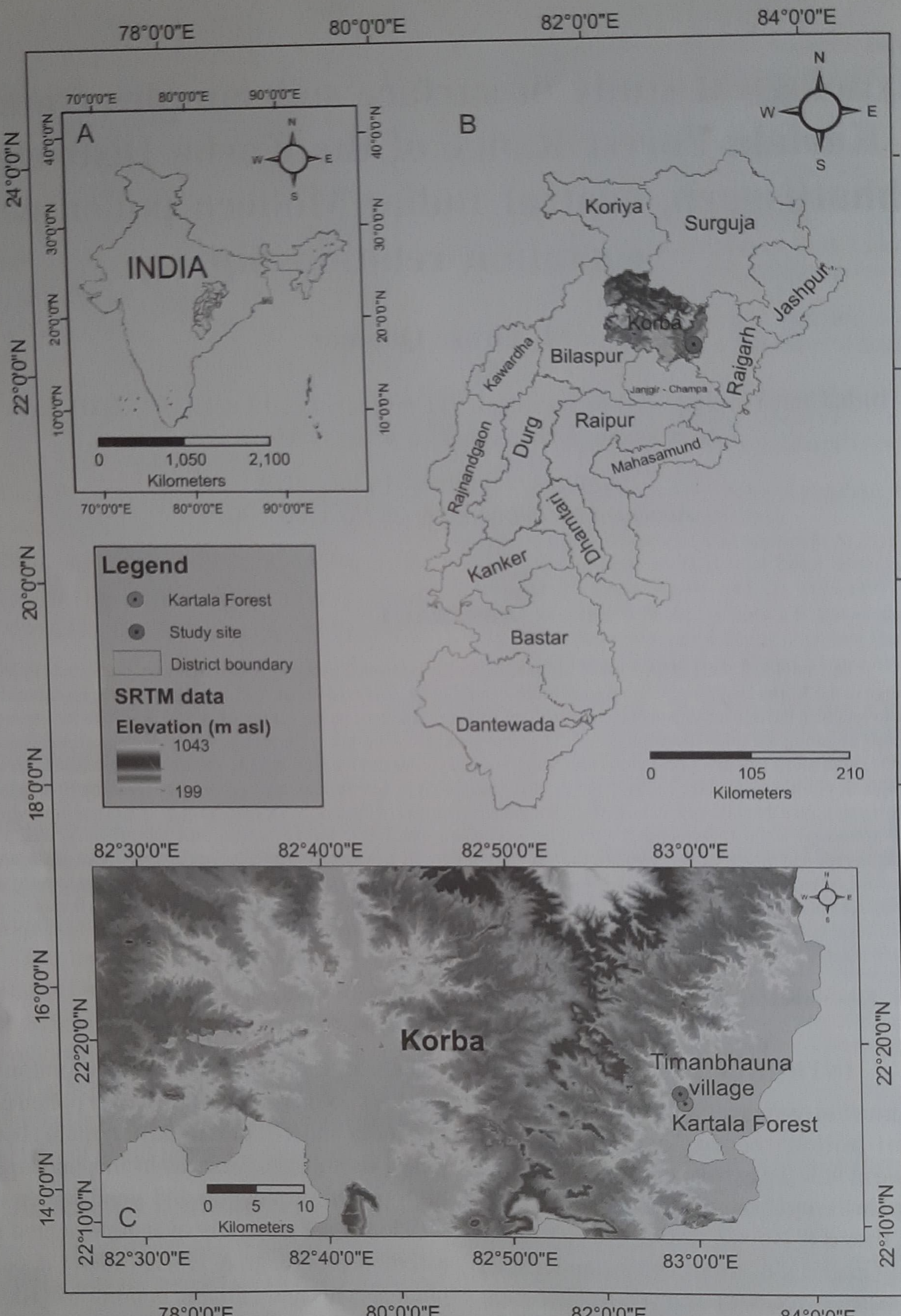
ABSTRACT

A palynological study of the surface soil samples collected from the edge of forested areas of the Kartala Forest Range in the Korba District of Chhattisgarh State, central India, was carried out. The objectives of the present study are to establish the relationship between the modern pollen-rain and extant vegetation and also to look into the various factors affecting the study in various ways. The recovered palynomorphs included the pollen of tropical deciduous forest (both moist and dry types) elements (both trees and shrubs), along with aquatic and marshy herbaceous taxa, as well as pteridophytic, algal, fungal spores, and transported pollen (drifted taxa) exclusively from the Himalaya. The major pollen documented include *Madhuca indica*, members of the family Sapotaceae (e.g. *Manilkara hexandra* and *Mimusops elangi*), *Terminalia*, *Schleichera*, *Emblica officinalis*, *Shorea robusta* and *Diospyros* as well as Acanthaceae and *Strobilanthes*, amongst the tree and shrubby elements of the arboreals, respectively. Also, Poaceae, Cerealia, Amaranthaceae, Tubuliflorae (Asteroideae; a sub family of the family, Asteraceae), amongst the terrestrial herbaceous plant pollen taxa are well documented. The recovered palynomorph assemblages revealed the dominance of arboreal pollen taxa (APs; trees and shrubs) over the non-arboreal pollen taxa (NAPs; herbs), suggesting open forest vegetation around the area of investigation.

Key-words: Vegetation, surface soil, palynology, Korba District, Chhattisgarh, central India

INTRODUCTION

Reconstruction of vegetation-based past climate using fossil pollen records necessitates the understanding of how the extant vegetation of an area is represented in the modern pollen spectra (Moore & Webb 1978, Faegri & Iversen 1989). The non-linear relationship (Fagerland effect; Fagerland 1952) between the extant vegetation and modern pollen-rain, however, exists because of the differences in pollen production, dispersal and preservation capacity of plant species (Birks & Birks 1980, Xu et al. 2006, 2007, Birks & Berglund 2017, Quamar & Kar 2018 and references cited therein). Plants with entomophilous mode of pollination produce fewer pollen grains and are either under-represented or remain absent in the pollen assemblages; whereas anemophilous plants with high pollen production and good pollen dispersal efficiency are generally over-represented in pollen assemblages (Faegri & Iversen 1964); depending on plant species and climatic conditions (Hicks 2001, Spieksma et al. 2003). Various studies have been conducted to address the relationships between the modern pollen-rain and extant vegetation in the Indian scenario (Kar et al. 2015, 2016, Quamar 2017,



Text-Figure 1. Maps of the study area. A. Geographical map of India, showing Chhattisgarh state, central india, B. Geographical map of Chhattisgarh, showing Korba District, **C.** Shuttle radar topographic mission (SRTM) digital elevation map (DEM) of Korba District of Chhattisgarh state, central India, showing the location of the study area in Kartala Forest Range (the "red circle" shows the sampling site). Source of Text-Figure. 1: The text-figure 1 is created using ArcGIS 10.3.

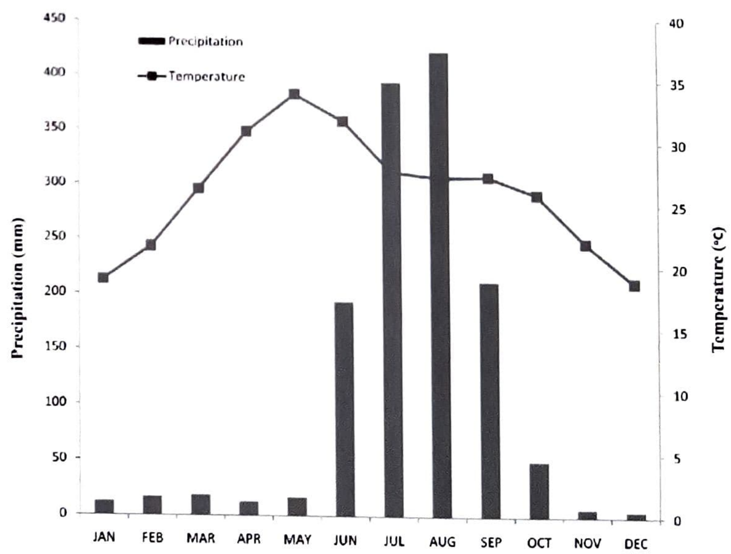
Quamar & Bera 2014, Bajpai & Kar 2018, Quamar et al. 2018a, b, Quamar & Kar 2018 and references cited therein). However, little attention has been paid to this aspect of pollen-vegetation relationships for the tropical deciduous forests of Chhattisgarh State (but see Quamar & Bera 2014a, 2014b, 2015, 2016a). Hence, in the present study, 20 surface soil samples, collected from the edge of forested areas of the Kartala Forest Range around Timanbhauna village of the Korba District, Chhattisgarh State, are palynologically analysed in order to understand the relationships between the extant vegetation and the modern pollen-rain. The study will provide the modern analogues, which are a prerequisite for calibrating the fossil pollen assemblages. In addition, the factors affecting the very relationships are also looked into, so as to have reliable information on the accurate scenario of the relationship, thereby, improving the interpretation of fossil pollen data for the reconstruction of past vegetation and associated climate change (Webb et al. 1981, Bradshaw & Webb III 1985, Calcote 1998) at different spatio-temporal scales.

STUDY AREA, VEGETATION AND CLIMATE

Timanbhauna village (22° 17' 12.80" N: 82° 59' 05.22" E; ~300 m a.s.l.) is situated about 45 km east of Korba Township under Kartala Forest Range (Text-Figure 1) in the Korba District of Chhattisgarh State, central India. The study area, physiographically, falls under the Korba Basin, which is drained by the Hasdeo River and its tributaries. The average altitude of the area ranges from 250-350 metre above the mean sea level. Red-yellow soil, laterite soil and sandy-clay soil are the chief soil types of the area, which have originated from a wide variety of parent materials formed under different geological formations of the 'Chhattisgarh Supergroup', resting on the 'Archaen Rocks' (District Handbook of Korba, Chhattisgarh, central India, 2016). The plain area is under agricultural activity by the local inhabitants, including tribal people (Quamar et al. 2018c).

The vegetation of the region is characterized by the presence of mainly tropical deciduous forests (both moist and dry types) (Champion & Seth 1968). Following four different types of forests, however, constitute the vegetation around the area of investigation: i) Teak (*Tectona grandis* L. f.) Forest, ii). Sal (*Shorea robusta* Gaertn. f.) Forest, iii) Bamboo (*Bamboosa arundinacea* (Retz.) Willd.) Trees and iv) Mixed Forest (Erdtman 1943). The common and usual associates of the forests are shown in Table 1.

The study area experiences both the Aw (Tropical savannah-type climate) and Cwg (Mesothermal climate-Gangetic Plain type climate) climates (Köppen 1936). The average summer temperature is 34.33 °C, whereas the average winter temperature is 17.15 °C. The average annual rainfall is 1090.1 mm (District Handbook of Korba, Chhattisgarh, central India, 2016). Nearest Climate Research Unit Time Series (CRUTS) 4.01, 0.5 x 0.5 gridded climate data points, 1901-2016, showing mean monthly precipitation and temperature around the site of investigation in Korba District of Chhattisharh, central India (Harris et al. 2014) has been represented in Text-Figure 2.



Text-Figure 2. Nearest CRU TS 4.01, 0.5 x 0.5 gridded climate data point, 1901-2016, showing mean monthly precipitation and temperature around the Kartala Forest Range of the Korba District, Chhattisgarh, central India.

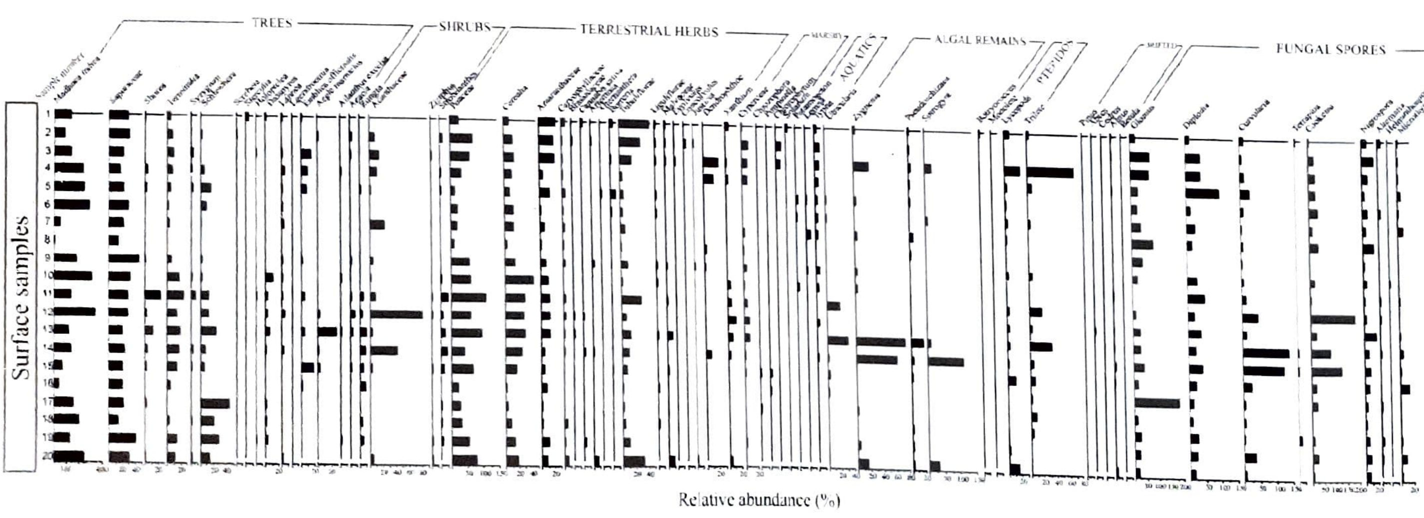
MATERIAL AND METHODS

A total of 20 surface soil samples were procured from a lacustrine area in the vicinity of Timanbhauna village of Kartala Forest Range (Korba District) to study the pollen deposition pattern in the region. The protocol adopted for the extraction of pollen and spores from the soil samples followed the standard acetolysis method of Erdtman (1952). Five grams of each sample was weighed for palynological preparation and treated with 10% KOH, 40% HF and an acetolysis mixture [concentrated sulphuric acid (H_2SO_4) and acetic anhydride ($C_4H_6O_3$) in 1:9 ratio] in order to disintegrate humus, silica, protoplasm and cellulose. Two millilitres (mls) of 50% glycerine solution were added to the treated substrate residues, kept in vial, for microscopic examination and further storage. In addition, two mls of phenol were also added to avoid any microbial contamination.

Temporary pollen slides were prepared from the final residue kept in the vial by pipetting 100 µl of the residue on to the slide. Microscopic analysis of the palynological studies was carried out on an Olympus BX50 microscope (transmitted light optical microscope) with attached DP 26 Software for photography using 40 X objective lens at the Quaternary Palynology Laboratory of Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow (India). Identification of palynomorphs (Plate 1) was assisted by authored reference material (Chauhan & Bera 1990, Nayar 1990, Quamar & Chauhan 2011-2013, Quamar & Bera 2017, Quamar et al. 2017; Quamar et al. 2019), as well as the regional reference collections held at the BSIP Herbarium, Lucknow, India. More than 300 terrestrial pollen grains (Total Pollen Sum; TPS) were counted per sample. Pollen percentages were calculated using the Total Pollen Sum (TPS) of terrestrial plants pollen only. Pollen of aquatic plants, marshy taxa as well as spores of algae, pteridophytes and fungi were excluded from the TPS, however, their percentages were calculated using the TPS. The pollen spectra (Text-Figure 3) were constructed using TILIA and TG View software (Grimm 1990). Taxa were arranged in the pollen spectra as trees, shrubs, herbs, marshy taxa, aquatics, algal remains, pteridophytic spores, drifted/transported taxa and fungal spores.

RESULTS

The pollen assemblages have demonstrated the dominance of arboreal pollen (AP) taxa and relatively less values of non-arboreal pollen (NAP) taxa. The pollen spectra (Text-Figure 3) revealed that amongst the tree taxa of the arborelas (trees and shrubs), *Madhuca indica* has very high values (average ~32% pollen), followed by Sapotaceae (average ~6%), *Schleichera* (average~2.21%) and *Terminalia* (average 1.45%). The rest of the tree taxa, such as *Shorea robusta*, *Syzygium*, *Screbera*, *Sterculia*, *Holoptelea*, *Diospyros*, *Emblica officinalis*, *Aegle marmelos*, *Ailanthus excelsa*, *Lannea coromandelica*, *Lagerstroemia* and *Acacia* contribute an average value of <0.5-1% pollen to the total pollen sum. Amongst the shrubby taxa, Acanthaceae (average ~2%), *Rungia*, *Ziziphus* and *Strobilanthes* (average <0.5% pollen) have sporadic representation in the pollen spectra. Poaceae (average 9.22% pollen) is the dominating herbaceous taxon in the total pollen rain. Cerealia (average ~3%) and Amaranthaceae (average ~2%) follow the Poaceae, whereas the other cultural plant pollen taxa, such as Caryophyllaceae,



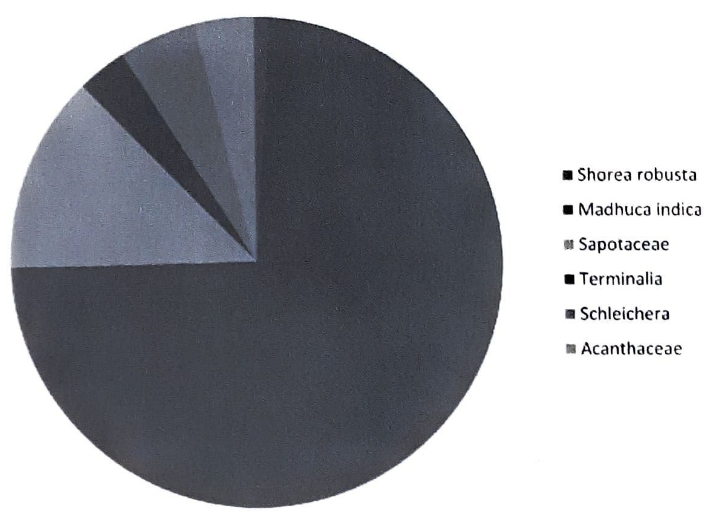
Text-Figure 3. Modern pollen spectra from Kartala Forest Range of the Korba District, Chhattisgarh, central India.

Brassicaceae, *Cannabis sativa*, *Artemisia*, *Alternanthera* and *Borreria* altogether contribute with low average pollen value of ~0.5-1 to the total pollen sum. Asteroidae/Tubuliflorae (average ~2.44%) have better representation compared to the other terrestrial herbaceous taxa, such as Cichorioideae/Liguliflorae, Malvaceae, *Evolvulus alsinoides*, *Convolvulus*, *Justicia* and *Xanthium*, which have been recorded with an average pollen value ranges from <0.5% to 0.5% in the total pollen sum. *Dendrophthoe* (*Loranthus*), a parasitic herbaceous taxon, has also been encountered (average<1% pollen). Cyperaceae and other marshy taxa, such as *Chrozophora*, *Pimpinella*, *Chlorophytum* and *Solanum* are meagre (average <0.5-1% pollen). The aquatic taxa, such as *Typha*, *Potamogeton*, *Lemna* and *Utricularia* (average <0.5 1% pollen) are infrequent. Algal remains, such as zygospores of *Zygnema* and *Spirogyra* (average ~1.29% and ~1.25%, respectively), *Botryococcus* (average <0.5%) and *Pseudoschizaea* (*Concentricystes*; average 0.5%) are recorded scarcely. The pteridophytic spores, such as trilete fern spores (average 1.34%) and lycopods (average ~1%) are scattered. The drifted pollen, transported from the Himalaya, such as *Pinus*, *Cedrus*, *Abies*, *Alnus* and *Picea* (average <0.5% each) are meagre. Fungal spores, such as *Glomus*, *Cookeina*, *Diplodia*, *Curvularia*, *Nigrospora*, *Tetraploa*, *Alternaria*, *Helminthosporium* and Microthyriaceae are recorded in variable frequencies.

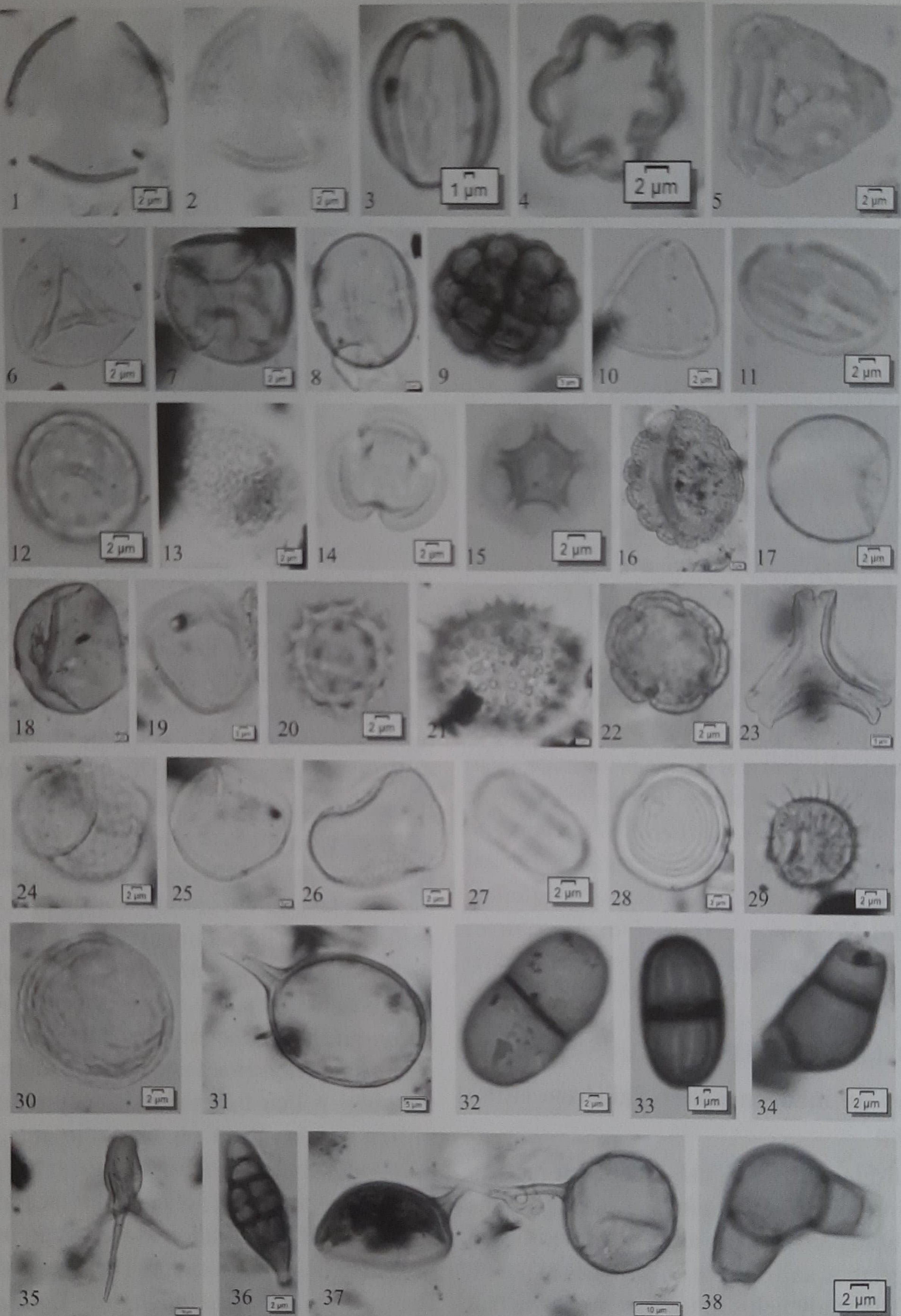
DISCUSSION AND CONCLUSIONS

Inferences on modern pollen-rain/vegetation relationship

Establishing the relationship between modern pollen-rain and extant vegetation is one of the indispensable aspects of pollen analysis (reconstruction of past vegetation and climate on the basis of pollen records). The study helps to understand the actual source of pollen influx prior to (the pollen) being deposited in a sedimentary environment. This has been executed also to generate a comparative database to estimate the extent of representation of various plant taxa/groups of present vegetation in the modern pollen-rain. The pollen spectra revealed the dominance of arboreal pollen (AP; trees and shrubs) taxa and comparatively low values of non-arboreal (NAP; herbs) taxa (Text-Figure 4). Among the tree taxa of the arboreals, *Shorea robusta*, despite being a high pollen producer [(about 60,000 pollen grains/flower (Atluri et al. 2004), however, 61,020–94,600 pollen grains have also been reported per flower (Bera 1990)], is encountered with an average value of ~0.5% only in the pollen spectra. This anomaly in the behaviour of *Shorea* plant pollen could be attributed to its poor preservation in the sediments as well as low (pollen) dispersal efficiency. *Madhuca indica* as well as members of the family Sapotaceae (e.g. *Manilkara hexandra* and *Mimusops elangi*) are recorded in high values (in the total pollen-rain), which could be attributed to its high pollen dispersal efficiency as well as good pollen preservation in the sediments. Besides, *Terminalia* and *Schleichera* are the other prominent plant pollen taxa in the pollen-rain, which could be due to their good preservation as well as preponderance around the sampling location. The other tree taxa, such as *Syzygium*, *Emblica officinalis*, *Aegle marmelos*, *Lagerstroemia*, *Lannea coromandelica*, *Holoptelea*, *Diospyros*, *Screbera*, *Sterculia*, *Ailanthes excelsa* and *Acacia* are, however, sporadically represented in low frequencies in the pollen spectra. The rest of the tree taxa, such as *Flacourtia*, *Annona*, *Maytenus*,



Text-Figure 4. Pie diagram showing the major tree and shrubby taxa of the modern pollen-rain around the Kartala Forest Range of the Korba District, Chhattisgarh, central India.



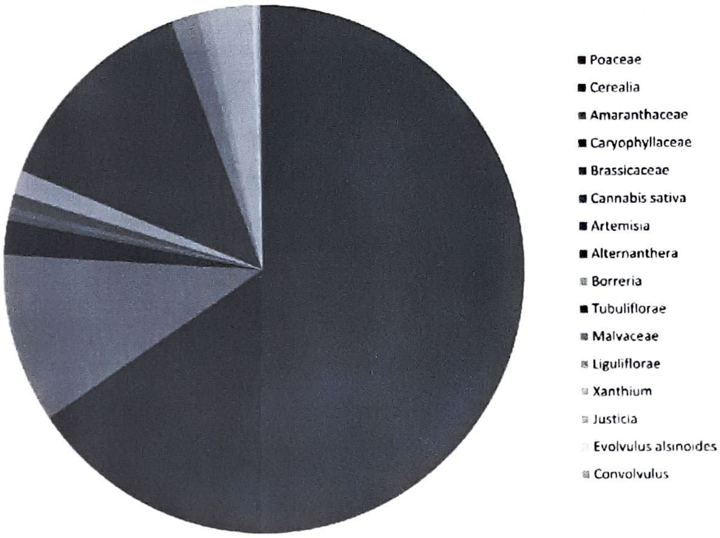
Explanation of Plate 1

Plate 1. Key palynomorphs recovered in the surface soil samples.

1 & 2. *Shorea robusta*, 3 & 4. *Terminalia*, 5. *Syzygium*, 6 & 7. *Schleichera*, 8. *Madhuca indica*, 9. *Acacia*, 10. *Zizyphus*, 11. *Rungia* (Acanthaceae), 12. Amaranthaceae, 13. Caryophyllaceae, 14. *Artemisia*, 15. *Alternanthera*, 16. *Borreria*, 17. *Cannabis sativa*, 18. *Cerealia*, 19. Poaceae, 20. Tubuliflorae (Asteroideae; Asteraceae), 21. Malvaceae, 22. *Evolvulus alsinoides*, 23. *Dendrophthoe* (*Loranthus*) , 24. *Xanthium*, 25. Trilete fern spore, 26. *Typha*, 27. *Polygonum plebeium* , 28. *Pseudoschizaea* (*Concentricystes*), 29. *Lemna* , 30. Zygospore of *Zygnema*, 31 & 37. *Glomus*, 32. *Diplodia*, 33. *Cookeina*, 34 & 38. *Curvularia*, 35. *Tetraploa*, 36. *Alternaria*

Gardenia, *Delonix regia*, *Bombax ceiba*, members of Anacardiaceae, Moraceae, *Symplocos*, *Mitragyna parvifolia*, *Adina cordifolia*, *Dalbergia sissoo*, *Albizia lebbeck*, *Anogeissus latifolia*, *Nyctanthes arbor-tritis*, *Ailanthus excelsa*, *Melia azedirach*, *Ficus religiosa*, *F. benghalensis*, *Anthocephalus* spp., and others remained palynologically silent, despite their occurrence in the region. The under-representation and/or complete absence of all these taxa in the recovered pollen record could be ascribed to their low pollen productivity owing to entomophily (Vincens et al. 1997, Quamar & Bera 2014, Quamar & Kar 2018 and references cited therein). High pH value of the soil and microbial degradation of their pollen in the sediments might also have been detrimental for the scarcity of pollen of these plants in the studied natural pollen trapping substrate/medium (Gupta & Yadav 1992, Quamar & Bera 2014). The shrubs contribute scarcely to the modern pollen-rain and are represented in low values.

Amongst the herbaceous elements, Poaceae (grass family) have relatively high frequencies. Cerealia, other cultural plant pollen taxa, such as Amaranthaceae, Caryophyllaceae, Brassicaceae, *Cannabis sativa*, *Artemisia*, *Alternanthera* and *Borreria* as well as other terrestrial herbaceous elements of the tropical deciduous forests, such as Asteroidae/Tubuliflorae, Liguliflorae/ Cichorioideae, Malvaceae, *Evolvulus alsinoides*, *Convolvulus*, *Justicia* and *Xanthium*, besides Poaceae, reflect their partial presence in the ground vegetation (Text-Figure 5). However, the presence of Asteroidae/Tubuliflorae in moderate values provides a clue to the pastoral activities around the area of investigation, as members of this family escape grazing because of their unpalatable nature to cattle and goats (Mazier et al. 2006). The presence of Cerealia, and other cultural plant pollen taxa, such as Amaranthaceae, Caryophyllaceae, Brassicaceae, *Cannabis sativa*, *Artemisia*, *Alternanthera* and *Borreria*, nonetheless, point towards the proximity of cultivated land and human habitation around the area of investigation. Moreover, Caryophyllaceae and *Artemisia* also point to the extensive grazing, indicated by open landscape types (van Joolen 2003). The record of Cyperaceae



Text-Figure 5. Pie diagram showing the major terrestrial herbaceous taxa of the modern pollen-rain around the Kartala Forest Range of the Korba District, Chhattisgarh, central India.

and other marshy taxa, such as *Chrozophora*, *Pimpinella*, *Chlorophytum* and *Solanum* implies wet conditions around the area of sample collection. The meagre pollen of aquatic taxa, such as *Typha*, *Lemna*, *Utricularia* and *Potamogeton* as well as algal spores (e.g. zygospores of *Zygnema* and *Spirogyra*, *Botryococcus* and *Pseudoschizaea* indicate the aquatic environment around the sampling area (Pišút et al. 2010). Trilete and monolete fern spores as well as lycopods signify damp and shady environments around the study area as ferns and fern allies remain dominant in high rainfall regions reflecting high water dependence and presence of mesic habitats (Kato 1993). The meagre record of pollen of *Pinus*, *Abies*, *Cedrus*, *Alnus* and *Betula* is due to their long-distance transport exclusively by wind from the Himalaya (~1000 km away). The presence of *Glomus*, *Diplodia*, *Curvularia*, *Cookeina*, *Nigrospora*, *Helminthosporium*, *Alternaria* and *Tetraploa* suggest warm and humid climate around the area of investigation (Mandaokar et al. 2008, Quamar 2015 and references cited therein).

Factors affecting the modern pollen-rain/ vegetation relationship

Following factors must be considered, in addition to the varying pollen production capacity, dispersal ability as well as transport and preservational capability

Table 1. Common associates of the forests in and around the study area.

Name of Taxa	Habits	Name of Families
Madhuca indica J. F. Gmelin	Tree	Sapotaceae
Terminalia chebula Retz	Tree	Combretaceae
T. bellerica (Gaertn.) Roxb.	Tree	Combretaceae
T. arjuna (Roxb. ex DC.) Wight et Arn.	Tree	Combretaceae
T. tomentosa Wight et Arn.	Tree	Combretaceae
Azadirachta indica A. Juss.	Tree	Meliaceae
Diospyros melanoxylon Roxb.	Tree	Ebenaceae
Schleichera oleosa (Lour.) Oken.	Tree	Sapindaceae
Syzygium cumini (L.) Skeels	Tree	Myrtaceae
Buchanania lanzan Spreng.	Tree	Anacardiaceae
Acacia catechu (L. f.) Willd.	Tree	Mimosaceae
Dalbergia sissoo Roxb.	Tree	Fabaceae
Boswellia serrata Roxb. ex.- Colebr	Tree	Burseraceae
Holoptelea integrifolia Planch.	Tree	Ulmaceae
Gmelina arborea Roxb.	Tree	Lamiaceae
Aegle marmelos (L.) Correa	Tree	Rutaceae
Emblica officinalis Gaertn.	Tree	Euphorbiaceae
Anthocephaleous cadamba (Roxb.) Miq.	Tree	Rubiaceae
Lagerstroemia parviflora Roxb.	Tree	Lythraceae
Mitragyna parvifolia (Roxb.) Korth.	Tree	Rubiaceae
Adina cordifolia (Roxb.) Hook. f. ex.- Bedd.	Tree	Rubiaceae
Eucalyptus sp. L'Hér.	Tree	Myrtaceae
Butea monosperma (Lam.) Taub.	Tree	Fabaceae
Ficus benghalensis L.	Tree	Moraceae
Semecarpus anacardium L.f.	Tree	Anacardiaceae
Ziziphus mauritiana Lam.	Shrub	Rhamnaceae
Strobilanthes sp.	Shrub	Acanthaceae
Acacia spp.	Shrub	Mimosaceae
Holarrhena antidysenterica (L.) Wall.	Shrub	Apocynaceae
Ricinus communis L.	Shrub	Euphorbiaceae
Grasses (Members of Poaceae)	Terrestrial herb	Poaceae
Ageratum conyzoides L.	Terrestrial herb	Asteraceae
Sida rhombifolia Roxb. ex Fleming		Malvaceae
Hyptis suaveolens (L.) Poit	Terrestrial herb	Lamiaceae
Blumea spp.	Terrestrial herb	Asteraceae
Leucas aspera (Willd.) Link.	Terrestrial herb	Lamiaceae
Chenopodium album L.	Terrestrial herb	Amaranthaceae
Amaranthus spinosa L.	Terrestrial herb	Amaranthaceae
Achyranthes aspera L.	Terrestrial herb	Amaranthaceae
Xanthium strumarium L.	Terrestrial herb	Asteraceae
Mazus japonicas (Thunb.) Kuntze	Terrestrial herb	Mazaceae
Sonchus spp.	Terrestrial herb	Asteraceae
Oxalis acetocella	Terrestrial herb	Oxalidaceae
Justicia simplex D. Don.	Terrestrial herb	Acanthaceae

Euphorbia hirta L.	Terrestrial herb	Euphorbiaceae
E. thymifolia L.	Terrestrial herb	Euphorbiaceae
Ajuga sp.	Terrestrial herb	Lamiaceae
Commelina benghalensis L.	Terrestrial herb	Commelinaceae
Scirpus sp.	Marshy herb	Cyperaceae
Cyperus rotundifolia L.	Marshy herb	Cyperaceae
Carex sp.	Marshy herb	Cyperaceae
Ammania baccifera L.	Marshy herb	Lythraceae
Rumex sp.	Marshy herb	Polygonaceae
Polygonum plebieum R. Br.	Marshy herb	Polygonaceae
P. serrulatum Lag., *Mentha arvensis* L.	Marshy herb	Polygonaceae
Mentha arvensis L.	Marshy herb	Lamiaceae
Hygrophila auriculata (Schumach.) Heyne.	Marshy herb	Acanthaceae
Pimpinella tomentosa (Dalzell & Gibson) C.B. Clarke	Marshy herb	Apiaceae
Solanum xanthocarpum Schrad et Wendl.	Marshy herb	Solanaceae
Ocimum americanum L.	Marshy herb	Lamiaceae
O. sanctum L.	Marshy herb	Lamiaceae
Typha latifolia L.	Aquatic herb	Typhaceae
Trapa sp.	Aquatic herb	Trapaceae
Nymphoides indica (L.) Kuntze	Aquatic herb	Menyanthaceae
Potamogeton purpurascens Seidi ex J. Presl et C. Presl	Aquatic herb	Potamogetonaceae
Lemna paucicostata Hegelm.	Aquatic herb	Araceae
Dryopteris prolifera (Retz.) C. Chr.	Pteridophytic herb	Dryopteridaceae
Adiantum philippensis L.	Pteridophytic herb	Pteridaceae
Diplazium esculentum (Retz.) Sw.	Pteridophytic herb	Athyriaceae
Selaginella semicordata N. Wall.	Pteridophytic herb	Selaginellaceae
Lycopodium cernuum	Pteridophytic herb	Lycopodiaceae

of individual taxon (causing non-linearity of the relationship), while making discussion on the very aspect in question:

i) *Flowering periodicity and long-term sampling*: The flowering periodicity varies in many tropical plants. So, these irregularities of flowering periodicity act as an impediment in capturing the full range of inter-annual variations in pollen production, especially in high-diversity lowland tropical systems. As a consequence, correlations between pollen and climate underestimate year-to-year variability in pollen outputs amongst even the most commonly sampled plant taxa, and overemphasize the degree of taxonomic turnover at a single site (Haselhorst et al. 2013). Hence, long-term sampling is suggested for modern pollen-rain studies to ward off the existing differences in flowering periodicity.

ii) Differences in pollen transport distance: The pollen transport distance differ amongst the various concerned forest elements (please read tropical deciduous forest elements here) owing to the physical properties of pollen grains themselves. This difference could be playing a pivotal role behind the irregularity in the representation of modern pollen grains, deposited in the sediments/various natural pollen trapping media/substrates.

iii) *Sporopollenin content and pH of the soil*: Low sporopollenin content in the exines of the pollen grains could be another prominent factor affecting their preservation in the sediments (Sangster & Dale 1965, Havinga 1967, 1984). In fact, it becomes easier for pollen having lower amount of sporopollenin to be oxidized and more difficult for the pollen to be preserved in the sediments. The structure and ornamentation of the external exine also play crucial role in pollen preservation. Pollen grains with psilate exines are somewhat less resistant to oxidation than those with ornamented exines in certain depositional environments (Xu et al. 2016).

Dimbleby (1957, 1961) suggested that the concentration of pollen taxa decreases with an increase in pH values. In other words, there exists an inverse relationship between the pollen concentration and pH values. When a pH value was higher than 5.5, it was observed that the pollen concentrations lowered sharply, meanwhile, the upper limit set for the pH value is 7.6 (Dimbleby 1957, 1961, Li et al. 2005). Therefore, high pH values of the soil, low sporopollenin content in the exines of the pollen wall structure and ornamentation of exine, as well as oxidation coupled with action by fungi (and/or bacteria) (Gupta & Yadav 1992), could be causing the erroneous recovery of plant pollen taxa in the studied samples.

iv) *Vegetation heterogeneity*, *inter-specific variability* (*of various taxa*), *climatic factors* (such as temperature, precipitation/rainfall, relative humidity, air pressure, wind speed and direction) and Human disturbances (affecting the original vegetation) could be influencing the study in various ways (Sugita 2007a, b).

v) *Taxonomic bias*, *representation bias* and *count-size bias* could also be affecting the entire relationship in various ways (Felde et al. 2016, Birks et al. 2016).

Further studies with Extended R-value (ERV) models approach (Parsons & Prentice, 1981, Prentice & Parsons 1983, Sugita 1993, 1994) is required in order to have the best available approximation of a "pollen sample's view" of the landscape (Prentice & Webb 1986, Sugita 1994, Calcote 1995). The modelling approach correct the non-linearities (Fagerland effect, Fagerland 1952), arising from the use of pollen percentage data, as well as aid in defining the relevant source area of pollen (RSAP) and the distance-weighted plant abundance (DWPA), which help improve the pollen representation (pollen production and dispersal), as well as transport and preservation, and ultimately the modern pollen-rain/ vegetation relationship.

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