Chapter 3

Results
PART-I

3.1 TOKWA

3.1.1 Study area-

The archeological site of Tokwa (lat. 24°54’20”N; long. 83°21’65” E) is situated at an elevation of 146 m MSL, on the confluence of the Adwa and Belan river in Lalganj subdivision, Mirzapur District (Fig. 3.1.1), Uttar Pradesh. The southern margin of the site is flanked by Adwa river and northern margin of the site is faced by Belan river. The western margin resembles the peak of triangle (Fig. 3.1.3), while eastern margin of the site stretched towards Tokwa village. As one walks eastward, the width of the site increases. The major portion of the site is undisturbed while the triangular portion is cut vertically by rivers showing cultural depositions. The ancient site covers an area of about 27,597 sq. m. During 2000-2003, the archeological excavations were started for this site by VD Misra, JN Pal and MC Gupta from University of Allahabad (Ancient history and Archeology department). The position of Tokwa is as a midway station in the Vindhyan Neolithic culture complex (Fig. 1.1) between Mahagara, Koldihwa, Pachoh on one side, all situated in Belan Valley and Kunjhun in the Son valley at another side (V. C, Srivastava, 2008). The entire site is divided into three sub areas, for the sake of convenience, which are Tokwa 1, Tokwa 2 and Tokwa 3.

The climate in this area is tropical monsoonal. Hot scorching summers (April to mid June), moderate monsoon rains (mid June to October) and cold winters (November to February) are main features of this area. The mean annual temperature of the region is around 25.65°C whereas mean annual rainfall is 1099.2 mm (Nagal et al., 2014). About 80% of the annual rainfall occurs during the rainy season from the southwest monsoon. A detailed account of climate and flora/fauna and geology is described in Introduction part.
3.1.2 Brief archeology of the site

Tokwa is the most well preserved and extensive site regarding Vindhyan Neolithic culture. At Tokwa 1, four trenches were laid, H-8 and H-9 (Fig. 3.1.4) in 2000 and I-8 and I-9 in 2003, each measuring 5 sq. m., along with control pit. The excavation of various trenches and pits revealed that it is a multicultural site containing relics of Neolithic, Chalcolithic and Iron age cultures.

The combined testimony of the excavation of three trenches divides the occupational strata of site into 16 layers, measuring around 4.00 m (Misra et al., 2001). The various layer wise cultural periods are described below:

Layers 1 and 2 composed of yellowish, slightly compact deposit, measuring 58 cm. containing shreds of NBPW and various black and red ware and black slipped ware. Besides ceramics these layers contained various animal bones, terracotta beads, beads fashion on semi precious stones, arrowheads, glass bangles, pieces of qurens and mullers, sandstone fragments and iron and copper objects. The interesting find of the site is a hollow bone container (cylindrical in shape), having cover on both side. Presence of burnt clay lumps with reed impressions, pit hearths and post holes suggest the wattle and daub construction.
Fig. 3.1.1: Location and Geomorphological map of study area
Layer 3 and 4, measuring a depth of 46cm, constitute the pre-NBPW period associated with iron, this stratigraphic position resembles well with other evidences revealed from a number of sites. These layers yielded black slipped ware, shreds of black and red ware, various types of reed ware, bone arrowheads, animal bones, beads of semi-precious stones and terracotta, some copper objects, fragments of querns and mullers, hammer stones and plenty of carbonized cereal remains. Structural hearths and pit hearth were also present. Presence of clay lumps with reed impressions and post holes suggest a wattle and daub structure. It is considered that the ceramics of this phase is a continuum of ceramics of underlying Chalcolithic culture.

Layer 5 to 7, measuring 50 cm, made up of light, yellowish, loose and ashy deposits revealed Chalcolithic culture of the site. This section contains various shreds of black and red ware including black slipped ware and red ware. The red wares are divisible into various sub groups. A variety of characteristic potteries were yielded containing variety of dishes, bowls, footed and perforated basins, bowls, storage jars, medium sized vases, and pedestalled bowls. Few paintings which is not feature of this culture were also found. The pots are well fired and manufacturing clay is somewhat levigated. Pottery is wheel made. Besides this ceramics few copper objects, bone arrowheads, animal bones, semiprecious beads and terracotta beads, blade fragments along with fragments of hammer, stones, querns, and mullers were found.

An important feature belonging to this culture is digging of various pits. A number of hearths including both structural and pit hearths were exposed. Occurrence of postholes indicates presence of hut like structures. Brunt clay lumps were found indicating wattle and daub structure. Carbonized cereal remains in good quantity were also obtained. Distribution of postholes on hut periphery floors exhibits a circular/semi circular wattle and daub structure.
The layers from 8 to 16 reflect the Neolithic culture of the site. The depth of the layers is 2.47 m. Ceramic industry of this culture is handmade. Cord impressed pottery was an important finding from this horizon including rusticated ware and burnished black and burnished red ware. The spouted vases were prevalent. Besides this other antiquities were yielded which are bone arrowheads, fragments of querns, mullers, hammer stones, and beads made of semi precious stones and terracotta. Microliths made up of semiprecious stones includes blades, flakes, blade fragments, triangles, scrapers etc. However the the shapes of ceramic tradition were limited in comparison to Chalcolithic culture A number of carbonized plant remains like rice, wheat, barley, moong (green gram), mustard, til, fruits, beans along with burnt Charcoal were also retrieved. On the basis of excavation it can be said that habitation at Tokwa was started by Neolithic people. The features of this culture associate with Vindhyan Neolithic culture.

3.1.3 Chronology of the site

Three radiocarbon dates of charcoal samples from different levels of studied trench H-8 are given in table no., including calibrated values in BP and BC/AD.

<table>
<thead>
<tr>
<th>Trench</th>
<th>Depth (cm)/Layer</th>
<th>Lab. no</th>
<th>14C date</th>
<th>Calib BC/AD</th>
<th>Calib (BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. H-8</td>
<td>0-10 (Top)</td>
<td>IUACD-TKW-1</td>
<td>314±80</td>
<td>1435-1683 AD</td>
<td>516-267</td>
</tr>
<tr>
<td>2. H-8*</td>
<td>220-225/12</td>
<td>BS-2054</td>
<td>3410±70</td>
<td>1860-1622 BC</td>
<td>3810-3572</td>
</tr>
<tr>
<td>3. H-8*</td>
<td>300-330/14</td>
<td>BS-2369</td>
<td>6850±200</td>
<td>5976-5561 BC</td>
<td>7926-7511</td>
</tr>
</tbody>
</table>

Table 3.1.1 Radiocarbon dates obtained by charcoal samples from trench H-8 *(after Pokharia et al., 2011)*
Fig. 3.1.2: Age depth model for Tokwa site based on C\textsuperscript{14} dates
Fig 3.1.3: View of Tokwa site from northern side

Fig. 3.1.4: Position of trench H-8 and H-9 at Tokwa 1
3.1.4 Analysis of plant microremains (Phytoliths)

Diverse morphotypes of phytoliths have been recovered from all 15 samples from Tokwa. Excluding undetermined morphotypes a total 26 phytolith morphotypes were identified. Among total morphotypes, the Grass Silica Short Cells (GSSCs) were dominant followed by other grass and non grass cells and dicot types. Various GSSCs morphotypes identified were bilobate, cross, rondels, trapezoids and saddles. Bilobates and cross mainly occur in subfamily Panicoideae, which corresponds to warm and humid climate. Saddles are characteristics of subfamily Chloridoideae which corresponds to dry climate. The rondels and trapezoids, corresponding to subfamily Pooideae, are indicators of cool climatic conditions (Mulholland and Rapp, 1992; Bremond, 2008; Calegari et al., 2013). Other grass phytoliths recorded are elongate and bulliform types. Cyperaceae phytoliths were identified by achene seed phytoliths, cone and hat like projections. Palmae (Arecaeae) phytoliths represent the spherical shape and spiny ornamentation (Kondo et al., 1994, Bremond, 2008; Piperno, 2006). Various phytoliths related to woody elements, like scalereids, terminal tracheids, spiral tracheids, vessels, vessels with silicified bordered pits etc. were also retrieved.

Presence of double peak phytoliths from rice husk along with silica skeleton and other crop remains is an important finding from this site. As it is an important Neolithic site and it is an indication of rice cultivation in or around site at this time. The Humidity Aridity index value (IPh%) was also calculated as it is a reliable phytolith index and can be applied in tropical areas successfully (Bremond et al., 2005).

The distribution of phytolith morphotypes along the Trench H-8, at Tokwa is presented in (Fig. 3.1.5). Four zones, TKW I, TKW II, TKW III and TKW IV have been identified in the profile, which are based on the frequency distribution of
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phytolith assemblages, cluster analysis was done using Tilia programme (Grimm, 1990). The percentage of Panicoide, Chloridoide and Pooideae morphotypes and with IPh values are given in (Fig. 3.1.5a & b)

Zone I (TKW-I)

This zone show dominance of Grass Silica Short cells (GSSCs) phytoliths, ranging from 58% to 64%. Among GSSCs the lobate phytoliths range from 34% to 40 %, saddle from 9 % to 10 %, cross from 5 to 6.7%, trapezoid from 2.3 to 3.7 % and rondel from 2.9% to 5.4 %. Other grass phytoliths recorded are elongate types and bulliform types. The elongate phytoliths are of two types dendritic and psilate, the percentage of these types range from 3.2 to 5 % and 3 to 10%. The percentage of bulliform phytoliths range from 7.8 to 10.6 %. The characteristic rice silica skeletons and double peak phytoliths were also retrieved, though the percentage is lowest in this zone. Cut phytoliths and multicellular crop aggregates, indicating anthropogenic activities, range from 1 to 1.2 % and 1 to 1.4 %. Other phytoliths like trichomes, spiny phytoliths, sqare and rectangular shaped phytoliths were also found which does not bear any taxonomic significance. Some phytoliths related to dicot origin are epidermal sheets and mesophyll cells. While undetermined forms account for 2-3%. Cyperaceae morphotypes, achenes, were also present from 1 to 1.8 %.

Another interesting finding is presence of various phytolith morphotypes which are valuable indicators of forest or arboreal vegetation. These types are spiral tracheids around 2-4.9 %, terminal tracheids around 1 %, bordered pits 3.1 to 4.6 % and few verrucate spheres around 1 %. The frequency of pits and and spiral tracheids was highest in this zone.

The value of Humidity–Aridity index (IPh %) is low ranging from 18% to 20 % (Fig. 3.1.6b)
Fig. 3.1.5: Phytolith assemblage along with lithological sequence of trench H-8, Tokwa
Fig 3.1.6: (a) The humidity – aridity index (IPh%)  (b) Total GSSCs percentage in Tokwa

**Zone II (TKW-II)**

This zone too shows dominance of GSSCs but percentage is low in comparison to zone I, ranging from 45% to 57%. The frequency of lobate phytoliths is from 28 to 34 %, saddle phytoliths from 9.2 to 11%, cross being lowest ranging from 3.4 to 5.2 %, rondel from 2.4 to 5.4 %, trapezoid being lowest from 2.4 to 5.2%. While non GSSCs include elongate dendritic ranging from 2.2 to 4.6%, elongate psilate from 2.7 to 4.1 %. Bulliform cells account from 7.9 to 15 % being highest in the whole profile. Trichomes range from 3.9 to 4.1 %, while epidermal sheets, verrucate sphere, mesophyll cells, spiny were less than 1%.

Cyperaceae phytoliths percentage was from 1.7 % to 2.5%, slightly higher than earlier zone. Cut phytoliths, Multicellular crop aggregates range from 1.6 to 2.5 % and from
Results

53 to 2.4 %. Double peak phytoliths and silica was highest in this zone from 2.7 to 3.6 and from 4.1 to 9.6 %.

Phytoliths representing woody or arboreal vegetation like bordered pits, spiral tracheids were also found. Silicified bordered pits range from 2.2 to 3.3 % and spiral tracheid percentage range from 2.2% to 4.6 %. Undermined forms represent 1.5 % of whole profile.

The Humidity –Aridity index value (IPh%) range from 22% to 22.6 %.

Zone III (TKW-III)

This zone show highest percentage of GSSCs ranging from 55% to 65%. Among GSSCs lobate morphotypes range from 29.5 % to 33.7 %, saddle from 11% to 16.8%, cross from 4.66 to 7 %, trapezoid from 2.67% to 5.92% and rondel from 3 to 5%. Non GSSCs include elongate dendritic and elongate psilate from 4% to 7.76% and from 1.9 % to 6.21%, being highest in this zone. Bulliform phytoliths range from 3% to 9.6%. Trichomes were present from 3.6% to 5 %. Cyperaceae phytoliths account from 2.2 to 2.4%. While verrucate spheres, epidermal sheets, mesophyll cells account for less than 1 %.

Silica skeletons and double peak phytoliths were present from 1 to 2% and 2 to 3%. Cut phytoliths and multicellular aggregates range from 1% to 2 % and 1.5 to 2 %.

Among arboreal elements besides tracheids and bordered pits, presence of sclereids and fibers was noticed. In earlier zones no fibers or sclereids were retrieved. The percentage of terminal tracheid around 1.5 %, spiral tracheid range from 1.9% to 3.85 % and scalereids were present in two layers ranging from 1 to 1.5%. While bordered pits range from 1.8 % to 4.1 % being highest. In one layer few vessels were noticed. Undermined forms were present from 1.4 to 4 %.
The value of Humidity–Aridity Index (IPh%) is somewhat higher than earlier zones, ranging from 23.4% to 29%.

**ZONE IV (TKW-IV)**

This zone comprises of lobate phytolith ranging from 22% to 24%, saddles from 17% to 22% being highest, cross from 4.7% to 6.6%, trapezoids from 3% to 5.1% and rondel from 2.5 to 5% among GSSCs. The GSSCs percentage range from 54% to 63%. Elongate dendritic account for 4.7% to 7% and elongate psilate from 3.1% to 6.5%. Trichomes account for 2.2% to 7% while verrucate spheres, spiny types, squares, rectangels, and mesophyll cell were in negligible quantities. The Cyperaceae morphotypes range from 1.2% to 2%.

Bulliform phytoliths were present from 3.8% to 7%. Double peak and silica skeletons of rice were found to range from 1.2% to 3% and 2% to 4.6%. The cut phytolith and multicellular aggregates range from 1.5% to 4% and from 1.6% to 2.2%.

In this zone the arboreal indicators like sclereids range from .6% to 4.4% being highest in profile, terminal tracheid from 0.6% to 1.5%, spiral tracheid from 1.5% to 4.7% highest in profile. The percentage of bordered pits was highest in this zone ranging from 0.6% to 4.7% and fibers account for 0.6% to 1.5%. The undetermined forms accounts for 1.8% to 3%.

In this zone the Humidity Aridity Index (IPh%) is highest from 32.9% to 41.2%.

**On-site rice processing**

An interesting finding from Tokwa samples is that it has revealed evidences of on-site rice processing. As in the whole phytolith assemblage the phytoliths from different parts of the rice plants were retrieved like ‘scooped bilobates from the leaf and double peak cell and silica skeletons from rice husk (lamna and paleas of the husk). To test
whether both phytolith types are originated from the same input pathway, the quantities of both types were compared by using correlation analysis.

The results show that both types were brought into the site via same pathway, so it is possible that there was practice of on-site rice processing at Tokwa. A detailed analysis of phytoliths can further determine whether the rice phytoliths belong to cultivated or wild species. Besides this presence of some other crop phytolith along with sedge phytoliths, which could be present as weeds, indicate rice cultivation practices.

![Correlation Graph showing same input path of double peak rice glume phytoliths and scooped bilobate phytolith from Tokwa](image)

Fig. 3.1.7: Correlation Graph showing same input path of double peak rice glume phytoliths and scooped bilobate phytolith from Tokwa
Fig. 3.1.8 Various grass phytoliths obtained from Tokwa, (1-12) represent GSSCs; (13-22) other grass phytoliths except (19 &20) which belong to Cyperaceae
Fig. 3.1.9: Various phytolith morphotypes from Tokwa, (1-13) woody arboreal type phytoliths; (14-17) rice double peak and silica skeletons; (18 - 23) various crop aggregates
Fig. 3.1.10: Various phytolith morphotypes and other microremains from Tokwa, (1 & 2) trichomes; (3-9, 11, 12) undetermined types; (10) vessel element (13) crysophycean cyst; (14 & 15) fungal spore and fungal body and (16) pollen (*Pinus*)
PART-II

3.2 HETAPATTI

3.2.1 Study area

Hetapatti is an important Neolithic site of Middle Ganga Plain, situated on the left bank of the Ganga, around 20 km away from Allahabad in north-east direction (Lat.25° 29' 0" N., Long. 81° 55' 31" E.). The ancient site is made up of three mounds, HPT-I, II and III. Among these the HPT-II mound is the only mound which contains archaeological deposit from Neolithic to early medieval period (Fig. 3.2.2). The height of this mound is about 10 m. While HPT-I & HPT-III, are about 6 m high and contain archaeological deposit till NBPW and Kushana periods respectively. There is vast exposure of 7m high geological formation on which the archaeological deposit is resting. In this way on the left bank of the Ganga a platform was already created by geological formation of late Pleistocene and early Holocene period, on which the human activities in subsequent period were performed (Pal and Gupta, 2005).

According to geologists the Ganga plain, which is a peripheral foreland basin came into existence in Early Miocene. In the Middle Miocene it further expanded and came into its present form in the Late Quaternary. It is dotted with surface cover of Holocene sediments of variable thickness throughout (Singh, 1996). The typical climate of this region is humid subtropical type largely influenced by South west monsoon, denoted as Cwa in the Köppen climate classification system. The annual rainfall is 1027 mm and annual temperature ranges from 40°C to 45°C in summers and from 2°C to 24°C in winters (Kasim and Usman, 2016). Four distinct seasons are spring (Mid February to Mid March), summer (Mid March to Mid June), rainy (end of June to the end of September) and winter season (November to the middle of February). Sometime occasional rains in winters are experienced though the
atmosphere remains dry. Details of climate, flora/fauna and geology are given in Introduction part.

3.2.2 Brief archeology of the site

The site was brought to light by the Department of Ancient History, Culture and Archaeology, University of Allahabad as early as in 1998 and extensive exploration on the site resulted in the discovery of a good number of the chunks of semiprecious stones such as chert, jasper, chalcedony, etc. along with flakes and flake fragments, blades and blade fragments and a few finished tools. This indicates that the earliest people who visited the area might have been the microlith using people. This supposition gets confirmation from the occurrence of microliths at Jhusi, Nibikalan, Jamunipur, etc. Besides the microliths handmade corded and rusticated potsherds, the diagnostic traits of the Neolithic culture in the area were also obtained in good number suggesting thereby that the site might have been occupied during the Neolithic people. Chalcolithic pottery comprising black-and-red ware, black slipped ware and red ware were also obtained. In the light of recent excavations at Jhusi, the chronological position of these wares was Chalcolithic. Sherds of NBPW were also obtained suggesting thereby that during the NBPW period also the site was in occupation. Extensive exploration on the highest mound (HPT-II) lying to the south east led to the discovery of Kushana pottery along with bricks. The available archaeological material thus indicates that there might have been some gap between the NBPW and beginning of the Kushana period. For the sake of convenience the mound HPT II includes 2 trenches, A1 and WA4. As it was not possible to excavate A1 trench continuously, at the depth of layer 12 another trench at the distance of 4 m was excavated. Combining both trenches we get whole profile of Mound HPT II from layer 1 to 24 (from Neolithic to Kushana period). A brief account of layer wise cultural periods from mound HPT-II is given below-
Fig. 3.2.1: Location and Geomorphological map of study area
Results

Trench A1, layer 1 to 10 revealed a good number of potsherds of red ware, terracotta and semiprecious stone heads. The structure of ceramics and bricks indicate that these artefacts belong to Kushna period. Besides this mullers and sharpeners made of sand stone, bone arrowheads, iron objects, ghata and arecanut shaped terracotta beads, terracotta human figurines, glass bangles, terracotta and pottery discs, terracotta balls etc. Layer 11 and 12 belong to late NBPW phase. Further the continuation of excavation in trench WA4 the archeological material, from layer 11 to 18 is marked by NBPW sherds and associated red ware belonging to NBPW culture. The antiquities from this phase are made of antimony rod of copper, arecanut and ghat shaped terracotta beads etc. Some pit activities were also demarcated.

Layer 19 and 20 is characterized by deposit of pre NBPW or Chalcolithic culture, containing potsherds, charcoal, and pieces of animal bones. A pit sealed by this yielded animal bones and pottery.

From layer 20 to 24 the yellowish hard clay deposit yielded handmade pottery of red ware along with burnt clay lumps, animal bones, charcoal etc. Evidently this thick deposit belongs to Neolithic culture. After this natural virgin yellowish clay was excavated, no archeological artifact was found. Layer wise lithological details are given in Fig. 3.2.3. The stratigraphic chronological details are given in table 3.2.1.
## 3.2.3 Chronology of the site

<table>
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<th>Lab code</th>
<th>Trench/ Layer</th>
<th>Depth (cm)</th>
<th>δ13C per mil</th>
<th>Fraction of modern</th>
<th>Radiocarbon</th>
<th>Calibrated Age (Cal BP) median</th>
<th>Calibrated Age (Cal BC)</th>
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<td>70.835</td>
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Table 3.2.1: Radiocarbon dates obtained by bulk samples from trench A1 and WA4, from HPT-II
<table>
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<tr>
<th>Zone boundary</th>
<th>Depth (cm)</th>
<th>boundary Calibrated age, 68% range (cal BCE)</th>
<th>Calabarated age, 95% range (cal BCE)</th>
<th>Calibrated age median (cal BCE)</th>
<th>Calibrated age median (cal BP)</th>
</tr>
</thead>
<tbody>
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<td>(-110)-(-1278)</td>
<td>(-273)-(-1943)</td>
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<td>1270</td>
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<td>Z4/Z5 boundary</td>
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<td>Z3/Z4 boundary</td>
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<td>(-687)-(-158)</td>
<td>-278</td>
<td>2225</td>
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<tr>
<td>Z2/Z3 boundary</td>
<td>218</td>
<td>(-761)-(-411)</td>
<td>(-883)-(-200)</td>
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<td>2510</td>
</tr>
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<td>(-3031)-(-990)</td>
<td>(-32360)-(-992)</td>
<td>-2206</td>
<td>4155</td>
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<tr>
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<td>(-5337)-(-6806)</td>
<td>(-5221)-(-5722)</td>
<td>-5722</td>
<td>7670</td>
</tr>
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</table>

Table 3.2.2 Modelled age of palaeoecological/palaeoclimatic zone boundaries.
Fig. 3.2.2: Bayesian age-depth model of the Hetapatti sequence. The wider and lighter shade represents 95% probability distribution range, whereas the narrower and darker shade represents 68% probability distribution range. Open squares indicate the modelled age medians of palaeoecological zone boundaries. LB = lithological boundary. Calibrated age distributions of the five AMS dates (Table 3.2.1) are plotted, with their calibrated medians shown in open circles.
Fig. 3.2.3: View of HPT II mound and excavated trenches A1 and A4

Fig. 3.2.4 Combined Lithological details for whole sequence of mound HPT-II
3.2.4 Analysis of Plant micro remains (Phytoliths)

All 24 samples from Hetapatti, belong to from Neolithic to Kushana period, yielded diverse phytolith morphotypes (Fig. 3.2.8 & 3.2.9). Excluding undetermined morphotypes a total 15 phytolith morphotypes were identified. Among total morphotypes, the Grass Silica Short Cells (GSSCs) were dominant followed by other grass and non grass cells and dicot types. Various GSSCs morphotypes identified were bilobate, cross, rondels, trapezoids and saddle. Other grass phytoliths recorded are elongate and bulliform types. Cyperaceae phytoliths were identified by achene seed phytoliths, and Palmae (Arecaceae) phytoliths represent the spherical shape and spiny ornamentation (Kondo et al., 1994, Bremond, 2008; Piperno, 2006). Contribution of dicot and woody phytoliths was very less. Cereal crop aggregates and rice phytoliths were also recovered from some layers, indicating some agricultural activities around the site.
Fig. 3.2.5 Phytolith assemblage of whole sequence from HPT II mound
Fig 3.2.6: (a) The humidity–aridity index (IPh%)  (b) Total GSSCs percentage from HPT II sequence

The humidity-Aridity index (IPh %) was used to understand the ratio of mesophytic and xerophytic grasses.

The combined distribution of phytolith morphotypes in HPT II profile is graphically presented in (Fig. 3.2.5). Based on the frequency distribution of phytolith assemblage four zones HPT I, HPT II, HPT-III and HPT IV have been identified, using cluster analysis in Tilia programme (Grimm, 1990). The percentage of various morphotypes of Panicoideae, Chloridoide and Pooideae phytoliths along with IPh values are given in (Fig. 3.2.6 a & b). The zone wise distribution of phytolith assemblage is given below-
**Zone I (HPT I)**

This zone shows dominance of Poaceae phytoliths especially GSSCs. The contribution of GSScs is around 75% to 79%. Among GSSCs the percentage of lobate phytoliths ranges from 39% to 41% being highest in the profile, cross from 3% to 5.8%, saddles from 10% to 12%, trapezoids from 10% to 12% and rondels from 9% to 12%. The another types of grass phytoliths include bulliform and elongate type ranging from 1.8% to 5.8% and from 10% to 13%. Multicellular crop phytoliths ranging from 1.2% to 2.8% also found which indicate anthropogenic activities around site. Cyperaceae phytoliths were present from 1.2% to 2.3%. Trichomes and dicot origin phytoliths were also found ranging from 1.2% to 2.7% and 0.6% to 2.3% and bearing no taxonomic value. Unidentified forms range from 1.9% to 2.7%.

The value of Humidity-Aridity index is lowest in this zone (Iph %) is from 19.1% to 20.6%.

**Zone II (HPT II)**

In this zone, the dominant phytolith are from Poaceae GSSCs ranging from 75% to 80%. Among them the lobate phytoliths range from 33% to 39%, cross from 3.7% to 6.6%, saddles from 17% to 19%, trapezoids from 8.6% to 11%, and rondels from 7.7% to 11%. Cereal crop aggregates range from 2.3% to 4.3%. While bulliform and elongate phytoliths account from 1% to 4% and from 9% to 11%. Trichomes account for 1% to 2.6% while proportion of dicot or arboreal phytoliths range from 0.3% to 2.6%. Cyperaceae phytoliths were recorded from 0.5 to 0.6% to 3.7%. In this zone characteristic palm phytoliths were also noticed ranging from 1.1% to 1.4%. Contribution of unidentified phytolith forms range from 1% to 2.3%.
The value of Humidity – Aridity index was slightly higher than earlier zone from 28.2% to 32%.

**Zone III (HPT II)**

This zone shows dominance of GSSCs ranging from 75% to 79%. Among them lobate phytoliths range from 32% to 37%, cross from 2.93% to 6.9%, saddles from 19% to 23%, trapezoids from 3.7% to 9.8% and rondels range from 9.8% to 13%. Other grass phytoliths viz., bulliforms and elongates account from 1.5 to 6.7% and 6% to 9%. While Cereal crop aggregates account from 1.7% to 4.3%. Trichomes and dicot type phytoliths vary from 2% to 5.6% and 0.3 to 2.7%. Cyperaceae phytoliths are presented from 0.9% to 1.8%, while unidentified forms range from 0.8% to 2.1%.

The value of Humidity – Aridity index (IPh%) range from 33.3% to 37.8%.

**Zone IV (HPT IV)**

In this zone the major contribution of phytoliths is from GGSCs ranging from 74% to 88%. Among them lobate phytoliths contribution range from 32% to 39%, cross from 4.6% to 6%, saddle from 23% to 27%, trapezoid from 5.8% to 8.6% and rondel from 5.6% to 9.8%. Bulliform and elongate phytoliths range from 1.4% to 5.2% and 5% to 9.2%. The percentage of cereal crop aggregates is from 1.2% to 4%. Cyperaceae phytoliths range from 1% to 2.9% palm phytolith was also noticed at one layer. Trichomes and dicot types range from 1% to 4% and 0.6% to 2%. Unidentified forms range from 0.6% to 2.3%.

In this zone the value of Humidity aridity index was higher than preceding zones, ranging from 37% to 40.6%. Highest iph value at the upper part was noticed 53%.
Zone V (HPT V)

Similarly like earlier zones this zone too shows dominance of GSSCs ranging from 81% to 84%, highest in the whole profile. Among GSSCs lobate phytolith range from 28% to 36%, cross from 3.2% to 4.2%, saddle from 27.5% to 37%, trapezoid from 5.8% to 8% and rondel from 7% to 8%. Cereal crop aggregates range from 2% to 4.5%. Other grass phytoliths like Bulliforms and elongates account from 2% to 3.2%, while trichomes and dicot types range from 2.3% to 4.5% and from 0.6 to 1.6%. Cyperaceae achenes were observed but proportion was very low. Unidentified forms were noticed from 1.6% to 2.6%.

The Humidity aridity index was highest in this zone, in whole profile recorded from 41.5% to 44.5%.

3.2.5 Isotope analysis (δ¹³C)

The δ¹³C values in profile vary from −19.3 to −11.0‰ covering a range of 8.3‰ (Table 3.2.2). While the TOC in the de-carbonated samples of profile ranges from 0.34 to 1.12% showing significant enrichment in carbon. The TN in the bulk samples shows variation which ranges from 0.03 to 0.07% (Table 3.2.2).

The C/N ratio in the profile range between 7 and 20 with average value of 13. Overall, C/N ratios indicate sources of organic matter is from land plants as well as aquatic plant or bacteria in which the high ratio ~20 indicate dominant source of organic matter is from land plants whereas low ratio ~6 suggests dominance of aquatic organic material.

The C₄ and C₃ abundance was also calculated, C₄ abundance ranges from 62.2% to 100% and C₃ abundance range from 0 to 38% in the whole profile (Table 3.2.2 & Fig. 3.2.7)
Zone I-In this zone $\delta^{13}$C range from -19.3 to -14‰ and carbon percentage range from 0.34 % to 0.40 %. The C$_4$ and C$_3$ abundance was calculated which range from 62.3% to 92.3% for C$_4$ and from 7.7% to 32 % for C$_3$ vegetation. The C/N ratio in this zone range from 9 to 13.

Zone II-In this zone $\delta^{13}$C range from -19.05 to 16.07‰ and carbon percentage vary from 0.56 % to 0.86 %. Here C$_4$ abundance ranges from 63.5% to 86 % and C$_3$ abundance range from 20 to 36%. The C/N ratio in zone II range from 13 to 17.

Zone III-This zone shows $\delta^{13}$C values range from -19.28 to 13.17‰ and carbon percentage from 0.38% to 0.86%. The C$_4$ abundance varies from 62.2 % to 96.8 % and C3 abundance is from 3.2 % to 38%. The C/N ratio in zone III range from 11 to 17.

Zone IV-In this zone $\delta^{13}$C range from -17.35 to 15.74‰ and carbon percentage from 0.52% to 0.73%. In this zone C$_4$ abundance range from 73.2% to 79.1 % and C$_3$ abundance varies from 18% to 27 %. The C/N ratio in zone IV range from 10 to 21.

Zone V-In this zone the $\delta^{13}$C varies from -14.29 to -11.01‰ and Carbon percentage is from 0.78 % to 1.12%. In this zone C$_4$ abundance is highest then earlier zones ranging from 90.2 % to 109% while C$_3$ abundance is lowest ranging from -9 % to 9.8 %. The C/N ratio in zone V range from 12 to 14.

Sources of organic matter and associated biogeochemical changes within the sedimentary section can be assessed by elemental (TOC and TN) and stable isotope ($\delta^{13}$C) signatures. In the whole profile, TOC/TN varies from 7.1 to 21.2 (mean = 13±3.3) (Table 3.2.2) with distinct fluctuations. The plot between TOC and TN (Fig. 3.2.8) shows a positive relationship which indicates that both are derived from similar organically derived sources.
<table>
<thead>
<tr>
<th>Layer</th>
<th>δ13C (%; VPDB)</th>
<th>C%</th>
<th>N%</th>
<th>TOC/TN</th>
<th>Relative abundance of C₄ plants (%)</th>
<th>Relative abundance of C₃ plants (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-14.3</td>
<td>0.94</td>
<td>0.07</td>
<td>12.8</td>
<td>90.2</td>
<td>9.8</td>
</tr>
<tr>
<td>2</td>
<td>-14.3</td>
<td>0.83</td>
<td>0.06</td>
<td>14.2</td>
<td>90.4</td>
<td>9.6</td>
</tr>
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<td>3</td>
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<td>0.78</td>
<td>0.05</td>
<td>14.4</td>
<td>90.3</td>
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</tr>
<tr>
<td>4</td>
<td>-11</td>
<td>1.12</td>
<td>0.05</td>
<td>21.0</td>
<td>109</td>
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</tr>
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<td>0.05</td>
<td>16.0</td>
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<td>6</td>
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<td>0.05</td>
<td>11.0</td>
<td>79.1</td>
<td>21</td>
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<tr>
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<td>0.62</td>
<td>0.06</td>
<td>10.0</td>
<td>82.3</td>
<td>18</td>
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<tr>
<td>8</td>
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<td>0.06</td>
<td>10.5</td>
<td>73.2</td>
<td>27</td>
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<td>0.4</td>
<td>0.06</td>
<td>6.91</td>
<td>73</td>
<td>27</td>
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<td>0.06</td>
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<td>62.2</td>
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<tr>
<td>12</td>
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<td>0.38</td>
<td>0.05</td>
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<tr>
<td>13</td>
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<td>0.05</td>
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<td>96.8</td>
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<td>0.06</td>
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<td>0.06</td>
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<td>-16.1</td>
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<td>18</td>
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<td>75.1</td>
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<td>32</td>
</tr>
<tr>
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<tr>
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<td>0.04</td>
<td>11.0</td>
<td>62.3</td>
<td>38</td>
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<td>0.04</td>
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<td>0.34</td>
<td>0.04</td>
<td>9.3</td>
<td>92.3</td>
<td>7.7</td>
</tr>
</tbody>
</table>

Table 3.2.2: Value of δ¹³C, TOC, TN and C₄- C₃ abundance in HPT-II sequence.
Fig. 3.2.7 Graphical representation of $C_4$–$C_3$ abundance in HPT-II sequence.

Fig 3.2.8 The plot between TOC and TN values in HPT–II sequence, showing a positive relationship.
3.2.5 Ordination analysis

![Triplot showing the results from RDA analyses among the 4 parameters in Hetapatti](image)

Fig. 3.2.9 Triplot showing the results from RDA analyses among the 4 parameters in Hetapatti

First 4 axes of the principal components account for 69.5 % of total correlations in the data set and they are 29.7 %, 15.1 %, 13.7 % and 11.0 % (Fig. 3.2.9). Redundancy analysis, RDA has been performed to identify few explanatory variables among the 4 parameters such as C4, IPH, C/N ratio and age of the deposition. All the 4 explanatory variables constrained the variation till 41.2 % in the total correlations. Out of this 41.2 % constrained correlations, 28.2 % and 8.4 % correlations can be accounted by first 2 axes of RDA. However about 58.8 % of correlations were not able to explained by the 4 explanatory variables used in this study. From the permutation analysis, it is found that IPH (F-ratio: 8.41 and p-value: 0.5 %) and C4 (1.73 and 8.5 %) are the two important explanatory environmental parameters. Although Age and C/N ratio were shown to have higher F-ratio and lower p-value, the first i.e., Age is negatively correlated to and the other i.e., C/N is positively correlated to IPH and hence cannot be called independent explanatory variables. From this analysis, IPH seems to be a better environmental variable which can explain the most of the variability in the biotic (phytolith) data set.
Fig. 3.2.10 Various phytoliths obtained from HPT-II, (1-7) GSSCs; (8-10) Bulliform phytoliths; (11-12) Cyperaceae types; (13-14) elongate phytoliths and (15) silicified stomata
Fig. 3.2.11 Various grass phytoliths from HPT-II (1) Dicot origin; (2) cut phytolith; (3, 9, 13) undetermined; (4-10) crop aggregates; (11& 12) Fungal bodies
PART-III

3.3 KARELA JHEEL

3.3.1 Study area

The study site, Karela Jheel (Jheel is known as lake in local dialect) is an ox-bow lake which is located at Hulaskhera village near Lucknow (26º40′54″N, 81º10′38″E). This lake is adjacent to Hulaskhera archeological site (Fig. 3.3.1). The remarkable features of Ganga plain are presence of abandoned channels and meander cut-offs resulting into ox-bow lakes or ponds, supposed to be formed by disruption of fluvial channels due to tectonic activities. In this area a large number of ponds and lakes of varying extant is present, which are abandoned river channels. The Karela Lake is supposed to be originated as, cut-off meander of river Sai, which is now present at 10 km south of study site (Singh, 2005; Chauhan et. al., 2015). The lake is around 1km in circumference which is almost dry except for some water in the centre. During rainy season it gets filled by water and aids in irrigation of adjacent fields. According to revenue records, 3 decades back the lake was brimming with water, but gradually lake became shallow and attained its present form.

In general the region enjoys a humid subtropical type climate, largely influenced by South west monsoon, denoted as Cwa in the Köppen climate classification system. The annual rainfall is 896 mm and annual temperature ranges from 40°C to 45°C in summers and from 2°C to 24°C in winters (Kasim and Usman, 2016). There are four distinct seasons, spring (Mid February to Mid March), summer (Mid March to Mid June), rainy (end of June to the end of September) and winter season (November to the middle of February). This area receives its 80% of rainfall by Indian Summer Monsoon, while in winters due to western disturbances this region receives occasional
rains, though the atmosphere remains dry. The area is an example of high seasonality zone which is mainly covered by open grassland type interspersed scrubby forest strands (Champion and Seth, 1968). The vicinity of the lake is largely composed of open vegetation dominated by grasses with patchy occurrence of few trees. A detailed account of climate, flora/fauna and geology are given in Introduction part.

3.3.2 Brief Archeology of the adjacent site

The archeological excavation of an adjacent large mound on the southern flank of lake was carried by Archeological Survey of India. The survey retrieved a number of artifacts like coins, pottery pieces, terracotta images and brick structures which indicate human habitation around 1000 BC (3000 BP). These evidences indicate the settlement was a community of farmers and artisans. The cultural sequence revealed the existence of two successive cultures from 1000 BC to 700 BC, Black Slipped Ware (BSW) and Painted Grey Ware (PGW). These were succeeded by Northern Black Polished Ware (NBPW) from 700BC to 300 BC, then by various dynasties like Sunga – Kushana from 200 BC to AD 300, Gupta from AD 300-700. Finally Rajputana ruled the region from AD 700-1000. It is assumed a highly civilized culture flourished between 200 BC- AD 200, by AD 700 it declined and around AD 1000 it vanished from region (Tewari et al., 1996, Chauhan et al., 2015).
Fig. 3.3.1 Location map of Karela lake (after Tripathi et al., 2016)
Fig. 3.3.2 View of dried lake bed showing sampling site (modified after Tripathi et al., 2016)

Fig. 3.3.3 Lithological details of the sequence with radiocarbon dates (modified after Tripathi et al., 2016)
3.3.3 Chronology of the site

The conventional radiocarbon age obtained from BSIP (Chauhan et al., 2015), were used to construct an age depth model for Karela lake. The conventional radiocarbon dates are given in Table 3.3.1 and Table 3.3.2 depicts modelled age of palaeoecological/palaeoclimatic zone boundaries. The Bayesian age-depth model of the Karela Jheel is given in Fig. 3.3.4. In which the lighter and brighter color represents 95% probability distribution range, whereas the darker and narrower color represents 68% probability distribution range. The Open squares indicate the modelled age medians of palaeoecological zone boundaries. LB = lithological boundary. Calibrated age distributions of the four radiocarbon dates (Table 3.3.1) are plotted, with their calibrated medians shown in open circles.

<table>
<thead>
<tr>
<th>Lab code</th>
<th>Depth (cm)</th>
<th>Conventional radiocarbon age (yr BP)</th>
<th>Calibrated age 95% range (cal BP)</th>
<th>Calibrated age median (cal BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS-112</td>
<td>30-45</td>
<td>1970±107</td>
<td>2300-1627</td>
<td>1928</td>
</tr>
<tr>
<td>BS-113</td>
<td>90-105</td>
<td>3660±140</td>
<td>4412-3642</td>
<td>4003</td>
</tr>
<tr>
<td>BS-114</td>
<td>160-175</td>
<td>10360±110</td>
<td>12562-11809</td>
<td>12213</td>
</tr>
<tr>
<td>BS-115</td>
<td>245-260</td>
<td>13690±560</td>
<td>18182-15016</td>
<td>16566</td>
</tr>
</tbody>
</table>

* The radiocarbon dates were calibrated using OxCal v.4.2 (Bronk Ramsey, 1995) with IntCal 13 curve (Reimer et al., 2013).

Table 3.3.1 Radiocarbon dates from the Karela Jheel trench sequence and their calibration to calendar ages

<table>
<thead>
<tr>
<th>Zone boundary</th>
<th>Depth (cm)</th>
<th>Calibrated age, 95% range (cal BP)</th>
<th>Calibrated age, 68% range (cal BP)</th>
<th>Calibrated age median (cal BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z4 top</td>
<td>0</td>
<td>(-50)(-59)</td>
<td>(-50)(58)</td>
<td>(-54)</td>
</tr>
<tr>
<td>Z3/Z4 boundary</td>
<td>60</td>
<td>3341-2154</td>
<td>3129-2625</td>
<td>2858</td>
</tr>
<tr>
<td>Z2/Z3 boundary</td>
<td>110</td>
<td>6241-3649</td>
<td>4635-3941</td>
<td>4348</td>
</tr>
<tr>
<td>Z1/Z2 boundary</td>
<td>200</td>
<td>15507-12064</td>
<td>14473-12428</td>
<td>13663</td>
</tr>
<tr>
<td>Z1 bottom</td>
<td>260</td>
<td>18987-15118</td>
<td>17893-15998</td>
<td>16962</td>
</tr>
</tbody>
</table>

Table 3.3.2 Modelled age of palaeoecological/palaeoclimatic zone boundaries.
Fig. 3.3.4 The Bayesian age-depth model of the Karela Jheel (after Tripathi et al., 2016).
3.3.4 Analysis of various proxies-

The same core was used to study various proxies like phytoliths, diatoms, sponge spicules and thecamoebians to understand the past climatic variations. Then results were subjected to statistical analysis and four palaeoecological zones were identified based on the cluster analysis obtained using age-depth model. Zone wise names have assigned to each proxy like OPAZ (Opal Phytolith Association Zone), DAZ (Diatom Association Zone), TAZ (Thecamoebian Association Zone) and SSAZ (Sponge Spicule Association Zone). A detailed account of studied proxies is given below-

3.3.4.1 Phytolith analysis-

In the whole sequence only sediments from top to 200 cm depth yielded phytoliths. From 200 to 260 cm depth sediments did not yield any phytolith, probably due to preservation constraints (Fig.3.3.5). The phytoliths assemblage was dominated by Grass Silica Cells (GSSCs), but variety of phytolith types was less in comparison to Tokwa and Hetapatti site. Various GSSCs retrieved are bilobates, cross, saddles, rondels and trapezoids. Other grass phytoliths recorded are bulliforms and elongate types. Among non grass phytoliths like Cyperaceae achene seed phytoliths, cones and hat like projections were found along with Palmae (Arecaceae) phytoliths. While tracheids of dicot origin and verrucate spheres and were recorded bearing no taxonomic significance. Some common phytolith types are given in (Fig. 3.3.8, 1 -15). The majority of phytoliths in this area are likely to be derived from grasses so Humidity/Aridity index (Iph %) was used to access the climatic variations (Fig. 3.3.6a). Four Opal Phytolith Association zones (OPAZ) were identified (Fig. 3.3.5) as described below-
Results

OPAZ-I (260-200 cm): In this zone no phytoliths were recorded.

OPAZ-II (200-110 cm): This zone shows a high percentage of Poaceae phytoliths (Fig. 3.3.5). The GSSCs percentage ranges from 59%-78% (Fig. 3.3.6 b). While Non-GSSC forms like elongated phytoliths including both sinuate and smooth types and trichomes range from 7.5%-17%. The percentage of bulliform phytoliths was observed highest 22% in the upper part of this zone. Besides this the bulliform phytoliths of rice were also retrieved along with some crop aggregates, indicating initiation of agricultural practices. Among non GSSCs, Cyperaceae phytoliths range from 3%-4.5 % and the Palmae (Arecace) phytoliths range from 1.3%-3%. While tracheids, Verrucate spheres, fern phytoliths were found ≤1%.

The Humidity Aridity Index (Iph%) ranges from 18% -27%, being lowest around in the whole profile (Fig. 3.3.5a).

OPAZ-III (110-60 cm): This zone like preceding zones shows dominance of Poaceae phytoliths. The GSSC percentage ranges between 57%-61% while non-GSSC types ranges from 10%-12%. Bulliform phytoliths ranged from 15%-18%. Crop aggregates and rice phytoliths were also retrieved. Cyperaceae morphotypes were observed between 2.5% and 5%. While other forms present in low percentage (< 1%) like tracheids, verrucate spheres. In this zone no fern and palm phytoliths were observed.

There is a slight increase in Humidity Aridity index (Iph%) which range between 28%-36%.
Fig. 3.3.5  Graphical representation of all the proxy data from the Karela (Jheel) Lake sequence (after Tripathi et al., 2016.)
Fig. 3.3.6 (a) Humidity/Aridity index (Iph %) (b) Percentage of Grass silica short cells (GSSCs). (after Tripathi et al., 2016)

OPAZ-IV (60-0 cm): In this zone too, Poaceae phytoliths dominated, showing highest percentage of GSSC ranging from 58%-65% (Fig. 3.3.5). The non-GSSCs forms were present from 9% to 12%. The bulliform cells were found in low percentage ranging from 8%-14%. Cyperaceae phytolith percentage was 2.5%-3.5%. No fern phytoliths and verrucate spheres were noticed.

The Humidity Aridity index (Iph %) is highest in this zone ranging from 44% to 49%.

3.3.4.2 Diatom Analysis

Like phytoliths, diatoms were also recorded from only from 0-200cm depth only (Fig. 3.3.5). Diatom assemblage was composed of both pennate (benthic) and centric forms.
The diatom population was dominated by benthic forms like *Eunotia* species followed by varying proportions of *Achnanthes*, *Achnanthisidium*, *Amphora*, *Anomoeoneis*, *Aulacoseira*, *Brachysira*, *Bacillaria*, *Caloneis*, *Craticula*, *Cyclotella* (planktonic), *Cymbella*, *Diploneis*, *Gomphonema*, *Hantzschia*, *Navicula*, *Nitzschia*, *Neidium*, *Pinnularia*, *Tabellaria*, *Rhopalodia*, *Stauroneis*, *Surirella*, *Synedra*, and *Tabellaria* (Fig. 3.3.9). Four Diatom Association Zones (DAZ) were identified (Fig. 3.3.5):

**DAZ-I (260-200 cm):** In this zone, the diatoms were not found.

**DAZ-II (200-110 cm):** High proportion of diatoms were noticed in this zone. These comprise of *Eunotia* and *Aulacoseira* along little variations in *Cyclotella*, *Diploneis*, *Gomphonema*, *Navicula*, *Nitzschia*, and *Tabellaria* etc. *Aulacoseira* and *Eunotia* counts were found higher. Occasionally *Gomphonema Navicula*, and *Nitzschia* forms were found.

**DAZ-III (110-60 cm):** In this zone *Eunotia* is the dominant diatom taxa with minor variations in the *Navicula*, *Nitzschia*, *Gomphonema*, *Tabellaria* forms, while *Aulacoseira* is absent. In this zone the diversity of diatom species is higher but the counts were low. Higher *Eunotia* counts and and lower counts of *Navicula*, *Caloneis*, *Stauroneis* were noticed. The absence of *Aulacoseira* in this zone indicates shallowing of the lake level.

**DAZ-IV (60-0 cm):** In this zone, *Eunotia* counts were low but still it was dominant. However diversity of *Eunotia* sp. was reduced. Varying proportions of, *Achnanthisidium*, *Brachysira*, *Bacillaria*, *Caloneis*, *Hantzschia*, *Navicula*, *Neidium*, *Nitzschia*, etc. while *Amphora*, *Aulacoseira*, *Diploneis*, *Gomphonema*, *Stauroneis*, and *Surirella* forms were absent. Proportions of *Achnanthisidium*, *Bacillaria*,
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Brachysira, Caloneis, Hantzschia, Navicula, Neidium, Nitzschia, Pinnularia, Tabellaria forms were increased probably due to enhanced eutrophication in the lake.

3.3.4.3 Thecamoebian analysis-

Thecamoebians were present in all 26 samples from top to bottom. (Fig. 3.3.5). In the whole profile total Twenty one species were found in which two species were filose testate amoebae and nineteen species were lobose type. The genera Centropyxis including 7 species and Arcella including 5 species were dominant in the whole profile (3.3.10). In the whole profile Four Thecamoebian Association Zones (TAZ) were identified (Fig.3.3.5)-

TAZ-I (260-200 cm): In this zone, three genera were found Centropyxis (63.8%) which dominated and followed by Cyclopyxis (34.9%) and Trinema lineare (1.1%). The percentage of each species was, C. aculeata ‘aculeata’ (4.3%), C. aculeata ‘spinosa’ (3.8%), Centropyxis aerophila (25.5%), C. aerophila ‘sylvatica’ (17.4%), C. laevigata (6.5%), C. sphaginicola, (6.3%) and Cyclopyxis kahli (34.9 %).

TAZ-II (200-110 cm): In this zone diverse type of testate amoebae were recorded like Arcella. artocrea (5.0%), A. discoidea (7.2%), A. gibbosa (2.4%), A. megastoma (2.5%), A. vulgaris (4.6%), C. aculeata ‘aculeata’ (12.1%), C. aculeata ‘spinosa’ (0.9%), Centropyxis aerophila (11.0%), C. aerophila ‘sylvatica’ (6.0%), C. laevigata (8.2%), C. sphaginicola (5.2%), Cyclopyxis kahlii (13.6%), Cucurbitella (3.2%), D. elegans (2.6%), Diffugia lanceolata (2.7%) D. pulex (3.4%), Euglypha (2.9%), Lesqueresia (0.1%), and Trigonopyxis arcula (1.0%), Trinema lineare (4.1%).

TAZ-III (110-60 cm): This zone exhibit high frequency of Centropyxis aerophila (38.7%), followed by C. aerophila ‘sylvatica’ (6.3%), C. sphaginicola (12.6%), C. aculeata ‘aculeata’ (1.3%) C. aculeata ‘spinosa’ (2.7%) C. laevigata (4.2%), A.
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discoides (1.4%), A. artocrea (1.3%), Trigonopyxis arcula (0.4%), Cyclopyxis kahlrii (3.6%), Difflugia pulex (0.4%), Euglypha (2%), and Trinema lineare (24.1%).

TAZ-IV (60-0 cm): In this zone percentage of Centropyxis aerophila was highest (11.6%) followed by C. aerophila ‘sylvatica’ (5.0%), C. sphaginicola (4.5%), C. constricta (3.0%), C. aculeata ‘aculeata’ (9.7%), C. aculeata ‘spinosa’ (14.7%), C. laevigata (12.2%), Arcella megastoma (6.6%), A. vulgaris (4.8%), A. gibbosa (2.1%), A. discoides (1.9%), A. artocrea (3.1), Trigonopyxis arcula (1.4%), Cyclopyxis kahlrii (8.7%), Difflugia lanceolata (0.8%), Difflugia pulex (2.4%), Difflugia elegans (2.9%), Lesqueresia (0.4%), Euglypha (1.4%) and Trinema lineare (2.5%).

3.3.4.4 Sponge spicule analysis

In the whole profile sponge spicules were retrieved only from 0 to 200 cm depth, like phytoliths and diatoms. Various types of sponge spicules were found in sediment which include Megascleres, Microscleres and Gemmoscleres (Fig. 3.3.8, 16-24). Based on the morphotypes and depth four Siliceous Spicule Association Zones (SSAZ) were constructed (Fig. 3.3.5).

SSAZ-I (260-200 cm): No sponge spicules were retrieved from this zone.

SSAZ-II (200-110 cm): In this zone high diversity and high frequency of Megascleres, Microscleres and Gemmoscleres were noticed.

SSAZ-III (110-60 cm): This zone shows a decreased diversity and frequency of sponge spicules in comparison to earlier zone.

SSAZ-IV (60-0 cm): This zone show very low frequency and diversity of sponge spicules, probably due to an increase in water table, because in shallow waters sponges are less common.
3.3.5 Ordination Analysis

The ordination analysis on the thecamoebian data set and humidity aridity index was performed, it was noticed that samples from layer 1 to 3 are similar (highest aridity) and samples from layer 15 to 19 are alike (lowest). On the other hand samples from layer 5 to 13 and from layer 20 to 26 are same in terms of medium index values. This study shows that Genus *Centropyxis aculeata* ‘spinosa’ was most positively influenced by humidity aridity index while and the most negatively influenced one is *Difflugia lanceolata* (Fig. 3.3.7 a).

However, taking phytolith data and humidity aridity index, the ordination analysis shows that samples from layer 1 to 5 are similar (highest) and from layers 18 to 20 are similar (lowest). It was found, among phytoliths the saddle morphotype was most positively influenced by this index (Fig. 3.3.7 b). The influence of humidity aridity index on diatoms was found insignificant (p-value = 0.12) whereas, age/depth has some influence (21.3 %; p-value = 0.070) on the diatoms. The ordination analysis shows a probability presence of diatom sp. *Aulacoseira* is more at deeper depths whereas, *Gomphonema* is tend to found least near the shallow depth (Fig. 3.3.7 c). The ordination analysis did not show any significant influence of humidity aridity index on sponge spicules (Fig. 3.3.7 d).
Fig. 3.3.7 Triplot showing the results from principal component analyses (PCA) of a) thecamoebian, b) phytolith, c) diatom and d) sponge spicules. The centralized data (of both response data and explanatory data) were used for the analyses. Each green line indicates a particular centralized IPH value. For clarity, only first three letters of each species/types were used, as - (a)Thecamoebians: Cen=Centropyxis, Cas=C. aerophila 'sylvatica', Csp=C.sphaginicolal, Cau=Centropyxis aculeata 'aculeata', Cpi=Centropyxis aculeata 'spinosa', Con=C. constricta, Cla=C. laevigata, Cyc=Cyclopyxis kahlil, Tri=Trigonopyxis arcula, Ame=Arcella megastoma, Aar=A.arctica, Avu=A. vulgaris, Adi= A. discoides, Agi=A. gibbosa, Dif=Difflugia lanceolata, Dle=D. elegans, Dpu=Difflugia pulex, Tri=Trinema lineare, Eug=Euglypha, Cuc=Cucurbitella, Les=Lesqueresia. (b) Phytoliths: BIL=Bilobate, CRO=cross, SAD=Saddle, TRA=Trapezoid, RON=Rondel, BUL=Bulliform, ELO=Elongate, TRI=Trichome, OGC=Other grass cells, ACH=Achene, PAL=Palm, FEV=Fern vascular, VER=verrucate sphere, TRA=Tracheid, UND= Undertermined. (c) Diatoms: Nav=Navicula, Nit=Nitzschia, Eun=Eunotia, Nei= Neidium,Cal =Caloneis, Bac=Baccilaria, Ano=Anomoneis, Gom=Gomphonema, Tab=Tabellaria, Pin=Pinnularia, Ach=Achnanthes, Han=Hantzschia, Bra=Brachysira, Achn=Achnanthidium, Sta=Stauroneis, Syn=Synedra, Cym-Cymbella, Amp=Amphora, Sur= Surirella, Cra=Cricula, Cyc=Cyclotella, Dip=Diploneis, Aul=Aulacoseira. Values of aridity are shown with green colour lines in each plot. (d) Sponge spicules: Meg=Megascleres, Mic= Microscleres, Gem=Gemmoscleres. (after Tripathi et al., 2016)
Fig. 3.3.8 Various phytolith morphotypes and sponge spicules obtained from Karela Lake sequence (1) bilobate; (2) cross; (3) saddle; (4) rondel (5,6,7) bulliform; (8,9) achene phytoliths of Cyperaceae; (10) elongate dendritic phytolith; (11) spiral tracheid (12-15); grass aggregates; (16) Megascleres with fern spore; (17) Gemmosclere with birotules; (18) microsclere; (19) megascleres; (20) Chrysophycean cyst attached with Megasclere; (21) various spicules and bulliform cell; (22) a detached birotule of gemmosclere; (23) unknown spicule and (24) mega and microscleres (after Tripathi et al., 2016)
Fig. 3.3.9 Types of diatoms obtained from Karela lake (1) Stauroneis anceps; (2) Amphora ovalis (girdle view); (3) Eunotia sp.; (4) Pinnularia gibba; (5) Frustulia sp.; (6) Gomphonema parvulum; (7) Eunotia sp.; (8) Cyclotella meneghiniana; (9) Encyonema sp.; (10) Diploneis smithii; (11) Nitzschia sp.; (12) Tabularia sp; (13) Navicula sp.; (14) Rhopalodia sp. and (15) Craticula cuspidate. (after Tripathi et al., 2016)
Fig. 3.3.10 Types of thecamoebians obtained from Karela Lake: (1) Centropyxis aerophila; (2) C. aerophila ‘sylvatica’; (3) C. sphaginicola; (4) C. constricta; (5) C. aculeata ‘aculeata’; (6) C. aculeata ‘spinosa’; (7,8) C. laevigata; (9) Arcella megastoma; (10) A. vulgaris; (11,12) A. gibbosa; (13,14) A. discoidea; (15,16) A. artocrea; (17,18) Trigonopyxis arcula; (19) Cyclopyxis kahlii; (20) Difflugia lanceolata; (21) Difflugia pulex; (22) Difflugia elegans; (23) Cucurbitella; (24) Lesqueresia; (25) Euglypha and (26) Trinema lineare. The scale given in the figure is 10 mm. (after Tripathi et al., 2016)