

Unravelling the hidden truth from Vigukot in the Great Rann of Kachchh, western India by surface and sub-surface mapping

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The Vigukot Fort is in ruins lying along the northern fringe of the Great Rann of Kachchh, Gujarat, India. This settlement is located on the left bank of the palaeochannel of the Nara river – a tributary of River Indus. We conducted Real Time Kinematics and Ground Penetrating Radar (GPR) surveys for surface and subsurface. The digital elevation model (DEM) reveals an average elevation ranging from 2 to 4 m from mean sea-level. Two elevated areas: EA1 (site 1) and EA2 (site 2) represent residential areas in the township. EA1 located on higher ground (3–4 m amsl) in the eastern portion comprised of a housing complex of larger dimensions. Two rooms with an area of 650 and 250 sq. ft respectively, possibly indicative of living rooms attached with a courtyard suggest that high-ranked authorities occupied this portion of the township. EA2 with low-elevation (3 m amsl) marked by a smaller residential complex may be indicative of a trade complex along the western flank of the township. On the basis of 3D GPR survey we infer two levels of settlement at EA1 and one level of settlement at EA2. EA1 remained as a residential complex as reflected from both the levels, whereas EA2 was a trading complex close to the main gateway G1. Probably two scenarios prevailed: (1) Both areas flourished likewise at the first level and might have got disturbed by an earthquake; later EA1 may have been reoccupied while EA2 was left to be an open trading complex at the second level (recent). (2) During the first level of occupancy, EA1 was probably a residential complex (having enclosed walls), and EA2 might be the trading complex (with partially enclosed walls lying opposite to G1). Both the areas were affected during the disaster, and the second level of occupancy EA1 was rebuilt and occupied, whereas EA2 was used without renovation. Moreover, the 1819 earthquake probably destroyed both the areas completely and led to their abandonment.

Keywords: Ground Penetrating Radar survey, regression of settlements, surface and subsurface mapping.

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Introduction

MAJOR river valleys have sustained a large number of civilizations and empires across the world. One such example is the Indus Valley Civilization that flourished along the banks of the Indus and Saraswati rivers in the northwestern part of the Indian subcontinent – one of the mighty rivers emerging from Himalaya (Figure 1 a). The Harappan Civilization flourished from 2600 to 1800 BCE. It was well known for its urban planning with baked brick houses, extensive drainage and water management systems, and for its art and craft¹. The Harappan Civilization declined probably because of natural calamities such as floods, earthquakes, high-amplitude monsoonal fluctuations, etc.

Natural disasters are hazardous; they have resulted in the destruction of major settlements around the world, and have also led to complete desertion of a few ancient sites. However, on a positive note, a few events may result in the development of better platforms with replenishment of the resources required for the re-emergence of existing settlements or for re-occupation by a new community. After the decline of the Indus Civilization, the rise of the Achaemenians was seen around 500 BCE, followed by Alexander's conquest around BCE 320 (ref. 2). The eastern bank of the Indus river was under the Mauryans around 300 BCE, and was taken over by Bactrian Greeks in 180 BCE followed the rule of Scythians, Parthians, Kushans and Sassanians of Iran till CE 350 (ref. 2). Around, 400 CE, the region was occupied by the Guptas and later came under Rai dynasty, Brahman dynasty and was encountered by Arab conquest around 700 CE (ref. 2). Then came the independent kingdoms like Habaris, Soomras, Sammas, Kalhoras and Talpurs till 1800 CE, and later the British assumed power². Hence, the diverse rule over the region for a long time has left behind a large body of ruins of minor settlements that are found distributed around the lower reaches of the Indus river². As of now, these sites remain as abandoned fortifications with well-preserved architectural features. Along the east bank of the Nara channel, few abandoned fortified sites can be

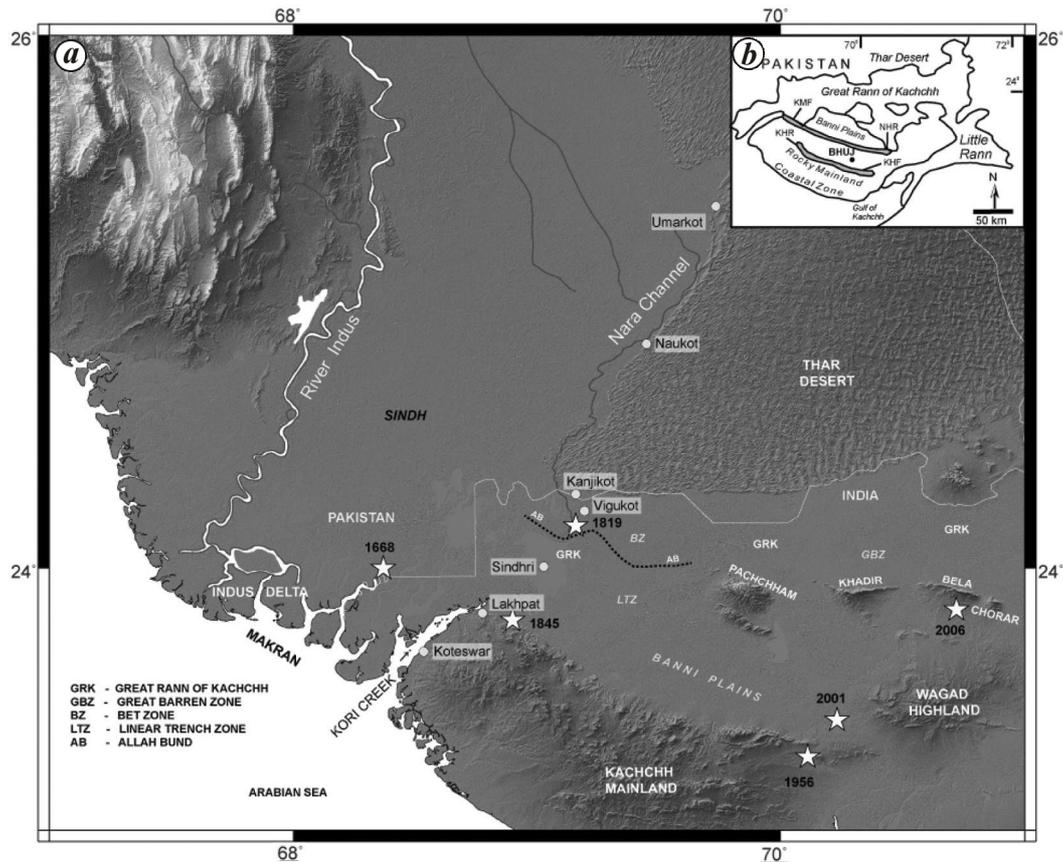


Figure 1. *a*, DEM showing the Indus delta associated with River Indus and northwest India indicating various geomorphic divisions of both Kachchh and Great Rann of Kachchh, Gujarat. Locations of ancient sites that existed along the left bank of River Nara, Rann and west of Kachchh Mainland are shown in green circles and the earthquake epicentres are shown as yellow stars. *b*, Outline map showing major geomorphic zones in Kachchh.

seen, which represent individual settlements (Figures 1 *a* and 2 *a*). These sites are unexplored and completely isolated due to the prevailing hostile conditions. The names of each site end with similar letters 'kot', which literally means 'fort'. The site near the ancient shoreline is Vigukot, which was earlier known as 'Veego-gud' (Figure 2 *a-c*). This was once a port city carrying out maritime trading activity. The gems and precious stones available in the region supported this activity. The river flowing by the settlement debouches into the sea, thus facilitating easy access to maritime movement (Figure 2 *a* and *c*).

Regression of settlements in Vigukot

Vigukot located in the Great Rann of Kachchh (GRK), was once an ancient city lying on the shore of northwestern Kachchh (Figures 1 and 2)³. Obviously the Kachchh region is arid and unsuitable for agricultural activity. It is evident that the settlements in Kachchh were likely to exploit the trading options using available marine resources⁴. According to Wynne³, Vigukot, Sindhri (Sindree) and Rahim ka Bazar (Roamaka Bazar) flourished on

the banks of the River Nara (Nurrah or Pooraun river), which has branched from the River Indus at Sukkur, Pakistan (Figures 1 *a* and 2 *a-c*). However, the earthquake event of 1819 CE affected the people of northwest Kachchh (Figures 1 and 2).

During 1700s, the area located north of Lakhpat (Lukput) was known as 'Sayra or Sahra', which was a fertile rice-producing country³ (Figure 2 *a* and *c*). However, the land of Sayra became a part of the Rann in early 1800s due to the construction of bunds along the river, thereby obstructing the course of freshwater source. The dry conditions prevailed until the occurrence of sudden depression near Sindhri towards the north of Lakhpat and in the vicinity of Nara river which was ensued due to the occurrence of the great earthquake on 16 June of 1819 (ref. 3; Figures 1 *a* and 2 *a-c*). The depression resulted in the inundation of Sindhri by the ocean currents (Figure 2 *b*). The depth of the shore dramatically increased from 2 to 6 m at Lakhpat³. Along with the submergence of Sindhri, the landscape marked by flat land north of Sindhri was uplifted resulting in the formation of 6–9 m high south-facing scarp extending for about 80–90 km in east-west direction⁵⁻⁸ (Figure 2 *a* and *c*). The natives called this

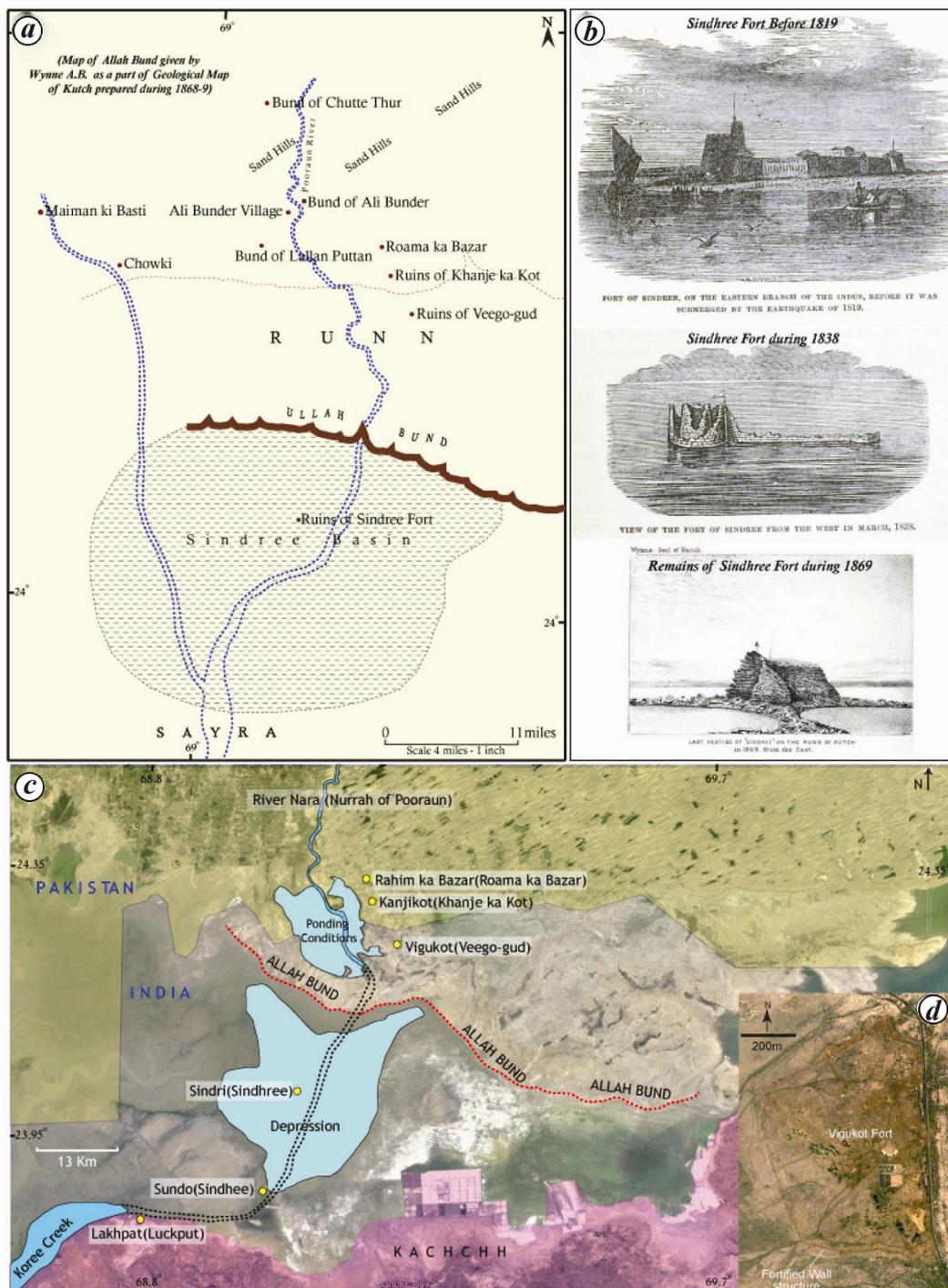


Figure 2. *a*, Map of Rann by A. B. Wynne as a part of the geological map of Kachchh prepared during 1868–69 showing the past scenario after the formation of Allah Bund. *b*, Drawings of Sindree by Charles Lyell and Alexander Burnes (before 1819 and during 1838) and by A. B. Wynne (during 1869) illustrating the damage. *c*, Google Earth imagery of present-day Great Rann of Kachchh elucidating the surface manifestations of past tectonic activity that took place in the region. Red dotted line indicates the Allah Bund and black dotted line shows traces of the palaeochannel, which is now lying as a dry channel in the Great Rann of Kachchh. The Allah Bund uplift resulted in the ponding conditions of Nara channel and led to the depression in the Sindhee region. *d*, Google Earth image showing fortified structure of Vigukot Fort.

mound as ‘Allah bund’, which disrupted the Nara river that flowed into the Arabian Sea (Figure 2 *c*)³. Due to the occurrence of the above unprecedented earthquake event, the river shoaled thereby impeding navigation. Hence, the

people of Vigukot moved south and settled at *Sindhee* or *Sundo* and in due course moved further down the stream to Lakhpat following the limits of deeper ocean water (Figure 2 *c*). Following another earthquake of 1845, the

Lakhpat fort collapsed and eventually the site was deserted.

The only potable water resource available in the proximity of the region was from Nara river, which was used for both livelihood and trading purposes as it emptied itself into then existing Arabian Sea in the area of the Great Rann of Kachchh through the Kori Creek (Figures 1 *a* and 2 *a* and *c*). However, the course of the Nara river was disrupted due the uplift of Allah Bund during the 1819 CE earthquake resulting in the damming of the river, and formation of local ponding conditions north of the uplifted land mass (Figure 2 *c*)⁹. Due to the occurrence of abrupt activity, the Nara, originally an independent river is now a dry riverbed. With these changes in the drainage and morphology of the landscape, the living conditions deteriorated, and the settlements in the vicinity of the river banks gradually declined and vanished. The dried-up Nara channel is quite well preserved in the west, while the eastern extremities have been altered by aeolian activities in the region. According to Malik *et al.*⁹, the delta zone was supposed to have extended up to the Kachchh Mainland during mid-Holocene (6–4 ka), after which continuous tectonic activities along the faults and transgression of sea led to the present-day configuration of the landscape. It has been suggested that the Kachchh region in its present condition is one of the most hostile terrains in the Indian subcontinent that does not favour human settlement, because of hot climate, sparse rainfall, non-availability of freshwater, etc.³. However, the presence of remnants of ancient settlements, viz. Dholavira, Junj Kuran, Sur Kotada, Vigukot, etc. clearly suggests that the area was well populated during the recent past. This further suggests that the Great Rann of Kachchh, which is presently occupied by a thick encrustation of salt was navigable with substantial number of water bodies that facilitated harbour for commercial trade with adjoining Gulf countries³. Therefore, it is possible that climate and tectonics were probably the two factors responsible in shaping the present landscape of the Rann of Kachchh.

Rajendran and Rajendran¹⁰ have carried out trenching studies in Vigukot to understand the 1819 CE earthquake and have found two levels of settlement, the younger one being destroyed by the 1819 CE earthquake and the older one by a similar sized earthquake that occurred around 800–1000 years ago. In this article, we report the results of our investigations carried out at Vigukot with an aim to understand the alignment and architecture of the settlement based on signatures on the surface, and to know the buried ancient structure preserved in the sub-surface (Figure 1 *a*).

Geomorphology of the Great Rann of Kachchh

The Great Rann of Kachchh comprises of a unique tract of land characterized by monotonous flat surface of dark

silt, clay and white salt incrustations. It stretches over an area of ~16,000 sq. km and is bounded by the Thar Desert in the north, Kachchh Mainland in the south, Aravalli Ranges to the east, and Indus Delta to the west¹¹ (Figures 1 *a*, *b* and 2 *a*, *c*). The GRK is divided into four major geomorphic units¹²: (i) the bet zone marks slightly elevated incised landscape above the tidal influence comprised of medium to fine micaceous sand; (ii) the linear trench zone is a narrow, low-lying terrain trending east–west extending from Kori Creek in the west to Pachcham Island in the east; (iii) the Banni Plain is a lowland occupied by mudflats between Kachchh Mainland and Pachcham, Wagad and Bela uplifts, and (iv) the great barren zone is a shallow depression towards the east of GRK (Figures 1 *a*, *b* and 2 *c*). During monsoon, a considerable portion of the Rann assumes the appearance of an extensive shallow pool of concentrated brine. The evolution of the Rann has remained a matter of speculation for researchers. However, it is believed that tectonism and eustasy were responsible for the present-day morphology of the Rann¹². Further, it has been suggested that the configuration of the Rann and its sediment characters clearly reveal the significant role played by successive uplift and subsidence along well-defined lineaments and faults during the Quaternary¹².

Historical seismicity

Kachchh lies in seismic zone V of the Seismic Zonation Map of India. Several earthquakes that have occurred in the Kachchh region along the E–W trending major faults from the Cenozoic have led to the evolution of the present landscape as well as structural pattern of the region. The record of earthquakes that occurred in Kachchh till today includes events with varying magnitudes, i.e. $3.5 \geq M_w \leq 7.8$ (refs 9, 13 and 14). The earthquake of 1668 ($M_w > 7$) caused sinking of 30,000 dwellings at Sanawani, Sindh Province, one of the largest Mughal towns^{15,16} (Figure 1). The first ever documented earthquake, the 1819 Allah Bund (M_w 7.8), was one of the largest and strongest earthquakes in the region and has resulted in the formation of 6–9 m high south-facing fault scarp with a rupture extending for about 80–90 km along the E–W strike (Figure 1)^{7,8}. The 1845 earthquake ($M_w > 7$) resulted in the flooding of Kori river and also uplifted Sunda area by 1 m located about 40 km south of Allah Bund^{17–19}. The 1956 Anjar earthquake (M_w 6.1) was a moderate magnitude event that occurred during post-instrumentation period with no surface rupture reported²⁰. One of the most damaging intraplate earthquakes was experienced on 26 January 2001 (M_w 7.6) that occurred in the failed rift of Kachchh on a blind thrust and resulted in vast destruction and casualties (Figure 1)^{14,21}. During 2006, a moderate magnitude earthquake of M_w 5.5 occurred in the Wagad Highland¹⁴.

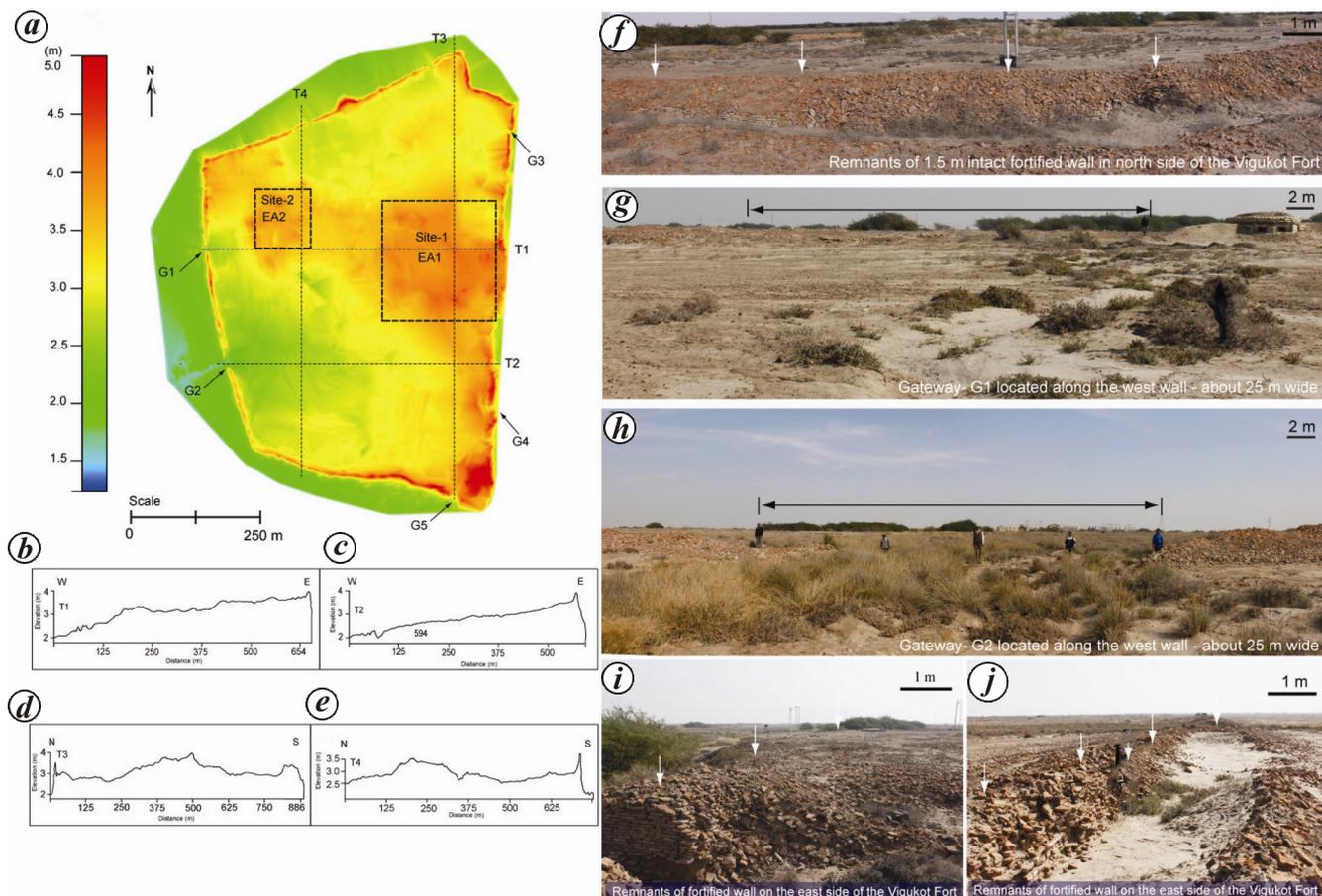


Figure 3. a, DEM of Vigukot showing the fortified area. A total of five gateways were identified – G1 and G2 on the western side; G3 and G4 on the eastern side, and G5 in the southeast corner. Surveyed sites: site 1 (EA1) and site 2 (EA2) are marked by box with black broken line. Length of east wall is about 0.80 km; west wall 0.60 km, north wall 0.60 km and south wall is 0.50 km. b, c, Topographic profiles T1 and T2 obtained from DEM in the E–W direction. d, e, Topographic profiles T3 and T4 obtained from DEM in N–S direction. f, Photograph showing remnant of 1.5 m intact fortified wall structure in the north side of Vigukot Fort. g, Gateway-G1 located along the west wall. It is about 25 m wide. h, Gateway-G2 located along the west-wall; it is also about 25 m wide. i, j, Remnants of fortified wall on the eastern side of the fort showing intact brick-walled structure.

Methodology

For an adequate analysis of any settlement pattern, data collected using geographic information systems (GIS) are the most advantageous²². Also, they provide the most sophisticated alternative for the tedious traditional excavation, recording and archival practices. The major advantage of on-site digital archaeology is that the past is elucidated with the highest degree of accuracy while taking care of most precious commodities like time and framework²². Likewise, archeological geophysics has garnered wide acceptance during the past decade and its roots lie in its potential ability in locating, mapping and imaging the buried remnants^{23,24}. One of the major advantages of using GPR amongst other geophysical techniques is that it is easy to carry out the non-destructive survey in an economical manner. Further advantage could also be attributed to its ability in generating three-dimensional georadar image of subsurface stratigraphy. This is true

exclusively for the huge amounts of reflection data available for three-dimensional processing^{23,25}. Moreover, sophisticated migration algorithms were developed to handle the data acquired through complex wave paths²⁶. In this context, detailed mapping was carried out at the ancient site of Vigukot with an aim: (a) to understand the architectural trends using integrated real time kinematic–global positioning system (RTK–GPS) survey (with Leica GS-14 GPS system) to map the surficial signatures of the older township, and (b) to conduct GPR survey (with GSSI SIR 3000) for subsurface mapping to know the existence of buried ancient structures, if any, preserved in the area (Figures 3–7).

For RTK–GPS survey measurements were carried out using two GPS receivers. A reference station was located over a fixed point and a rover was moved all around the site for recording the data intended for actual positioning (*X*, *Y* and *Z* coordinate) measurements. Close transect paths were followed in E–W and N–S directions to

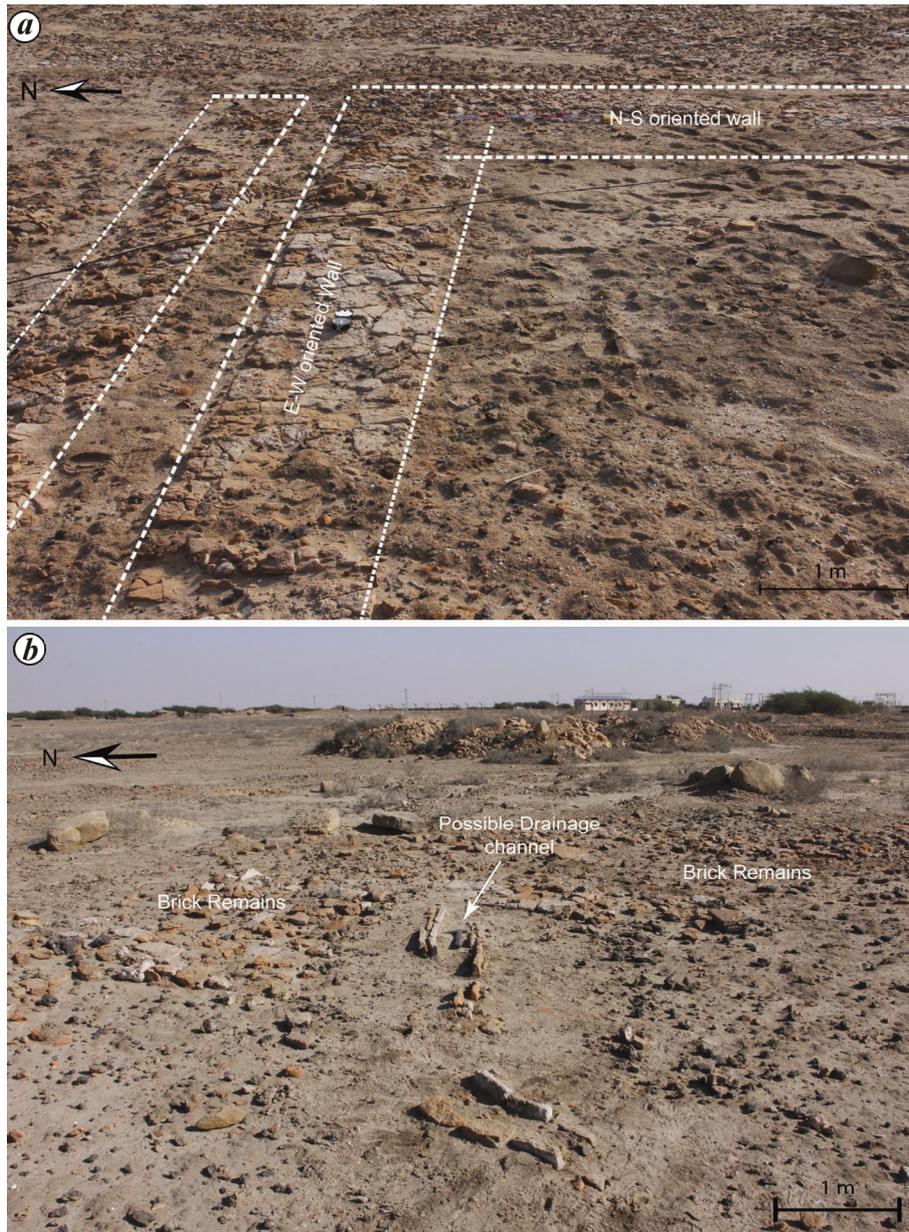


Figure 4. *a*, Photograph illustrating the alignment and orientation of remnants of the structures seen on the surface. *b*, Brick remains on the ground surface demonstrating the possible drainage outlet existing within the residence.

collect denser data points for generating high-resolution digital elevation model (DEM) of the area. The collected raw data were extracted from the field controller corresponding to the rover and processed in Leica Geo-Office (LGO). Then the DEM for the study area was prepared in Global Mapper using projected coordinate system (UTM Zone 42 N).

Based on the DEM, two sites were identified to carry out GPR studies – site-1: around the elevated portion on the eastern side, and site-2: towards the western side, with an aim to examine and compare the nature of subsurface structures (Figure 5). GPR is a non-destructive

and non-invasive method and is often considered ideal because of its capability to produce high-resolution images in real time²⁷. GPR works on the basis of the emission of electromagnetic waves and the reception of their reflections generated depending upon different material properties. The properties that guide the nature of electromagnetic energy in a medium are dielectric permittivity (ϵ), electrical conductivity (σ) and magnetic permeability (μ)²⁸. The selection of the optimal operating frequency for a GPR calls for an adjustment of spatial resolution, a function of frequency of the electromagnetic wave, and depth of penetration. The lower frequency

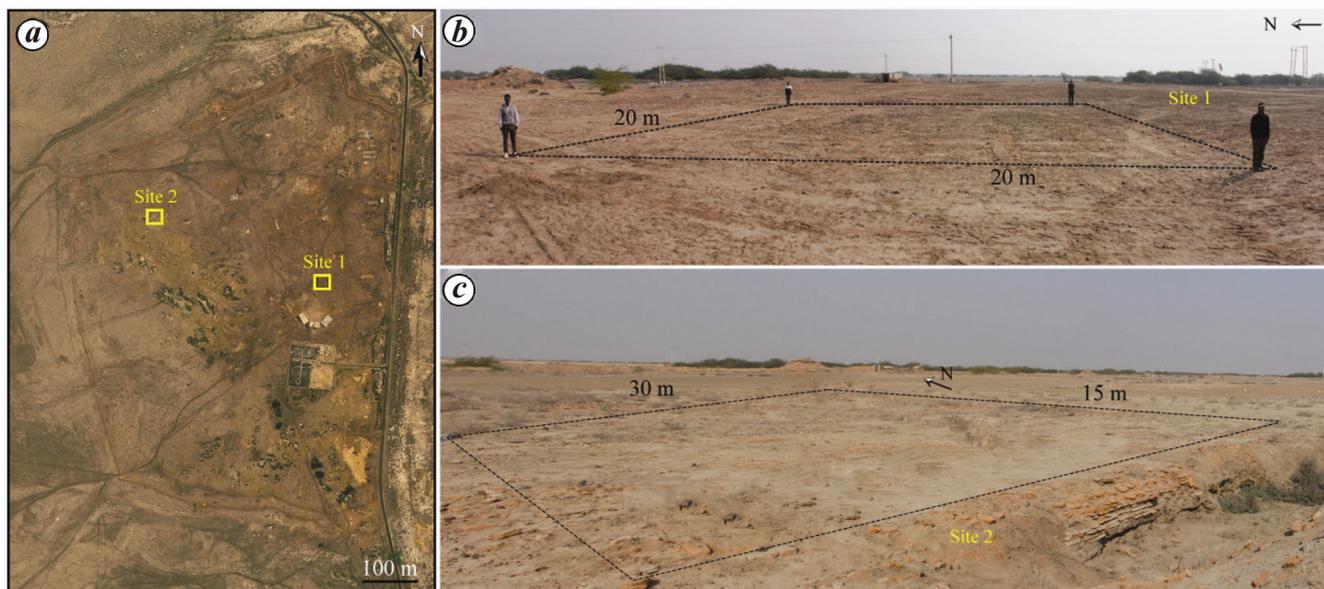


Figure 5. *a*, Google Earth image of Vigukot showing the two sites considered for GPR survey. *b*, 3D grid of 20 m × 20 m collected at site-1 using 200 MHz antenna of GSSI with 1 m × 1 m spacing. *c*, 3D grid of 30 m × 15 m collected at site-2 using 200 MHz antenna of GSSI with 1 m × 1 m spacing.

antennas generate a larger wavelength that enables the wave to penetrate to a greater depth, which in turn results in a low spatial resolution of the reflections. Whereas, the higher frequency antennas are suitable for collecting data limiting to shallow depth since they produce data with high spatial resolution²⁹. Thus, the antenna frequency is chosen considering the following three parameters: (i) desired lateral and vertical resolution; (ii) clutter limitations, and (iii) exploration depth, which control frequency selection. The 3D GPR survey was carried out in Quick 3D mode, which shows the propagation direction, depth and length of the stratigraphical subsurface features present in the survey area.

GPR profiles were collected with SIR-3000 system using 200 MHz shielded antenna, with a penetration depth (z) of 8 m, and a vertical resolution (V_r) of 0.26 m in common-offset continuous mode with Quick 3D module. Acquisition parameters were preset during fieldwork, which include position correction, high-pass and low-pass infinite impulse response (IIR) filters, and stacking to avoid delay in further processing. Filters are designed to change the shape of individual traces using mathematical manipulation, enhancing or eliminating certain features²⁹. The IIR filter is a recursive filter where the current output depends on previous outputs, whereas a finite impulse response (FIR) filter is a linear combination of a finite number of samples of the signal. In general, FIR is preferred in digital signal post-processing³⁰. The collected geo-radar profiles from Vigukot were processed with GSSI RADAN 6.5 post-processing software for the subsurface feature extraction and interpretation³¹. The geo-radar profiles were collected with 512 sample/scan, 16

bits/sample, 64 scans/s, 64 scans/m and dielectric constant 8.0. Considering that the area is comprised of finer sediments (mainly very fine sand–silt) these parameters were the most appropriate for mapping near subsurface stratigraphy. The parameters enabled us to reach a depth of ~6 m. The profiles were processed in the order starting from time-zero correction, application of filters and auto-gain restoration. Time-zero correction was applied to remove the uppermost high-amplitude reflections resulting from direct airwave (DW) and ground wave (GW), and for the successful realignment of underlying reflections. The low- and high-pass filters with background removal were used to alienate interference (noise) produced by extraneous objects such as vegetation, high-tension electric lines, if any, mobile phone signals, etc. Automatic gain control (AGC) was used to enhance the clarity of low-frequency features.

Surface mapping – RTK–GPS survey

A detailed mapping was carried out at Vigukot Fort with an integrated RTK–GPS to understand the topographical variations (Figure 3). The preliminary survey shows that the area had no standing structure from the past. The ruins of the fortified wall structure can be seen bordering the Vigukot Fort marked by a 1.0–1.5 m high brick boundary (Figure 3 *a–f*). The brick boundary has been partially modified by the border security force (BSF) unit.

Along the fortified wall structure with dimension of 0.8 km × 0.5 km, we observed at least five openings. While the two larger ones (G1 and G2) were along the

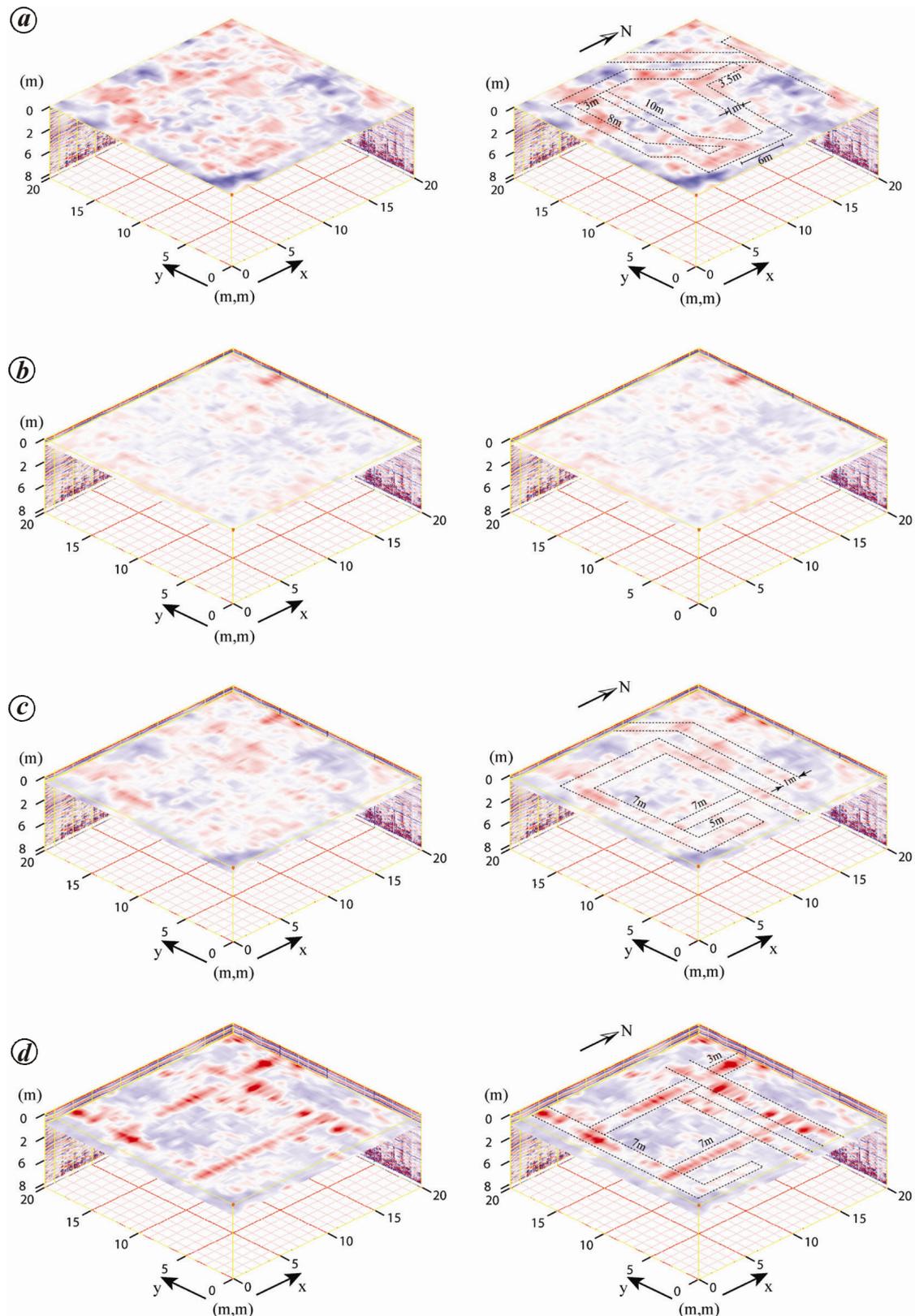


Figure 6. *a*, High-amplitude traces seen on the z slice at 0.2 m reveal a specific trend of alignment of the buried structure suggesting two enclosed wall structures of dimensions $10\text{ m} \times 6\text{ m}$ and $8\text{ m} \times 3\text{ m}$ respectively, with cross walled structures visible in NW–SE direction cutting across the corners of these EW- and NS-oriented walls. *b*, Traces of z slice moves at 0.45 m; the disintegration of cross walls is seen. *c*, At a depth of 0.56 m, a new pattern of wall can be seen where the cross wall joins an EW-orientated wall, and the size of the enclosure becomes large and merges into a single room of $7\text{ m} \times 7\text{ m}$. *d*, Pattern and size of the room remain the same with distinct EW-orientated walls till a depth of 3.8 m and disintegrate further. (Refer to Figures 3 and 5 for location of GPR profiles.)

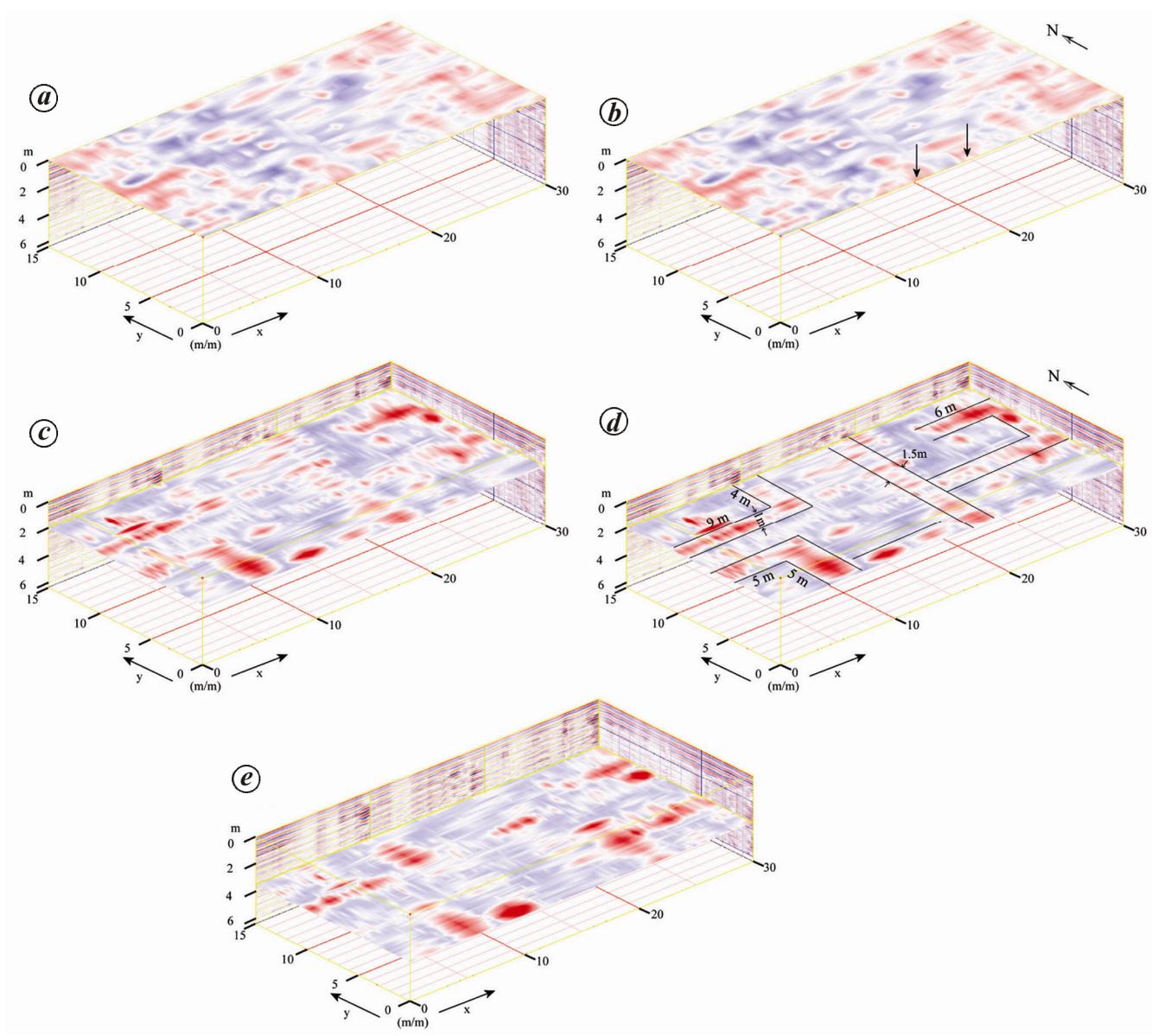


Figure 7. *a, b*, Depth slice at 0 m showing the walls exposed along the southern side of the grid and indicated in black arrows in *(b)*. *c, d*, At 2 m depth, distinct reflections are visible of width 1.5 m in NS direction and 1 m in EW direction. On the western edge of the grid, the adjacent structures of 9 m × 4 m and 5 m × 5 m can be seen as indicated in *(d)*. Also, a 1.5 m thick wall can be seen running in the NS direction at 20 m on the x-axis. Towards the eastern flank of the grid, another partially closed structure with an open wall of width 6 m in the EW direction can be seen. All the reflections continue till 3.5 m depth and starts disintegrating further as shown in *(e)*. (Refer to Figures 3 and 5 for location of GPR profiles.)

western side, two comparatively smaller ones (G3 and G4) were along the eastern side, and one near the eastern edge (G5) of the south wall (Figures 2 *c* and 3 *a-f*). G1 and G2 with 25 and 20 m of width respectively, may represent the major gateways to the city in historic times located on the left bank of Nara river (Figures 3 *a* and *c* and 4 *a*). The DEM generated from the RTK survey suggested that the eastern portion (elevated area; EA1) of the town is comparatively elevated, with a relative elevation ranging from 2 to 4 m (Figure 3 *a-e*). The western portion (EA2) is comparatively low with elevation ranging from 2 to 3 m. The variation in height can be well observed in

topographic profiles: T1 and T2 oriented in E–W direction and T3 and T4 in N–S direction (Figure 3 *a-e*). Being the lowest elevation point in the study area, presently small channels have developed along these two gateways (i.e. G1 and G2). We postulate that these openings might have served both as gateways for people and drainage outlets during the time when the site flourished (Figures 2 *a* and *c*, and 3 *a, g* and *h*).

Major part of the area was covered by silty-sand, but towards the eastern portion of the township, foundation of walls representing the buried structures were visible on the surface (Figures 3 *a* and 4 *a-b*). Most of the walls of

these structures were orientated along E–W and N–S directions enclosing rectangular or square-shaped areas (Figure 4a). These are indicative of well-planned residential quarters with larger dimensions, while smaller ones could be suggestive of shops in the downtown area. We also found 0.5 m wide narrow passage among the remains, which could be probably the drainage feeds (Figure 4b). All the above structures were made of burnt bricks of size 32 cm × 19 cm × 3.5 cm, and 30 cm × 20 cm × 4 cm. The use of bricks could be attributed to both non-availability of stones and abundance of clay in the Great Rann of Kachchh area. We found numerous weathered copper coins of diameter ranging from 0.5 to 1.0 cm scattered over the ground. This also clearly indicates the prevalence of active trade in ancient times with the countries adjoining the Arabian Sea. Along with these we also found ornamental stones, beads and broken pieces of glassware indicating an urban lifestyle. All these signatures explicitly indicate that the people were quite civilized, and Vigukot was a well-planned and developed city of its time.

Subsurface mapping – GPR survey

Based on the DEM generated from RTK–GPS survey and also considering the spread of brickbats on the surface, two sites were identified to conduct 3D GPR survey within the fortified walls of Vigukot in order to identify the subsurface buried structures. The first site was chosen in an elevated area (EA1) where a few brick structures were visible on the surface, while the second site was chosen where the brick wall was exposed (Figure 5a and b).

Site 1 was located towards the eastern part of the fortified region, which marks the elevated region (EA1) in the DEM (Figure 3a and 5a–c). A 20 m × 20 m grid with edges aligned in N–S and E–W directions was marked (Figure 5b). In total 21 transects were collected at 1 m interval in each direction in zigzag mode. Site 2 located towards the northwestern side of the fortified area was identified as an elevated area (EA2) from the DEM (Figures 3a and 5a and c). The grid was 30 m (E–W) × 15 m (N–S) and mapped in zigzag mode by 16 transects at 2 m interval in E–W direction and 16 transects in 1 m interval in N–S direction (Figure 5c).

Site 1 (EA1) – GPR survey

The profile obtained from site 1 was sliced in x , y and z directions to identify the anomalous subsurface features (Figure 6a–d). The high-amplitude traces seen on the z -slice at 0.2 m reveal a specific trend of alignment of the buried wall structure. We interpret that these traces are suggestive of two enclosed wall structures with dimensions 10 m × 6 m and 8 m × 3 m (Figure 6a). The larger dimension corresponds to an area of approximately

650 sq. ft. and could have been a courtyard, while the smaller one with an area of about 250 sq. ft could be a living room. Also, cross-walled structures are visible in NW–SE direction cutting across the corners of these E–W and N–S oriented walls (Figure 6a).

As the z -slice moves deeper up to 0.45 m, the cross walls start disintegrating and at 0.56 m, a new pattern emerges, where the cross-wall joins an E–W-orientated wall (Figure 6b and c). Here the cross-walls trending NW–SE were not observed. As we move further down, the cross-walls totally disappear and only N–S and E–W-orientated walls are visible quite distinctly (Figure 6d). Based on this we infer that the enclosure was bit large and merged into a single room of 7 m × 7 m (Figure 6c and d). The pattern and size of the room remained the same till a depth of 3.8 m and when moved further deep the reflections fell flat. The different wall patterns seen at different depths probably suggest the presence of at least two settlements in the area. It can be suggested that the newer settlement occupied the ruins of the earlier settlement by constructing new structures over the remains of the earlier culture.

Site-2 (EA2) – GPR survey

The profile obtained from site 2 was also sliced in x , y and z directions to understand the subsurface anomalies (Figures 3a, 5 and 7a–e). The slice at 0 m shows the walls exposed along the southern side of the grid (Figures 5c and 7b). At 2 m depth, distinct reflections are visible, which could be interpreted as walls of width 1.5 m in N–S direction and 1 m in E–W direction (Figure 7c and d). On the western edge of the grid, adjacent structures of 9 m × 4 m and 5 m × 5 m were identified (Figure 7d). At the centre of the grid, at 20 m on the x -axis, a 1.5 m thick wall was observed running in N–S direction, which could be the exposed wall along the side of the grid (Figure 7d). Towards the northern flank of the grid another partially closed structure with an open wall of 6 m in E–W direction could be seen (Figure 7d). These structures continue till 3.5 m depth and then start disintegrating (Figure 7e).

Conclusion

Vigukot located near the India–Pakistan border in the Great Rann of Kachchh, Gujarat, was one of the ancient sea-ports that flourished since the Late Harappan period on the left bank of Nara river, and facilitated the essential internal and external trade route. However, till date little is known regarding the cause of its abandonment. The seismicity records from the region reveal that the area might have experienced a number of large magnitude earthquakes, viz. AD 1668 (M 7), 1819 Allah Bund (M 7.7 ± 0.2), 1845, 1956 Anjar (M_s 6.1) and 2001 Bhuj

(M_w 7.6). Possibly, the AD 1819 Allah Bund event considerably affected the site, and could be the major reason for its abandonment.

RTK–GPS survey carried out in this area helped us in understanding its topography with the help of DEM. The region was found to be about 3–4 m ams level with the eastern side at a higher elevation compared to the western side along with 1.5 m high partially intact brick wall representing the fort-wall. We presume that the actual fortified wall would have been as high as 10–15 m.

The GPR survey at the two sites (sites 1 and 2) revealed existence of well-planned structures made from bricks marked by NW–SE cross walls intersecting the NS and EW-oriented walls at the surface. These houses had two rooms with an area of 650 and 250 sq. ft respectively, possibly indicative of living rooms attached with a courtyard. This pattern extended up to about a depth of 0.45 m. A new pattern of walls emerged with single room of 500 sq. ft area that continued up to a depth of 3.8 m, which could be indicative of the earlier older settlement. The cross-cutting pattern of wall structures are indicative of two settlements that flourished at the same location during recent past. We infer that the newer settlement occupied the ruins of the earlier settlement by constructing new structures over the remains of the older cultural level. The reasons for destruction is unknown; possibly the major earthquake in the region along Allah Bund Fault or Nagar Parkar Fault was the main cause. Similarly, the second site revealed reflections of disconnected walls, which extend to a depth of 3.5 m. These walls may belong to the same structure as suggested by the close connectivity of the edifice.

Taking into account both surface as well as subsurface mapping, we infer that the township of Vigukot had two residential complexes located at EA1 (site 1) and EA2 (site 2). However, the size and the ruins available at the site suggest that EA1 had larger residential complexes for the elite, whereas EA2 with smaller residential complexes could be a trading centre located on the western side of the township. Similarly, the 3D GPR survey at EA1 revealed two levels of settlement, whereas at EA2 only one level of settlement was inferred. This suggests that EA1 remained as a residential complex as reflected from both the levels, whereas EA2 might be a trading complex located close to the main gateway, G1.

From these results, either of the two scenarios might have prevailed in the ancient city. Scenario-1: Both the areas flourished likewise at the first level and might have got disturbed by a disaster, could be an earthquake as suggested by Rajendran and Rajendran¹⁰. Later EA1 may have been reoccupied while EA2 was left to be an open trading complex at the second level (recent). Scenario-2: During the first level of occupancy, EA1 was a residential complex (having enclosed walls) and EA2 might have been a trading complex (partially enclosed walls near G1). Both the areas were affected during the disaster, and

during the second level of occupancy EA1 was rebuilt for occupation, whereas EA2 was used such without any renovation. Moreover, the 1819 earthquake probably destroyed both the areas completely and led to their abandonment.

As mentioned in the written records, the most dramatic landscape change took place in the Great Rann of Kachchh after the devastating earthquake of 16 June 1819 (ref. 32). A brick structure of about 150 sq. ft known as Sindhri (Sindhree) Fort, situated on the banks of the erstwhile Puran (Nara) river was inundated by a surge of water from the ocean covering the tract and converting the area into an inland lake, now known as Sindri Lake. Another spectacular change witnessed was the uplift of land about 4 km north of Sindhri Fort, which was later named as Allah Bund (the Dam of God) by local people³². It has been suggested that Allah Bund blocked the course of the Nara river resulting into the formation of a shallow pool upstream. The uplift along the Allah Bund Fault is considered as the main cause of the drying up of Nara river to its south. We envisage that the landscape changes due to earth movement in the vicinity of Vigukot brought remarkable effects on the economy of the area. As freshwater supply ceased, cultivation in the area was affected. Apart from cutting down the freshwater supply, formation of the Allah Bund also disrupted ancient trading route that existed along the course of the Nara river. The decline of economy and local ecological changes, owing to landscape changes as a consequence of earthquakes seems to be the main reason for migration and abandonment of the site.

Based on the reconstruction of sea-level curve, it has been suggested that high sea prevailed in the Kachchh area during 6–4 ka (ref. 33). Thus, it clearly indicates that the Rann of Kachchh was navigable during that period, and had facilitated major settlements towards commercial trade with the neighbouring Gulf countries. Therefore, drying up of the Rann of Kachch could be attributed to seismic activities that played a significant role in raising the floor of the Rann, resulting into a barren land³.

The results of the present study reveal new aspects for research in the Great Rann of Kachchh, and leave us with more questions that need to be answered. Were there more levels of settlements in Vigukot? When people came here and flourished to such an extent with developed urban planning, what was the exact cause for the abandonment of these settlements? Could tectonic activities (earthquakes) or some influence of climate change have affected these settlements? Addressing these questions may reveal interesting facts, which are still lying buried beneath these abandoned ruins.

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