Chapter 2
Landscape Morphology and Spatial Patterning of Archaeological Signatures When Viewed from Above

Preamble
We will refer to the landscape in the vicinity of a site as its *spatial context*. For a given site, we would like to identify features in satellite images of its spatial context that may provide new archaeological insights for that site. Images may directly show certain surface features, while some subsurface features may only be visible indirectly through certain morphological expressions. To help readers recognize features of potential interest, this chapter will examine several examples of such landscape features in synoptic views. (In subsequent chapters, we will see how these features in satellite images can sometimes be enhanced using a variety of sensors, or through image processing techniques). We will also explain why these features are not always visible in satellite images. This will require a complex argument, but the key reason is because a site's spatial context is not constant—it undergoes continuous evolution due to a combination of natural and human factors which depends significantly on the type of landcover. With this understanding, we will appreciate why no single approach to identify such features is likely to work at all sites.

2.1 Gradual Versus Rapid Change

A site's spatial context is continually undergoing gradual change, caused by a combination of *natural factors* (e.g. when a structure is weathered by wind or water, or buried by the deposition of sand or silt, or covered by vegetation) and *anthropogenic* or *human factors* originating in human activity (e.g. opportunistically mining material for reuse). Figure 2.1 illustrates gradual change to a deserted fort and moat caused by gradual natural and human factors. Rapid change can also occur sporadically, once again due either to natural factors (e.g. natural disasters) or human factors (e.g. large-scale redevelopment or conservation efforts). We will briefly discuss the

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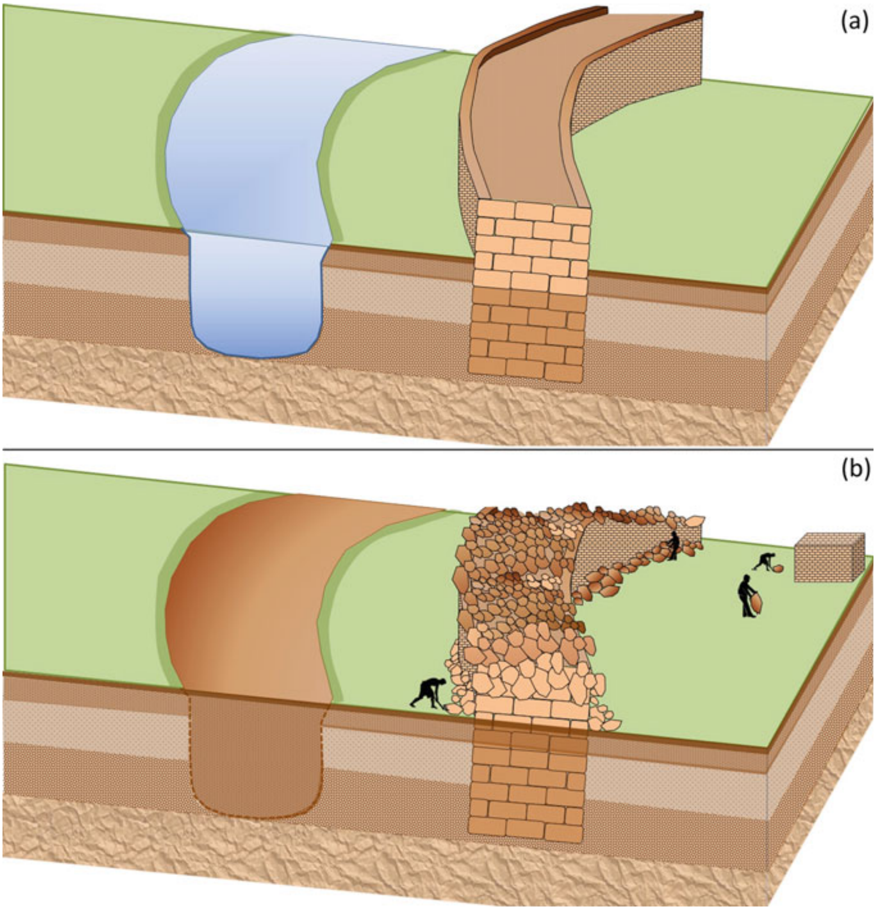

Fig. 2.1 Diagram showing **a** a typical fort structure with an adjoining moat; **b** the same after a period of gradual deterioration

former type in the following subsection and the latter (which can be mitigated by using geospatial technologies) in Chap. 6. However, the bulk of this chapter will focus on gradual change, primarily because it occurs all the time at every site.

2.1.1 Rapid Changes Due to Disasters

Landcover can change suddenly and drastically because of natural and anthropogenic disasters. When such events occurred before the availability of aerial views, their effects were not easy to detect. Today, we usually have images from before and after the event. Comparing these images can be extremely helpful in assessing the extent of the damage and in planning mitigation. For example, the mud-built citadel of Bam in Iran crumbled due to an earthquake on 26 December 2003, which measured 6.6 on the Richter scale. Satellite imagery and aerial views were used to assess the overall damage that the site incurred (Rouhi 2016). Precisely one year later, a Tsunami triggered by an earthquake in the Indian Ocean had a devastating effect on life and property along the coasts of Indonesia, Sri Lanka, India, and several other countries. In India, the force of the receding waves also washed away the sediments on the shore and uncovered several objects of archaeological interest. One of these was a tenth-century inscription engraved on a boulder at Saluvankuppam (6 km north of Mamallapuram) indicating the existence of a Subramanya temple. A subsequent excavation exposed a whole temple complex (Bhadreenath et al. 2011). Figure 2.2 shows the site before Tsunami and after excavation.

Fig. 2.2 Saluvankuppam **a** before the December 2004 Tsunami; **b** showing the Subramania temple after excavation

2.1.2 Gradual Changes

When we look at a site's spatial context today, we see only the present point in its evolutionary trajectory. For some sites, we may have historical spatial records that provide multiple snapshots of these spatial contexts as they change over time. These records may date from a few years ago (e.g. Google Earth images) to a few decades ago (e.g. Corona and other satellite imagery) to a few centuries ago (e.g. old maps, paintings, and spatial descriptions in historical texts). Even with multiple snapshots for a site, our data is generally too sparse to precisely infer the sequence of gradual changes to its spatial context. This lack of data forces us to guess how the spatial context evolved and to use these guesses to explain why we can or cannot observe certain features. While this may seem highly unscientific, it is standard practice in science to explain observations based on a minimal number of plausible guesses (or *hypotheses*), and to be proved wrong if contradictory evidence is found.

Formulating these guesses becomes quite intuitive with practice. To help build this intuition, we split our discussion of gradual change into multiple sections, each of which considers different dimensions along which features can vary. We note that the insights presented in these sections are based on our experience with a diverse but limited set of sites. It is quite possible that further experience will grow this collection of insights and add nuance to the discussions that follow.

2.2 Indirect Versus Direct Evidence

Certain large-scale features provide indirect evidence for past settlements, i.e. the presence of such features does not necessarily imply the presence of nearby settlements. These features, which include palaeochannels (past rivers or streams that are now inactive), mudflats, and coastal strandlines (features which may indicate past coastlines) typically span multiple kilometres. Because of their size, they are sometimes difficult to see amid the extraneous clutter of small-scale features in high-resolution satellite images. Instead, large-scale features are often easier to identify in medium-resolution images (~20–30 m per pixel). Figure 2.3a shows the palaeochannel in northern Rajasthan along which many Harappan sites lie (see also Sect. 4.1). The meandering pattern of the erstwhile river is visible as a darker tone in the Landsat image (30 m per pixel). The extreme top-right of this image (the spatial context of the site Kalibangan) is shown at a higher resolution in Fig. 2.3b. Notice that the shape of the palaeochannel is inconspicuous amid the details of parcel boundaries, roads, settlements, etc.

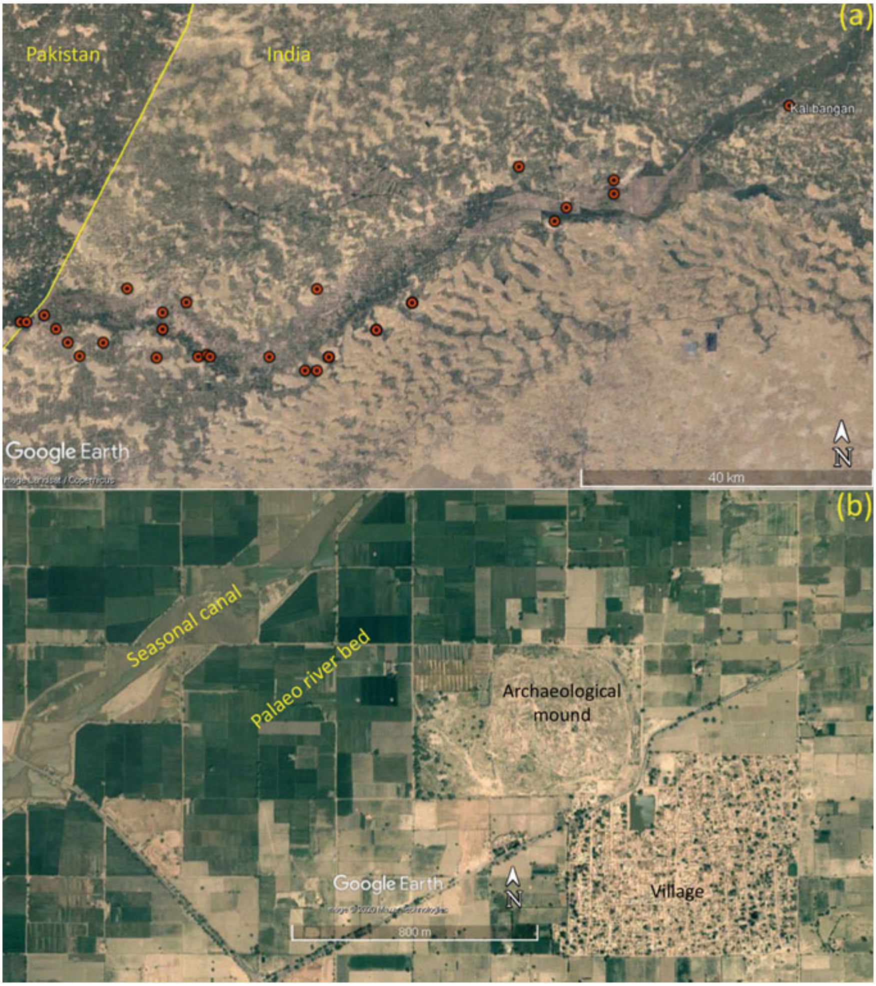

Fig. 2.3 **a** Harappan sites dotted along the seasonal stream and palaeochannels of Ghaggar-Hakra in northern Rajasthan (the site Kalibangan is on top-right corner), Landsat/Copernicus; **b** Kalibangan and environs seen on high-res image (GE Maxar Technologies)

Man-made features such as buildings (whole or partial), ditches, pits, canals, moats, tanks, and ponds constitute direct evidence for past settlements. Even when none of their remains seem visible at ground level, these features can leave traces that are sometimes seen in satellite images in the form of cropmarks, soil marks, field boundaries, or urban land-use boundaries. These comparatively small-scale features typically span a few tens to a few hundreds of metres and are best identified in high-resolution images (5 m or less per pixel).

2.3 Differences in Landcover

A site's spatial context often has one predominant type of landcover. The type of landcover often limits the set of plausible changes that could have occurred within that spatial context. We therefore consider several typical types of landcover in the following subsections. We note that some spatial contexts may have multiple types of landcover.

2.3.1 Arid Soil

Arid lands have little or no plant cover and are often sparsely inhabited. Thus, the landcover is characterized by bare soil that is largely uniform in colour. However, even a seemingly homogeneous land parcel can show slight variations in colour, caused by differences in mineral and organic content of the soil and its moisture content. When these colour variations appear as anthropogenic patterns (Fig. 2.4), they suggest traces of past settlements. Thakker (2001) has demonstrated the value of identifying such patterns in revealing the existence of archaeological sites in parts of Kutch (Gujarat). Soil marks can also be visible in non-arid or comparatively wet and fertile land when the soil is left uncultivated.

Buried structures can also influence the colour, tone, and texture of surface soil, depending on how much residual building material is on the surface. Figure 2.4 shows four examples. When the surface material is not fully removed and gets covered over time, it can produce a ridge (Fig. 2.4a) or a series of intermittent mounds (Fig. 2.4b). Even when the structure is entirely buried, variations in the colour or tone of the soil due to differences in moisture content (Fig. 2.4c) or vegetation cover (Fig. 2.4d) can reveal patterns that indicate the underlying structure. Figure 2.5 shows the rectangular external wall and foundations as well as some internal walls of the archaeological settlement at Dholavira (an example of Fig. 2.4d). This cropmark is indicated by Babul trees that grow like a weed in the region. This site was excavated from 1989 to 2005, but the Corona image shows these cropmarks prior to their excavation. The buried remains of a fortification at Ahichhatra, U.P. (Fig. 2.6), is an example of the patterns illustrated in Fig. 2.4a, b.

2.3.2 Agricultural and Semi-agricultural Land

We use the term *semi-agricultural* when the predominant landcover is agricultural together with small settlements and water bodies. For agricultural land, buried archaeological remains often affect the health of crops, creating positive or negative cropmarks which reveal themselves as large patterns when viewed synoptically (Bradford 1957; Wilson 2000). Cropmarks are not only one of the most common signals for

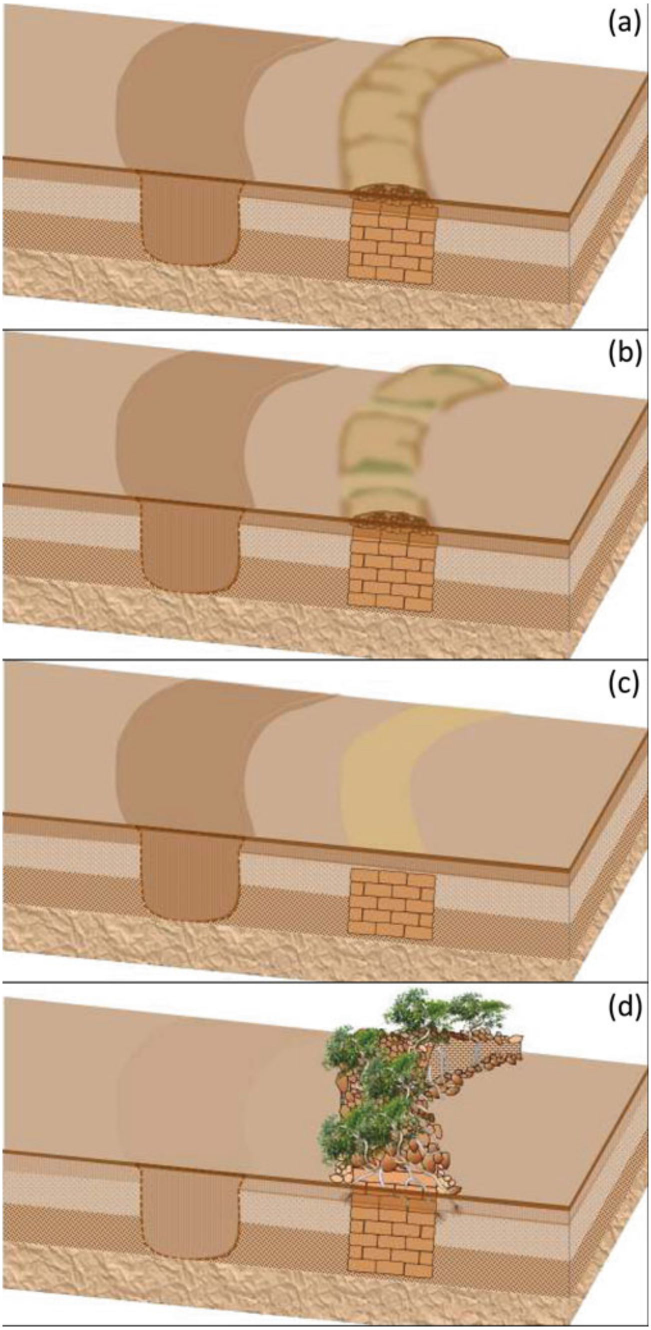

Fig. 2.4 Diagram showing typical patterns observed in arid soil indicating buried heritage structures

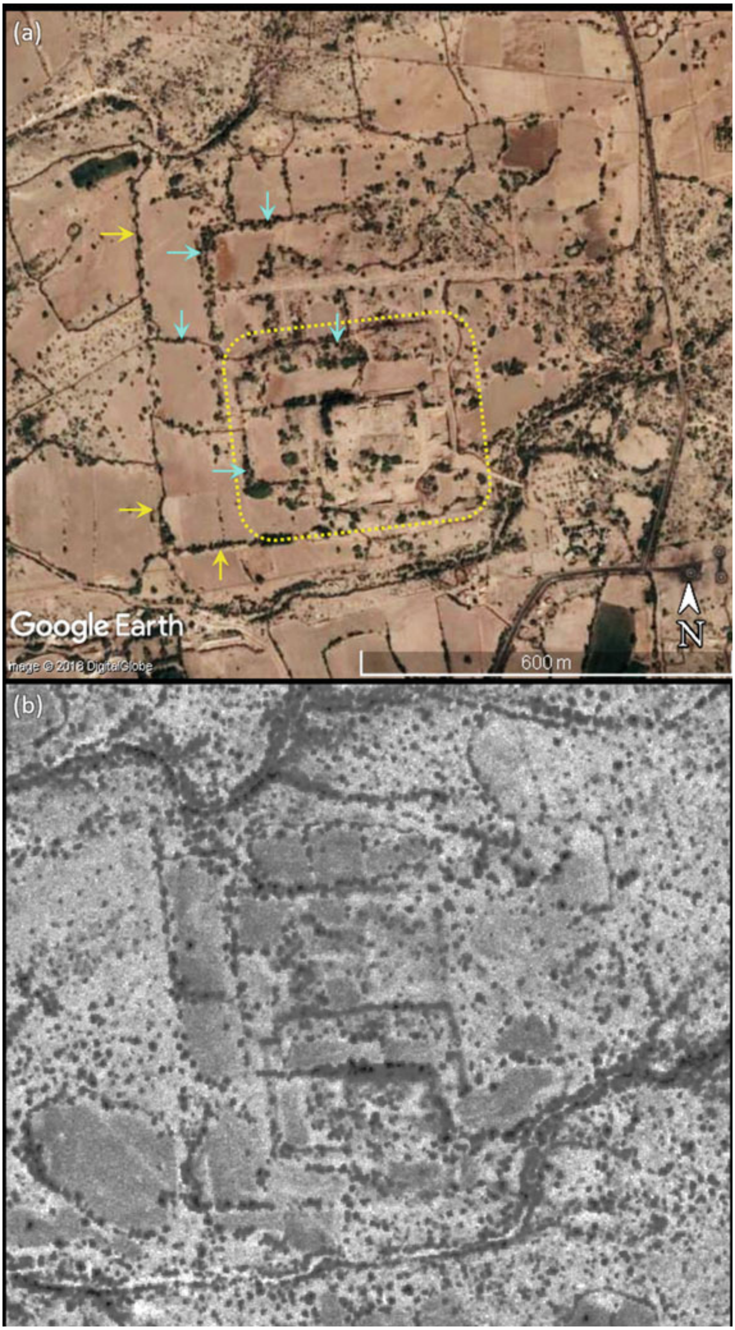

Fig. 2.5 Dholavira **a** as seen on 31 December 2016 (yellow arrows indicate external walls, cyan arrows indicate internal walls, and the yellow dotted line marks the excavated region); **b** Corona image taken on 31 December 1965

Fig. 2.6 Buried remains of fortification at Ahichhatra, Uttar Pradesh

detecting archaeological remains, but also one of the oldest—they were seen in aerial reconnaissance photographs taken in World War II and recognized for their archaeological importance (Trumpler 2005). Cropmarks can reveal disused moats, canals, tanks, and pits. Since these features (when buried and silted) often hold additional moisture, they typically appear as positive cropmarks in agricultural land (Fig. 2.7a). In contrast, when archaeological structures such as brick/stone walled foundations, streets and solid floors are buried beneath soil, they tend to inhibit the growth of vegetation because they obstruct plant roots (Fig. 2.7a and Fig. Box 1), and hence, they appear as negative cropmarks.

Since most crops have an annual cycle, cropmarks need not be visible in all seasons. Depending on the depth to which roots penetrate and the depth of archaeological remains, it is possible that cropmarks are only seen during extreme weather conditions such as peak summer, when moisture and nutrients in the upper layers are exhausted and roots must penetrate deeper. Further, they may only be visible when viewed in certain wavelengths (see Sect. 3.2.1). Hence, it is advisable to analyse images from multiple seasons using a variety of sensors to identify such features with greater confidence.

Neat and well-defined cropmarks as illustrated in Fig. 2.7a get created when the subsurface composition is nearly uniform across the feature. If subsurface material in the foundation of a structure was partially mined for reuse, there may be irregular cavities that hold moisture. In such cases, we might see an irregular mixture of positive and negative cropmarks (Fig. 2.7b). Generally, linear features (e.g. caused by fort walls and moats) are easier to detect than nonlinear features (e.g. caused by buried remains of buildings). Depending on how much building material has been

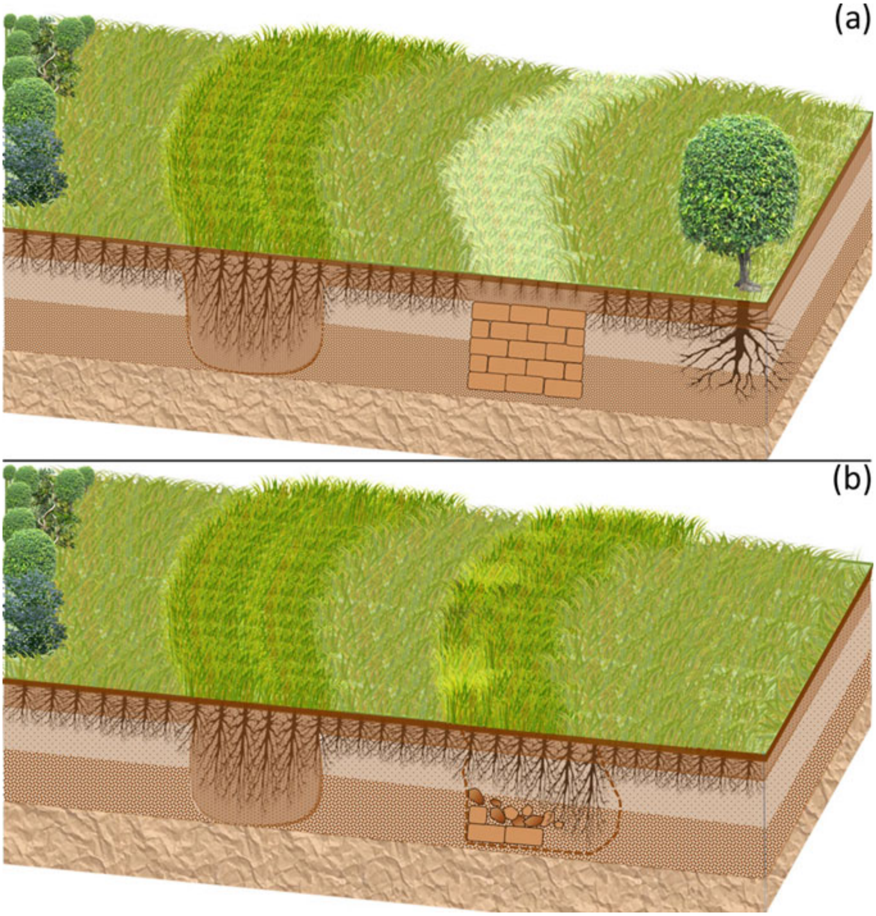

Fig. 2.7 Diagram showing **a** positive and negative cropmarks in agricultural land; **b** irregular mixture of positive and negative cropmarks when subsurface material has been partially mined

removed from the subsurface foundation, the cropmark can be sharper or obscure. If the surface building material is not fully removed, then the remains of separate structures can form individual mounds.

Former water bodies that subsequently became agricultural land also form non-linear features. Figure 2.8 illustrates an example of a cluster of temples (labelled as 3,4,5,6) and water bodies (labelled as 1 and 2). Figure 2.8a illustrates the condition when these were active and Fig. 2.8b shows the locations of structures and water bodies covered by agricultural vegetation. Figure 2.8c reflects the same condition as Fig. 2.8b, but it is visualized as a false-colour image using the infrared band (Sect. 3.2.1) and shows both positive and negative cropmarks in starker contrast.

The landcover within a single parcel of land tends to be homogenous, which causes variations such as those shown in Fig. 2.7a, b to stand out. Another possibility

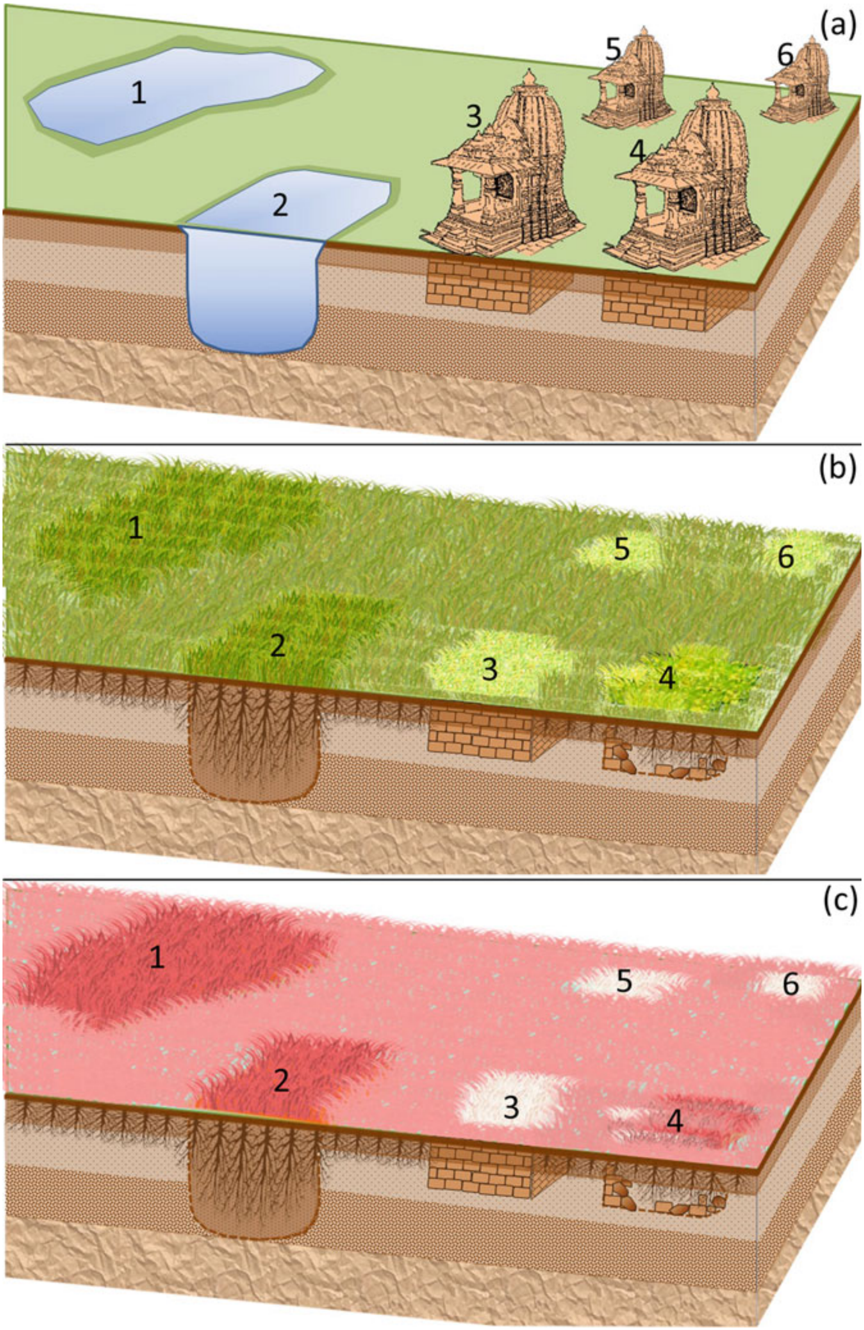

Fig. 2.8 Diagram showing **a** a site with temple structures and water bodies; **b** positive, negative, and mixed cropmarks indicating buried remains; **c** enhanced contrast between cropmarks as they might appear in infrared images

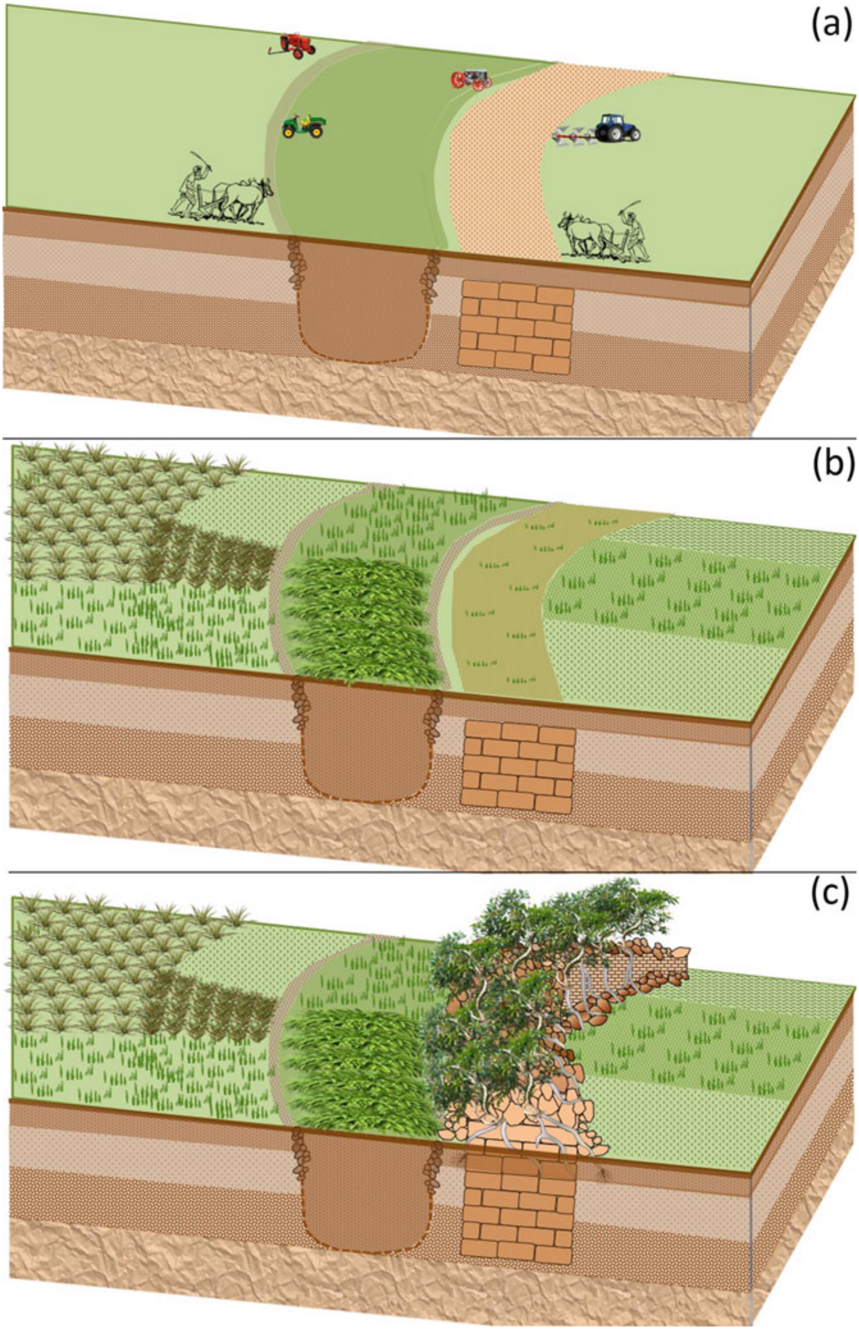

Fig. 2.9 Diagram showing buried structures revealed by a sequence of field boundaries

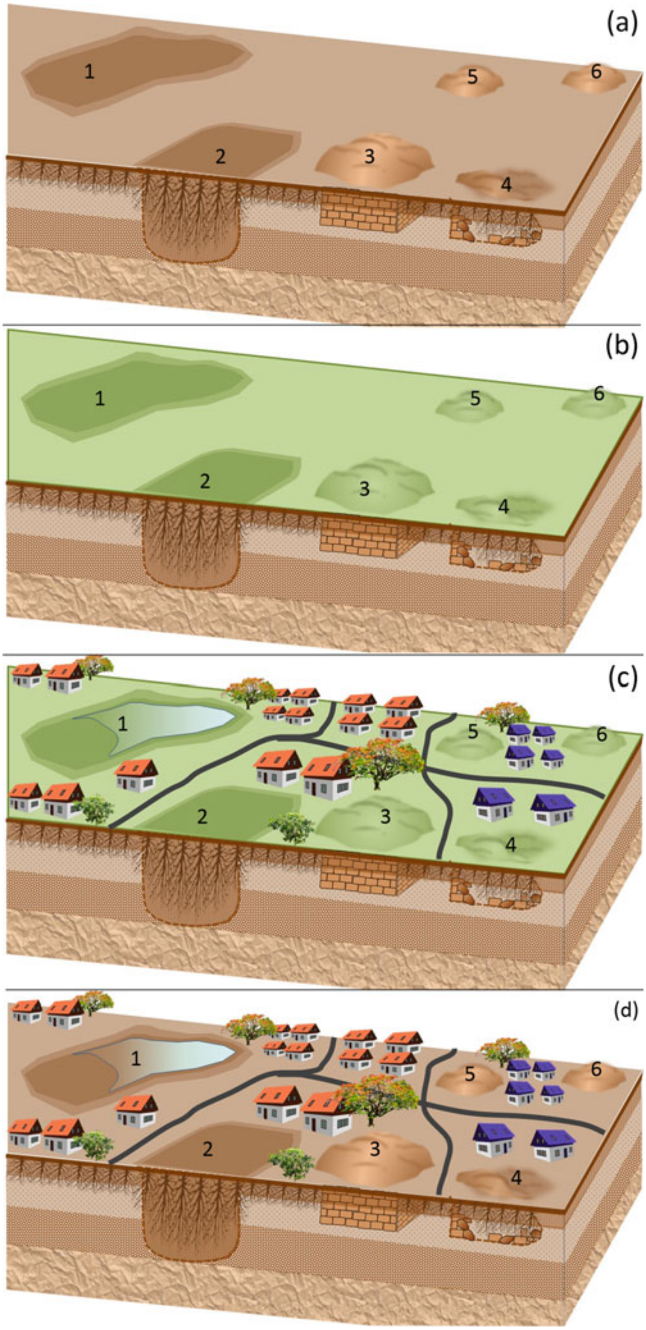

Fig. 2.10 Diagram showing mounds amidst settlement

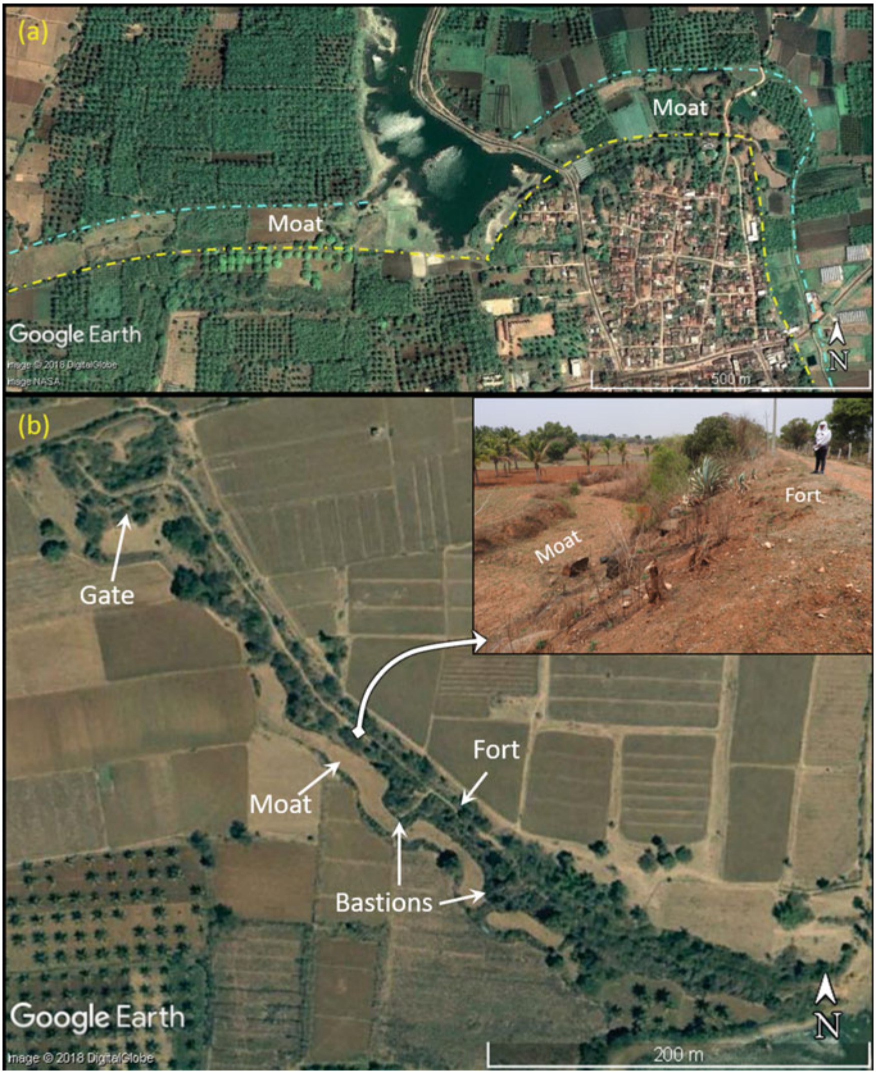

Fig. 2.11 Halebidu, the fortified capital of the Hoysala dynasty. **a** Continuous multiple agricultural field boundaries indicating the shape of a past moat north of the fortified area; **b** thick vegetation on remains of a fort to the south-west; inset a field photograph

is that subsurface material causes enough hindrance to agriculture that it dictates the division of parcels. When this happens, a sequence of field boundaries forms a collective pattern that reveals the buried structure. This is illustrated schematically in Fig. 2.9. Individual buried structures may initially appear as distinct mounds even as the landcover undergoes changes due to natural factors (Fig. 2.10a, b). However,

Fig. 2.12 **a** Settlement of Baragaon and Surajpur together with its environs, north of the excavated site of Nalanda; **b** close up of the unexcavated mound in Baragaon

when humans build subsequent settlements, these distinct mounds may amalgamate (Fig. 2.10c, d).

A large settlement may lie beneath multiple types of landcover. By way of illustration, we now look at two such settlements that exemplify many of the changes we have discussed above. First, consider the fortified settlement of Halebidu, the capital of the Hoysala dynasty which ruled much of what is now Karnataka in the

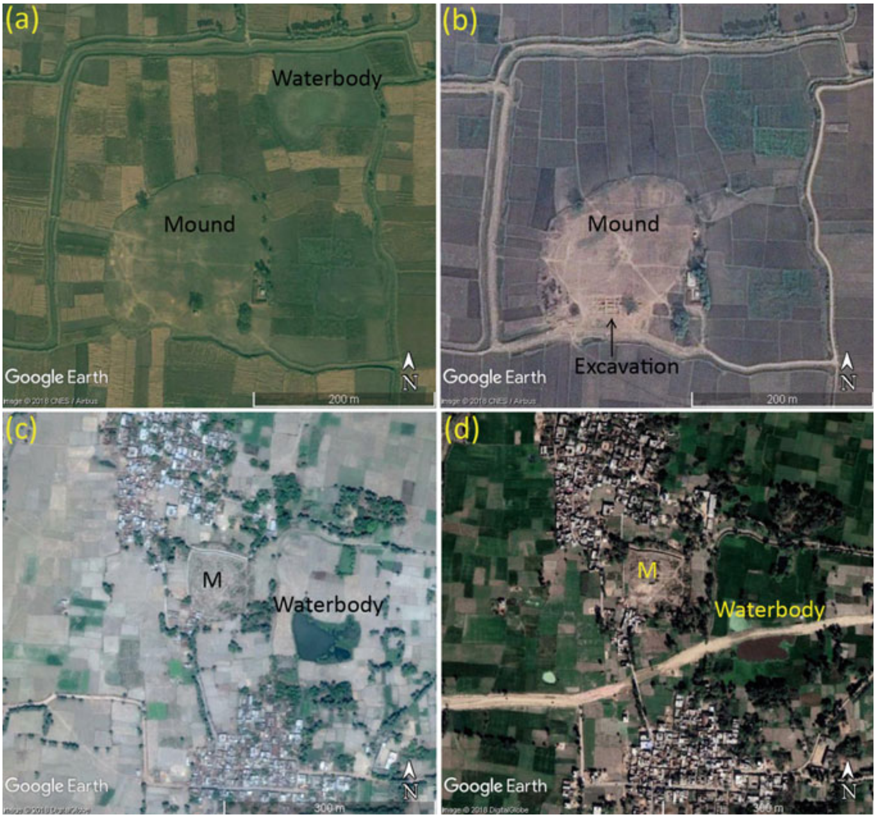

Fig. 2.13 Archaeological mound of Jagdispur, 2 km south-west of the site of Nalanda: **a** 20 November 2006, **b** 4 December 2015; mound (M) in the settlement of Jeofardih 1.5 km west of Nalanda: **c** 8 May 2010, **d** 7 March 2018

twelfth century CE. The landcover is predominantly agricultural—except for the settlement at the northeast corner. The northern portion shows a sequence of several land parcels that reveal the curvilinear shape of the moat (Fig. 2.11a), even though almost no structural material of the fort survives here. In contrast, ruins of the fort made of huge stone blocks survive to the south and west. On the south-west, the remains of the fort lie beneath thick vegetation that is distinct from the vegetation in adjacent agricultural fields (Fig. 2.11b). This vegetation reveals the shape of the fort, including its bastions, because the plants here appear to have found ample moisture and nutrients within cavities (as illustrated in Fig. 2.9c) (Rajani and Kasturirangan 2014, Das and Rajanai 2020).

As a second example, consider the spatial context of Nalanda. Figure 2.12 shows the area north of the excavated site of Nalanda with an active tank and two positive cropmarks indicating past water bodies that are now used for cultivation. In addition, we see a settlement (Baragaon), an unexcavated mound, and an excavated structure (Temple 14). Figure 2.13 shows another mound in this spatial context (Jagdispur;

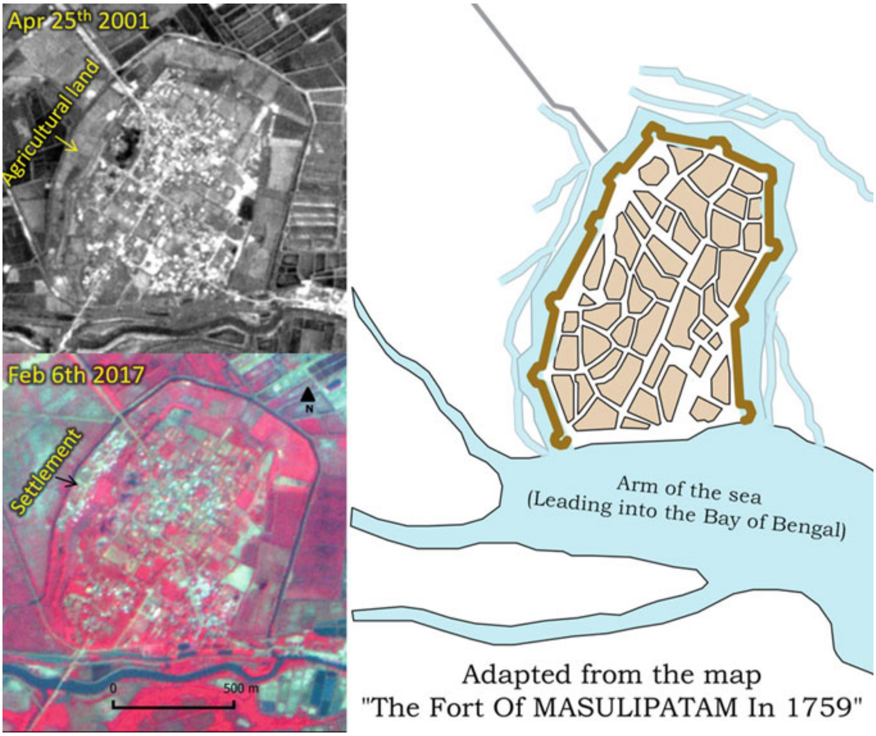

Fig. 2.14 Gradual change in the landcover of individual parcels at Masulipatnam over time

1.5 km south-west of excavated site). It is located on agricultural land and is distinctly visible from the surrounding. The two images (a) and (b) are taken on different dates—a water body on the northeast side of the mound is clearly visible in Fig. 2.13a, but not in Fig. 2.13b. The most probable explanation for this is that the water body is depressed relative to its surrounding area—it gets flooded in the rainy season and is used for cultivation at other times. South of this mound (Fig. 2.13b), a checkered pattern of excavation can be seen. Figure 2.13c, d are of Jeofardih, which is amidst both agriculture and settlement. Its shape is therefore more obscure than Jagdispur in a satellite image. Jeofardih (1.3 km west of excavated site of Nalanda) also has an adjacent tank and Fig. 2.13d shows the construction of a new road that cuts the tank into two halves. This may cause the tank to dry up completely.

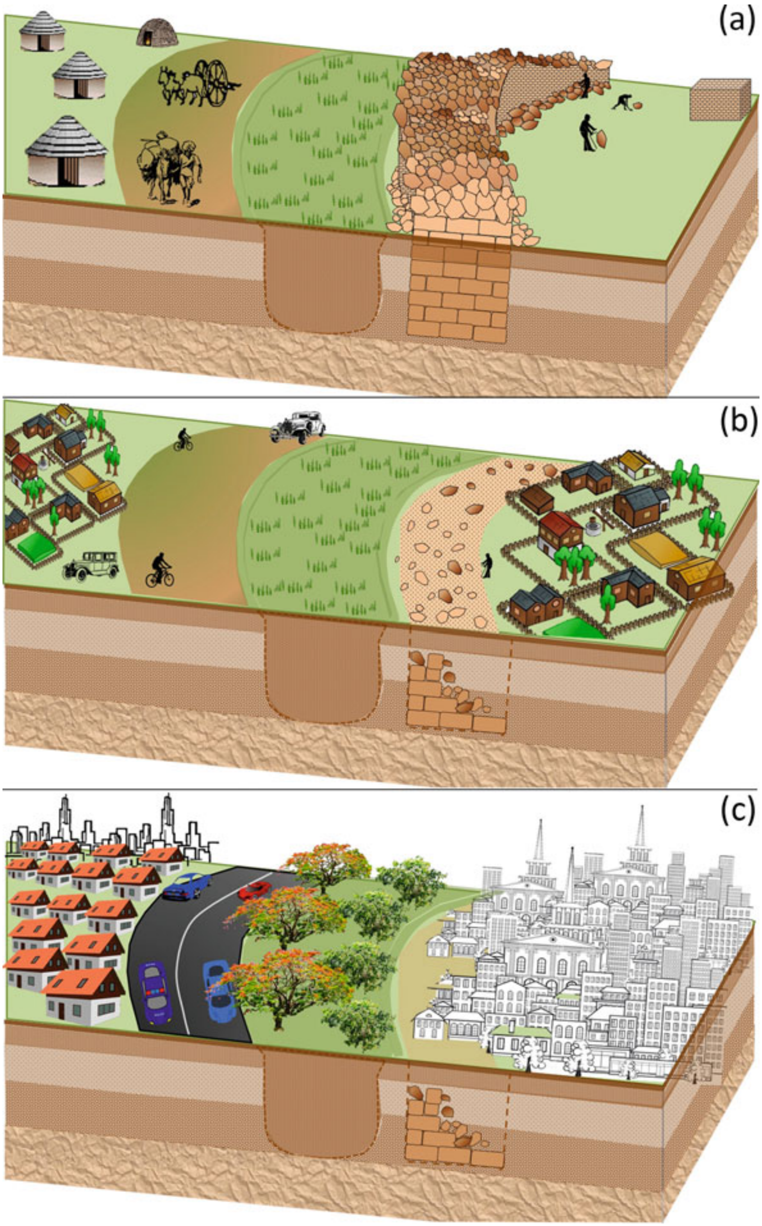

Fig. 2.15 Diagram showing morphology in urban landscapes

Box 1: It is critical to understand key properties of soil, because it is the medium through which the presence of subsurface archaeological remains are communicated before they are revealed by surface vegetation. Soil is biologically active and porous and has developed in the uppermost layer of the Earth's crust. Soil is composed of distinct layers called horizons that run roughly parallel to the surface (Fig. Box 1).

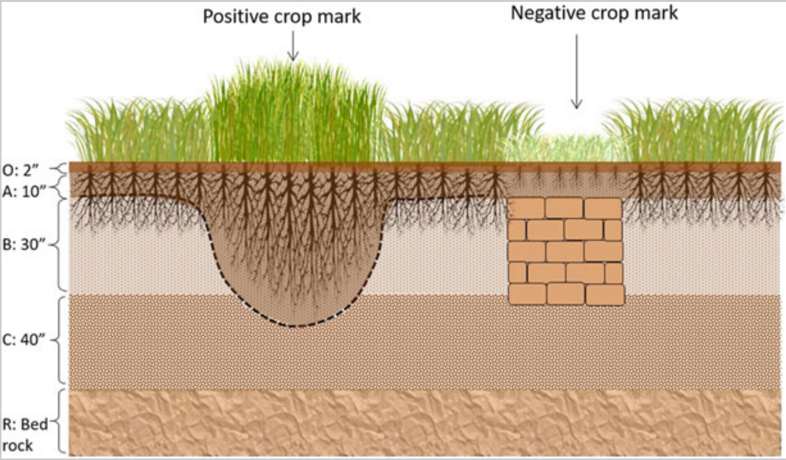

Fig. Box 1 Diagram showing positive and negative cropmarks over buried archaeological features

Each horizon has different properties and characteristics. A soil profile is a vertical section that extends from the surface to the underlying rock material. The surface horizon or O-horizon is comprised of organic material in various stages of decomposition. It is most prominent in forested areas where there is accumulation of debris fallen from trees. The A-horizon lies below the O-horizon and largely consists of minerals (sand, silt and clay) mixed with considerable amounts of organic matter and soil life. Below this lies the B-horizon, which is a site of deposition of certain minerals that have leached from the layer(s) above. The C-horizon is the least weathered and is comprised of large pieces of loose rocks. Finally, the R-horizon is the bedrock underlying the soil, which largely comprised of continuous masses of hard rock that cannot be excavated by hand (Soil Profile 2007–2020). These horizons vary in thickness and colour.[1] When a moat was excavated in the past, a slice of these horizons would have been removed. The subsequent silt deposition would have occupied this cavity pushing the lower limit of the A-horizon further down and creating a large space for minerals, organic matter, and soil life. This would allow the roots of surface vegetation to penetrate further and avail more nutrients. As a result, these crops tend to be healthier and denser, creating positive cropmarks indicating the moat (Fig. Box 1). In contrast, buried walls prevent roots from penetrating deep below the surface, allowing only a thin O-horizon. Therefore, the surface vegetation tends to be stunted and sparse, forming negative cropmarks (Fig. Box 1).

2.3.3 Urban Land

Many modern cities have expanded from past fortified settlements. Unless there is disruptive change to the layout within the fortifications, we often see gradual changes to the landcover for individual parcels of land (or adjacent groups of land parcels). As an example of this kind of landscape morphology, compare the two satellite images of Masulipatnam in Andhra Pradesh (taken 16 years apart) with a map from 1759 CE (Beveridge 1900), showing how the erstwhile layout of the fort has mutated into individual land parcels (Fig. 2.14). It is clear from the satellite images that the landcover in these parcels has gradually changed. For instance, a parcel that was agricultural in 2001 was developed into a settlement by 2017. Archaeological settlements that now lie in urban landscapes typically change in a similar parcel-by-parcel change and apart from a few sacred structures, most structures are rebuilt or extensively modified over time. This period can vary from site to site.

In contrast to structures, arterial roads tend to remain intact and the shapes of fortified boundaries (past fort walls/moats) are usually preserved in the form of additional roads. The diagram in Fig. 2.15 illustrates a plausible chain of events. Figure 2.15a shows a dilapidated fort wall. Having become a hindrance for mobility, people and goods move along the hindrance rather than cutting through it, creating a path. Eventually, the path becomes road (Fig. 2.15b). In due course, the ruins of the fort that were once a hindrance are fully cleared, and the land use on either side of the road continues to evolve. By this time, however, the road has gained enough importance to serve as a permanent marker of the shape of the past fort/moat (Fig. 2.15c). An excellent example of such a change is seen in the transformation of urban landcover east of Qila Rai Pithora over a half-century period (Fig. 3.13a versus Fig. 3.13b).

[1] https://www.ctahr.hawaii.edu/mauisoil/a_profile.aspx. Accessed 12 Apr 2020.

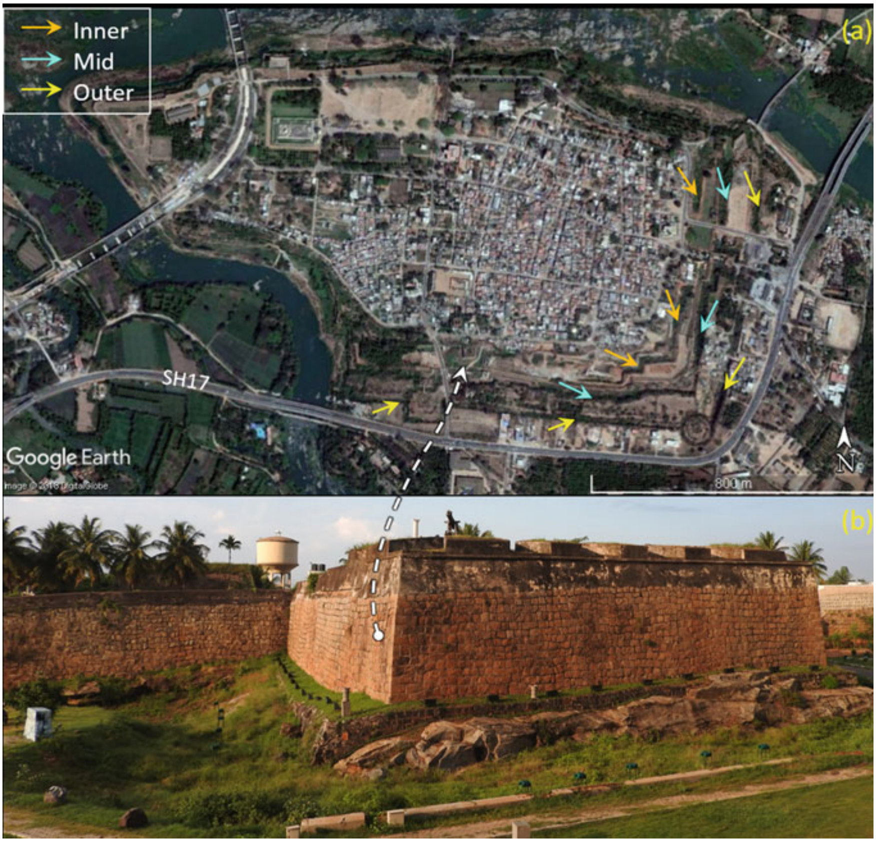

Fig. 2.16 Srirangapatna **a** yellow, cyan, and orange arrows point to cropmarks indicating three concentric moats (outer, middle, and inner, respectively) carved deep into the bedrock; **b** ground photograph showing a bastion built over the rock

As an example, the highway SH17 in Srirangapatna skirts the fort (Fig. 2.16). Similarly, several fortified settlements depicted in maps of Old Delhi/Shahjahanabad[2] (Fig. 2.17), Ahmedabad[3] (Fig. 2.18), Madurai[4] (Fig. 2.19) and Bombay Fort[5] (Fig. 2.20) are likely to have undergone similar transformations. In each of these cases, one can see the internal road still in existence, and more modern roads

[2]http://www.columbia.edu/itc/mealac/pritchett/00routesdata/1800_1899/ghalib/delhimap/delhimap.html Accessed 07 May 2020.

[3]https://commons.wikimedia.org/wiki/File:Ahmedabad_City_and_Environ_Map_1866.jpg Accessed 07 May 2020.

[4]https://ssubbanna.files.wordpress.com/2012/09/565cd-ma28city-map_1380140g-madurai-sepia.jpg. Accessed 07 May 2020.

[5]https://commons.wikimedia.org/wiki/File:Bombay_Fort_1771-1864.jpg. Accessed 07 May 2020.

Fig. 2.17 Fort feature from *Plan of Delhi 1857–58* overlaid on Google Earth (fort walls are marked in cyan and major roads are marked in magenta)

following the profiles of past forts. This morphology is not unique to Indian settlements, of course. We see a similar change in Vienna, where the shape of the fort and moat marked in historical maps of Vienna (including the esplanade) can be matched with the settlement and road patterns in the current layout of central part of the city.[6] The core settlement of old Bangalore also illustrates this phenomenon (Fig. 2.21) (Rajani 2007). The situation here is slightly different, because Bangalore's fort had two distinct components: the *kote* (the royal enclosure shaped like an oval pendant) and the *pete* (the rest of settlement to the north of the *kote*). Whereas the *pete*'s shape is preserved by the roads surrounding it as described above (particularly when visualized with false-colour satellite images discussed in Sect. 3.2.1), the shape of the *kote* is unrecognizable in the road pattern. This is probably because of the disruptive changes that began in the nineteenth century CE when the fort was dismantled in

[6]Georeferenced overlays of historical maps of many parts of Europe can be visualized in: https://mapire.eu/en/map/europe-19century-secondsurvey/?bbox=1817747.7219660091%2C6139735.8597633075%2C1829815.217806531%2C6143557.711177567&map-list=1&layers=158%2C164. Accessed 07 May 2020.

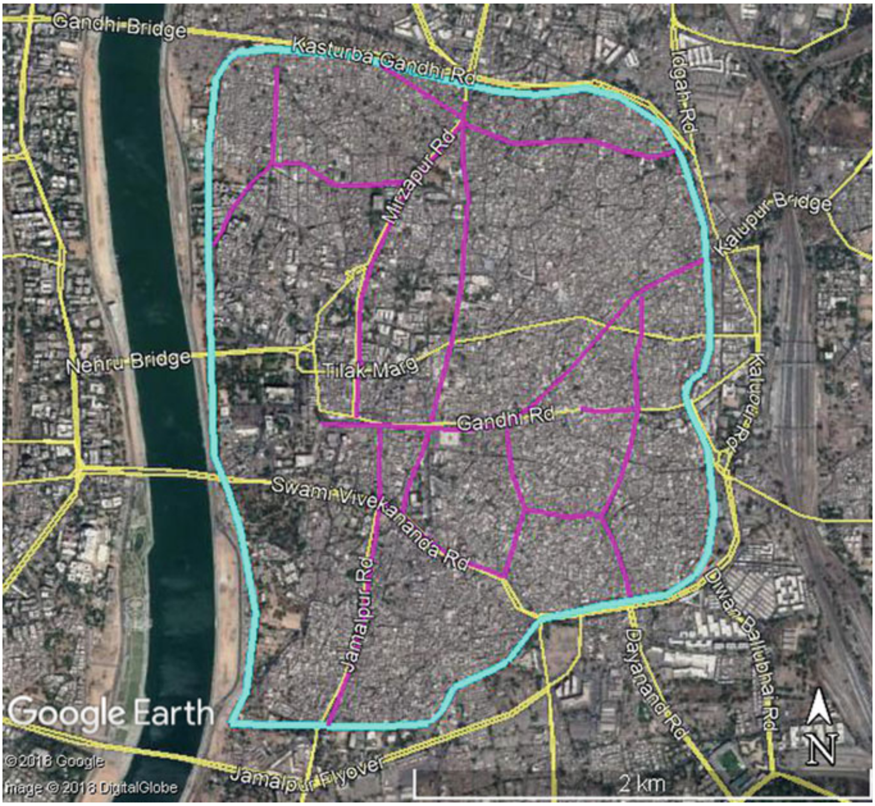

Fig. 2.18 Outline of the fort marked in the map *The city of Ahmedabad with its environs* (1866) overlaid on Google Earth (fort walls are marked in cyan and major roads are in magenta)

sections to make way for a fresh layout consisting of roads, colleges, schools, bus stands, and hospitals (Iyer 2019).

Srirangapatna, referred to earlier, is 115 km south-west of Bangalore. Located on a river island, this fort has not witnessed urbanization on the same disruptive scale as Bangalore. Further, the fort has three concentric walls with moats adjacent to each wall that are carved deep into the bedrock. Unlike the situation shown in Fig. 2.6a, b, these moats do not get fully silted up and the parts that are not subject to regular conservation are filled with wild vegetation. For these reasons, despite the urbanized landcover, the moats and fort bastions are easily visible in both the synoptic and ground views (Fig. 2.16).

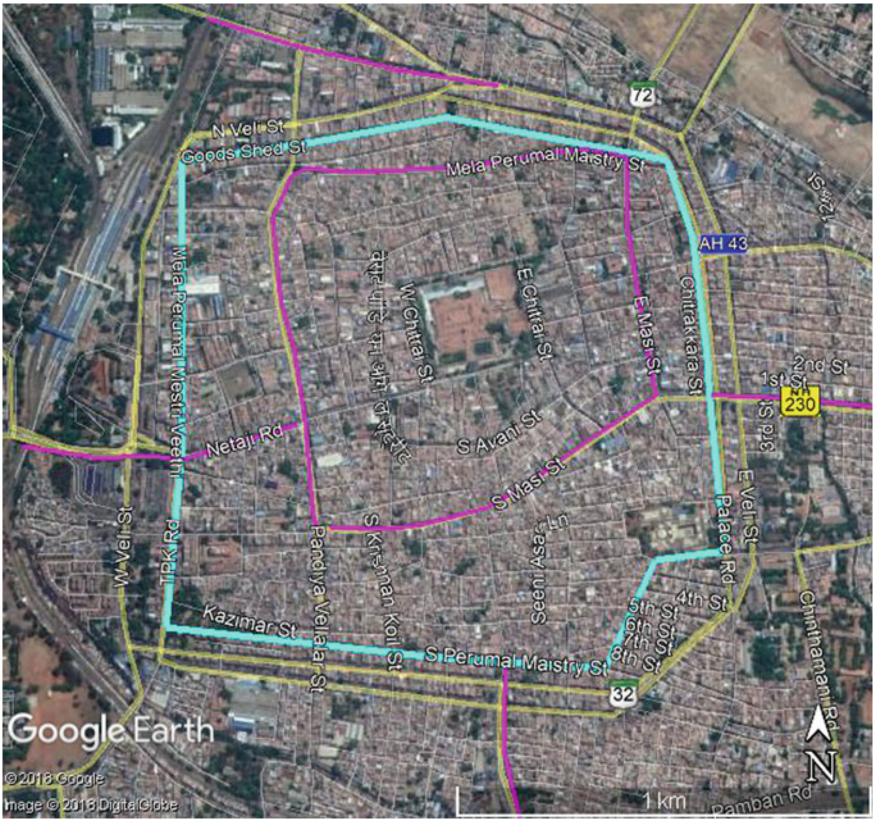

Fig. 2.19 Fort feature from *Plan of Madura* (1755) overlaid on Google Earth (fort walls are marked in cyan and major roads are in magenta)

2.3.4 Settlement Mounds in Rural Settings

The accumulated refuse generated by people living on the same site for several hundred years forms artificial mounds. If the settlement is abandoned, further layers of dust and silt can be deposited by wind or floods on these mounds. These mounds can sometimes assume the shapes of archaeological structures or layouts buried within them, provided they contain enough volume of intact material. Such mounds stand out for their anthropogenic shapes in contrast to their surrounding terrain. Figure 2.22a illustrates an example of a settlement which, over time, morphs into a mound (Fig. 2.22b). A later settlement may develop atop this mound, as shown in Fig. 2.22c. Within a larger mound, there can be smaller mounds that contain individual structures (Fig. 2.9c, d). To visualize such features geospatially, one needs to use digital elevation models (DEM) (discussed in Sect. 3.3).

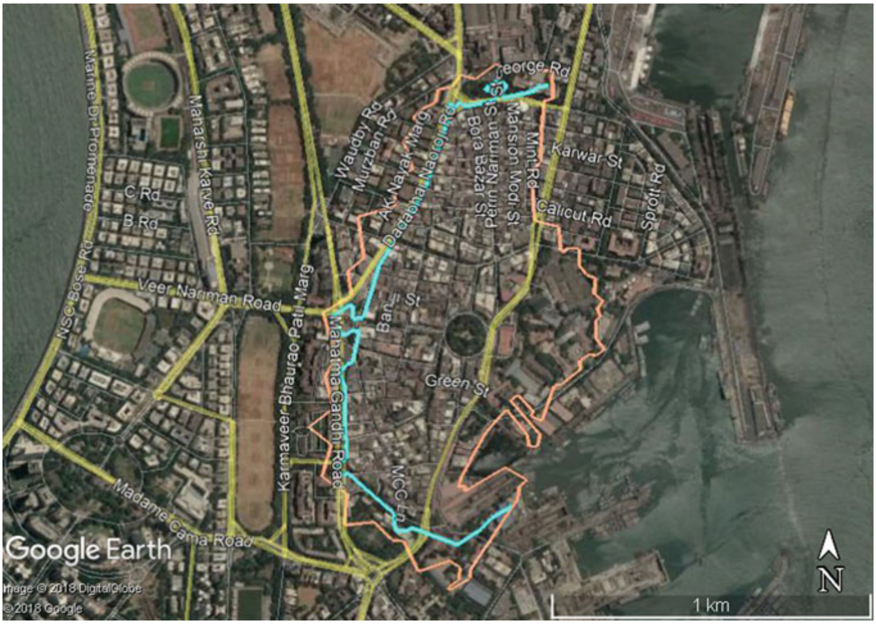

Fig. 2.20 Fort feature from *Bombay Fort 1771–1864* overlaid on Google Earth (fort walls are marked in cyan and the parapet is marked in beige)

2.3.5 Rocky Terrain

Humans have carved out rocks to create sacred structures and dwellings (e.g. the caves of Badami, Ajanta and Ellora). Aerial and satellite images are of little use in studying such structures because there are generally no traces visible from above. However, humans have also built structures on top of rocky terrain (e.g. the upper and lower Sivalaya in Badami). The morphology of rocky terrain is over geological timescales (i.e. much slower than archaeological timescales), and bare rocks do not accumulate silt (it gets washed off by rain). Thus, while such structures may deteriorate, their remains are usually visible on the surface (see Fig. 2.23a, b). Very high spatial resolution images are best suited for detecting such remains, since one is looking for individual structures rather than larger landscape features. When rocks are not bare but have some vegetation, built remains can be obscured and hence harder to identify (see Fig. 2.23c, d).

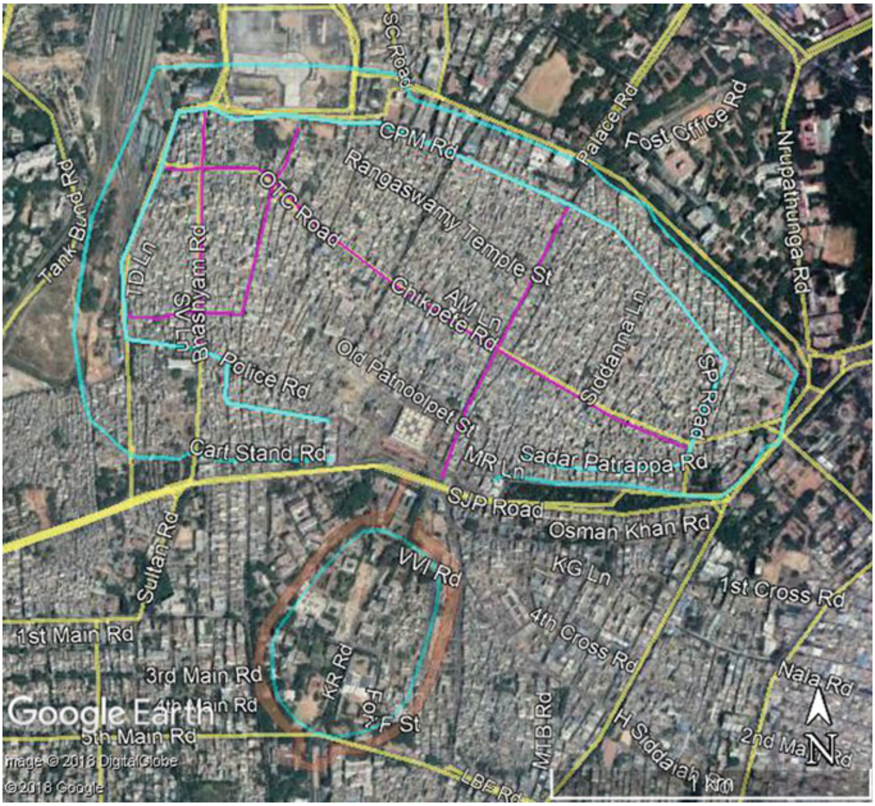

Fig. 2.21 Fort feature from *Plan of Bangalore* (1791) overlaid on Google Earth (fort walls are marked in cyan, major roads in magenta and the moat is marked in beige)

2.3.6 Riverbanks/Floodplains

Riverbanks and floodplains are mostly used for agriculture, which has been discussed in Sects. 2.3.2 and 2.3.4. However, a feature that is often associated with such a setting is a palaeochannel which may have served as a source of water for the settlement. (The source may have dried up or the flow may have changed course subsequently.) Synoptic views provided by satellite images are extremely useful in identifying such channels, which may not be visible while traversing the area on foot. Palaeochannels often have more subsurface moisture than their immediate surroundings, which results in a healthy vegetation similar to the effect that positive cropmarks have (see Sect. 2.3.2 and Fig. 2.7a), but the pattern has a distinct riverine shape and covers a larger area. A palaeochannel can stretch for many kilometres and span several fields and a variety of landcovers.

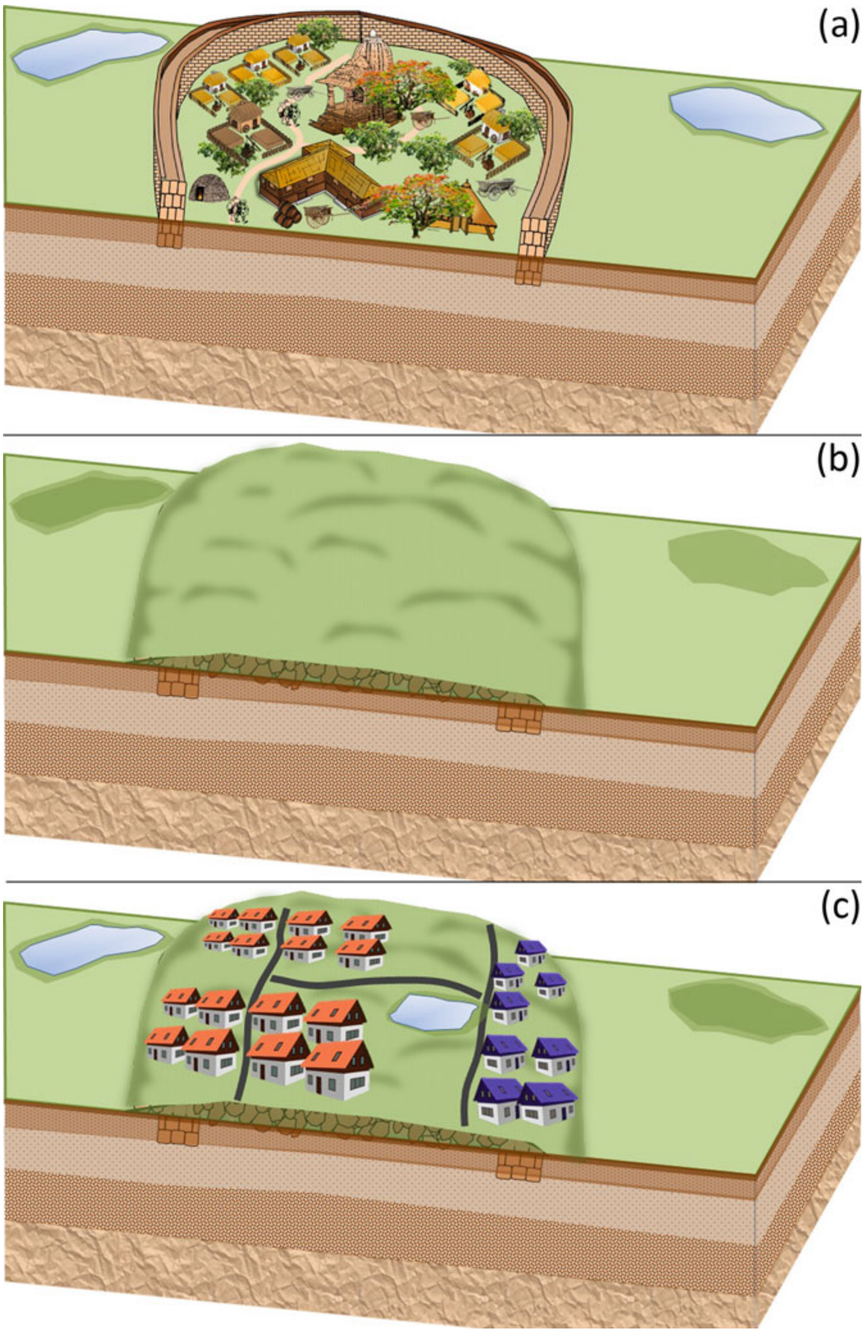

Fig. 2.22 Diagram showing the morphology of a settlement mound

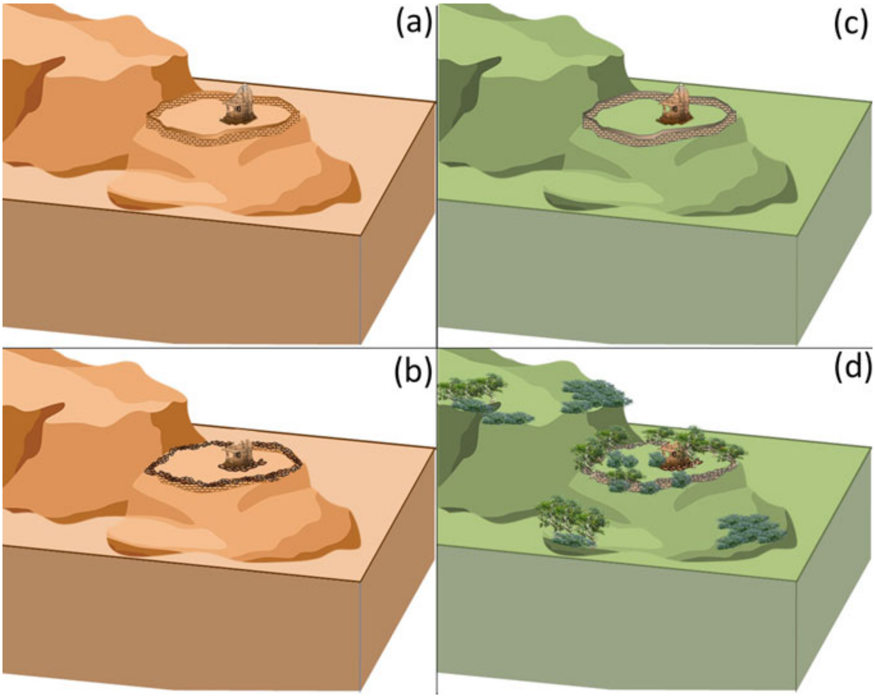

Fig. 2.23 Diagrams showing structures on rocky or hilly terrain

Figure 2.24 illustrates how palaeochannels manifest among agricultural fields: let us imagine a river flowing from right to left. Figure 2.24a shows two streams converging into one, meandering for some distance and then bifurcating. There is a temple on the bank, and further downstream (adjacent to the bifurcation) there is a triangular fort built strategically close to the flow. Figure 2.24b depicts a subsequent scenario where one of the tributaries has dried up and the other one has shifted slightly. The temple, which was originally on the riverbank, now stands isolated, and the fort no longer appears to have been deliberately constructed close to the flow. A good example of such morphology is seen in the crescent-shaped fortified settlement of Sravasti, the site of Buddha's Jetavana (the second monastery donated to Gautama Buddha after the Venuvana in Rajgir). Here, the concave curve on the north-west side would have followed the meandering river, which would earlier have flowed adjacent to the abutting fort (Fig. 2.25a, b). Figure 2.24c shows a scenario where the whole section of the channel is inactive and has subsequently been used for agriculture. However, the shape of the stream can be preserved (most often unintentionally) as property boundaries in the surrounding land. Thus, one can identify the serpentine shape of a former channel in the collective pattern of a sequence of field boundaries. A variation of this is depicted in Fig. 2.24d. Here, the spatial patterning of parts of the palaeochannel is not as distinct as in Fig. 2.24c because the contours of the parcels have obscured the meandering profile. The distinctness of the meandering shape may

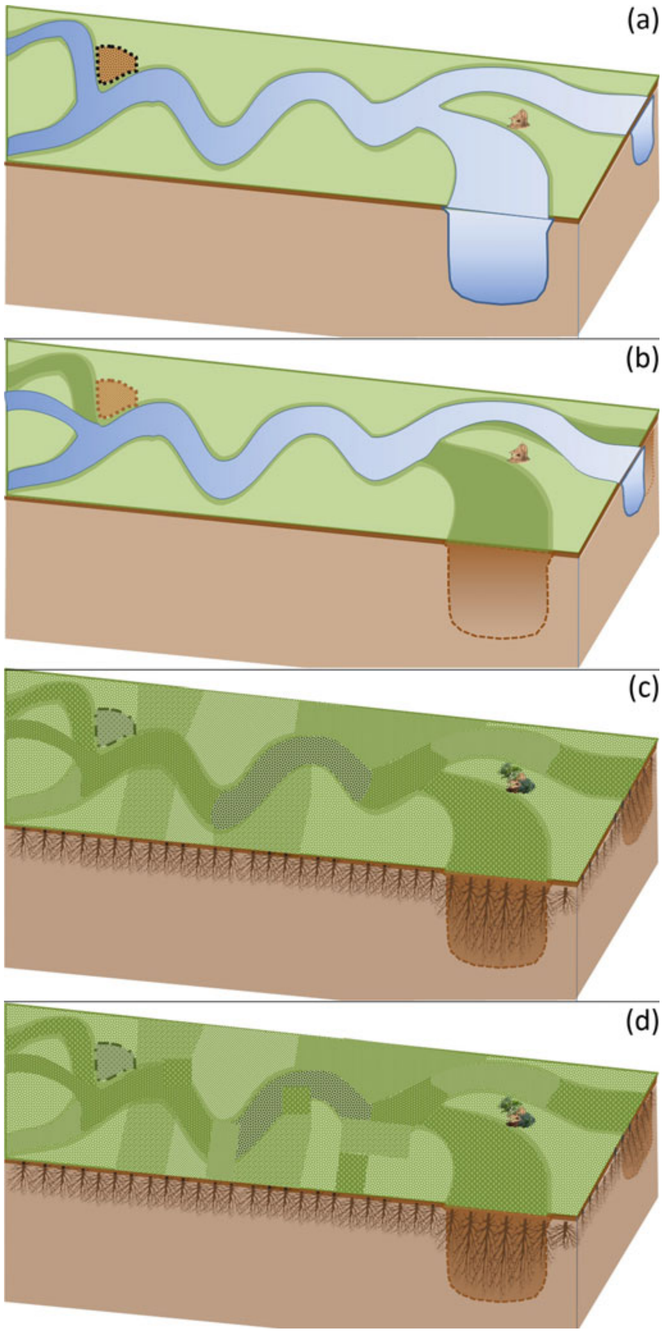

Fig. 2.24 Diagram showing how palaeochannels manifest among agricultural fields over time

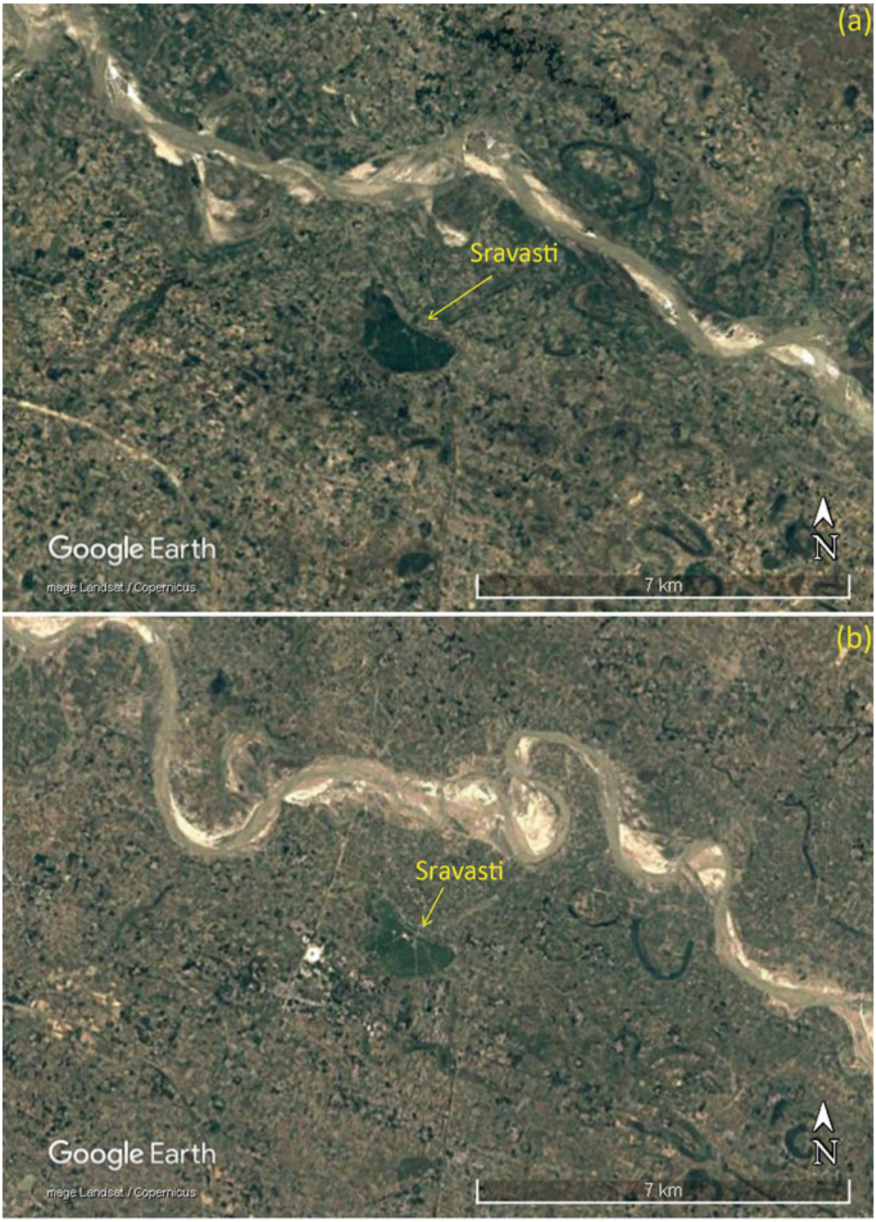

Fig. 2.25 Crescent-shaped fortified site of Sravasti in Uttar Pradesh. The shape of the meandering river as seen on December 1984 in (**a**); and December 2014 in (**b**)

also be subject to the season when the image was taken (i.e. before/after rains and annual crop cycle in the agricultural fields). For instance, a palaeochannel north-east of the site of Sarnath is visible in Fig. 2.26a, but it is less conspicuous in an image taken just two months later (Fig. 2.26b). Figure 2.26c, d show a snaky pattern in a sequence of field boundaries, but we don't see a positive cropmark because most of the parcels along the palaeochannel were fallow on the dates when these images were taken. Hence, it is very important to analyse images from multiple dates and seasons.

Channels can vary in width from a few metres for small streams and rivulets to several kilometres for large river systems, and s correspondingly vary in width. The palaeochannels of a major river system that flowed from the Himalayas to the Kutch have been identified (Rajani and Rajawat 2011). Several Harappan sites are located along the banks of this former river and its tributaries (see Sect. 4.1). Figure 2.3a shows a section in northern Rajasthan overlaid with the locations of Harappan sites.

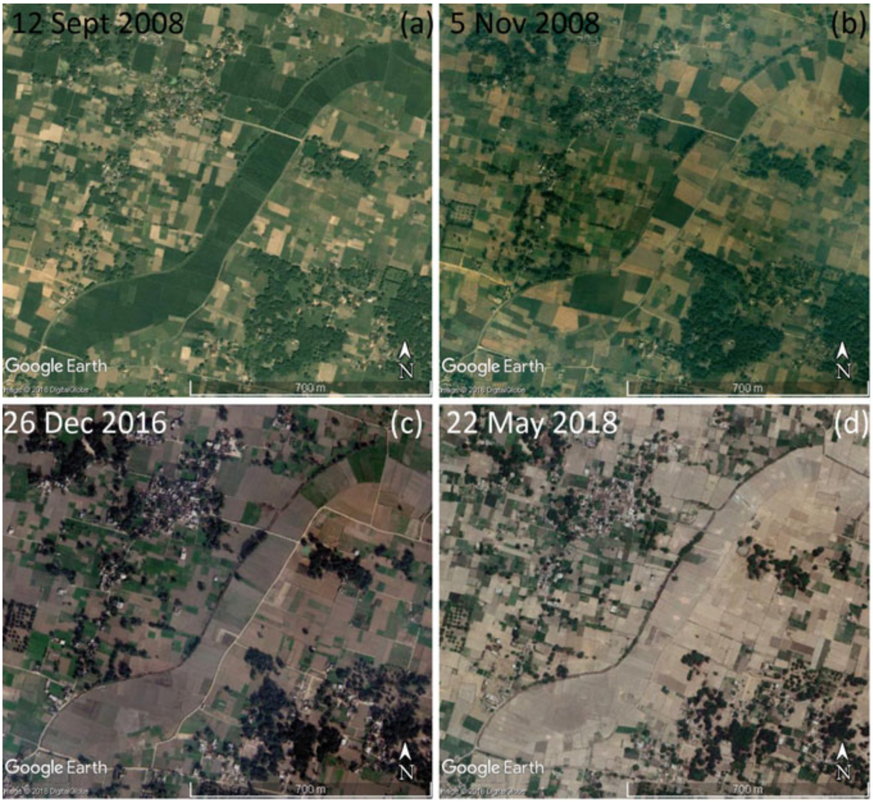

Fig. 2.26 Variations in the visibility of a palaeochannel north-east of Sarnath seen on four different dates

2.3.7 Coastal Regions

Many major cities across the world have been located along the coast, which provided easy access to resources, trade, and mobility via the seas. Historical spatial records often identify coastal structures in relation to the coast. This is unfortunate because the coast is characterized by the constant interaction of terrestrial processes and marine processes such as erosion, deposition, and storm surges. These processes heavily influence the spatial patterns we see in spatial contexts of coastal sites, which makes it difficult to match historical spatial records with present-day coastlines.

To appreciate this difficulty, consider the hypothetical coastal site shown in Fig. 2.27 with six structures, marked 1–6. Let us assume we have records for the time when the site was as depicted in Fig. 2.27a, where structures 5 and 6 were on the shore, structures 2, 3, and 4 were inland from the shore (structure 4 had a surrounding low wall), and structure 1 was still further inland. Figure 2.27b shows a different coastline, caused by some combination of erosion and sea level rise. Historical records from this time may fail to note structures 5 and 6 (because they are completely submerged) and may only note the structures 2, 3 and 4 located on the shore (the latter within an enclosing wall). Figure 2.27c shows further changes to the coastline, and records made at this time would indicate four coastal structures: 2, 3, 4 (partly eroded wall) and 5 (which has resurfaced but is in ruins). The apparent inconsistencies between these three historical reports are clearly due to the dynamic movements of the coastline, so the focus when reviewing these reports must be on immovable features: the built structures themselves, as well as large rocks, roads, etc.

Some of the earliest modern maps of India were coastal maps dating to the colonial period (sixteenth century CE onwards), when Portuguese, Dutch, French, Danish, and English colonists and traders settled on the Indian coasts. Sea charts and maritime maps facilitated the safe transportation of goods and the protection of settlements from rivals and were therefore guarded with great secrecy. Today, these archived maps provide archaeologists a wealth of spatial information for coastal sites.

As an example, consider the site of Mahabalipuram. This port city has many monuments from the Pallava dynasty dating from the seventh to the ninth centuries CE. Seven free-standing temples were visible near the shore to maritime travellers who sailed past this site during medieval times, and this unique landmark gave the site the toponym *Seven Pagodas*. However, from at least 1788 (Carr 1984) to today, only one temple stands close to the shoreline (there are more temples inland, and submerged ruins as well). This has led to much speculation about which seven monuments were being referenced, and whether they are on land or are submerged. A Dutch portolan chart from 1670 may resolve this mystery. It marks seven shrines along a coastline whose shape differs from the modern coastline (Fig. 2.28). Since this map dates from a period when the site acquired its name *Seven Pagodas*, it could be used to identify these seven monuments (see Sect. 5.5) (Rajani and Kasturirangan 2013). However, such maps can be subject to errors, biases, and limitations of technology of the time. These aspects of maps and the challenges involved in using them are further discussed in Sect. 4.3.3.

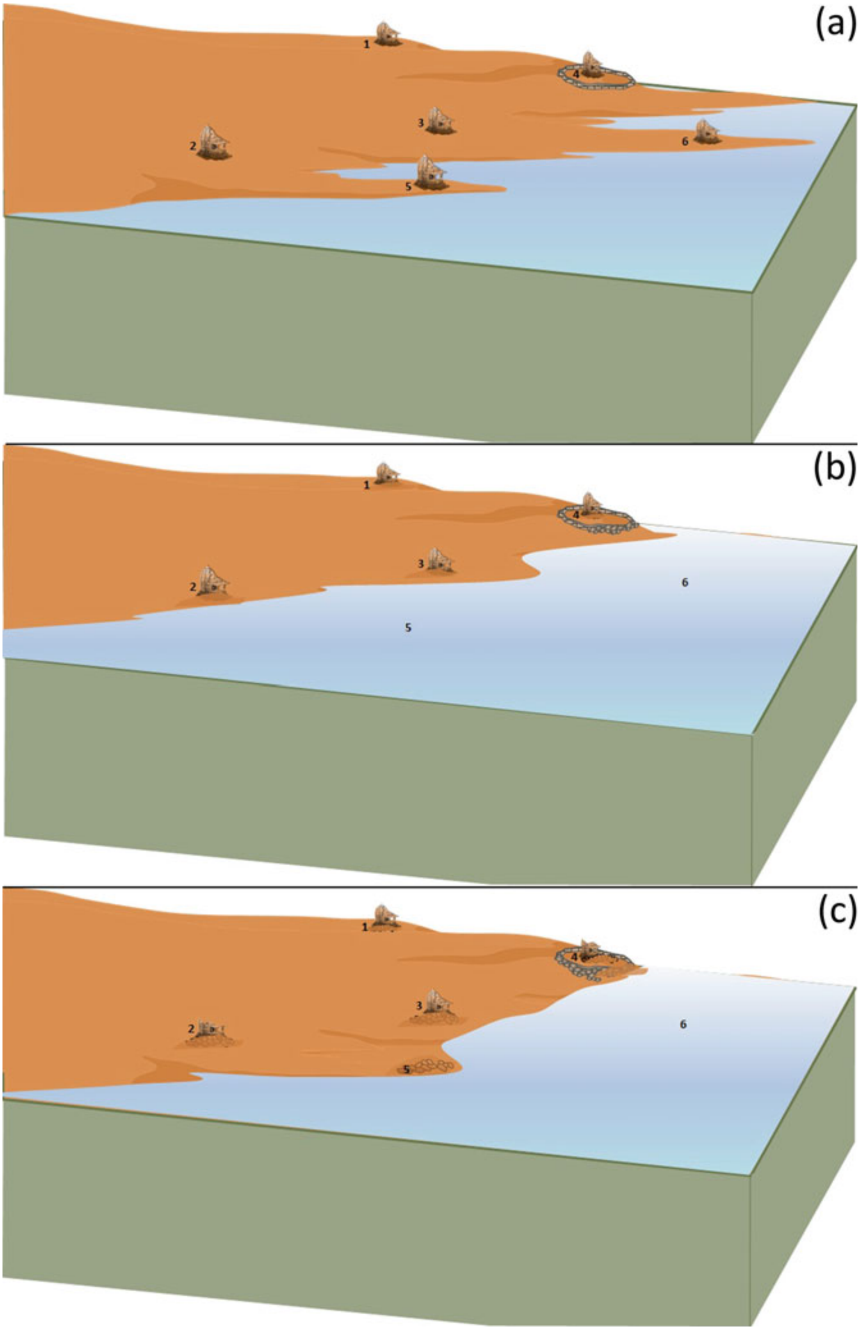

Fig. 2.27 Diagram showing a hypothetical coast with six structures at three different times

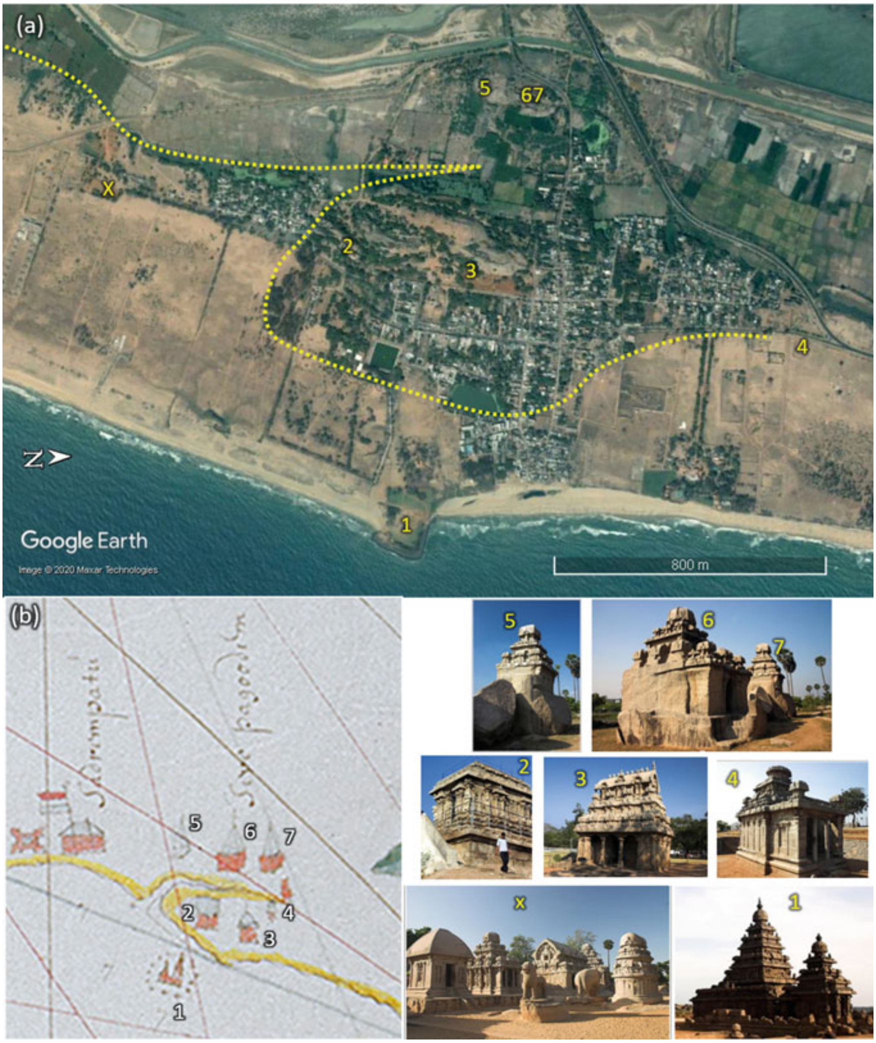

Fig. 2.28 **a** Locations and distribution of free-standing monuments at Mahabalipuram as seen on Google Earth image; **b** a portion of the Dutch Portolan chart of 1670 showing the monuments; 1—shore temple, 2—Olakkanatha or light house temple, 3—Ganesha ratha, 4—Mukunda nayanar temple, 5—Valiyankuttai ratha, 6 and 7—the two Pidari ratha, X—the five Pandava ratha

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