RESEARCH

Mapping the paleo-landscape features and middle or/and later Stone Age settlements of Tokar region, North-eastern Sudan using Radar Sentinel-1 (GRD) imagery

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Abstract

Along the western coastal plain of the Red Sea, the discovery of lithic tools proved that the occurrence of archaeological remains belonged to the Stone Age era. Unfortunately, until recently, most of the Stone Age site plans in the western Red Sea periphery have been unknown because of change in climate in addition to covering these sites with a large layer of sand. Recently, remote sensing (RS) data have proven to be effective at identifying buried archaeological sites using radar satellite imagery due to their ability to penetrate the land surface. This paper aims to identify and reconstruct several potential Stone Age sites using radar satellite images in the Tokar region, North-Eastern Sudan, on the western plain of the Red Sea. Radar (Sentinel-1 SAR GRD: C-band) data were processed utilizing the advantages of the Google Earth Engine platform and Snap software. The results of this research showed that some potential settlements belonging to the Stone Age era (expectedly dating back to the end of the Pleistocene and/or the initial phase of the Holocene) have subcircular shapes with some interior subcircles. These results shed new light on the potential construction technique, size, and function of the settlement in the Stone Age era and can provide some initial insights into the ancient lifestyle in this region. Additionally, this study can aid in future archaeological surveys and excavation missions in this region.

Keywords Stone Age settlements, Western coastal plain of the Red Sea, Radar satellite data

Introduction

The Red Sea region, particularly the coastal area, is full of archaeological and cultural artifacts dating from many historical periods [1]. Regrettably, this region has been less explored than the other regions and has not received much attention from an archaeological perspective, especially during the period of the Stone Age, which has impeded the ability to make an informed

evaluation of its role in supporting the survival and dispersion of early humans [2, 3]. The western edge of the Red Sea consists of three main geographic regions: the coastal edge (a zone of coral development), which extends up to 2 km inland; channelized plains, which extend up to 35 km inland; and the Red Sea Hills, a range of mountains that surround the entire coastal strip [4]. Irrespective of weather conditions, and particularly in drier climatic periods, the coastal plain would have always been more desirable than the desert interior, offering steady, core areas of human settlement from which populations would have frequently grown inside or escaped once more due to climate variation. Sea levels were low during several arid climate eras and some wetter episodes [5]. The study of settlement

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sites entails investigating the link between humans, particularly prehistoric people, and their environment and how they culturally and economically adapt to their surroundings [6]. This is a result of the simple interplay of three variables, namely, environment, technology, and social structure; these sites provide the main information about past cultures [7]. Hominins may have had constant access to the plains, especially during high humidity. When the channels leading from the mountain slopes to the coast were replenished with runoff, there would have been an abundance of freshwater reserves and a green landscape stretching between the Red Sea hills and the coastal plain.

It holds significant potential for early human settlement and is able to offer concentrated nourishment for both flora and fauna in specific areas [5]. Studying Stone Age sites in the Red Sea coastal region of Sudan indicates that the area was home to at least sporadic human settlements during the Pleistocene [8]. The Acheulean and MSA techno-complexes are usually believed to have evolved at distinct times alongside the emergence of discrete human species [3]. Different techno-complexes, including the Acheulean, Middle, and Later Stone Ages, have been discovered in these areas, indicating various human settlement periods [9]. The initial findings, including the abundance of hand axes, the hallmark tool of the Acheulean techno-complex between 1.8 and 0.5 Ma at various locations, indicate that *H. erectus* and/or possibly *H. heidelbergensis* populations resided in the area [10], which agreed with the theory that early Homo populations in Africa lived in two main regions throughout the early Pleistocene (2.1–2.1 million years ago) [11]. *Homo habilis-rudolfensis* is on one side, while *Homo ergaster*, which first appeared in East Africa 1.8 million years ago, is on the other [12]. Overall, the Red Sea settlements are highly important for understanding human evolution during the Stone Age, and they have provided valuable insights into early human population adaptation, technology, and social behavior. To understand why settlements were erected in these specific locations, it is necessary to examine the environmental characteristics, resource richness, and appeal to humans. Furthermore, the geographical landscape of the site can be reconstructed through permanent settlement, monsoonal settlement, system relocation, periods of dryness, and reorganization [6, 13]. In addition, the basic research goals of this study are to highlight the expected timeline of hominin settlements in the Tokar District, environmental and climatic conditions impacts on hominin survival in Tokar delta, the advantages of using remote sensing techniques in detecting the potential buried settlement locations, size, and distributions, etc.,).

The geological and environmental settings of Red Sea Hills

The Red Sea Hills belong to the Nubian segment of the Arabian-Nubian Shield [14–17]. The western Red Sea Plain is affected by regional crustal shifts caused by salt tectonics and isostatic coastal area warming due to external factors like ice loading [18]. These processes, along with changes in sea level, create a complex and interconnected dynamic in the region [19]. Torrential flooding occurs in the Red Sea, but the majority of the time, the plain sediments absorb the water [20]. Runoff water from the hills on the eastern periphery and ill-defined drainage systems is transported through minor khors or channels, with most of it not reaching the sea [21]. The coastal plain contains a Pleistocene detritus fan that has been dissected by recent stream activity. Alluvial deposits in the area are typically linked to periods of heavy rainfall [22]. During the Pleistocene, multiple glacial cycles occurred, resulting in fluctuations in climate. These cycles caused sea levels to rise and fall. On the other hand, during glacial periods, water was trapped in ice sheets, leading to a global drop in sea levels [19]. The Pleistocene's cooler glacial eras may have affected ocean circulation, marine life, and regional temperatures. Warmer interglacial periods could have impacted marine ecosystems with higher sea surface temperatures [23]. Glacial periods trapping moisture in ice sheets may have caused arid conditions, while interglacial periods may have brought increased rainfall and favorable conditions for plant growth [24]. Thus, lower sea levels during Pleistocene glacial eras affected the Red Sea. However, the scarcity of freshwater has always hindered human settlement in the region, even during wetter periods [25]. Climate fluctuations significantly impact water resources and alter land suitability for settlement, leading to expansions into desert regions during favorable climatic periods [5]. During interglacial periods, the eastern Red Sea Hills receive the highest rainfall in winter due to the northward shift of the Indian Ocean monsoon. Rainfall primarily originates from evaporated water in the Red Sea, carried over the mountains by strong northeast and southeast winds, resulting in precipitation [26–29]. Due to the absence of surface water in the dry season, human settlement in the study area heavily depends on groundwater. Rainwater from seasonal streams, called khors or wadis, replenishes the main aquifer system, which consists of hard rock aquifers with limited groundwater flow through fractures [30]. Thus, alluvial plains and valleys formed by ancient streams probably offered suitable settlement sites due to freshwater flowing from the Red Sea Mountains. During the wet season, the layout of the region, including alluvial fans, plains, valleys, and streams from the Red Sea Hills, likely influenced surface water runoff and aquifer replenishment [31]. Freshwater streams from the mountains

made the plains ideal for settlement, and the channel beds provided materials for making tools. The mountains also served as strategic locations for hunting and surveillance [8].

Tokar *Delta* environment

The Tokar Delta is located in the North Tokar District [32], in the southern part of the Sudan coastal plain of the Red Sea [33], between the shoreline and the Red Sea hills [22, 34]. Geographically, it consists of three main zones: the coastal plain, the Red Sea hills, and the wash zone plateau. The temporary watercourse "Khor Baraka" and its tributaries are the primary source of aquifer recharge during the flood season, along with direct precipitation [35]. Deltas typically form where rivers meet the sea, as river sediment mixes with the marine environment and undergoes various interactions, shaped over time by tidal currents, waves, and other marine processes [36]. Tokar is one of the few settlements directly situated on the plain. Variations in freshwater groundwater resources in this region, notably during the early Holocene epoch around 9000 years ago, showed a significant replenishment of freshwater levels in the Tokar Delta comparable to those of the Pleistocene period after the Holocene transgression [37]. On the other hand, the Tokar Delta is situated within a fault-controlled sedimentary basin running northwest to southeast [38]. Its Quaternary sediments mainly comprise alluvial fan deposits, primarily consisting of gravels, sands, and silts with occasional clayey layers, reaching a maximum thickness of around 500 m near the delta's center. These sedimentary processes have created a unique record that offers valuable insights into past environmental changes [39]. Although the basin doesn't have permanent rivers but has ephemeral ones like the Barka River in Sudan's Red Sea Hills, likely active during wetter Pleistocene periods [40, 41]. Tectonic activity impacts delta formation: subsidence allows sediment deposition and seaward expansion, while uplift causes river incision and limits delta growth [33]. Faults affect sediment movement in deltas, acting as barriers or channels [31]. Sea-level changes impact delta processes, particularly by altering accommodation space for sediment deposition [42]. Rising sea levels shift the coastline inland, providing more space for sediment accumulation in the delta. Conversely, falling sea levels reduce accommodation space, leading to erosion and sediment reworking [43, 44]. Sea levels were lower during the earlier Pleistocene than they are today, though they might not have reached the lowest levels of more recent glacial peaks. This implies that archaeological evidence of Pleistocene coastal settlements is probably not fully represented [15].

Remote sensing applications in archaeological studies

In terms of effort, time, and costs, archaeological survey missions are considered costly for identifying buried archaeological settlements [45–48]. More recently, specialized archaeologists have sought to use object-based methods such as (RS) techniques for the detection of buried archaeological sites and features [49, 50]. Consequently, the archaeology field has recently applied space RS and old settlements can be detected based on RS techniques [51]. More recently, radar satellite images have greatly improved the detection of buried archaeological sites based on differences in backscatter values influenced by anthropogenic transport, which supported our perception of past human–environment interactions [52, 53]. For instance, the integrated use of RS data, in situ surveys, and archaeological data is considered an initial indication of the reimagination of paleoriver traces in the case of no coring samples. Thus, the eastern course of the Seyhan River in the early or middle Holocene/Neolithic era was detected based on such available data. A major avulsion took place during the late Neolithic or Chalcolithic Period [54, 55]. On the other hand, the Paleolithic and Neolithic remains in the eastern region of the Sahara Desert were identified based on radar RS data [56–58]. In more detail, the age of space archaeology potentially started as early as the 1970s, when the first acquired satellite images, such as CORONA images, became useful and irreplaceable tools for finding buried and unknown archaeological sites. Consequently, archives of Landsat, SRTM, etc., have continued to be used to detect paleogeography, paleohydrography, and buried archaeological features based on differences in topographic and morphological land surfaces, soil, and crop marks [59–61]. In the field of archaeology, several satellite sensors have been used in multiple fields, such as in the field of cultural heritage management and in the detection of buried archaeological remains [62–65]. The freely distributed satellite images such as NASA and the Copernicus Programme have further helped ongoing research on the protection and detection of archaeological sites. Additionally, platforms such as the Google Earth Engine were needed for big data analysis [66–68].

The study aims

Three years ago, a research team surveyed the areas of Agig and Khor Baraka (two areas situated in regions close to the study area), and the team discovered some tools resembling those from the Acheulean and MSA technocomplexes. This growing body of evidence indicates that hominins enhance their chances of survival in the region by utilizing a variety of landscapes, while the majority of sites are situated inland; the most recent fieldwork

season has documented a distinct Acheulean presence [3]. This study aimed to use satellite images data to discover potential archaeological remains in the Tokar district. The area of interest was chosen based on published scientific work that mentioned the possibility of existing settlements that belonged to the Stone Age in Tokar Delta (the study area) [69]. Thus, because of the capabilities of radar data in discovering many archaeological sites due to its ability to penetrate the surface of the land, the authors preferred to use this technique to help in revealing some buried borders of the ancient communities in the Tokar district.

Area of interest
Along the eastern border of Sudan, the coastal plain of the Red Sea is situated in a crucial geographical position, which makes it an excellent area for studying the importance of coastal environments in the survival of early humans. It is possible that the region was home to several instances of hominin settlements [5]. Current evidence indicates that the area was home to at least sporadic human communities during the Pleistocene (2.5 Ma–12,000 [ka]) [8]. Thus, settlers were drawn as early as the Pleistocene [15]. The study area is situated in the Tokar district, Red Sea Province, particularly the Tokar Delta, with coordinates between 37° 45′ 12.547″ E

and 18° 37′ 54.641″ N (Fig. 1). The Tokar Delta is formed as sand and gravel are carried from the mountains by widespread, fast-flowing floods on the Baraka River [70]. The delta is situated in the southern section of the Sudanese coastal plain, approximately 90 km south of Suakin. It forms a roughly triangular area covering approximately 2450 square kilometers. Flooding occurred in the delta from July to September, although limited irrigation had been applied in the western region for many years. Earthen embankments (bunds) offer some flood control, while wells serve as an additional water source, primarily for growing vegetables. The average annual rainfall (1951–60) in Tokar and Port Sudan is 69.0 mm and 84.4 mm, respectively, with more than 75% of the precipitation falling in November and December. The monthly mean temperature varies from 23–25 °C between December and March to 30–36 °C from June to September, with maximum temperatures occasionally exceeding 50 °C [71]. However, this area is environmentally and socially delicate, as it lies within the arid Sahel zone, and the majority of the population is engaged in agriculture and livestock farming [72]. The delta formed due to the influence of a silt-laden channel known as the Baraka. Annually, this channel experiences spatewise flows originating from the mountainous areas of Eritrea and northeastern Ethiopia. Baraka has its source in Eritrea and was
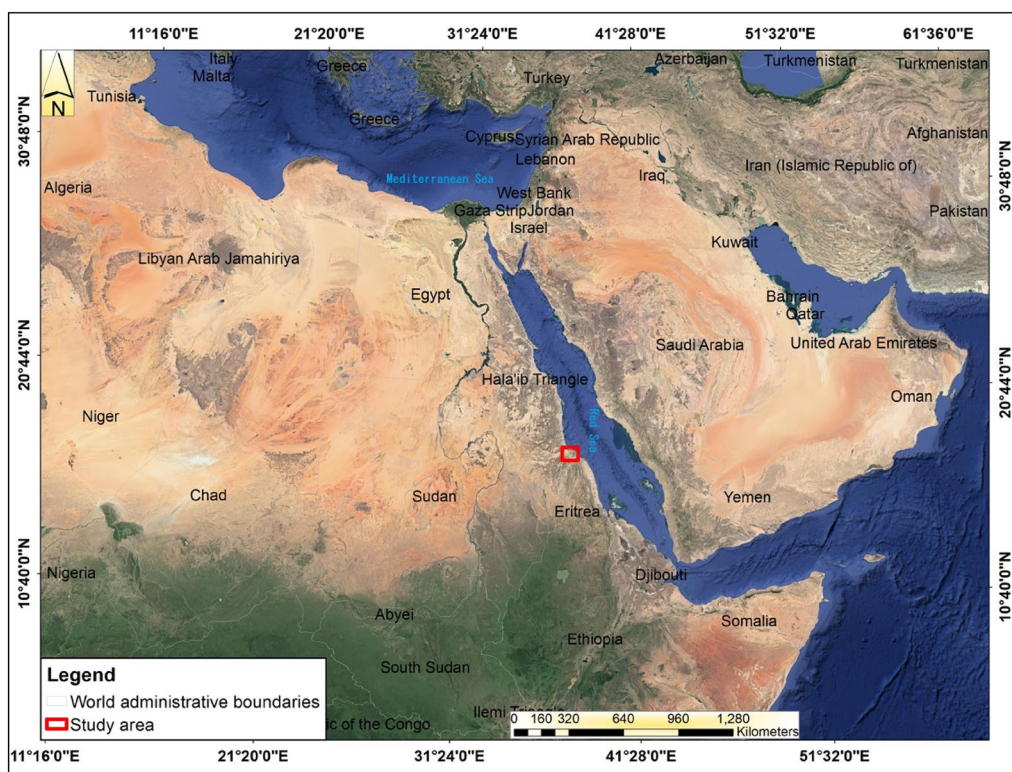

Fig. 1 Tokar Delta, the area of interest, situated in the western periphery of the Red Sea

joined by several sizable channels during its two-hundred-mile journey. Among these tributaries, the most significant southern tributary is Anseba from Ethiopia, while the two notable northern tributaries are Ambucta from Ethiopia and Langeb from Sudan. However, due to their progression through rocky and barren terrain, the latter two contribute little to the absence of silt during the Baraka flood [73]. Multiple paleo-rivers and paleo-channels are located throughout the area. The vast basin is punctuated by alluvial outcrops and rocky hillocks that generate slight topographical variation, forming the area between the channels [74].

Data and methods
Data
To show the geoenvironmental and paleolandscape settings of the study area, various topographic maps with a scale of 1:250,000 and multisentinel1 radar data (Table 1) were used and analyzed. Furthermore, in addition to the Google Earth Platform (GEE), ArcMap 10.6.1 and Snap 9.0.0 were used to preprocess, process, and postprocess the topographic maps and satellite images.

Methods
Digitizing the topographic maps
In this study, topographic map sheets were used to determine the landscape characteristics of the study area, such as the land use and land cover properties. Therefore, the topographic maps were first scanned and then geometrically corrected based on the projection coordinate system of the study area (WGS 84/UTM zone 37 N). Thus, the valleys, elevation points, Red Sea shoreline, etc., were digitized and matched with the satellite images. Furthermore, all these steps were performed, and the required layers were extracted using ArcMap 10.6.1 software.

Radar Sentinel-1 data processing
To show some buried settlements and paleorivers, Sentinel 1A and B (C-band) radar data were used and analyzed. In this study, Snap software and the Google Earth Engine platform were used to extract the required information from collected radar data as follows:

Sentinel1 processing using SNAP 9.0.0 software The input radar data in the raw case include various problems, such as orbit position, not correcting pixel values, speckle noise effect, and Sentinel-1 GRD data conversion to a map coordinate system from slant range geometry formatting. Therefore, five steps were arranged and applied: orbit file construction, radiometric calibration, multilooking, speckle filtering, and geometric terrain correction. Because the sentinel data are considered to be big data, a graph containing the five steps was prepared with Snap software to provide the time needed for the data analysis. On the other hand, radiometric calibration was applied based on Eqs. (1–8) [75]:

$$value(i) = \frac{|DN_i|^2}{A_i^2} \tag{1}$$

where depending on the selected look-up table (LUT),

$$value(i) = one\ of\ \beta_i^0, \sigma_i^0 or\ \gamma_i\ or\ originalDN_i. \tag{2}$$

$$A_i = one\ of\ betaNought(i), single\ Nought\ t(i), \\ gamma(i)\ or\ dn(i) \tag{3}$$

$$noise(i) = \frac{\eta_i}{A_i^2} \tag{4}$$

Table 1 Shows the properties, capture dates, and sources of the satellite imagery data and topographic maps used in this study

Data	Type	Resolution	Acquisition date	Source
Map	Topographic	Scale 1:250,000	June 1909	Library of Congress Geography and Map Division Washington
Sentinel1B	Radar, Level-1 GRD_IW_Polarisation Dual (VV+VH)	20×22 m	31 May 2016	NASA Earth data, Alaska data search
Sentinel1A	Radar, Level-1 GRD_IW_Polarisation Dual (VV+VH)	20×22 m	08 April 2017	NASA Earth data, Alaska data search
Sentinel1A	Radar, Level-1 GRD_IW_Polarisation Dual (VV+VH)	20×22 m	15 April 2018	NASA Earth data, Alaska data search
Sentinel1B	Radar, Level-1 GRD_IW_Polarisation Dual (VV+VH)	20×22 m	28 April 2019	NASA Earth data, Alaska data search
Sentinel1A	Radar, Level-1 GRD_IW_Polarisation Dual (VV+VH)	20×22 m	30 March 2021	ESA, Copernicus Open Access Hub
Sentinel1	Radar, Level-1 GRD_IW_pass direction (descending)	20×22 m	01 April 2014 to 30 July 2021	The image collected and processed by GEE

$$noise(i) = calibrated\ noise\ profile\ for\ one$$
$$of\ \beta_i^0, \sigma_i^0\ or\ \gamma_i\ or\ originalDN_i \quad (5)$$

$$\eta_i = noiseLut(i). \quad (6)$$

$$A_i = one\ of\ betaNought(i),\ single\ Noughtt(i),$$
$$gamma(i)\ or\ dn(i) \quad (7)$$

However, the radiometric calibration LUT application and the calibrated denoising LUT can be applied in one step as follows:

$$value(i) = \frac{DN_i^2}{A_i^2} \quad (8)$$

In the final step, the tool linear tofromdB was applied.

Radar Sentinel-1 data processing using the GEE platform In this study, a code was prepared inside the GEE platform window. This code allowed the large amount of radar data (stored inside the platform) to be quickly analyzed over the large-scale study area with accurate results and easy steps. In this code, the geometry of the study area was defined based on the coordinates of the four regions of interest corners as follows: [[37.699837113156406 E, 18.072255864442326 N]; [37.86943855358609 E, 18.072255864442326 N]; [37.699837113156406 E, 18.20210905819823 N]; and [37.699837113156406 E, 18.072255864442326 N]]. The second step was to detect the image collection, which in this study was 'COPERNI-CUS/S1_GRD'; this step was specified with a 'transmitter Receiver Polarisation', 'VV', and instrument Mode 'IW'; in addition, in this step, the bounds were filtered in geometry. After that, the orbit properties (pass) were filtered through two passes, DESCENDING and ASCENDING, and the collected data were chosen to cover the period between 1st April 2014 and 30th July 2021. On the other hand, the map set center was defined based on the coordinates of the study area between 37.518 E and 18.0382 N and on a scale of 10. The two passes of the DESCENDING and ASCENDING layers must have the values {min: −25, max: 5} and 'Multi-T Mean ASC', true) in the added layer-by-maps. Finally, the map with the required information was exported at the appropriate pass at the needed scale and maximum pixel value [76]. Figure 2 shows the flow-chart, which includes the general headlines of the study.

Results

Some of the discovered settlements in Tokar

The paleo-landscape setting of the study area included various ditches and paleo-rivers filled with moisture stored in these buried canals. Sentinel-1 SAR data were used to find such burial features because of their ability to penetrate the land surface. In more detail, buried archaeological features and paleo-rivers have some impact on the land surface and subsurface, and Sentinel-1 radar data can detect these impacts (e.g., soil moisture and soil roughness). The analyzed radar data revealed various potential settlements distributed across the study area. These settlements consist of many small three-quarters
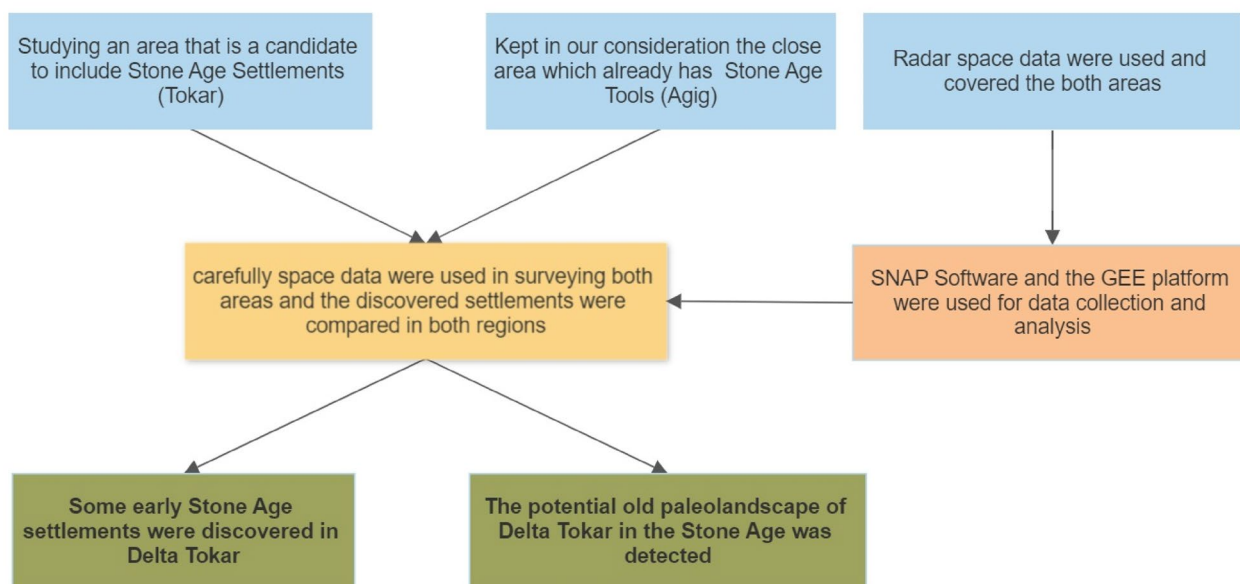

Fig. 2 Flowchart of the study, including the general processing steps and results
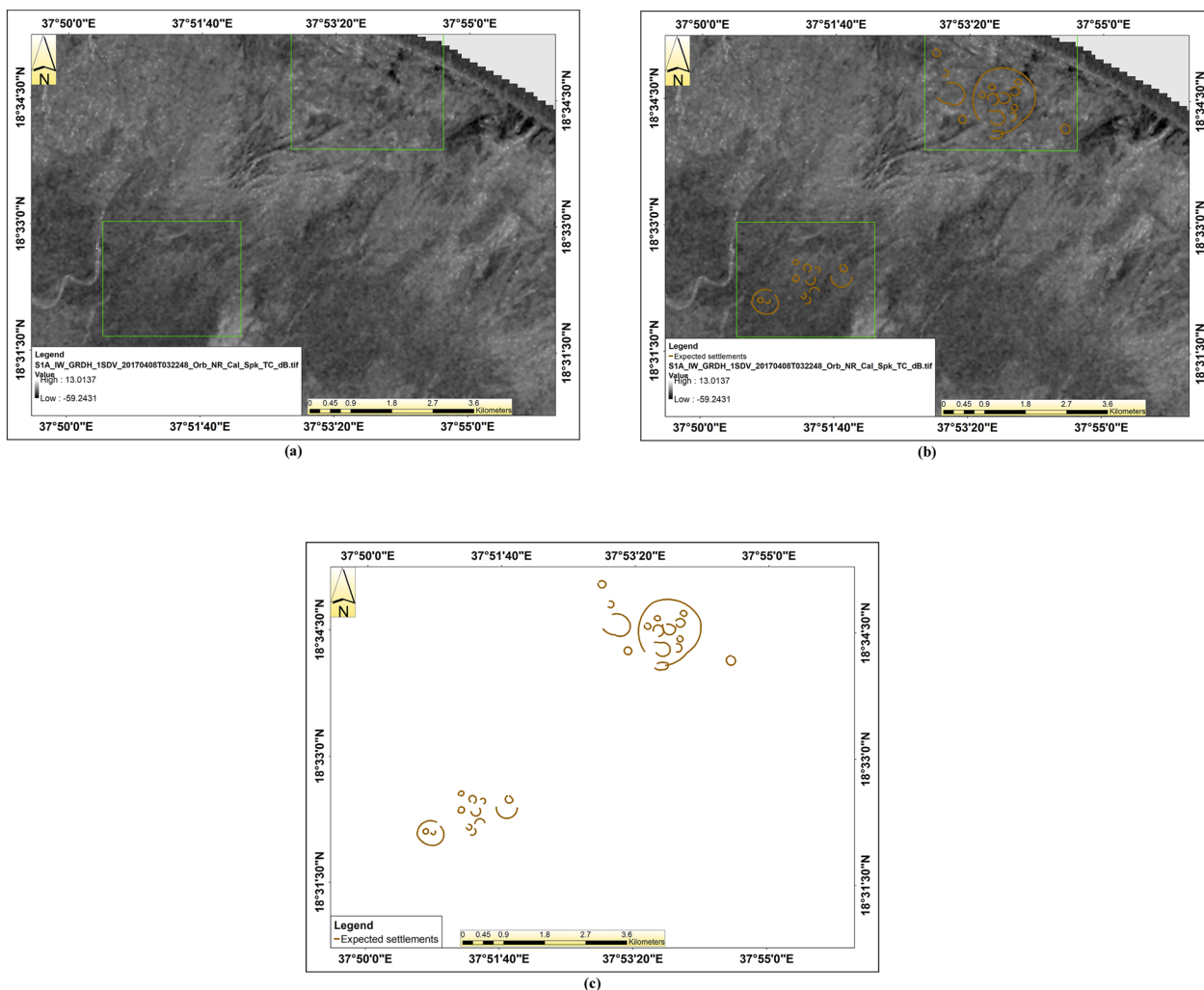
Fig. 3 Shows the general plan of the discovered settlements, which consist of various small circular trenches surrounded by large deep channels: **a** the settlements detected based on radar data; **b** the boundary of the settlements shown by radar images; and **c** the plan of the discovered settlements in two groups

circles surrounded by a large ditch (Fig. 3a–c). The main large outer discovered settlements have diameters between 500 and 1700 m as follows: the discovered settlement at 37° 48′ 21.893″ E, 18° 36′ 31.207″ N has a diameter of 912 m (Fig. 4a–c); the settlement at 38°0′ 31.61″ E, 18° 24′ 16.809″ N with a diameter of approximately 1034 m (Fig. 5a–c); and the discovered settlement at 37° 46′ 45.088″ E, 18° 37′ 6.667″ N with a diameter of approximately 1640 m (Fig. 6a–c). On the other hand, there are other settlements, such as the discovered settlement at 37° 35′ 23.273″ E, 18° 37′ 41.549″ N with a diameter of 1600 m (Fig. 7a–c); the settlement at 37° 53′ 46.268″ E, 18° 34′ 38.709″ N with a diameter of 1360 m (Fig. 8a–c); and the settlement at 37° 48′ 23.035″ E, 18° 36′ 31.824″ N with a diameter of 683 m (Fig. 9a–c).

Some discovered paleochannel traces

The landscape of the study area includes various wadies and subwadies, some of which are located at high elevations above the Red Sea level. These wadies flow eastward toward the Red Sea (for more details, please see the discussion section). Most of these channels are located in (or along) Khor beds, while a few can also be found on plains. Based on the radar data, many paleochannels (buried channels) were discovered and mapped (Fig. 10a–c).

Discussion

The coast of the Red Sea is considered one of the primary areas for comprehending anatomically modern human dispersal and migration processes, encompassing
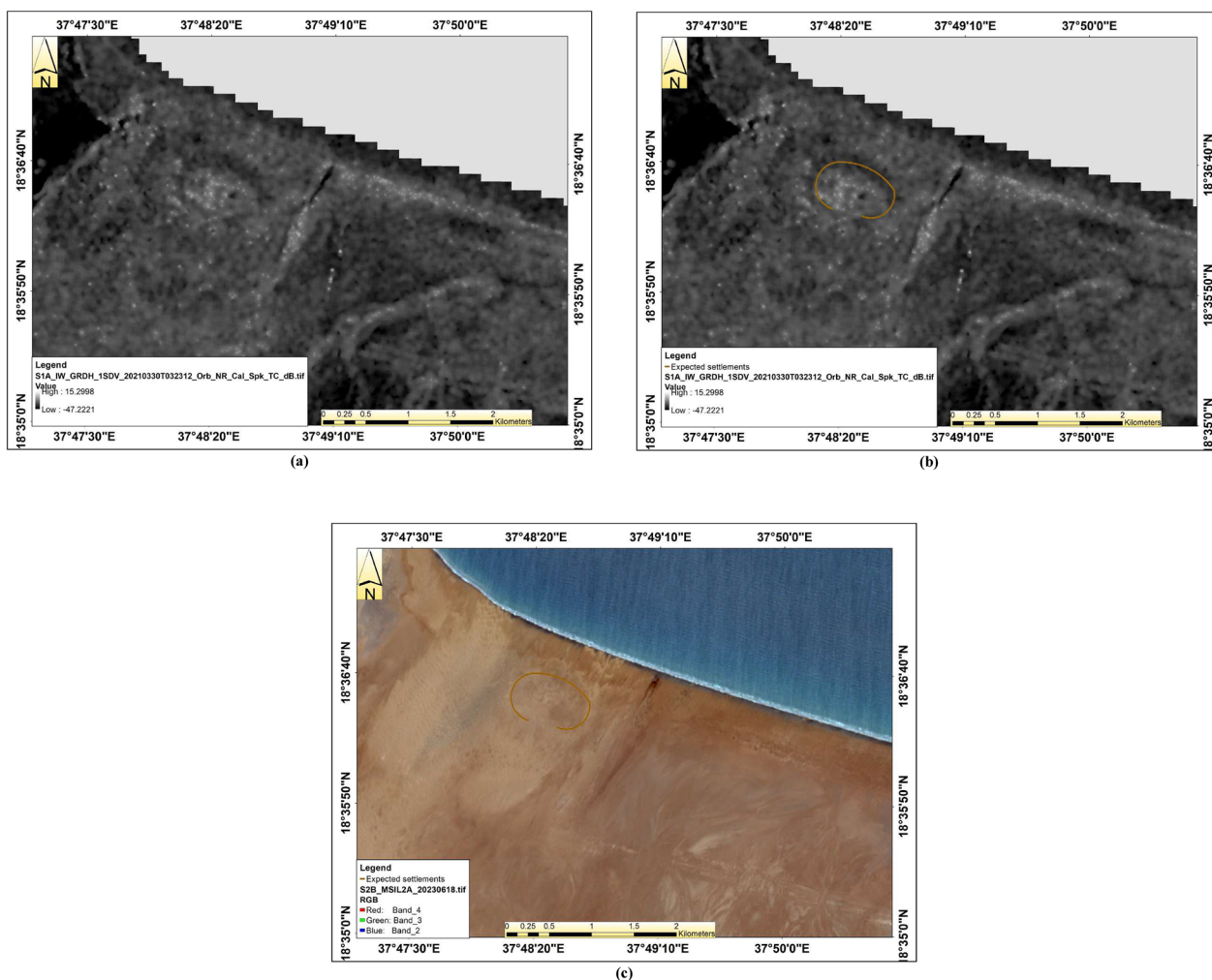
Fig. 4 Shows one of the discovered settlements situated close to the Red Sea coastline: **a** the settlement detected based on radar data; **b** the boundary of the settlements shown by radar images; and **c** the boundary of the settlements shown by optical images

the coastal regions of Egypt, Sudan, and Ethiopia [77]. According to Perlman, during the Paleolithic Age, coastal settlements were the areas with the highest population concentrations [78]. This was due to the availability of larger mammals for hunting, which resulted in population densities up to ten times greater than those in forest settlements. The Late Pleistocene Age witnessed a greater population density across landscapes than did the preceding periods, with a notable emphasis on the specialized pursuit of large-mammal hunting. Furthermore, one must consider the strain induced by the relatively rapid global loss of millions of square miles of terrestrial habitat due to rising sea levels [78]. The majority of evidence suggests that communities exhibit a high degree of mobility, and the resources available for exploitation are notably more restricted than those available during later periods. As a result, populations were smaller in size, and it is possible that less favorable habitats remained unoccupied [79]. As a whole, many factors should be discussed and checked before the determined of potential dating of the discovered areas such as how radar data can detect the buried features, the climate conditions in the ancient ages, the first known ditch-style settlements, and the closest discovered tools from the study area (Tokar Delta) which will overviewed as follows;

Remote sensing data analysis

Because of the difficult nature of the study area of interest and the old age of the studied archaeological features in our case study, radar satellite data can play an important role in detecting and documenting these archaeological sites. The use of RS data allowed us not only to detect buried archaeological features but also to produce spatial description maps of buried archaeological sites along with reconstructions of the potential boundaries of the covered archaeological settlements [68]. Using RS
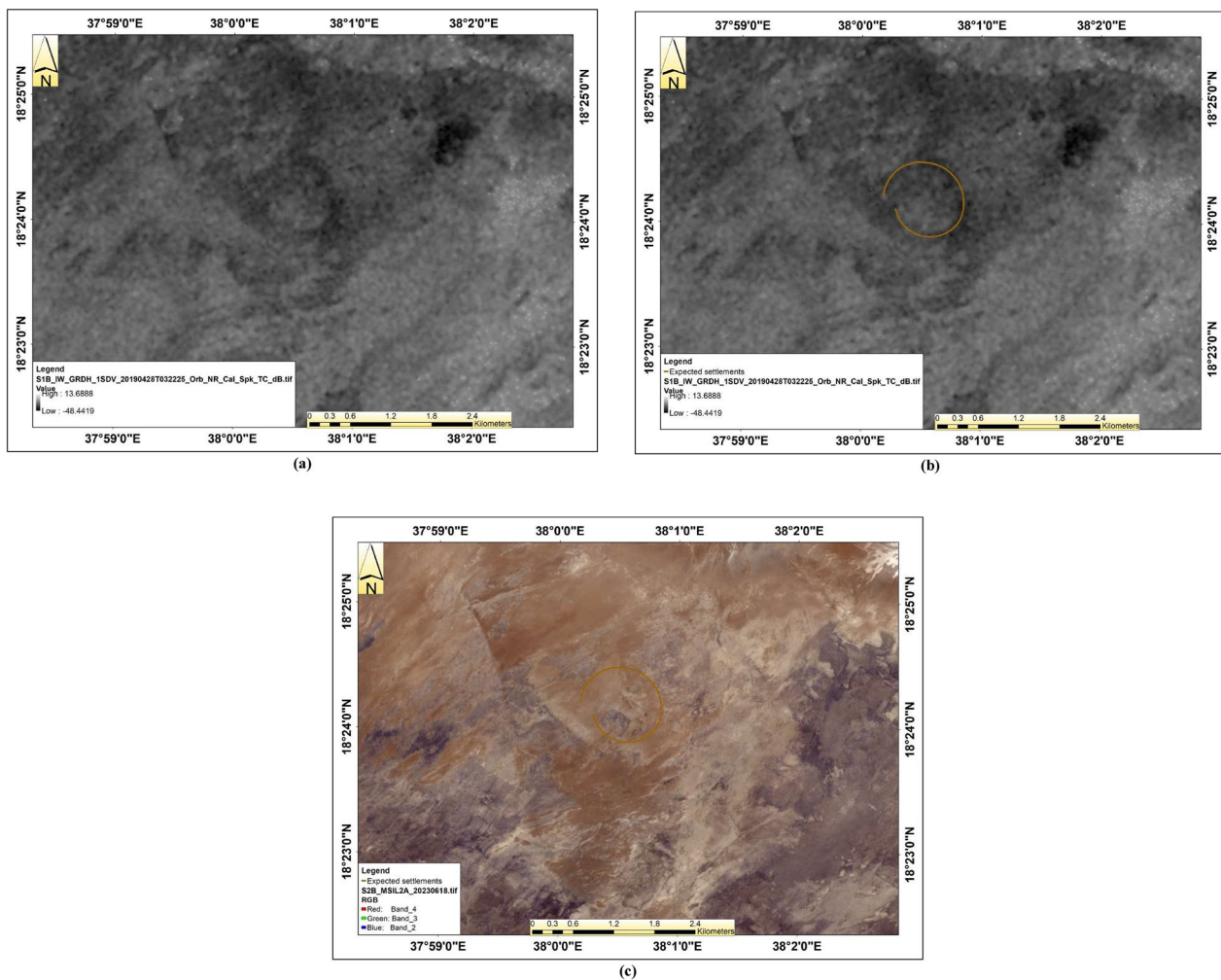
Fig. 5 Shows one of the discovered settlements situated close to the Red Sea coastline: **a** the settlement detected based on radar data; **b** the boundary of the settlements shown by radar images; and **c** the boundary of the settlements shown by optical images

data for studying ancient archaeological sites is being rapidly applied by archaeologists since it can provide valuable information in a shorter time than methodical archaeological excavations, which require more time and have high costs [80]. Human activities can cause landscape changes to be detected even after a very long time. Such traces can be detected based on changes in soil composition, superficial roughness, and/or moisture content, as revealed by radar satellite sensors [81]. The primary objective of RS is to detect changes in the contrast between the area of interest and its surrounding matrix. This contrast difference is named an "anomaly" until it can be identified, either directly through further image processing or most usually through a campaign of ground-based investigation (also known as ground truthing) [82]. The environmental conditions can explain this observation; higher altitudes experience more moisture due to summer rains, making the topsoil more compact

and richer in slime and clay, whereas on floors with less or no rainfall, the soil is loose and sandy. Consequently, arid geomorphic floors facilitate the 'etching' of people and pack animals, preserving these traces under pristine conditions. In contrast, areas with more moisture tend to have widespread vegetation accompanied by animals and compact, hard sediments [83]. Integrated satellite data have been used previously in various regions and have played a great role in detecting a high number of Neolithic sites [84]. Depending on the changes in soil chemistry produced by burial features, satellite sensors can observe, detect, and map the paleo-landscape features of the areas of interest [85–87]. Recently, Sentinel-1 SAR radar data have played an important role in discovering archaeological remains, taking advantage of the penetration capability of SARs due to increased radar wavelengths and subsurface porosities [88]. The penetration capability is strongly limited by surface characteristics
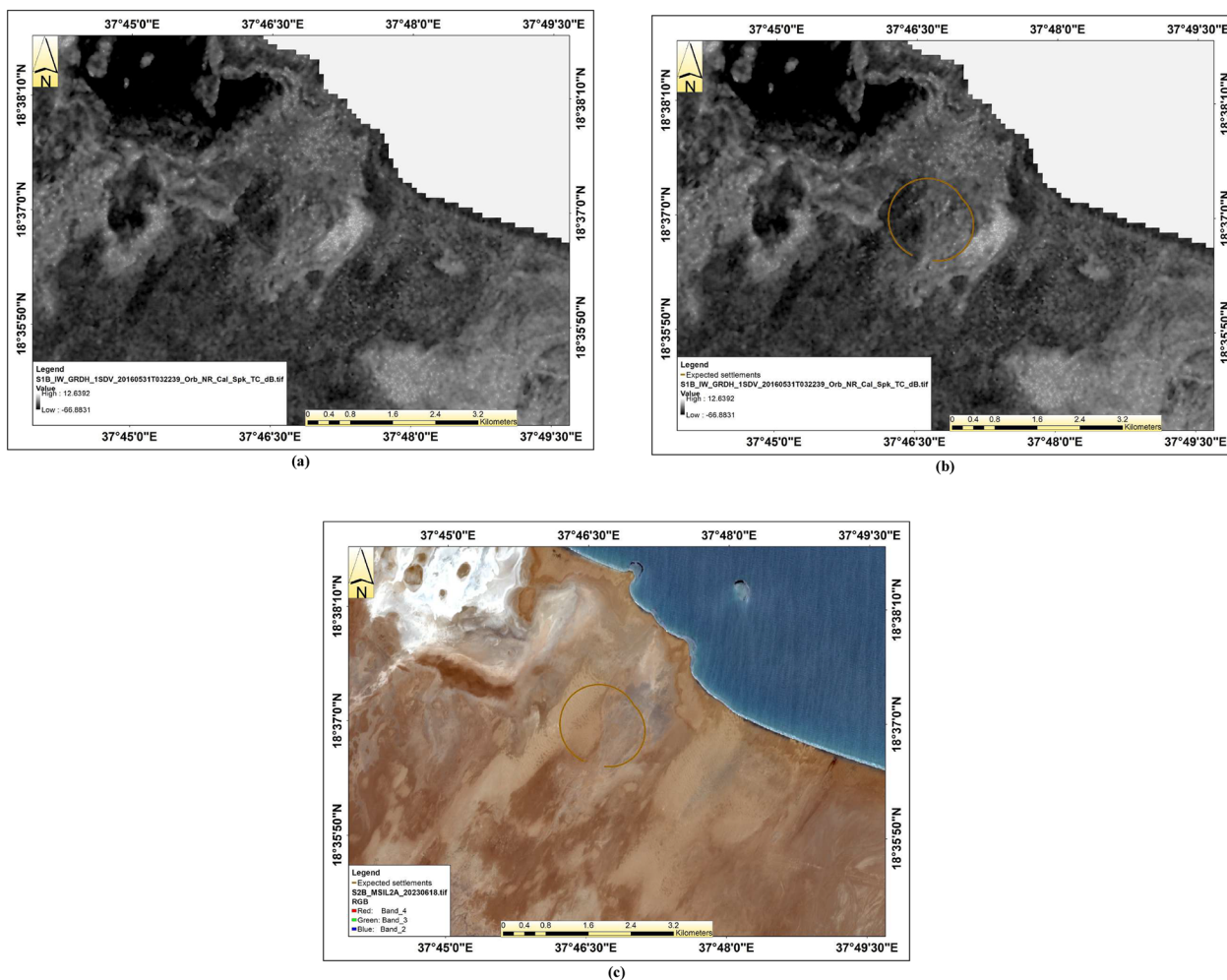
Fig. 6 Shows that one of the discovered settlements was situated close to the Red Sea coastline: **a** the settlement detected based on radar data; **b** the boundary of the settlements shown by radar images; and **c** the boundary of the settlements shown by optical images

and significantly limited by moisture content. This is the main reason why early applications of satellite SARs focused on desert areas [89, 90]. In this study, SAR backscatter intensity, coherence, and interferometry data are used to identify the paleo-landscape and archaeological remains in our study area. Recent published studies have mentioned that Sentinel-1 imagery as one of the useful data in detecting buried remains which can support our knowledge about the unknown archaeological sites [13]. The current developments in satellite capabilities are considered as the second generation of remote sensing technology which enabled us in terms of buried archaeological site detection [90]. SAR satellite imagery provided powerful information in the field of archaeological studies in both cultural heritage site management and archaeological discoveries [81, 91, 92] SAR applications also have been extended to observing large desert regions in order to detect the paleo-landscape features along

with detecting the potential archaeological sites [93]. Recently, the integration between the optical and radar data has been widely used as an effective tool to help in buried remains identification (e.g., Sentinel 1 and Sentinel 2 data) [94]. The power of Sentinel-1 data in penetrating the land surface (the limit of penetration is dependent on the nature of the region of interest) is returned to the microwaves that emitted by its sensor [95]. Furthermore, the high relative backscatter is a result of increased scattering from the presence of increased moisture. Such moisture differences may be a result of subtle differences in water drainage in the study area. On the other hand, the low backscatter may be a result of a lower dielectric constant due to lower levels of moisture in shallower soil [96]. Whereas larger features, such as paleo-rivers, can be directly mapped with SAR, smaller features will only become visible by changing the backscattering due to varying soil moisture [97] (Fig. 11a and b).
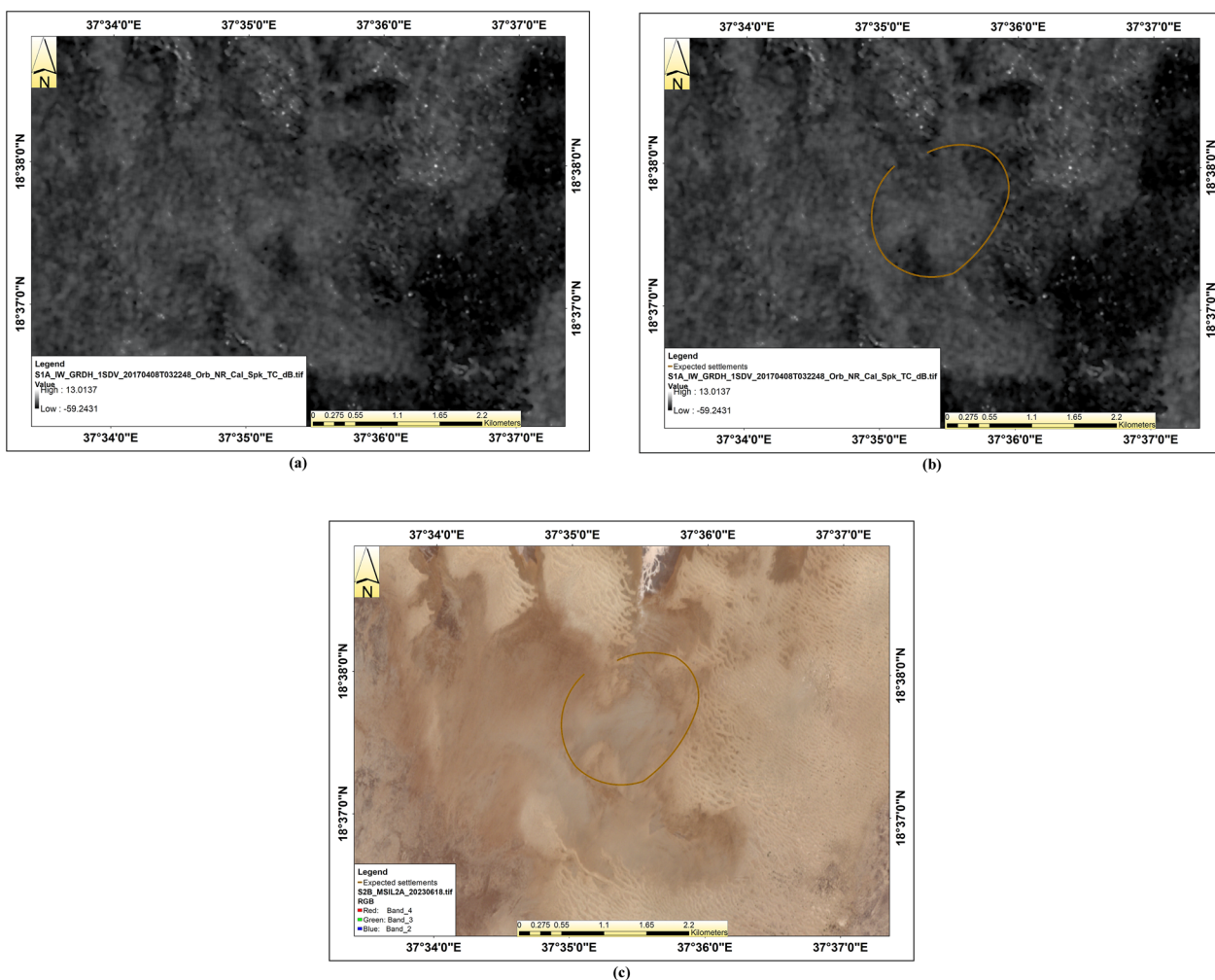
Fig. 7 Shows one of the discovered settlements situated close to the Red Sea coastline: **a** the settlement detected based on radar data; **b** the boundary of the settlements shown by radar images; and **c** the boundary of the settlements shown by optical images

The climate, landscape, and lifestyle of the ancient eras

Hominin populations began to grow during OIS 5, especially those of *Homo sapiens* (Group 3), as a result of climatic improvements. With increased population density, savannah/woodland habitats are present, and refuges and lake margins reach diverse places [98]. According to the documented climate status in the Pleistocene era, during the 1,500,000 years, there were notable changes in temperature and environmental conditions, occurring approximately ten times. With respect to several skills (cutting-edge technologies), inhabitants of the late Pleistocene quickly colonized almost all-important areas of the world [79]. The development of technology during the Early Pleistocene gave humans the ability to control their surroundings and resources, distinguishing them from other animals. Periodic resource instability during the Pleistocene encouraged technical advancement to increase resource dependability [99]. Technical developments likely improved the productivity of food sources that were previously less productive, but population growth offset these advantages, keeping the level of subsistence effort constant [100]. In terms of scale and quantity, site expansion, which includes marginal habitats, largely occurred during the terminal Pleistocene epoch. Most of the Holocene epoch appears to have seen a continuation of this pattern in varied contexts. However, collaboration was essential and persisted throughout Pleistocene hunter-gatherer communities both within and across groups, and the large degree of collaboration emphasized by Persson in explaining Upper Paleolithic improvements appears to have existed in human behavior since Acheulian times [79].

Due to several causes, our knowledge of Middle Stone Age (MSA) habitation systems in East Africa is limited. Few thorough surveys and excavations have been conducted, and numerous sites have yet to be identified.
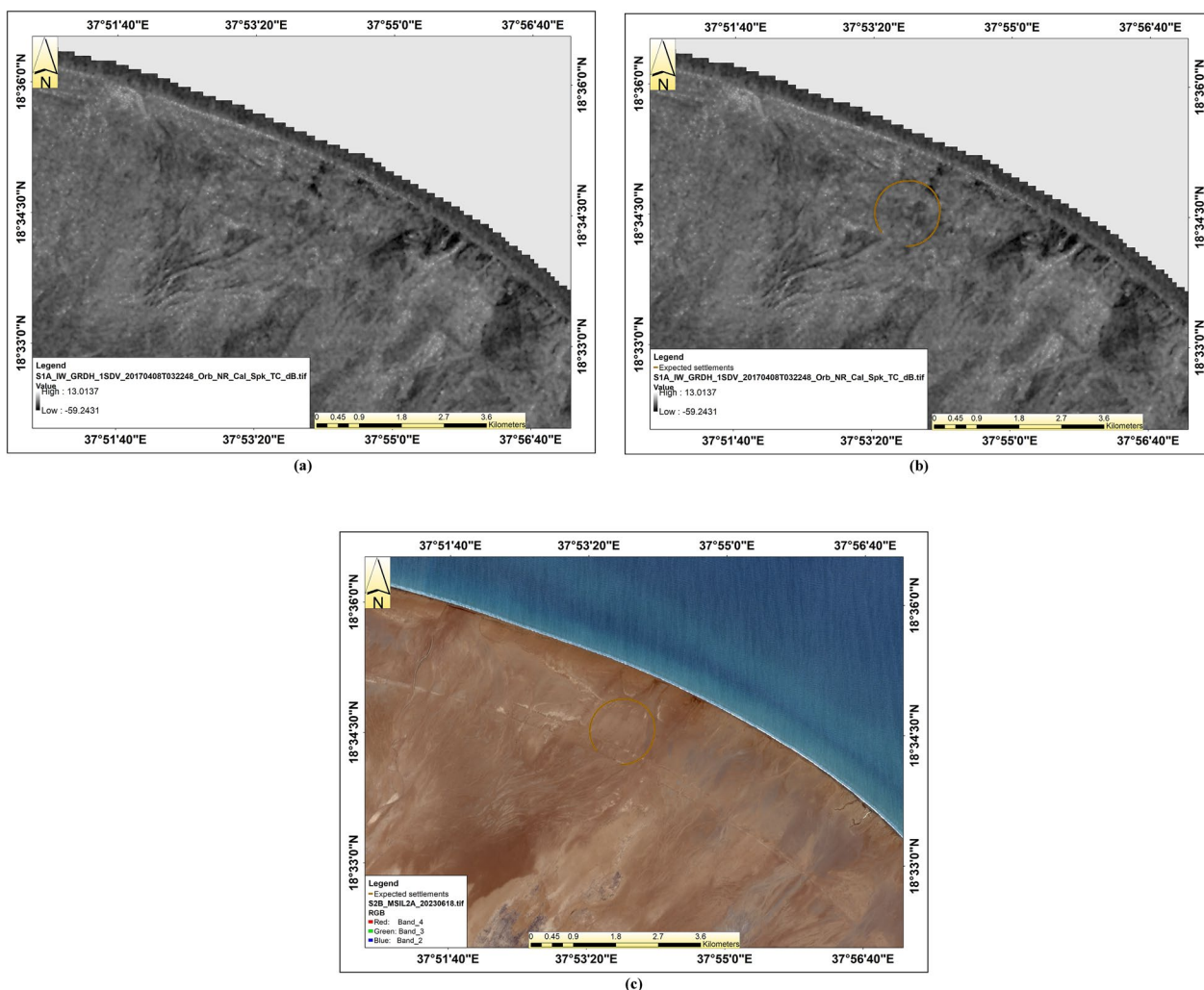
Fig. 8 Shows one of the discovered settlements situated close to the Red Sea coastline: **a** the settlement detected based on radar data; **b** the boundary of the settlements shown by radar images; and **c** the boundary of the settlements shown by optical images

Sites from the MSA are less common than those from the LSA, which may be related to exposure and visibility issues. A large number of MSA sites may have been buried or destroyed in the Rift region because of factors such as rapid alluvial deposition, high sedimentation, and erosion. Additionally, the lack of MSA locations may be influenced by behavioral and demographic factors. In the central Rift, MSA sites are clustered within a particular range of elevations, possibly indicating a preference for the ancient forest-savanna ecotone. There may be some bias given that many MSA sites are located in erosive regions, but this bias does not entirely explain the allocation. Higher mobility among MSA inhabitants could have resulted in less intensive site occupation and decreased visibility. There may have been fewer archaeological sites during glacial eras due to lower population density. These elements work together to reduce the

frequency of MSA events. MSA sites are often found in the central rift between 2000 and 2200 m above sea level, with very few below or above this range [101]. Eastern Africa experienced a significant loss of tree cover during the Last Glacial Maximum (LGM), which caused widespread desert, semidesert, and grassland areas to develop as a result of protracted aridity. This change presented potential obstacles for hominin communities. As a result, hominins probably gathered near the banks of large rivers and lakes. Coastal areas may have served as refuges even though sea levels frequently make them inaccessible [102]. According to this theory, *H. sapiens* departed from Africa approximately 125,000 years ago, and evidence from the Near Eastern sites of Qafzeh and Skhul supports this. This theory fits with the possibility of hominin expansion across the Nile Valley and the Eastern Sahara because of favorable climatic conditions [98]. The period
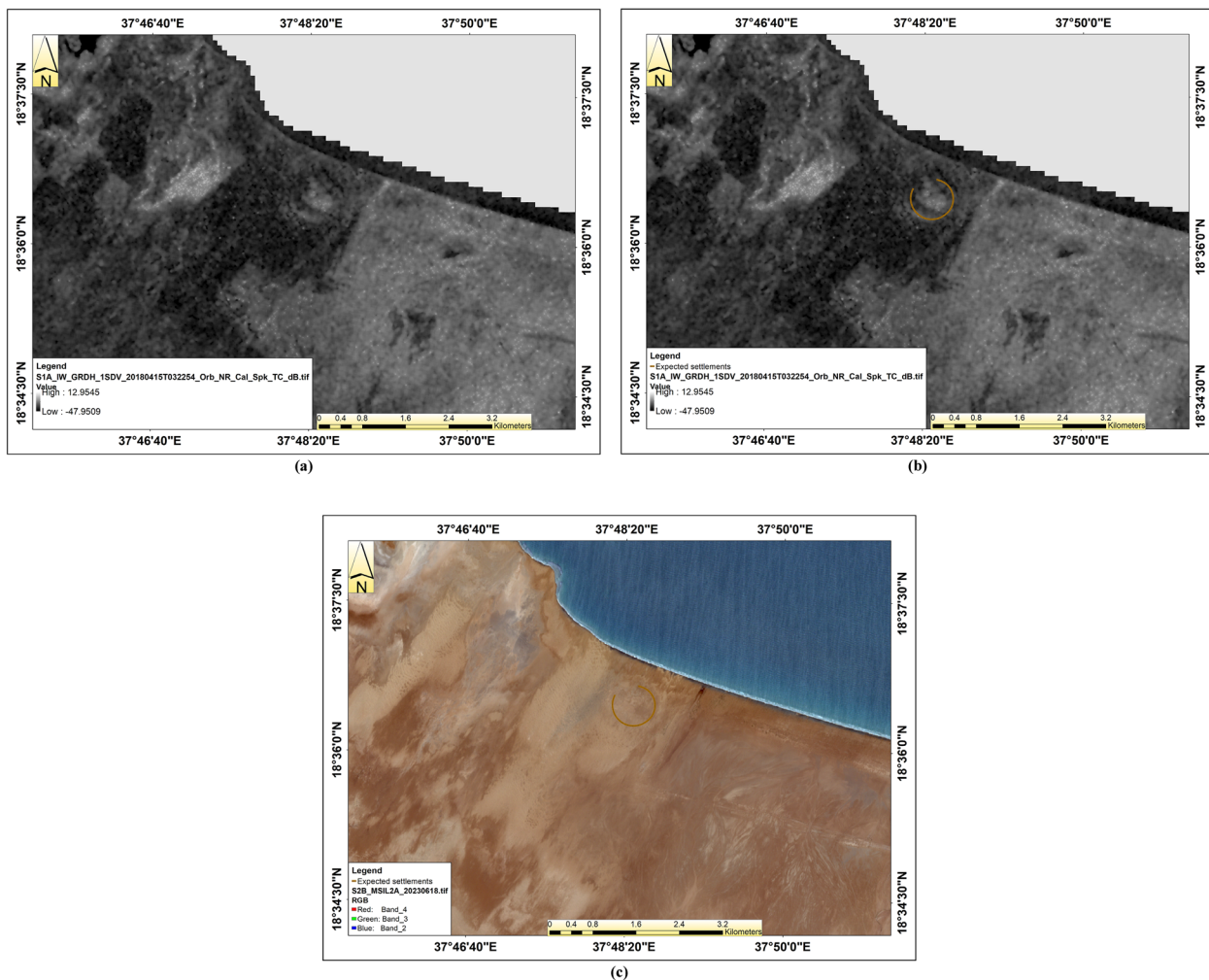
Fig. 9 Shows that one of the discovered settlements was situated close to the Red Sea coastline: **a** the settlement detected based on radar data; **b** the boundary of the settlements shown by radar images; and **c** the boundary of the settlements shown by optical images

between 140,000 and 212,000 years before the present (B.P.) is characterized by limited and insufficient evidence from central and eastern Sudan. This evidence suggests the potential existence of prehistoric sites that could offer valuable insights through systematic exploration [103]. On the other hand, MIS 5e at 130–120 ka shows a clear and strong association between wetter times and the early portion of the interglacial cycle over the past 130,000 years, as well as between the early Holocene (the early part of MIS 1) and approximately 11.5–6 ka. It rained during the latter 82–74 ka of the last interglacial period, or MIS 5a. The beginning of greater aridity was observed in MIS 4; however, at least one wetter interval occurred between 61 and 58 ka. This situation was less apparent during MIS 3, which was accompanied by the gradual advent of Northern Hemisphere glaciation. Although increased aridity, which peaked during the Last

Glacial Maximum at 22 ka, is the main climatic indication, based on radiocarbon-dated alluvial and lacustrine deposits, many wet intervals between 40 and 20 ka, as well as a wetter phase at approximately 15–13 ka, have been asserted [104].

On the other hand, in the protracted period of the Pleistocene, between 110,000 and 30,000 years ago, the sea level frequently fluctuated between 30 and 60 m below its present level. However, since 100,000 years ago, when the raised reefs were likely to have formed, the sea level has been at levels much lower than those of the present. However, in the middle of the warm glacial period approximately 30,000 years ago, the sea level was more than 100 m lower than it is at present. During this period, it is also likely that the climate of coastal Sudan was wetter than at present. Thus, streams leading from hills flow regularly, cut their courses across raised reefs, and
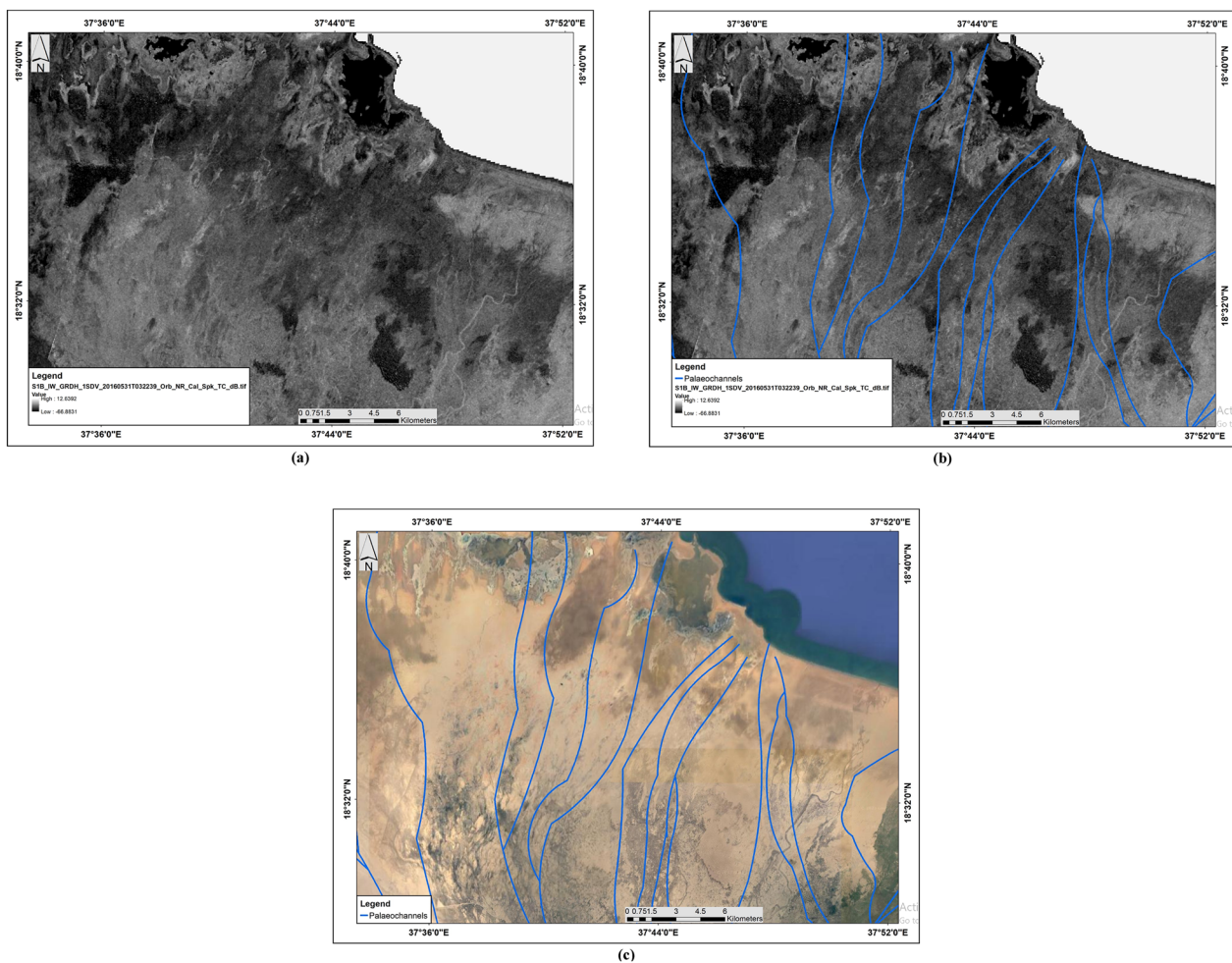
Fig. 10 Several of the detected paleochannels distributed across the delta of Tokar: **a** the paleochannels detected based on radar data; **b** the traces of the paleochannels shown by radar image; **c** the traces of the paleochannels shown by optical image

begin to cut their beds down to the low sea level during that period [105]. Additionally, heavy rainfall occurred between 35,000 and 17,000 years ago, causing a climate that resulted in widespread alluvial material movement and the construction of vast fan and outwash systems [106]. Wadies were cut to depths between 60 and 90 m below present levels during the Pleistocene due to low sea levels in the Red Sea and increasing rainfall. The surrounding ecosystem would have been severely impacted if the Red Sea had been completely cut off from the Indian Ocean circulation. A dry environment and almost full closure can result in a great evaporation-induced increase in salinity, which could cause many species of coral, particularly hermatypic coral species, to go extinct. According to recent fluctuations in Holocene Sea levels, sea levels increased by approximately one meter above current levels approximately 6000 years ago and then gradually fell to where they are today [107].

Ditch style

The digging of deep ditches, which enclose approximately circular or oval spaces, appears to have been carried out according to a predetermined plan, and the construction itself required the involvement of a significant portion of the population [108]. An effective argument for the prevalence of well-organized collective labor can be made by the choice to build enclosures as well as the effort and time put into their digging and maintenance [109, 110]. Many theories have been put out regarding the complicated network of ditches, including the likelihood that they serve as irrigation systems, for defensive purposes, or as barriers against precipitation flooding [111]. In some instances, fortifications and deep ditches surround settlements. These territorial boundaries were not always built to be defensive. A trench that was aligned with the dwellings may have been used to demarcate different zones or to designate a particular arrangement of the settlement's structure [112]. The exact purposes of
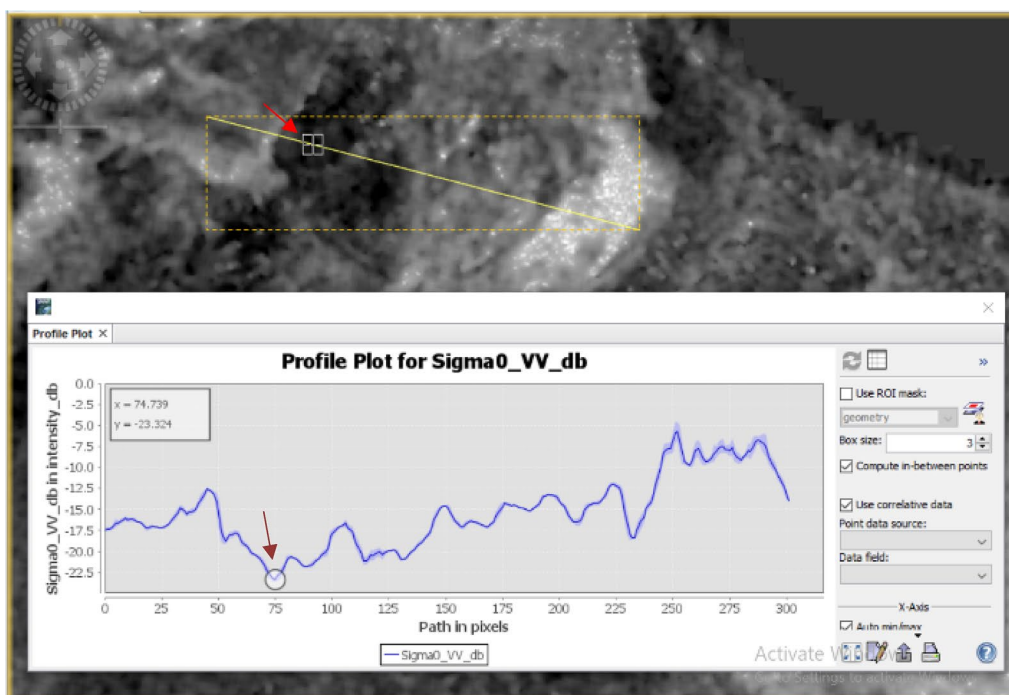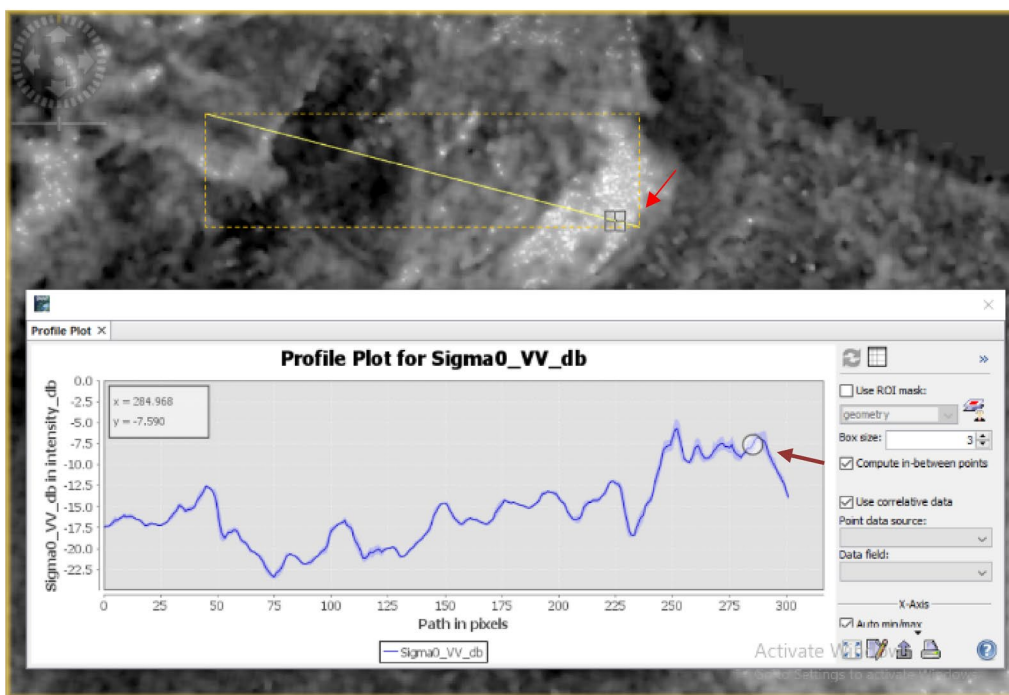
Fig. 11 The changes in the backscatter values due to the diversity of soil properties: **a** the low backscatter values of the VV polarisation due to soil moisture (wet soil) and the high backscatter values of VV polarisation due to dry soil

these complex ditch systems encircling villages must be further investigated [108]. Based on the recently discovered ditched sites, one of the earliest Neolithic settlement enclosures was found in the Eastern Balkans at approximately 6200/6000–5500 cal. Along the coast, particular attention was given to the excavation of ditches [109].

The neighboring areas

To understand why early hominins settled in Toker, as well as to try to determine the chronological date of the earliest settlement in this area, settlement patterns and the factors influencing these patterns in the Toker region had to be compared to adjacent sites. Insights into the area's historical settlement patterns can be gleaned by researching and analyzing their similarities and differences, studying stone tools from this era that are associated with the vegetation and animal environments. Thus, to achieve that, the two neighbor regions (Agig and Khor Baraka) will be concern and compare with the area of interest;

Ancient Agig

The early hominins who lived in the early/middle Pleistocene (ca. 2.0 Ma–200 ka) were situated in carefully selected places, allowing them to identify plant supplies, flooding, and animal activities across great distances. The locations were selected to be close to springs, stream channels, and a few quarries for stone tools [113]. On the other hand, the earliest settlements were situated in the foothills, while stone circles were built in the highlands [114]. However, a few isolated sites were found on relatively flat ground. Highland soils near settlements are generally unsuitable for erosion, while soils with structural advantages are more likely to occur on relatively flat terrain [115]. During this period, archaeological findings were found in various types of landscapes, such as terraces, hillsides with terraces, and the lower slopes of alluvial fans [69]. The landscape has changed due to human activities, erosion, altered rainfall patterns, and climate change, resulting in modifications in the soil structure and availability of grazing areas, depending on the prevailing climatic conditions [110]. The changes that occurred in the western coastal plains are not as apparent due to the lack of available information. In contrast, the changes that happened in the highlands were more substantial and noticeable. However, the transition seems to be more sudden in coastal plains than in coastal plains [109]. During a climate comparable to the current climate, the only habitable area during the winter months, which is currently the rainy season in the region, would be south of Port Sudan. The position of the Intertropical Convergence Zone (ITCZ), which marks the monsoonal rainfall belt, would have caused an increase in the amount of rainfall in the coastal plain, resulting in the activation of the drainage system along the coast when the climate was humid [69]. The most abundant and conducive conditions for plant and animal life occurred in interglacial periods characterized by elevated sea levels [5]. In this study, one of the sites that has been previously studied, including several Stone Age tools, was checked against satellite images data, and some buried settlements (stone circles) were detected based on radar imagery. Archaeological excavations in Agig have discovered numerous stone tools, including handaxes, cleavers, and scrapers, indicating human presence in the area for thousands of years. The "The Red Sea Palaeolithic Project" began in 2017 to study Stone Age sites in Sudan along the Red Sea, focusing on the Western Peripheral Red Sea (WPRS) [69]. The project found scattered stone tools across various landscapes, with bifaces or large cutting tools, primarily handaxes, being the most prominent artifact class. The Acheulean technocomplex, dating to 1.7–0.3 Ma in Africa, and points, scrapers, and prepared core products from the African Middle Stone Age (MSA) were also found [116]. The team is currently surveying more localities, focusing on promising deposits and conducting geochronological studies at artefact-rich sites (Fig. 12a and b).

Ancient Khor Baraka Basin

This area was briefly visited in the 2017 field season, the western Khor, which is located 60–90 km south of the Tokar Delta, was the main focus of the survey. Seven off-sites in three locations —Igayeb, Aslabeb, and Odwan were documented as a result of the visit. The most notable finds here, as in the Agig study region, are handaxes and bifaces knapped from locally accessible volcanic rocks. The majority of the sites that have been found are located close to inland drainage canals, indicating that they were likely exploited for terrestrial niches when conditions were likely wetter than they are now. Currently, the sites are situated in barren, bare environments with little to no freshwater sources. The lack of sites in the coastal zone may indicate that either shoreline erosion destroyed the sites, or hominins had not yet evolved the appropriate behavioural techniques to take use of the coastal niche [117]. Overall, the survey found that most find spots were characterized by stone artifacts, with no fossil remains found. Diagnostic elements, mainly handaxes, were recorded at Agig, and Khor Baraka areas, indicating hominins with Mode 2 technology. This technology is a hallmark of the Acheulean tradition, which flourished in Africa and Eurasia between 1.7 and 0.1 mya. *H. erectus* and *H. heidelbergensis* are potential candidate
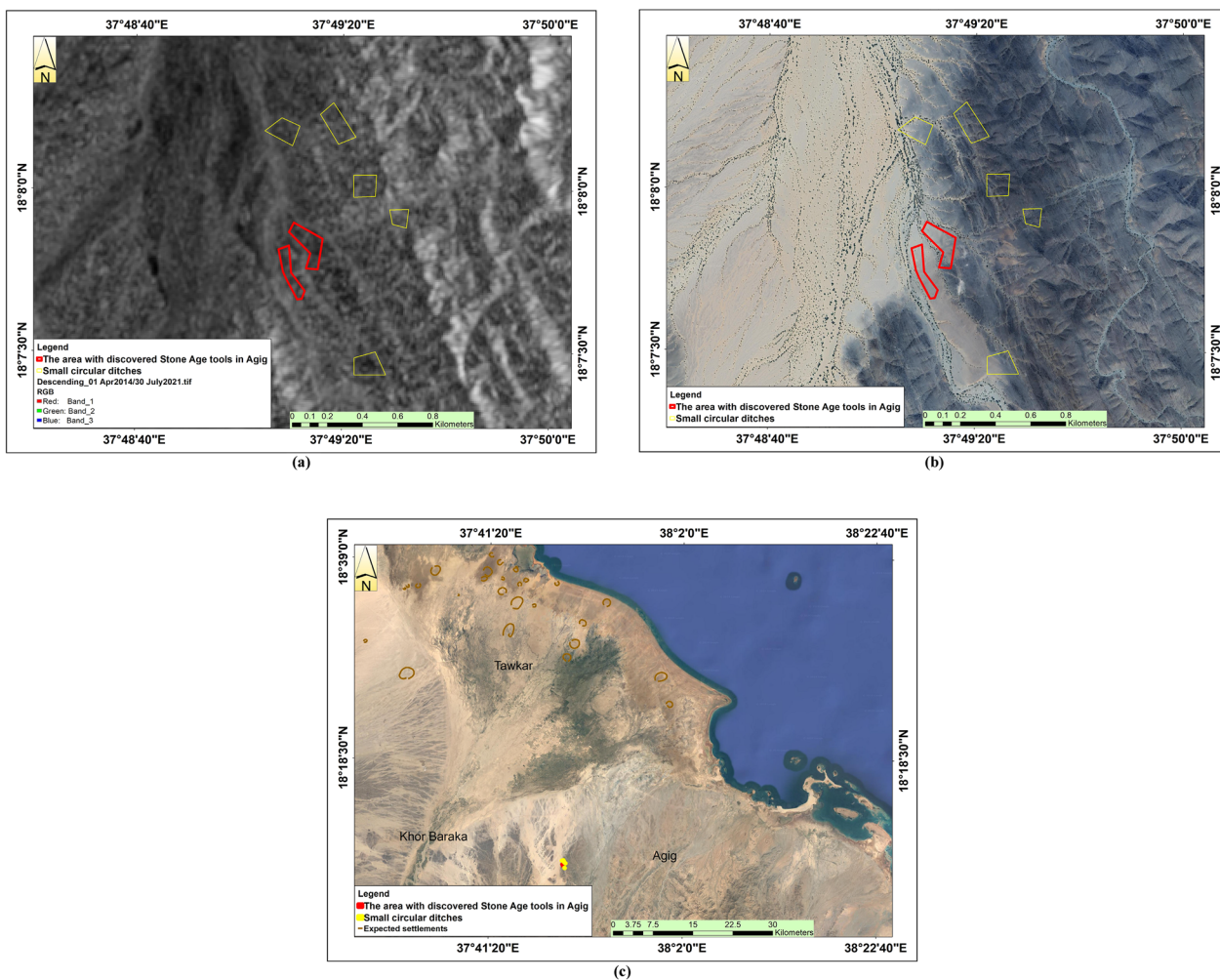
Fig. 12 Shows areas of Agig, Khor Baraka, and Tokar: **a** some stone circle settlements derived from Sentinel-1 data (the area with some discovered stone age tools in Agig by [69]); **b** the discovered settlement locations via Google Earth images; the study area of Tokar and the neighbors regions (Agig and Khor Baraka)

lineages associated with the Acheulean technocomplex in the study area. The inland plains were rich in stone raw material, including cobbles and large flake-blanks. The selection of these rocks, primarily fine-grained volcanic nodules, was a significant factor in the structure of hominin settlement. Handaxe-equipped hominins exploited various habitats, including savanna landscapes, and savanna landscapes, which were close to lakes and rivers. The distribution of raw material may not have been a significant factor in their settlement [118]. Improved freshwater supply was critical to hominin survival in these locations. Because handaxes were large, users concentrated on local resources. The channelized plains and low hills between the shore and the Red Sea Hills were ideal habitats for hominin-supported terrestrial species (Fig. 12c).

Expected Paleo-landscape of Ancient Tokar

To understand the paleo-landscape of the Tokar area, climate and land change dynamics should be studied. Overall, the increase in rainfall supported vegetation growth and human settlement in the region of Tokar [111]. A combination of higher rainfall to the south, the greater altitude of the Red Sea Hills in this area, and the large catchment area of the Baraka area results in a coastline built of silty stream deposits in this area. Khor Baraka is a seasonal stream with wide variations in annual discharge. Fewer available records show a variation in the duration of flow from 40 to 70 days per year and annual variations in discharge from 205 to 968 million cubic meters per year. In large flushes, it carries a very heavy load of silt and sand; in some measurements, up to 10.6% of the weight of the water was sediment in suspension. The

suspended material and the coarser-grained debris rolled along by the stream were deposited in a triangular delta with sides approximately 45 miles long, and this gradually extended seaward. To the south of the Baraka delta, smaller streams flow seaward from the coastal hills, providing a sandier coastal plain deposit near the southern frontiers of the Sudan. The delta's sediment-laden water inhibits the growth of active coral formations near the shoreline, resulting in the absence of fringing or uninterrupted barrier reefs in this region. However, further offshore, numerous small coral formations and islands demonstrate active coral development [105]. The analysis of subsidence history suggested a significant rate of overall subsidence, averaging 2–4 feet per 1000 years. This subsidence was primarily due to the accumulation of sediments from the Red Sea hills, which were transported toward the basin through conduits aligned with sutures and zones of weakness. The sediments move along these planes toward the sea, where they settle. This sediment accumulation exerts additional pressure on the underlying formations, and the resulting subsidence is largely attributed to this extra load [33]. In the Tokar Delta, which comprises barrier islands and lagoons, groundwater is found inside clastic sediments that have accumulated throughout time. Within the delta, the depth of the

groundwater fluctuates, with levels averaging 7–9 m in the top section, 10–12 m in the center, and 3–6 m in the lower portion. The general groundwater circulation follows the flow of surface water, which occurs mainly from the southwest to the northeast and from the south–southwest to the north–northeast. The waters of Khor Baraka and other small sporadic streams are the main sources of groundwater replenishment [119]. On the landward side, the region is divided among wind-swept rocky hills and channelized alluvial plains that are sporadically divided into low ridges. The plains would have supported several freshwater streams flowing from the nearby mountain fronts during ideal wet conditions, making them favorable for hominid habitation. In a similar vein, the channel beds would have provided raw materials for knappable stone [120]. By analyzing sediment cores, one core, near the Tokar coast (DSDP 228), spanned a large time range (late Miocene to present). The Western Palaeo-Red Sea (WPRS) in the 1970s revealed the occurrence of woodland grassland habitats during wetter times of the Pleistocene epoch [121]. Thus, if the African deserts continue to contribute sand and arid climatic conditions continue, drifting sand poses risks such as site burial [122]. These dune phenomena have encroached on the Tokar Delta for a very long time. Due to these conditions, satellite data

Fig. 13 Shows the expected plan of the Ancient Tokar paleo-landscape based on the discovered settlements and paleochannels

that can penetrate the land surface were used to detect the potential paleo-landscape of the study area. The extracted satellite image data revealed that many paleo-orivers and various buried settlements were distributed throughout the study area (Fig. 13).

The supposed immigration from Agig to Tokar

The presence of hominins in the Agig area was most likely associated with periods of heavier rainfall, which activated the drainage system and created optimal habitats for hominins and their prey [69]. The increasing aridity of the Agig region may have led to a greater need for a reliable source of water, which could be a key factor in why human settlements concentrated around the paleochannels in the plain [123]. It is possible that the earliest human settlement occurred in Tokar during the late Upper Pleistocene (approximately 200–12 thousand years ago) or early Holocene (approximately 12–8 thousand years ago), when the sea level was at its highest, potentially rising to one meter above current levels. The verdant woodland-savanna landscape encompasses channeled plains and low hills between the coast and the Red Sea Hills, which would have been ideal for

supporting terrestrial species, including hominins. Small, temporary settlements characterized by circular outer ditches and smaller circular structures emerged around the rivers [109]. We inferred that hominin lineages migrated from elevated locations, including some on the eastern slopes of the Red Sea Hills in Agig (1.8–0.05 Ma) [3], due to changing climatic conditions down to the coastal plain area in the Tokar Delta. Freshwater sources would have been essential for hominid survival in this area, and the abundance of water sources (khors or wadies) is a defining characteristic of Tokar. We propose that several surface sites found in the reaches of the drainage system in the Tokar Delta were occupied during the Upper Pleistocene (ca. 200–11.700 ka) or early Holocene (ca. 11. 700–8 ka BP). To ascertain the origins of settlement in Tokar and the factors that led to this difference, we compared the findings of the investigation in Tokar with the archaeological sites found in Agig from the Pleistocene era (Table 2). In general, it is possible that settlements in Tokar were more recent than were those in Agig. The large number of settlements, their considerable sizes, the lifestyles of the inhabitants, their techniques for preserving water, and

Table 2 Shows the comparison between the Agig and Tokar sites in ancient times based on the literature review and discovered settlements

Region	Agig Area with already discovered Stone Age tools	Tokar The study area
Residence Site	Foothill Basins, Pedi-plain environs	Coastal Plain
Age	During the Lower Pleistocene 1.8–0.05 Ma in Africa	Most likely, by the Late Upper Pleistocene and the Early Holocene
Elevation	Between 160 and 220 m	Between 10 and 70 m, the highest area is 170 m
Recent Distance from the Red Sea	44 km	Extended over the Red Sea shoreline
Red Sea Level	High Resulting from the reduction in land ice following the last glacial maximum	High Resulting from the reduction in land ice following the last glacial maximum
Water Resources	The Red Sea Mountains Rains form a few minor springs located in the mountain	Freshwater flows flowing from the fronts of the Red Sea Mountains Rains which form Wadies or Khors (groundwater)
Climate	Heavy rainfall	Humid Conditions
Settlement Shape	circular and semicircular stone features	Hand-dug wells (channels) with circular and semicircular features to store the rains water
Diameters of the discovered settlements	Small (20–60 m)	Big (500–1700 m)
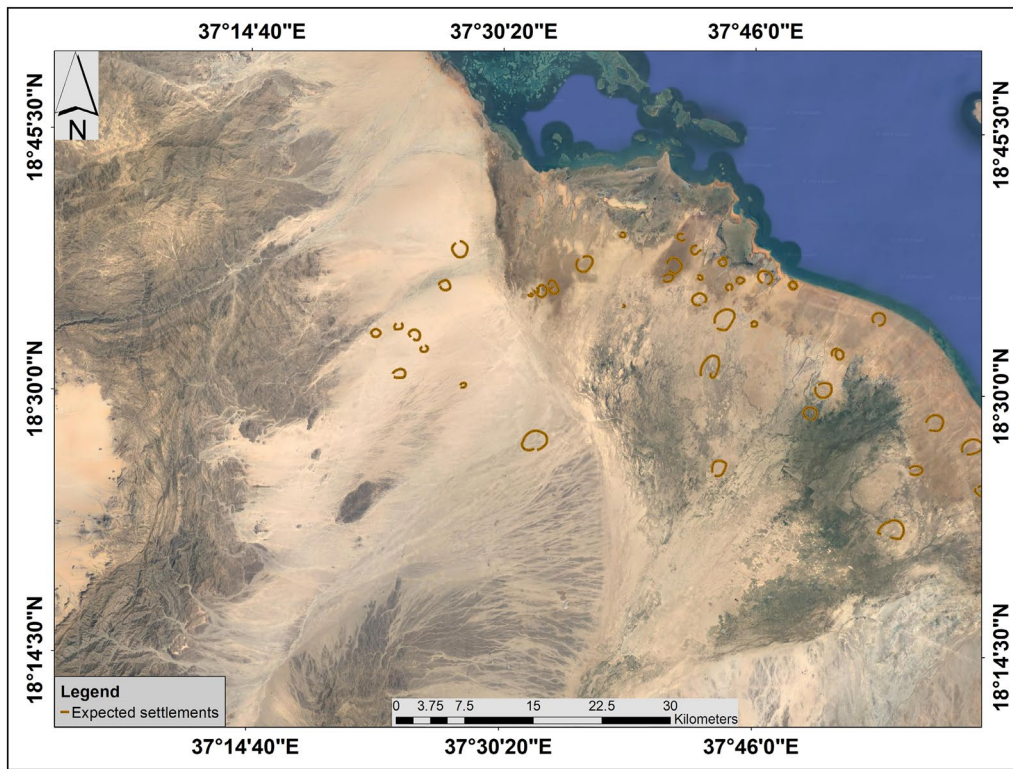
(a)
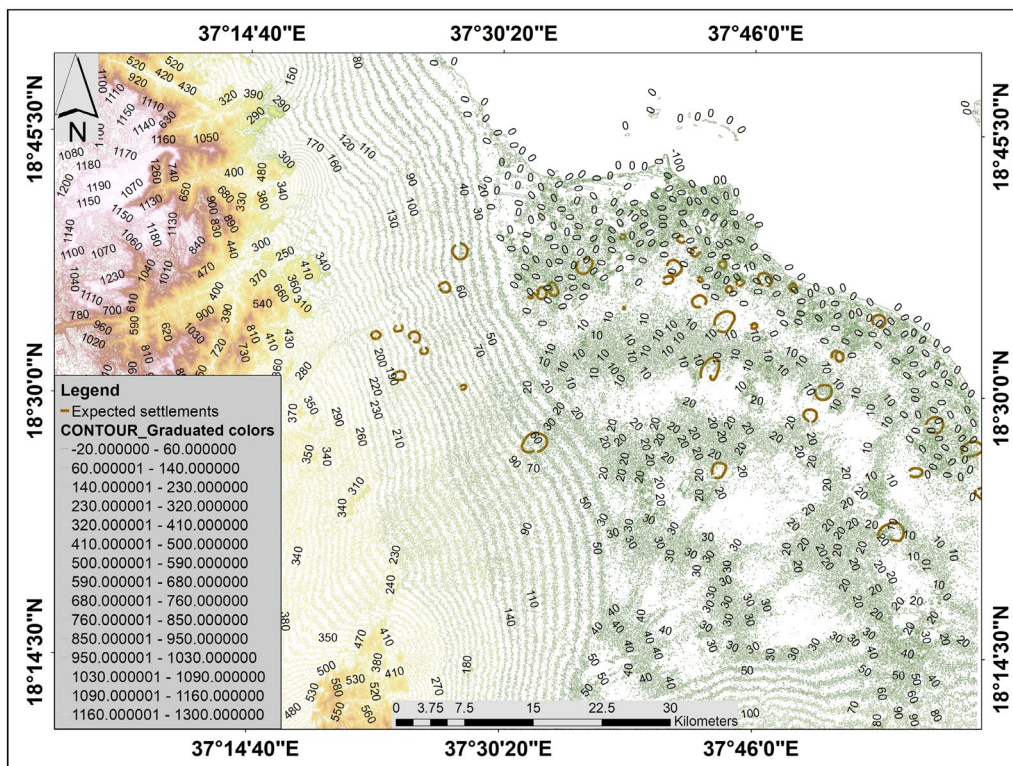
(b)

Fig. 14 The main landscape and elevation values of the study area: **a** the potential discovered settlements showed by sentinel-2 satellite image; **b** the elevation values of the area around the potential settlements

their organizations in family groups all suggest that the Tokar Plain may represent the beginning of the Plains Village Culture Concept. A program of systematic excavations in the region may help confirm this hypothesis. We inferred that hominin lineages migrated from elevated locations (Fig. 14a and b), including some on the eastern slopes of the Red Sea Hills in Agig [69], due to changing climatic conditions down to the coastal plain area in Tokar. Freshwater sources would have been essential for hominid survival in this area, and the abundance of water sources (khors or wadies) is a defining characteristic of Tokar (Fig. 15). Our theory suggests that the Tokar area had a humid tropical climate during the late Upper Pleistocene and early Holocene, with annual monsoonal rainfall of at least 400 mm. However, there was a progressive increase in aridity in Agig, and the mean annual rainfall decreased from approximately 300 mm to 100 mm. This led to the concentration of permanent settlements surrounding the khors in Tokar; more accurately, settlements became limited to these areas. The desiccation of the land away from the Khors zone and a decrease in effective local rainfall were the most likely causes of this trend. This theory offers a thorough framework for explaining the cultural changes seen throughout the transition from the Pleistocene to the Holocene by focusing on the idea of resource stress. This approach allows us to think about how early human societies interact with their surroundings, change with the availability of resources, and develop creative solutions to ensure their survival and well-being. This method emphasizes the complex dynamics of human adaptation and evolution over time while highlighting the dynamic and reciprocal interaction between culture and the environment [124].

Conclusion

The Red Sea Plain is considered an important area for research and exploration, and there is no doubt that future discoveries will continue to shed light on the origins and evolution of our species. This paper proposed a preliminary hypothesis that the Tokar region included hominin settlements during the Stone Age based on data extracted from radar satellite imagery in addition to the previously published study [69]. These settlements consisted of small ditches and huts surrounded by large circular ditches, representing a unique form of settlement. The distribution of these sites sheds light on a variety of adaptation-related issues, indicating that as the coastal plain population became more stationary, a new organized pattern of settlement gradually emerged. This may
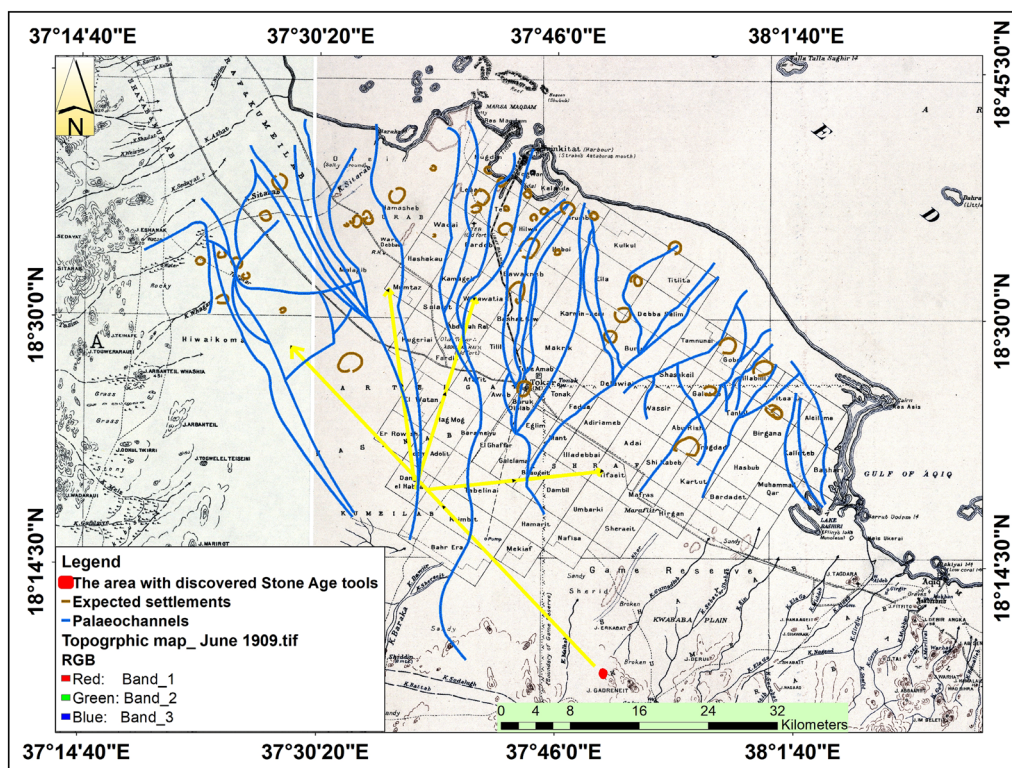

Fig. 15 The topographic setting of the study area includes the Agig and Tokar (the study area with the discovered potential settlements and paleoriver) regions

represent the beginning of the Plains Village Culture Concept, which focused on the social and demographic repercussions of coastal settlement. Tokar's strategic position makes it a prime location for studying the role of coastal environments in human survival and adaptation throughout evolution. The potential immigration phenomena that may have happened from the Agig to Tokar region during the late Upper Pleistocene proved that coastal sedentism would have promoted population expansion and immigration to the nearby hinterlands, where competition for limited resources may have sparked the early domestication of plants and animals. It is important to note that these findings are preliminary hypotheses and require further fieldwork to test their validity. By conducting a detailed analysis of the Tokar settlement sites, significant discoveries can be made. The distribution of these sites appears to be closely linked, indicating a potential role in the survival of hominids. However, the importance of the region in terms of hominid survival cannot be fully confirmed until additional fossil and archaeological data are gathered. The future of archaeology and environmental research in this area looks promising, and additional efforts should be made to produce more precise results. Based on the S-1 SAR data, Stone Age settlements are present in various locations, often located near waterways or routes that provide easy access to resources. The majority are found on somewhat low-lying ground, in lighter soils, in or near river valleys, or on the seaside. These settlements are identified by large circular or subcircular ditches, with outer ditches encircling the settlements and smaller inner ditches spreading through the shoreline of the Red Sea; possibly, many others have been submerged due to sea level rise. Additionally, the data indicates the presence of roadways and paleochannels linked with the mountain valleys. In conclusion, sites located on fertile soils close to water supplies and possibly along the main routes of transit through the landscape at that age fit the scenario of suitable locations for human habitation well. Therefore, ditches may be related to human settlement activity. However, it is still unclear what exactly this "settlement" was like, including how long it lasted, how permanent it was, and what kinds of actions it covered. It is essential to move this study beyond these somewhat related theoretical concerns to fully understand the pits and the wide variety of occupation practices connected to them. To gain relevant insights, the focus should be on carefully investigating the unique characteristics of particular sites and the archaeological artifacts found there. According to this justification, communities went through a phase of clustering during the late Pleistocene, where large groups of human beings, made up of tens of families, coexisted in roomy huts that ranged in size between 500

and 1700 m. In the past, factors such as access to water and the presence of sandy soils were thought to have had an impact on the choice of population sites throughout the Stone Age. This opinion was supported by data from a select few sites. It is now possible to statistically investigate how environmental characteristics relate to the choice of settlement places, however, because of the increase in the number of identified settlements in recent years [9]. An important discovery was that ditch sites had a clear preference for being located close to rivers and in regions with low elevations, and most of them were located less than 1 km from a river, which was a good fit with the larger pattern. Interestingly, some of the discovered settlement locations were farthest from any watercourse and had the fewest ditches, with each having just one pit. Finally, this article added the value of using remote sensing applications when discovering unknown archaeological sites, even deep buried settlements. In this study, the discovered sites are buried multiple meters deep under large layers of sand, clay, etc., that are impossible for the human eye to see. These techniques can help archaeologists reconstruct forgotten past civilizations, help excavation missions, and avoid destroying buried sites due to human activities. Overall, in this study, the RS data are used in the regions of Tokar and neighboring (Agig) which revealed contrasting topography and settlement patterns. Based on the data obtained from the radar satellite imagery, Tokar has many larger settlements that are dispersed across the plains, unlike Agig and Khor Baraka which are concentrated in the foothills and high terrain. Thus, the settlements in Tokar Delta were likely located near rivers, springs, and water bodies. As a result of climate conditions, the early hominins preferred elevated locations such as Agig and Khor Barka. After, due to the climate changes, aggressive changes occurred in the landscape altered soil structure and grazing areas which gave Tokar's location the preference for permanent settlement. This was shown by the expansion in size and number of communities, necessitating the presence of human-made stone tools in Tokar. The scenario and the data obtained from the satellite images will be verified when the research team finds suitable conditions to conduct a field survey in the Delta Tokar region.

Author contributions
In this article, AE and HE participated in the data collection, worked together in the data analysis process, participated in writing the initial version of the article, revised the original version, and prepared the last version of the article.

Data availability
No datasets were generated or analysed during the current study.

Declarations

Competing interests
The authors declare that there are no conflicts of interest associated with the data collection, analysis, results, or publication of this article.

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