International Journal of Archaeology
2025, Vol. 13, No. 1, pp. 21-36
https://doi.org/10.11648/j.ija.20251301.13

Research Article

The Implementation of a Geographic Information System (GIS) to the Palaeoenvironmental Reconstruction of the Prehistoric Al Qusais Necropolis (Dubai, U.A.E.)

Adrián Fernández-Sánchez[1, 2, *], Fernando Contreras[1], Alicia Alonso[1], Bader Al Ali[3], Mansour Karim[3], Hassan Zein[3], Manal Abdullah Al Masfari[3]

[1]Sanisera Archaeology Institute, Ciutadella de Menorca, Spain

[2]Geography Department, Complutense University of Madrid, Madrid, Spain

[3]Dubai Culture and Arts Authority, Dubai, United Arab Emirates

Abstract

The Al Qusais prehistoric necropolis (Dubai, United Arab Emirates), dated between 1,600 and 800 BCE) is one of the most important archaeological sites in the Arabian Peninsula, given its high number of individual and collective burials, and the unique grave goods recently found. In the vicinity of Al-Qusais, a sedentary population settlement was probably established and could sustain itself through the collection of mollusks, to fishing and hunting, thanks to the location's natural resources. As of today, Al Qusais lies within a typical dune system environment, almost nine kilometers away from the coast. This research is part of a project developed by *Sanisera Archaeology Institute* in collaboration with *Dubai Culture & Arts Authority*, with the aim of reconstructing the past natural environment, in accordance with archaeological evidence discovered and recorded in the Al Qusais necropolis. The Geographic Information Systems (GIS) applied to Al-Qusais combined various sources of information with the intention of generating analytical studies, in order to understand the strategic physical location of the necropolis. Reconstructions show that, during prehistoric times, the necropolis was located just 700 meters away from an ecosystem comprising mangroves and shallow coastal waters with intermittent episodes of marine flooding.

Keywords

Palaeoenvironment, Shoreline Evolution, Geoarchaeology, Water Archaeology, Al Qusais, Necropolis, Arabian Gulf Archaeology

1. Introduction

The necropolis of the Al-Qusais cemetery (Dubai, United Arab Emirates) is one of the archaeological sites with the largest variety of finds in the Arabian Gulf region for the period between 1600 and 800 Before Christ (BC), the time when the Magan culture developed.

Its importance is due to the large number of existing burials that include individuals of varying physiography and age [1], inhumated with a large repertoire of goods.

*Corresponding author: adrferna@ucm.es (Adrián Fernández-Sánchez)

Received: 18 February 2025; **Accepted:** 4 March 2025; **Published:** 31 March 2025

The prehistoric necropolis is currently located in an Islamic cemetery that has protected the area from any type of subsoil remodeling. For this reason, Al-Qusais has not been so affected by the urbanization and transformation of space that has affected land around the cemetery.

While the vicinity of Al-Qusais has undergone deep modifications in the physical and natural environment, the site's area has remained relatively intact. It has not been therefore possible to adequately know the environmental context of areas outside the Al-Qusais cemetery, since no topographical evidence or geomorphological features accurately identifiable in the field have been preserved.

Al-Qusais is marked by an apparent disconnection from nearby natural resources. It is located 9 kilometers away from the present-day coastline, there are no permanent watercourses (*Wadis*) and it lies close to the first dune beds on the edge of the city of Dubai. Moreover, during archaeological expeditions of the 70s [2] or in maps of the Dubai area dating to the 1950s, the modern Al-Qusais area is described as "uninhabited." [3].

Given the number of burials and individuals found in the Al-Qusais necropolis, it is known that the population living there had sedentary characteristics to a certain extent, and must have comprised a considerable number of inhabitants [2], [4]. Al-Qusais must have been located in a strategic place, close to natural resources enabling the survival of communities.

The Arabian Gulf's ancient civilizations had a close relationship with natural resources in their environment. In fact, certain authors consider the Arabian Gulf region as a demographic refuge for the first modern humans of Southwest Asia, providing freshwater springs and river courses. The region is described nowadays the "Gulf Oasis." [5].

Some research gathering evidence on the food waste of the inhabitants of the entire Arabian Gulf indicates that the primary sources of food were fishing and collecting mollusks as from the 5th millennium BC until the late Islamic period [7]. Secondary food resources were probably domesticated animals, such as goats, but also the catch from the hunt of medium-sized animals, for instance turtles or gazelles [8].

Specifically, past cultures like those located in the Al-Hallaniyat archipelago (in Oman, 4200 – 4000 BC) based their survival and food source on fishing [6].

Marine resources played a crucial role in the Bronze Age, providing food as well as the products of as maritime trade. In the vicinity of the first maritime corridors, the domestication of animals and certain agricultural techniques may have been "dispersed" [9].

The main hypothesis of this study is that Al-Qusais was a society probably basing its survival on the same resources as prehistoric cultures, and thus had to be close to water, food or faunal environmental resources.

The stratigraphic and paleoenvironmental analysis carried out around Al-Qusais was limited to thorough analysis of the soil and sediments lying on the surface. Due to the respect shown to the Islamic Al-Qusais cemetery, the place has not undergone any major transformation. One can for sure say that the cemetery is therefore a place of great potential for sedimentological study.

Sedimentary analysis during excavation of the archaeological site [1] was fundamental to understand the stratigraphic sequence and past possible environmental conditions. The digging of sedimentary trenches and the carrying out of field surveys have allowed the team to identify stratigraphic features enabling the reconstruction of the past environment.

On the other hand, one should mention that medium- to small-sized geomorphological indications such as fossilized marine low mounds, beach ridges or hydrological features of any type have also disappeared as a result of urban expansion. The morphologies of these features could have been of much utility in identifying the paleo-environment surrounding Al-Qusais. With this goal in mind, it was decided to observe and classify large geomorphologies (greater than 500 meters) based on an aerial photograph from 1965, prior to Dubai's urban development of (Figure 1).

Figure 1. *Aerial photography of Dubai in 1965 before urban development [10].*

Palaeo-environmental reconstructions based on geomorphological studies in the Arabian Gulf region have proven to be useful. Parker and Goudie [10] were able to explain the Arabian Peninsula's population decline in 4100 BC, from geomorphological reconstructions indicating a severe arid period, and comparing them with results from other sites in the Arabian Southeast.

Geographic Information Systems and spatial and topo-

graphic analysis software have also shown great potential in solving problems such as the possible disconnection of Al-Qusais with its surroundings. GIS allows the integration of various variables, whether environmental or of any kind, with the possibility of spatial superimposition and interrelation between the elements of data.

GIS has served as the basis for a large number of studies, both archaeological and paleoenvironmental reconstructions [11]. Some research has pointed out the importance of the use of GIS in deciphering human-environmental interactions, especially in historical and archaeological sciences. [12].

In turn, GIS is an especially useful tool for not only reconstructing the paleoenvironment itself, but also integrating archaeological documentation into spatial databases. The latter allow landmarks or archaeological findings recorded in the field to be related according to proximity to environmental situations occurring in the past.

Topographical, geophysical or morphological interpretation of data can provide plenty of information on landscape patterns, which, once integrated into the GIS, make it possible to understand the paleo-landscape. Studies carried out in Italy or East Africa are a clear example of this integration of variables in GIS for the reconstruction of past landscapes [13-15].

Moreover, the use of Geographic Information Systems in reconstructions of not only paleoenvironmental, but also paleo-coastal environments, has provided the most accurate indications for missing settlements, as in the case of Liman Tepe (Izmir, Turkey), a location with archaeological evidence from the Chalcolithic-Bronze Age. GIS permitted estimating the ancient coastline's position and finding the nowadays settlement [16].

The aim of this research is the reconstruction of the Al-Qusais necropolis environment during the 2nd and 1st millennia BC based on multivariate methodologies. The integration of all the evidence within a GIS helps to understand the site's environmental context.

To achieve this, various objectives were completed, such as: a stratigraphic analysis of the necropolis and of sedimentary trenches, geomorphological mapping, malacological analysis, a hydrological modelling and the evolution of the coastline, as reflected by the GIS.

The investigations on Al Qusais Tombs 2020 and 2024 projects, carried out by the *Sanisera Archaeology Institute* in collaboration with *Dubai Culture & Arts Authority*, seek to obtain comprehensive grasp of the necropolis, contextualizing it in its contemporary natural environment.

2. Materials and Methods

2.1. Materials

This research has been based on a considerable volume of public and private sources of information, these being: Digital Elevation Models (DEMs of the ASTER and GMTED program), Historical Aerial Photographs (Records of the Defense Mapping Agency), ecological investigations, sea level heights, archaeological documentation, stratigraphic and sedimentology surveys made to analyze sedimentology and sampling process from field surveys.

Table 1. *Main sources.*

Material	Source	Use
Digital Elevation Model (Topography)	GMTED program [17] ASTER [18]	Shoreline estimation
Aerial Photographies (1965 and 1973 years)	U.S. National Archive [19, 20]	Geomorphology.
Archaeological documentation	Taha M. and Qandil, H. [4]	Necropolis locations.
Geological deposits	Surface trench	Palaeonvironment.
Extent of the mangrove	Own measures and Bunting, P. [21]	Shoreline estimation
Shoreline height	Research papers. (See Table 3)	Shoreline estimation

2.2. Methods

2.2.1. Geomorphological Cartography

As an initial step for the paleo-environmental reconstruction, a geomorphological map was made to represent the topography associated with geological action processes. To develop the cartographic model, ArcGis Pro software was used, in order to georeference an aerial photograph, taken by an American spy plane flying at high altitude, on 10-8-1965 (Figure 1). Another cartographic resource used for calibration in the georeferencing process was an image from 1973 [19].

Geomorphological work consisted of the photointerpretation of forms such as deposits, erosion areas and rock outcrops, derived from natural processes.

In the 1965 aerial photograph, the land closest to Al-Qusais in its natural state, intact and yet unaffected by the urban impact of Dubai, can be identified.

The area limits corresponds to 220.5 square Kilometers (Km^2), with the northwestern coastal boundaries of Dubai (Deira) and the city of Sharjah; the right bank of Dubai Creek; the wind zone to the East; and in the South, in the Creek's most inland reaches.

Palaeoenvironmental geomorphology were classified into four types:

1. *Aeolian morphologies*, consisting in dunes, sand sheets and *barkhans* or barchans (crescent-shaped dunes).
2. *Hydrological morphologies* from intertidal plains, ancient lakes or historical mangrove areas.
3. *Fluvial morphologies* based on drainage systems or watersheds.
4. *Rocky outcrops* composed mainly of gypsum or rocks protruding from deposits.

Within these four types, some 33 subgroups have been specifically listed. Total subgroups and detailed cartography and their description can be found in the Supplementary Material below.

Based on the map prepared, a paleoenvironmental reconstruction of the archaeological study area affecting Al-Qusais was proposed.

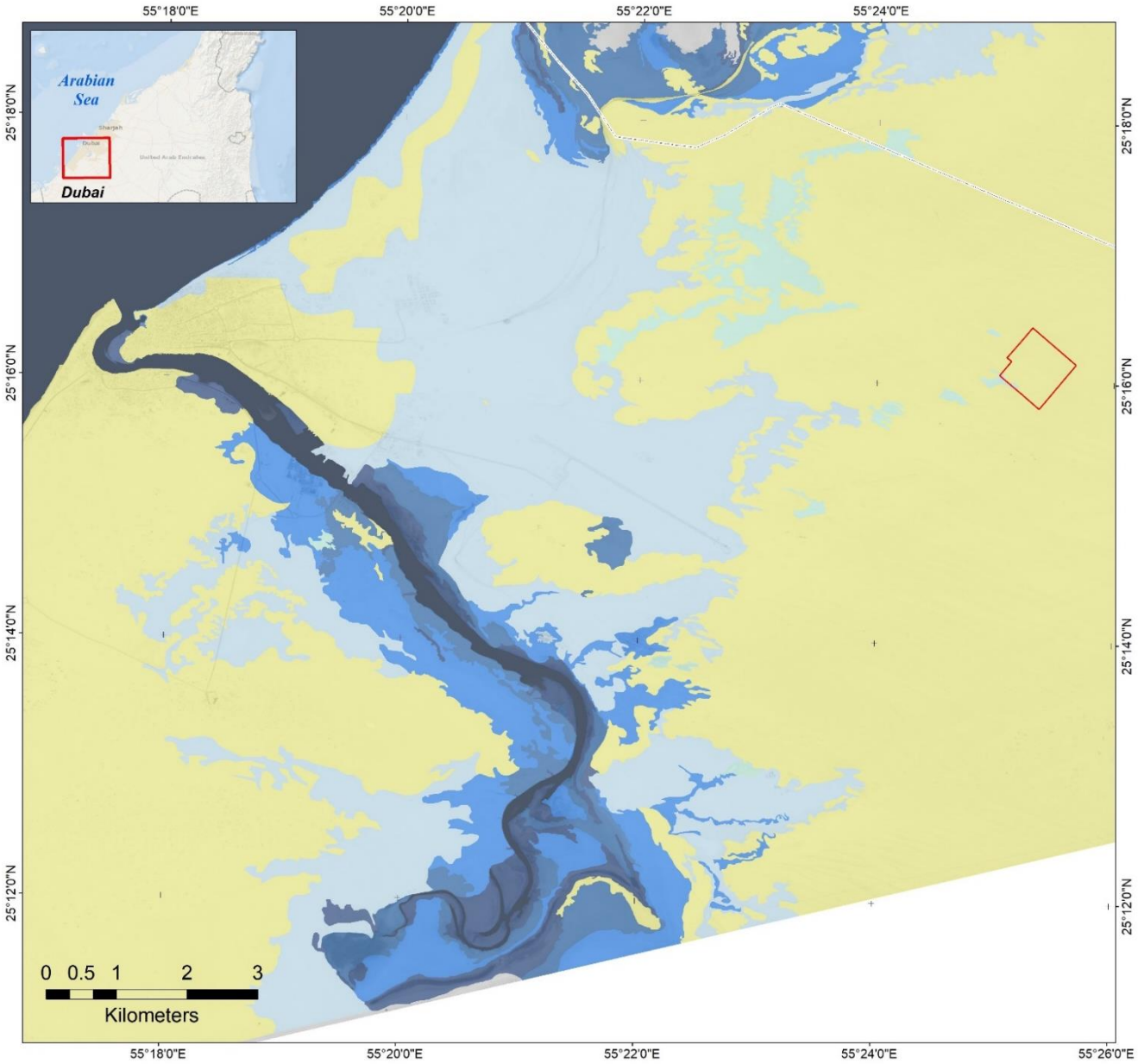

Figure 2. *GIS charted archaeological model derived from geomorphological interpretation. 1965 Aerial Photography as a base map. Detailed cartography with description can be seen in the supplementary materials. Depiction of seawater, where the most intense color corresponds to the deepest geoforms and the lightest tones correspond to the shallowest ones. Al Qusais in red.*

In Figure 2 it can be noticed how extensive lands marked by wind lies in the eastern part of Dubai, as well as in areas to the southwest. Relatively close to Dubai's Khor, there are a series of deposits that aerial photography shows as dark textures interpreted as either intertidal flats, intertidal channels, swash, foreshores or marine deposits. All these geomorphological characteristics indicate how during the past, marine waters were advancing towards inland positions, with areas temporarily flooded during high tide. The body of evidence shows how marine waters could enter the mainland through Dubai's Khor. In Figure 2, intertidal deposits, or at least those related to sea water, reached the necropolis of Al-Qusais itself.

2.2.2. Stratigraphic and Sedimentary Analysis

Once the geomorphological analysis of the coastal area of Dubai was completed, it was decided to check whether the recognized sediments could be detected in a stratigraphic survey.

The sedimentary trench was dug north of the modern cemetery of Al Qusais, at the location X: 341118.849, Y: 2795880.884, in an excavation measuring 2 m long. x 2 m wide, which reached a depth of 1.95 m. (Figure 3).

The location was chosen because the area was undisturbed, as confirmed by satellite imagery of the past decades.

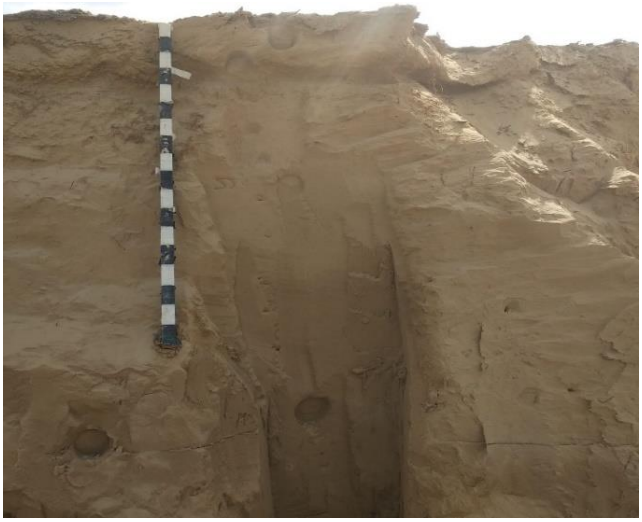

Figure 3. *Stratigraphic sequence north of the Al-Qusais modern cemetery after sampling process.*

Interpretation was made by analyzing of the sedimentary profile, based on the observation of sheets and depositional structures, the classification of fauna, erosive contacts due to wind or marine action, intervals between strata and peculiarities of the sand and silt particles. Continuous samples were taken at 5 cm intervals.

Once the sedimentary section was analyzed, it was broadly confirmed that the stratigraphic column corresponded to at least two marine transgressions, which after some time were transformed into mangrove and marsh ecosystems, and subsequently converted to arid environments with wind dominance. In no stratum of the survey were any anthropic remains found.

Up to four different depositional sequences were recognized, composed of various strata (Figure 4). The stratigraphic sequences are described below, from the most modern to the oldest:

Sequence 1 (0 – 12.5 cm) is composed of two strata. The first stratum, 1 cm thick, is a dry crust of clay and silt related to periods of superficial flooding and subsequent desiccation. In the second part of this sequence, cross-stratification sheets of fine sands modulated by wind action and oriented with a northerly component of the wind were observed, which fully confirms the arid state of the landscape.

Sequence 2 (12.5 – 66 cm) integrates three strata. In the first stratum at a depth of 12.5 to 3 cm, a structure of wave ripples was observed, with particles of sub-angular shapes and decomposed roots of *Avicenia marina* and marsh vegetation of *Puccinellia stricta*, also including nodules of 1 to 2 cm in diameter of marl or mudstone type sediments. In conclusion, this stratum showed clearly a marine surface water environment.

Continuing in the same sequence 2, the next stratum, whose depth is between 31 and 50 cm, corresponds to a massive sand deposit that includes roots decomposed in orthogonal patterns, demonstrating that the ecosystem was a mangrove. As for the third stratum, the last one of this second sequence, it was identified between depths of 50 and 66 cm, and corresponds to a typical *Sabkha* deposit composed of massive sands with intercalations of calcium carbonate and small shells of *Tellinimactra Angulata* and *Anodontia edentula* in a living position confirming a somewhat deeper marine transgression.

Sequence 3 (66 – 132 cm) includes five strata. From 66 cm to 115 cm, the first three strata reflecting arid environments could be distinguished: a stratum of massive sands (66 – 75 m), groups of cross-stratification (75 to 87 cm) and a third one of thick sands (87 to 115 cm).

The fourth stratum of sequence 3, within an interval between 1.15 and 1.32 m, shows a massive sand layer that includes in the upper part decomposed mangrove roots of the *Avicennia Marina* type. The fifth stratum, typical of a more consolidated mangrove ecosystem, with water somewhat deeper than those of the fourth stratum, may have been composed of bivalve-type marine organisms such as *Tellinimactra Angulata* and *Anodontia edentula*, as well as *Terebralia Palustris* [22] in living position.

Sequence 4 (1.32 – 1.95 m) integrates two transitional strata of massive sands modelled by the wind and lacking organic elements (fauna or malacology). They indicate that during this period, the landscape became a desert or an arid plain, at an unspecified time, possibly in the early Holocene period.

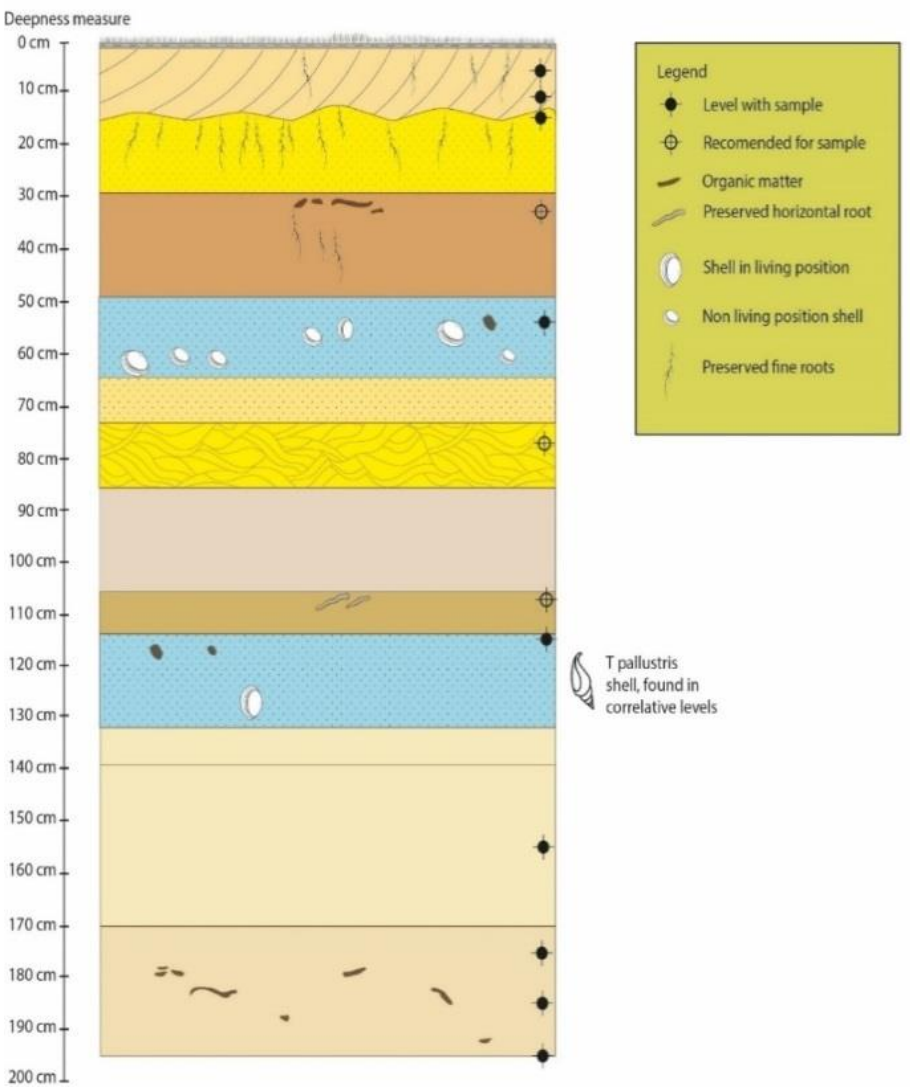

Figure 4. *Stratigraphic column derived from trench interpretation in field and postlab pictures.*

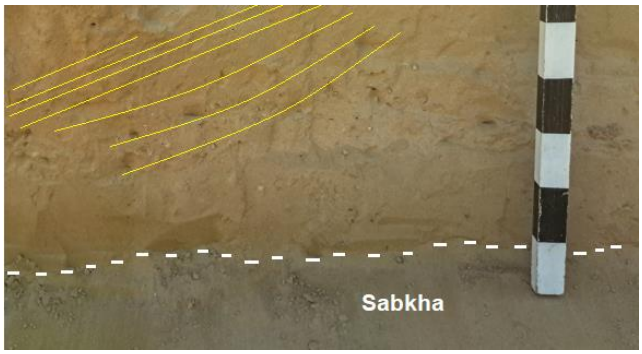

Figure 5. *Stratigraphic section of the Al-Qusais necropolis (Area A). Yellow lines show cross stratification sets oriented to the north and with an eroded base above mass sands. The white line represents the tomb level, excavated in Sabkha deposits.*

When comparing the stratigraphic section of the survey carried out in the modern cemetery's northern part with the archaeological stratigraphy of the necropolis, what could be observed was that both have similarities: both show evidence of a marine transgression and an episode of aridification.

Sequence 2 of the northern stratigraphic section, at a height between 12 and 50 cm, would correspond to the natural stratum that covers the excavated necropolis area's *Sabkha* (Figure 5). Moreover, between 50 and 66 cm in sequence 2, a *Sabkha* with identical characteristics to that of the necropolis can be found. This was used as a platform for the construction of the tombs.

2.2.3. Shell Analysis

In the vicinity of the prehistoric Al-Qusais necropolis, deposits of sandy sediments interspersed with instances of sabkha were observed. They included a wide variety of seashells that usually cover the modern surface. For this reason, it was decided to carry out a reconnaissance of the area; a total of 58 specimens were collected, of which 27 appear to have been fractured by anthropic action. This group of mol-

lusks was located using a field GPS to reconstruct the paleoenvironment and determine the possibility of locating archaeological sites. The samples were classified by species [22-24] and by quantity, and are shown in Table 2, along with a plausible description of the past environment.

Table 2. *Shell specimens found classified by specie and quantifyied.*

Species	Number	Environment
Hexaplex kuesterianus	5	Shallow waters, on rocks
Terebralia palustris	18	Mangrove area [22, 25, 26]
Callista erycinoides	9	Mangr. (Miocene) [24]
Ceritrophis Greenii	1	Multiple ecosystems
Dinocard. Robustum	2	Mangrove (Eocene) [24]
Mesalia Consobrina	1	Mangroves and others
S. gibberulus	3	Multiple ecosystems
Acrosterigma lacunosum	3	Intertidal or Mangrove
Gari maculosa	2	Intertidal or Mangrove
Donax scalpellum	1	Mangrove area
Anodontia edentula	7	Mangrove area [27]
Melanella Martini	2	Shallow – low waters
Tellinimactra Angulata.	4	Mangrove area [28]

*Dinocard. meaning Dinocardium.

Figure 6. *Fragments of Terebrallia Palustris found during a surface survey in the Al-Qusais modern cemetery.*

As can be observed, most of the shells found come from mangrove ecosystems and intertidal waters. Some, such as the *Hexaplex Kuesterianus*, are also typical of shallow waters. The species *Callista Erycnoides* and *Terebralia Palustris* (29 specimens), identified during the survey work, do not currently exist in the United Arab Emirates (U.A.E.) [22, 24].

Most shells found were fragmented by human action as a food resource (Figures 6 and 7). Some authors mention that *Terebralia Palustris*, as well as other specimens, were usually broken with awls that would leave the upper "head" separated from the main body as a fragment [29].

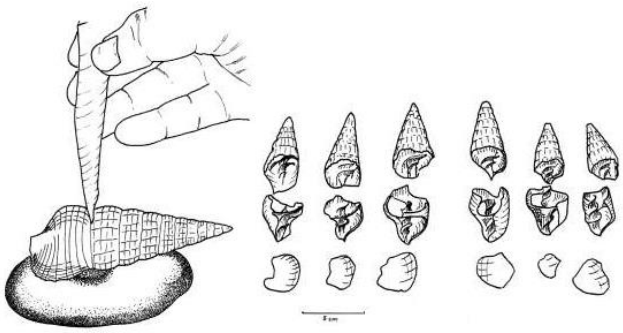

Figure 7. *Opening by means of an awl of a mangrove shell (in this case a Terebralia Palustris), for human consumption [29].*

2.2.4. Hydrological Modelling

A hydrological modelling has been carried out to determine whether ancient rivers connected the coast and mountainous areas of eastern of the U.A.E.

Hec-GeoHMS software [30], an ArcGIS extension, was used to model the direction of surface waters in a fluvial or marine drainage system.

Hec-GeoHMS is a modelling software that uses base topography (DEM) to generate a drainage network that includes both flow data and the direction of water through the landscape. This extension permits documenting watershed characteristics, performing spatial analysis, and delineating sub-basins and streams.

The topography used for hydrological modeling would be the DEM from the ASTER program [18], with a 30 meters pixel size. The tools used were: Fill Sinks, Flow Accumulation, Flow Direction, Stream Link y Watershed.

The analysis carried out at Al-Qusais made it possible to distinguish a hydrographic basin to the east of the city of Dubai, which would interfere with the existing dune system generating a parallel topography through which water would actually infiltrate.

In the western area, Figure 8, What may be a basin morphology can be seen around the Dubai Khor. This morphology may not belong to a river system, but would be related to a past migration of Dubai's Khor itself. As regards the result, the direction of the water would be towards the Dubai Khor, indicating that it is not a river network. This morphology is more similar to that of a sea inlet or intertidal zone.

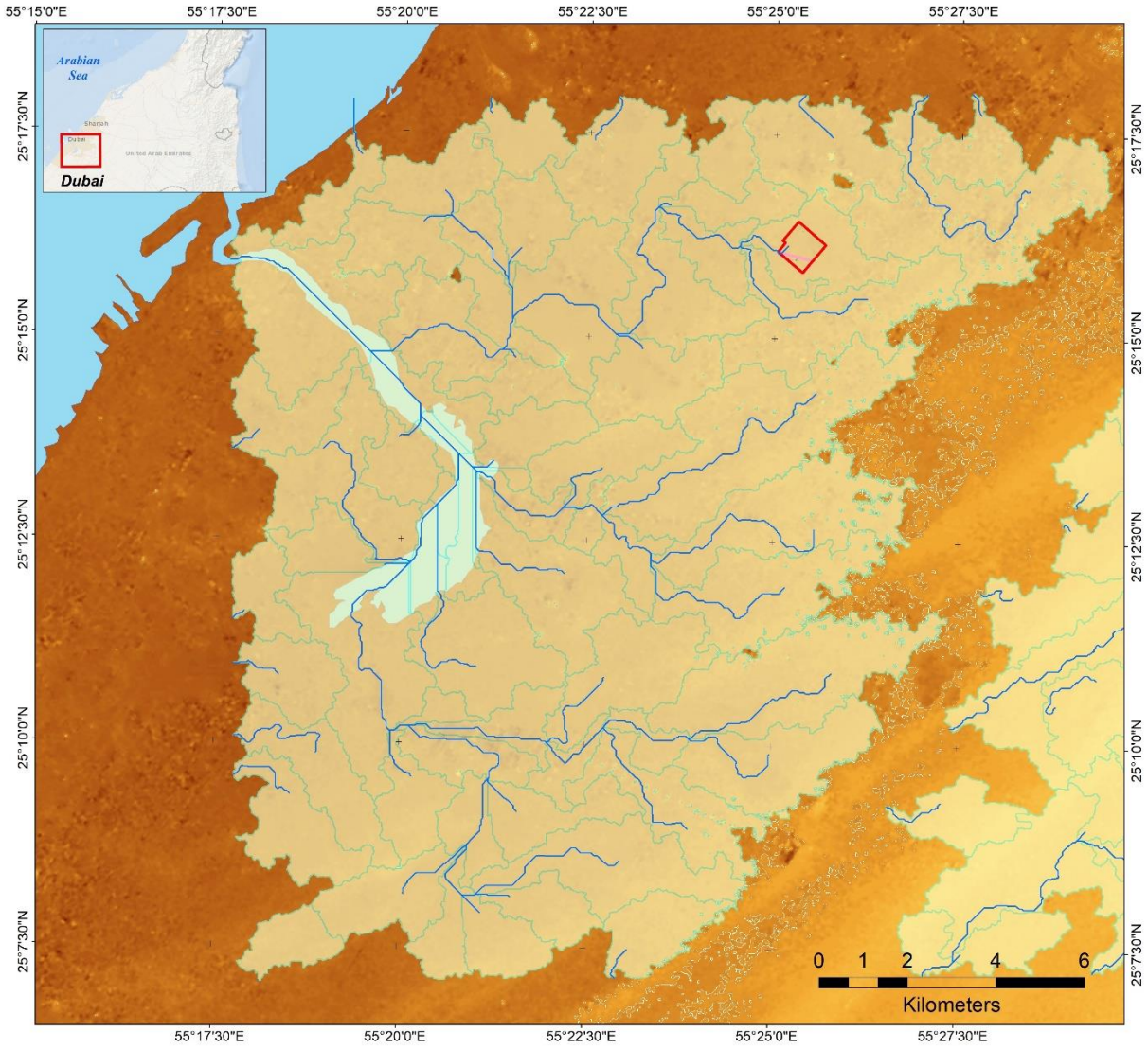

Figure 8. *Result of the hydrological modelling, including the direction of water at any point in space. Dubai's Khor is shown in light blue.*

That the concentration or lowest point of the modelled drainage network reached just as far as Al-Qusais seems to indicate that this area was the lowest and held water for a longer time. The water was either marine or from another source.

Precipitations for this basin are too scarce to consider this ecosystem as a river basin that could accommodate the drainage of fluvial waters.

2.2.5. Ancient Shoreline Evolution

As indicated by recent research, the ancient coastline of the Emirate of Dubai may not have been where it is today. One possibility is that the coast was located in a much more inalnd strip or transgression into the interior.

To locate the old coastline, studies on sea level height from U.A.E. were reappraised, and focused on the Abu Dhabi, Dubai, Umm Al-Quwain and eastern Saudi Arabian seashores. These investigations studied in particular the time frame between 2,500 - 1,500 BC. Studies place the coastline of that period between 5 – 4 meters (Table 3) above current sea level.

Table 3. *Bibliography on shoreline estimations.*

Location	Height (*a.p.s.l)	Reference
Marawah Island, Abu Dhabi (U.A.E.)	5 – 4 meters (m)	Evans *et al.*, [31]
Al Jubali and Dubai	4.4 – 3.8 m	Wood *et al.*, [32]

Location	Height (*a.p.s.l)	Reference
Abu Dhabi (U.A.E.)	4.8 – 4.0 m	Evans *et al*., [33]
Al Jubali (Saudi Arab)	4 m (uplift)	Ridley and Seely, [34]
Southern Arabian Gulf	3.5 m	Alsharhan Kendall [35]

*a.p.s.l. meaning "above present sea level".

Once the estimated height of the coastline was found, the water level was extrapolated by applying a Digital Elevation Model of the current topography. It has not been possible to find a topographic reconstruction reflecting the last 4,000 - 3,000 years Before Present (BP). Despite this, the general shape of the topography shape has not undergone too many changes and looks similar to that of the past.

GMTED topographical data was incorporated into the Al-Qusais GIS project (ArcGis Pro), in order to estimate the coastline's location. GMTED is a Digital Elevation Model (DEM) referring to current conditions. This DEM has 250 meters of pixel side and was created with data from the 2010s [17]. The DEM is a simplification from various official sources such as SRTM DEM [36], Canadian DEM (CDED [37]) or satellite images from the SPOT-5 French program [38].

Based on these data, it was therefore possible to reconstruct the ancient coastline in the 2nd and 1st millennium BC.

A perimeter zone of the mangrove and marsh ecosystem was integrated to the study. The coasts and shallow waters of the Arabian Gulf region typically have developed expanses of mangroves around the shoreline.

To calculate the size of possible mangroves and marshes, an estimate was used based on the current average dimensions of the mangrove ecosystem in this region of the U.A.E. The average extent was determined by GIS measurement of mangroves and salt marshes in the emirates of Umm Al-Quwain, Dubai, Ajman, Ras Al Khaimah and Abu Dhabi.

Table 4 presents the measurements taken. A mean of 1.074 metres was estimated and translated into the cartographies from the *Buffer* tool in A*rcGis Pro*.

Table 4. *Mangrove longitudes measured for estimation.*

Location	Longitude	Human modification
Khor Ajman (Ajman)	400 m	Yes
Khor Ajman inner bar	250 m	Natural
Al Houtah (Umm Alqwain)	200 m	Natural
Al Houtah inner bar	1,400 m	Natural
As-Sinniya bar (Umm Al-Quwain)	840 m	Natural
As-Sinniya eastern island (U.A.Q)	1,060 m	Natural
As-Sinniya western island (U.A.Q)	1,300 m	Natural
Meshara (Umm Al-Quwain)	1,340 m	Natural
East of Umm Al Quwain City	890 m	Natural
Khor Al-Yeefrah (Umm Al-Quwain)	2,140 m	Natural
Umm Al-Thuob (Umm Al-Quwain)	1,070 m	Natural
Al Mahabeeb (Ras Al-Khaimah)	1,040 m	Yes
Al-Ghellah Island (Umm Al Quwain)	1,510 m	Natural
Ghannadah (Abu Dhabi)	3,360 m	Yes

*U.A.Q. the acronym for Umm Al-Quwain.

3. Results

This section provides a concise description of the main findings for the estimation of the shoreline's position.

The calculations carried out with ArcGis Pro using the information described above have concluded with a map with the most probable location of the coastline in the 2nd millennium BC (Figure 9).

It is observed how the sea level would be about 700 m away from Al-Qusais, as well as the line of mangroves would be positioned in the current cemetery enclosure, in its southwest corner, coinciding with the area where the most shells have been discovered. when prospecting its surface.

The sea to the south of the coast would have extended inland for some 7 km, while to the north it would have advanced between 12.1 and 6.8 km. Areas with surface waters of 0 to 1 meter depth would have paralleled the coastline, while intermediate waters would have extended from 1 to 3 meters deep.

The coast's physiography, thus, reflects four larger islands in the current Dubai's districts of Deira, Shindaga, Al-Fahidi and Al-Hamriya, with also some other smaller islands.

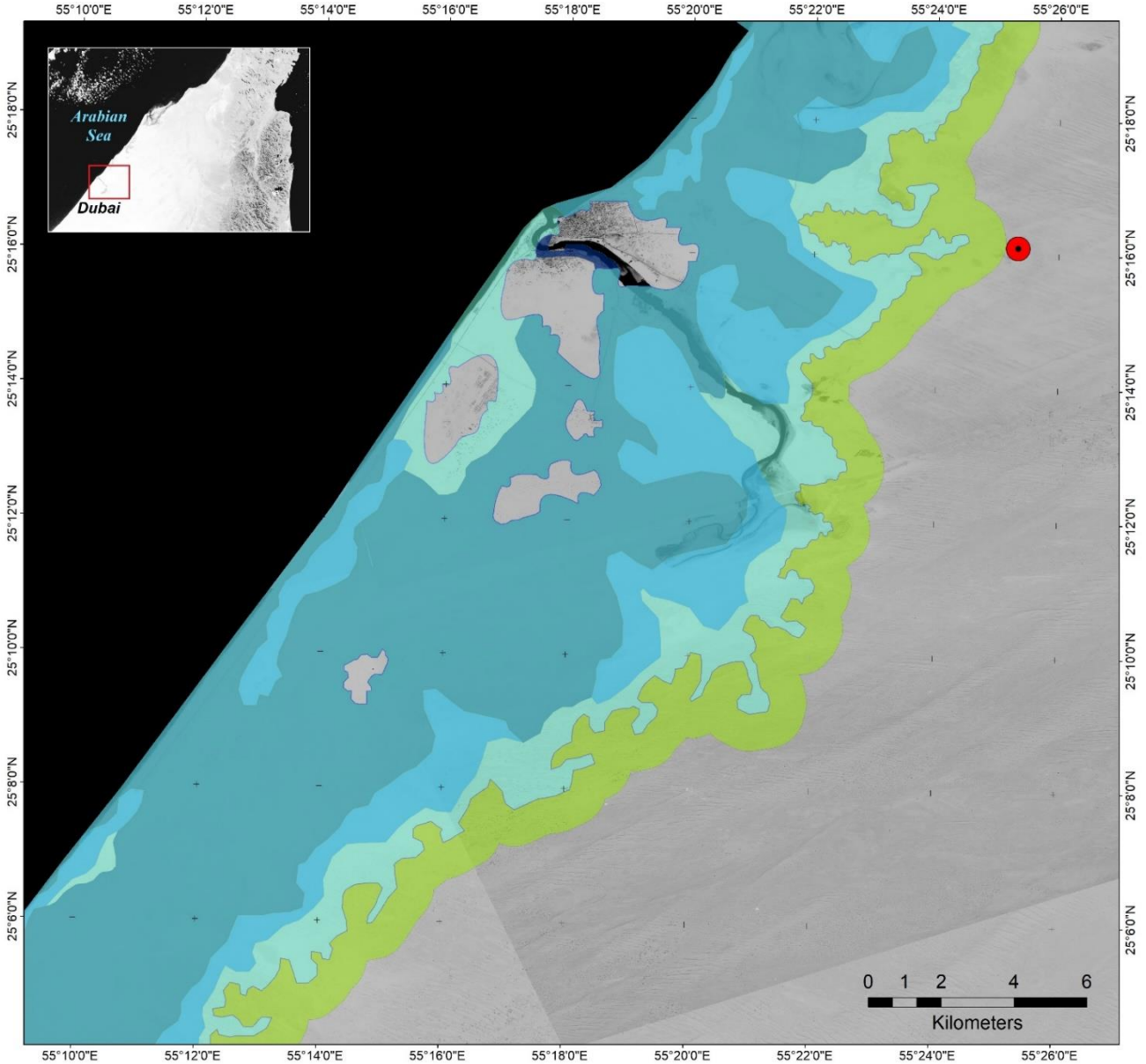

Figure 9. *Estimation of the location of the shoreline in the 2nd millennium BC. The darker blue colors indicate deeper water, while lighter blue is for shallower waters Greens indicate the extent of the mangrove. Red dot represents Al-Qusais necropolis.*

4. Discussion

Geographic Information Systems have been used to develop archaeological research in recent decades [39-41]. GIS has shown to be a very useful tool when contextualizing archaeological sites in their environmental and social setting.

The processing done through this software, that integrates archaeological documentation, sea level variables and topographic modelling, has made it possible to assess coastal evolution between the 2nd and 1st millennium BC.

The possibility that the coastline in the past differed from the current one has been suggested by various authors. Sea level reconstructions suggest that, at the end of the Pleistocene, the Arabian Sea began to rise to its highest point (5.3 m above the modern-day level), reaching its highest point during the mid-Holocene (5,500 BP, 3,500 BC, [35, 42]). From this point on, the sea level started to decrease to current levels (though the descent was not continuous and was interrupted by various marine transgressions - between 5 and 3.5 meters above today's levels - until 4.0 kiloyears (ky) BP or 2,000 BC [31-34, 43, 44].

This coastline would have allowed the growth and settlement of populations in ancient times, at sites currently located several kilometers from the sea [45]. Some human occupations in the emirate of Umm Al-Quwain preceding the Bronze Age already show remains of cultural adaptation to changing past environments [46]. The Ubaid site of Abou Khamis, in Saudi Arabia is described as having been closely associated with its paleogeographic environment and is no longer the case today [47]. In fact, recent research suggests that human occupations of the Arabian-Persian Gulf may have survived hyper-arid oscillations thanks to "refuge" locations offered by the coast and its changing margins. [5].

The "Arabian Seashores" project also explored the Omani coast, discovering that a large number of archaeological sites from the Paleolithic, Neolithic, and early Bronze Age were associated with regional coastal evolution [6].

The coastline of the 2nd – 1st millennium has not only been identified as having been higher than the current sea level, but it also must have necessarily been located near Al-Qusais, since in order to sustain a population such as the one buried in the necropolis, proximity to natural essential resources would has been crucial. Al-Qusais can be considered as another important example in research on past sea levels.

GIS work has concluded that Al-Qusais was possibly only seven hundred meters from the coastline. The environment would have been typical of an ecosystem of mangroves and marshes during the period between the 2nd and 1st millennium, i.e. a favorable environment for the occupation and establishment of human settlement. This would have been the best environment nearby, since Al-Qusais was then subjected to a period of aridification. The proximity of a mangrove swamp or area of intermittent waters would have made conditions favorable to sedentary occupation.

Mangrove ecosystems were fundamental for the subsistence of the Arabian Peninsula's ancient cultures [48]. In Oman, for example, mangroves closely influenced the food strategies of Neolithic people [49, 50].

Prehistoric fisher-gatherers along the Arabian Sea and Gulf of Oman coasts relied primarily on fishing, collecting mollusks and shellfish. So, marine and mangrove resources were widely exploited during favorable periods of coastal adaptation. [51]. There is evidence of the inhabitants of the east coast of Saudi Arabia also being closely related to mangrove ecosystems between the Neolithic and Islamic periods [52]. More specifically, in the U.A.E., it was highlighted that some settlements may have exploited the mangroves, or would have at least consumed mollusks living in this ecosystem [53].

The deeper Sabkha deposits detected in the northern stratigraphic section of the cemetery, are older than the Al-Qusais necropolis, and are consistent with wetter conditions perhaps beginning around 5.0 ky BP (3rd millennium BC) lasting until 3.8 k and BP (1,800 BC) [49, 54]. Later, a period of aridification probably affected the region, although there were some increases in precipitation between 3.6 (1,600 BC) and 3.2 ky BP (1,200 BC), according to the isotopic record of Qunf cave [55]. The isotopic record from Hoti Cave shows a relative increase in humid conditions around 2.8 ky BP (800 BC), and subsequently a gradual decrease in humidity stabilizing in 1,000 AD [55, 56].

Regarding the stratigraphic sequence of Al-Qusais, both the strata of the necropolis and the northern trench coincide with the stratigraphy located at Al-Soufouh site (Dubai). The Al-Soufouh deposits indicate the existence of mangrove ecosystems from 7,200 to 7,000 years BP (5,200 to 5,000 BC), followed by an extensive marine transgression until at least 5,900 BP (3,900 BC) [57]. In this profile, mollusks of the *Anodontia edentula* type, originating from mangrove areas, were identified and dated [27]. Their life could coincide with the marine transgression observed in the sedimentary profile of the northern trench (at about 65 to 50 cm), and the Sabkha of funerary occupation level at Al-Qusais.

Research on Al-Soufouh has found no traces of mangroves during the 3rd and 2nd millennia BC [58], although these existed in previous periods. This fact may be the consequence of a generalized arid period, coinciding with the sequences found in Al-Qusais. It may also be because Al-Soufouh may have been below sea level during the 2nd and 1st millennia AD, as these research results demonstrate.

The existence in the vicinity of Al-Qusais of a large number of individuals belonging to the species *Terebralia Pallustris*, native to mangrove ecosystems [22, 25, 26, 59], confirms the possibility of the existence of these ecosystems in recent periods. Most of these mollusks appeared with signs of anthropic breakage using a hammer and an awl [29], and were therefore food source. The possibility that these mollusks were consumed recently has been ruled out, since some research denies the existence of the *Terebrallia Palustris* species on the current coast of the U.A.E. [22].

Photointerpreted geomorphology confirms the existence of

marine transgressions along the entirety of Dubai's Khor (Dubai Creek) as well as on the Dubai coast to Sharjah.

All these facts considered together confirm that in the past, the location of the Al-Qusais necropolis was not disconnected from natural food resources, but rather was in a marine ecological context, a mangrove ecosystem or in intertidal plains conducive to human settlement.

Most of the deposits in this region of the U. A. E. are found in places close to the seashore, especially on mangrove or marsh surfaces. It is for this reason that Dubai Emirate authorities are urged to carry out archaeological surveys and reconnaissance in areas that are currently not urbanized and coincide with the estimates of the coastaline given by this investigation.

Figure 10. *Suggested areas for survey. The range of colors from green to red indicates the lowest to highest probability of finding archaeological remains. Dark green, Very low probability; Light green, low probability; Yellow, medium probability; Orange, high probability; Red, very high probability. Polygons with red stripes indicate areas of medium to high probability that are not currently urbanized.*

It would be of the greatest interest to plan a program to carefully survey the areas described in the maps as mangrove (Figure 10) and in general, all coastal shorelines represented.

In turn, it is suggested that all other archaeological authorities from each emirate carry out the mapping of past coastlines in order to identify new archaeological sites, either on present dry land or submerged.

5. Further Research and Future Work

Palaeonvironmental analysis is a key research tool for explaining how past environments conditions could be linked to the development of cultures. Some unexplained sites in the U.A.E. could be better understood if palaeonvironment is analyzed, setting answers between the site location and nowadays possible disconnection to natural resources.

It could be interesting if the shoreline reconstruction and geomorphological analysis carried on in this work, is extended to all the coastal area of the United Arab Emirates or, at least, to the Dubai Emirate. Once extended, the relative position to past coastal lines could be analyzed in other to contemplate if site location is linked to past environmental conditions.

The GIS and geomorphology reconstruction methods could also be implemented in the near future in other inland sites, such as Saruq Al-Hadid (Dubai), Al-Sufouh (Dubai), Hatta (Dubai) or even Mleiha (Sharjah). Authors encourage all the research teams working in the U.A.E. to apply the same methodology of reconstruction and reconfirmations that has been applied in this research.

6. Conclusions

Geographic Information Systems (GIS) have proven to be a useful tool for carrying out palaeoenvironmental reconstructions. GIS enables the archaeological discipline to understand the strategic position of sites and their connections with other neighboring locations of similar chronology. They also allow organizations responsible for archaeological heritage to explore areas in order to identify archaeological sites and areas under threat, which may be lost due to the dynamics of urban construction currently affecting the cosmopolitan city of Dubai.

GIS estimates of sea levels for the 2nd millennium BC have revealed that the Al Qusais-site would have been located only 700 meters away from the coast and would have been inside the mangrove and marsh ecosystem.

The geomorphological maps, interpreted by aerial photographs from 1965, shows that the surroundings of Al-Qusais may have comprised intertidal plains with intermittent water, confirming the hypothesis of a rising sea level gradually flooding continental areas.

In turn, the sediments analyzed to the north of the modern Al-Qusais cemetery suggest the existence of a mangrove and a marsh ecosystem contemporary with the construction of the tombs in the ancient necropolis. One also finds in the vicinity of the necropolis shells of bivalves and mollusks of mangrove origin, displaying features of man-made opening that may indicate the location of a sedentary coastal settlement.

Abbreviations

BC	Before Christ
GIS	Geographic Information Systems
DEM	Digital Elevation Model
Dinocard	Dinocaridum
U. A. E.	United Arab Emirates
BP	Before Present
AD	Annu Domini
A.p.s.l	Above Present Sea level
U.A.Q	Umm Al Quwain
Ky	Kiloyears

Acknowledgments

The authors want to acknowledge the support and help provided by the *Dubai Culture & Arts Authority* during the excavation and throughout the entire duration of the project. Many thanks, also, to the staff of the *Sanisera Archaeology Institute* for their efforts made under challenging environmental conditions. We also would like to thank Dr. Gary R. Feulner, Dr. Anja Zander and Dr. Helmut Brückner for their precious support in the understanding of Dubai's geological and faunal setting. Authors send special thanks to Dr. Martin Makinson who technically assisted the team for publishing this paper.

Author Contributions

Adrián Fernández-Sánchez: Conceptualization, Data curation, Methodology, Formal Analysis, Investigation, Software, Resources, Validation, Writing – original draft, Writing – review & editing

Fernando Contreras Rodrigo: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Writing – review & editing

Alicia Alonso: Conceptualization, Investigation, Methodology, Visualization, Writing – review & editing

Bader Al Ali: Funding acquisition, Project administration, Supervision

Mansour Karim: Funding acquisition, Project administration, Supervision, Validation, Visualization, Writing – review & editing

Hassan Zein: Funding acquisition, Project administration, Supervision, Validation, Visualization, Writing – review & editing

Manal Abdullah Al Masfari: Supervision, Validation, Visualization

Funding

The project has been developed within the framework of a collaboration between Dubai Culture Authority & Arts and Sanisera International Archaeology Institute under Limited Tender No. 38 of 2024 regarding the survey and excavation at the Al Qusais archaeological site.

Data Availability Statement

The data that support the findings of this study can be accessed at: https://earthexplorer.usgs.gov/. Other data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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Research Field

Adrián Fernández-Sánchez: Climate Change, Palaeo-climatology, Palaeo-geography, Geoarchaeology, Environmental Geology, GIS Analysis, Flood Hazard.

Fernando Contreras Rodrigo: Archaeology, Cultural Archaeology, Bioarchaeology, Underwater Archaeology, GIS Analysis, Bronze period, Near Eastern Archaeology, Roman period, Heritage Management.

Alicia Alonso: Bioarchaeology, Phyisical Anthropology, Biology, Photogrammetry, Osteology, Experimental Sciences, Radio-diagnostic imaging.

Bader Al Ali: Archaeology, Cultural Archaeology, Bioarchaeology, Underwater Archaeology, GIS Analysis, Bronze period, Neareast Archaeology, Roman period, Heritage Management.

Mansour Karim: Archaeology, Cultural Archaeology, Bioarchaeology, Underwater Archaeology, GIS Analysis, Bronze period, Near Eastern Archaeology, Roman period, Heritage Management.

Hassan Zein: Archaeology, Cultural Archaeology, Bioarchaeology, Underwater Archaeology, GIS Analysis, Bronze Age, Near Eastern Archaeology, Roman period, Heritage Management.

Manal Abdullah Al Masfari: Archaeology, Cultural Archaeology, Bioarchaeology, Underwater Archaeology, GIS Analysis, Bronze period, Near Eastern Archaeology, Roman period, Heritage Management.