SRYAHWA PUBLICATIONS

Annals of Archaeology
ISSN: 2639-3662 | Volume 8, Issue 2, 2026
https://doi.org/10.22259/2639-3662.0802005

RESEARCH ARTICLE

Palaeoenvironmental Reconstruction of the Dubai Emirate (U.A.E.) Coastline from the 3rd Millennium BC. To 1st Millennium AD. Based on Geographic Information System Techniques

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Received: 29 August 2026 Accepted: 14 September 2026 Published: 21 September 2026

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Abstract

The apparent disconnection of coastal archaeological sites from surrounding natural resources poses a significant challenge for interpreting prehistoric human–environment interactions, particularly in dynamic landscapes such as the Emirate of Dubai. Sites including Al-Qusais, Al-Soufouh, and Jumeirah, which today seem distant from productive shorelines or freshwater sources, were likely once closely linked to coastal and estuarine ecosystems. This contrast reflects long-term Holocene environmental transformations, including sea-level fluctuations, sediment deposition, and climatic shifts.

This study applied Geographic Information Systems (GIS), sedimentology and malacology to reconstruct past shorelines between 4000 BC and 1000 AD, integrating geological, faunal, and archaeological data to model prehistoric coastal landscapes. Sea levels according to composite values combining a modest relative sea-level (RSL) highstand with the still-unfilled marine accommodation space, the upper limit of the tidal frame, and vertical crustal movement. Because the mapped marine units are predominantly intertidal, they are referenced to high water rather than to mean sea level. Sedimentary and geomorphological analyses revealed multiple marine transgressions, mangrove–marsh development, and later aridification. Evidence from Al-Qusais site indicated two to three shallow transgressions followed by mangrove ecosystems, possibly overlapping with Wadi Suq occupation (2000–1500 BC). Comparable patterns appear at Al-Soufouh site, while Jumeirah likely bordered a small marine inlet.

GIS estimations suggested these sites were situated very close to ancient coastlines, embedded in resource-rich environments. Archaeological evidence further implies even closer proximity, highlighting adaptive settlement strategies closely tied to evolving coastal environments.

Keywords: Palaeoenvironmental Reconstruction, GIS, Geoarchaeology, Shoreline Evolution, Arabian Gulf Archaeology.

1. Introduction

The coastal region of the Emirate of Dubai (United Arab Emirates, UAE) contains some of the most important prehistoric archaeological sites in the Arabian Gulf. The sites of Al-Qusais and Al-Soufouh are of great importance in terms of funerary practices and the grave goods found in the burials. These archaeological sites date from the Umm an-Nar period (ca. 2700–2000 BCE) at Al-Soufouh (Benton & Qandil, 1996) and between Wadi Suq and the Iron Age (1400 BCE to 750 BCE) for the Al-Qusais site (Contreras et al., 2025). The Al-Jumeirah site, for its part, could be considered a point of connection between regions such as India, Iraq, and China, and would have contained occupation during the Abbasid Islamic period (900 AD) until probably 1100 AD (Juchniewicz et al., 2025).

Citation: Adrián Fernández-Sánchez, Fernando Contreras Rodrigo, Bader Al Ali, *et al.* Palaeoenvironmental Reconstruction of the Dubai Emirate (U.A.E.) Coastline from the 3rd Millennium BC. To 1st Millennium AD. Based on Geographic Information System Techniques. Annals of Archaeology. 2026;8(2): 75-93.

Beyond their location in southeastern Arabia, the three sites share their relative proximity to the Arabian Sea, though they lie more than 600 m — and up to 8 km at Al-Qusais — from the present coast. Recent surveys at Al-Qusais have recovered seashells of species now extinct in the UAE bearing human-made openings for feeding (Fernández-Sánchez et al., 2025). Yet all three sites appear disconnected from present coastal environments, in arid settings without nearby natural resources.

Taking into consideration the evidence present in these sites and the dependence on coastal resources that has been described in a large part of the archaeological sites of the southeast of the Arabian Peninsula (e.g. Cerro Linares, 1999; Charpentier et al., 2023) , it is possible to think that these would have had to be inserted in environments different from those existing today.

Holocene climate in southeastern Arabia has fluctuated, with phases wetter than today. The last humid maximum probably occurred ca. 10,000 years ago (Preusser, 2009); since then δ18O records from Qunf Cave (Oman) show an overall trend toward aridity (Fleitmann et al., 2007a), interrupted by two relatively humid windows — 4.4–4.2 ka (2400–2200 BCE) and 3.6–3.4 ka (1600–1400 BCE) — that may coincide with the onset of occupation at Al-Soufouh and Al-Qusais (Benton & Qandil, 1996; Contreras et al., 2025).

Such wetter conditions could have favoured rivers, lakes and lagoons, and richer vegetation and fauna around the Dubai coast, offering primary resources to its inhabitants. Together with the lateral migration of coastal features such as khors and inlets (Wen et al., 2023) and possible regional sea-level change (Evans et al., 2002), these processes would have brought the past coastline closer to the settlements, a position more conducive to resource use.

Geographic Information Systems (GIS) are key tools for the integration of different spatial variables, such as environmental variables, topographic features, and point-based information related to sea-level elevation. Their value in palaeoenvironmental reconstruction lies in their capacity to bring together datasets that are otherwise incommensurable: a sea-level index point is a single dated elevation at a single locality, a geomorphological map is a two-dimensional interpretation of surface form, and an archaeological site is a point of known age and position. GIS allows these to be combined within one georeferenced framework, so that a vertical value derived from stratigraphy can be projected across a terrain model and expressed as a shoreline position that can be compared directly with the distribution of settlement.

GIS has been widely applied to coastal reconstruction — combined with remote sensing to quantify historical shoreline change (Seghir et al., 2018; Pepe et al., 2023) and project future configurations (Palanisamy et al., 2024), and in archaeology to model site location against past environmental variables (Brandt et al., 1992; Contreras Rodrigo & Fernández Sánchez, 2022). Reconstruction reliability is bounded by the vertical accuracy of the terrain model and the quality of the sea-level input; in low-gradient settings this is acute, since small vertical errors produce large horizontal shifts of the modelled shoreline (Section 4.1). The approach here is therefore framed as an estimation with quantified uncertainty, not a determinate reconstruction.

This research is part of a GIS project developed by Sanisera Archaeology Institute in collaboration with Dubai Culture & Arts Authority. The aim was to reconstruct the past natural environment from the 3rd millennium BC to the 1st millennium AD, in accordance with archaeological evidence discovered and recorded at the Al-Qusais necropolis, Al-Soufouh and Jumeirah sites.

1.1 Study Area

The study area encompassed the entire coastal zone of the Emirate of Dubai, in the United Arab Emirates, located in the western part of this region. The Dubai coastline extends from 24°55’27.14»N, 54°54’59.27»E, the border with the Emirate of Abu Dhabi, to 25°19’3.25»N, 55°20’55.77»E, the border with the Emirate of Sharjah. The study also included the inland coastal zone, as this article addresses past coastal evolution. Therefore, three archaeological sites were considered, which are currently several kilometers from the coast (Figure 1), but are thought to have been closer in the past:

- The archaeological site of Al-Soufouh, which is located 990 meters from the current coastline, at coordinates 25° 6’43.15»N, 55°10’29.19»E. It stands at an elevation of between 1 and 2 meters above current sea level.
- The archaeological site of Jumeirah, located 660 meters from the current coastline at coordinates 25°11’50.50»N, 55°14’28.85»E and at an altitude of 2 meters above current sea level.

- The archaeological site of Al-Qusais, which is located between 8 and 9 kilometers from the current coastline at coordinates 25°16'11.31»N, 55°25'13.92»E and at an altitude of between 5 and 6 meters above current sea level.

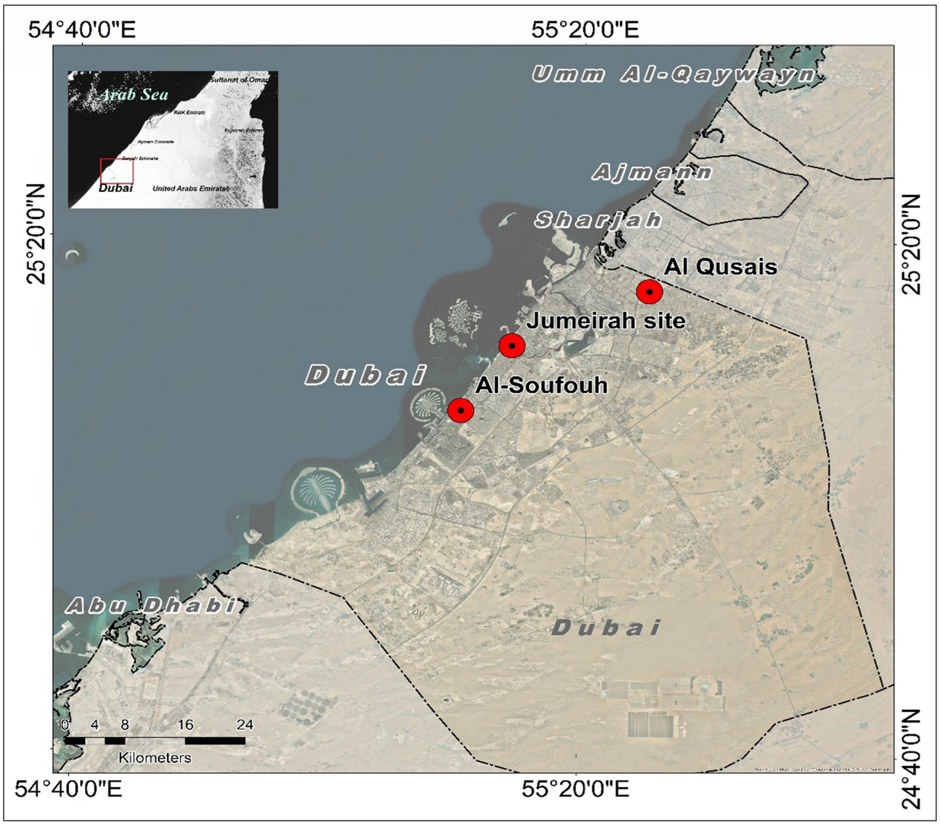

Figure 1. *Location map of the study area showing the current coastline of Dubai and the three sites considered.*

Today the Dubai coastline is almost entirely developed, except a small area in the southwest (Hyessan, near Palm Jebel Ali); it remained largely undeveloped until the mid-1960s, when the city was confined to present-day Deira and Al Ras. Geologically, sabkhas and carbonate sandy sediments cover most of the surface, while older or more inland marine areas are overlain by quartz sands and silts of aeolian origin (United Arab Emirates University, 2017).

1.2 Aims and objectives

The main objective of this study is to reconstruct the position of the coastline of the Emirate of Dubai across five successive 1,000-year intervals, spanning from the 3rd millennium BC to the 1st millennium AD.

In addition to this primary objective, the study also aims to some secondary tasks:

- Identifying the main geomorphological features associated with past shoreline dynamics.
- Evaluating the influence of sea-level fluctuations on coastal evolution with potentially submerged areas through time.
- Analyzing two sedimentological trenches in Al-Soufouh and Al-Qusais.
- Calculating a perimetral mangrove area through remote sensing.
- Estimating the position of the shoreline (RSL) in five 1,000-year intervals (3rd millennium BC to 1st millennium AD) for all the Dubai Emirate.

2. Materials and Methodology

This research was drawn on both public and proprietary datasets, summarised in Table 1 and described here by category.

Regarding topographic data, two digital elevation models were consulted: ASTER GDEM (30 m) and GMTED2010 (250 m). The coarser GMTED product was ultimately preferred for the shoreline modelling because the higher-resolution ASTER surface incorporated the built environment of modern Dubai, whose artificial elevations and reclaimed coastline introduced systematic distortions into any projection of a palaeo-water plane. The trade-off in vertical precision is discussed in Section 4.6.

Declassified aerial photography flown in 1965, with supporting coverage from 1973, was obtained from the Records of the Defense Mapping Agency held at the U.S. National Archives (1996). The 1965 survey predates large-scale urban development and coastal reclamation in Dubai and therefore preserves the geomorphological configuration of the coastal plain in a substantially natural state; it forms the basis of the geomorphological mapping described in Section 2.1.

Published Holocene sea-level index points and shoreline elevations for the southeastern Arabian Peninsula were compiled from the regional literature (Table 2), together with recent syntheses for the Gulf as a whole. Entries were classified according to the type of indicator from which they derive, since storm-berm elevations and mean sea-level indicators are not interchangeable.

Table 1. *Materials used during the research.*

Material	Use	Resolution	Source
1965 Corona image	Geomorphology	8 meters	USGS (U.S. National Archives, 1996)
Digital Elevation Model (DEM)	Coastal estimations	250 meters	GMTED 250.
Published papers	Sea level estimation	--	Various
GIS mangrove measurements	Mangroves area estimation	--	1965 Corona, Sentinel 2 (2024)
Airbus imagery	Mangroves area estimation	20 cm	Airbus, 2024

For the sedimentological and stratigraphic data, two trench sections were available: one excavated by the Sanisera Archaeology Institute north of the modern Al-Qusais cemetery in March 2020, sampled at 10 cm intervals or by stratum, and one excavated at Al-Soufouh by a team from Ajman University in March 2006, reassessed here from photographic records. Surface shell assemblages collected during field survey at Al-Qusais in 2020 and 2024 were classified against one regional and two global reference databases.

For the archaeological documentation, excavation records and published chronologies for the three sites were used to establish the temporal framework against which the compared reconstructed shorelines, including the necropolis stratigraphy that provides the relative dating control for the trench sections.

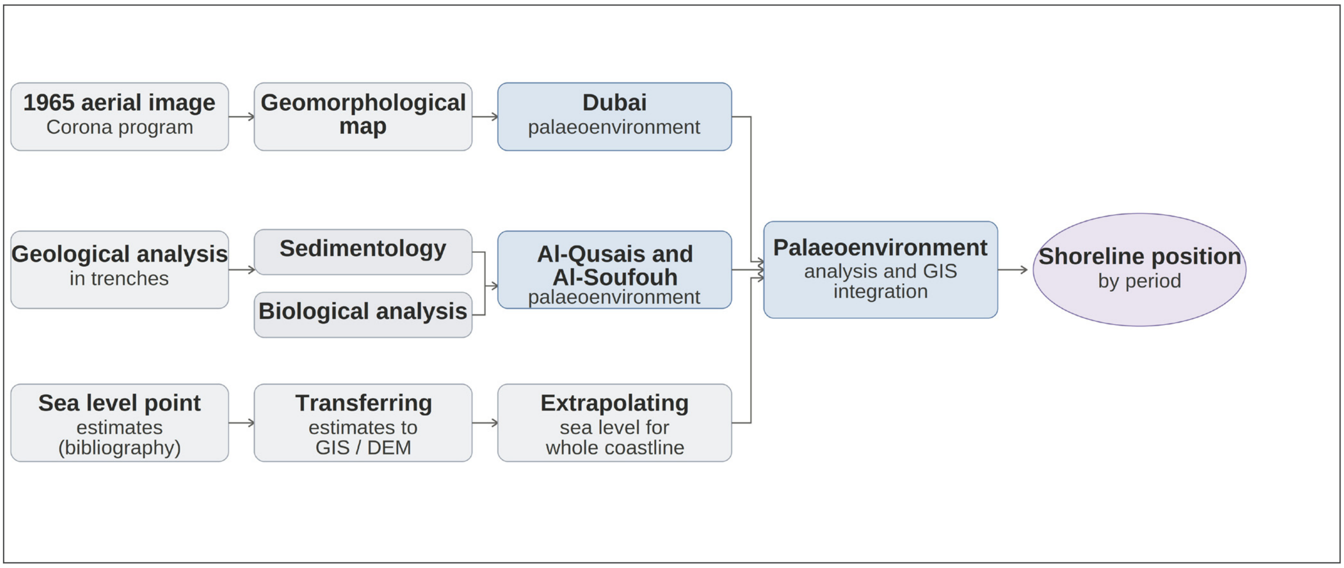

Figure 2. *Workflow used during the research process.*

A series of methodologies were applied in order to reconstruct the palaeoenvironmental situation during the prehistoric period in Dubai Emirate. The research counted on different stages such as a Geomorphological map drawn from historical aerial images, sedimentological analysis of archaeological trenches and Geographic Information Systems modelling based on geological and shoreline research. The Figure 2 shows a scheme with the workflow that has been used in this research.

2.1 Geomorphological Cartography

The palaeoenvironmental reconstruction began with geomorphological interpretation through the creation of a map representing topographic features linked to geological processes. ArcGIS Pro was used to georeference a 1965 aerial photograph, supported by a 1973 image (U.S. National Archives, 1996). Photointerpretation was focused on landforms such as depositional areas, erosion surfaces, and rock outcrops. The 1965 imagery preserved largely natural conditions prior to major urban development in Dubai, allowing the identification of original and recent geomorphological features. The geomorphological cartography comprised 220.5 square Kilometers

(Km^2) adapted to the emirate boundaries and year 1965 coastline.

The geomorphological map identified the ancient landform features. The palaeoenvironmental features were classified into four types:

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

Within these four types, some 33 subgroups were specifically listed. Total subgroups and detailed cartography and their description can be found in the results.

2.2 Stratigraphy and Sedimentological Analysis

Thanks to the ongoing archaeological excavation projects, it was possible to analyze and revisit two sedimentological trenches. The analyzed trenches were located at Al-Qusais site and Al-Soufouh site.

At the Al-Qusais site, the sedimentary trench was dug north of the modern cemetery, at the location 25°16'20.29"N, 55°25'19.45"E, 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 relatively undisturbed, as confirmed by satellite imagery of the past decades. This trench was dug by SANISERA Archaeological Institute in the very beginning of the COVID-19 pandemic in March 2020.

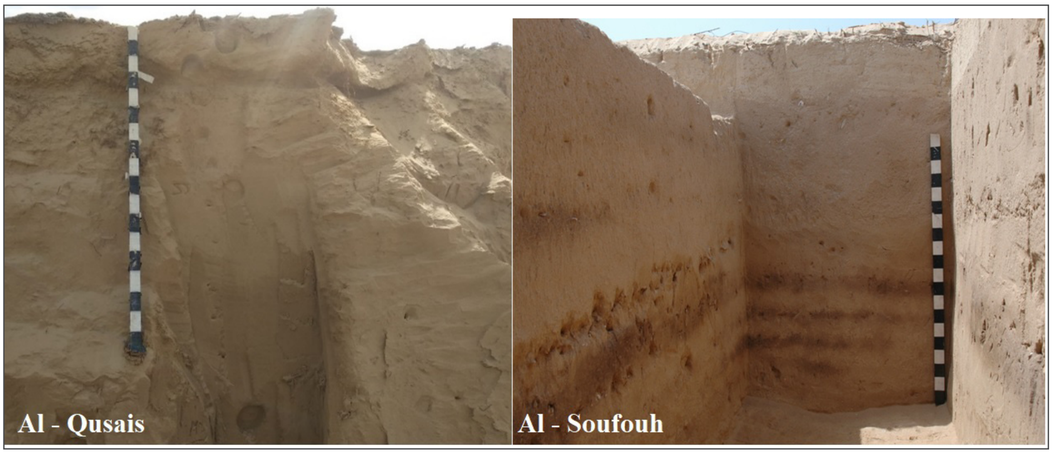

Figure 3. *Sedimentary analysis and sampling process in the Al-Qusais trench (left) and Al-Soufouh (right). Source for the Al-Soufouh trench, Dubai Municipality, 2006.*

In the case of Al-Soufouh, the sedimentary trench was dug by another team from Ajman University in March 2006. The location was at 25° 6'46.24"N, 55°10'34.79"E, and the depth is around 2.5 meters (Figure 3).

The Al-Qusais trench was analyzed for sedimentology through stratigraphic sampling at 10 cm intervals or per stratum, while Al-Soufouh trenches were reassessed using photographic records. Interpretation considered stratigraphy, depositional features, faunal remains, and sediment characteristics, and was also applied to grave excavations at Al-Qusais. Field surveys at Al-Qusais allowed the collection and classification of 55 surface shells (27 fragmented), whereas at Al-Soufouh only photographic evidence was available. The samples were compared with three reference databases, one regional (Fowler, 2005) and two global (Flandes Marine Institute, 2025; Young, 2006), and are listed in Table 3.

2.3 Biological Analysis in the Dubai Coast and Al Qusais

Additionally, two field surveys (one in 2020 and another one in 2024) were conducted in Al-Qusais to identify altered and non-altered marine shells exposed at the surface around the site. A total of 55 shells or fragments were recovered. In the case of Al-Soufouh, images (taken during the 2006 campaign) of the malacological fragments were analyzed,

An analysis of identification specimens and measurements was done, together with a description about the possible breaking patterns that the shells could have sustained. Photographical evidence were taken.

2.4 Shoreline Estimations with Geographic Information Systems

Geographic Information Systems are powerful tools for conducting spatial analyses through the integration of topographic and/or geological variables. In numerous studies, GIS have been used to estimate the position and historical evolution of coastlines in the past (Seghir et al., 2018) through the consideration of hydrodynamic and topographic variables, such as Digital Elevation Models (Palanisamy et al., 2024; Pepe et al., 2023).

The study assumed that past coastlines extended further inland than at present. Critically, this inland displacement is not attributed to sea-level elevation alone. Following the framework of Lokier et al. (2015) and Mauz et al. (2022), a distinguishing between (i) relative sea level (RSL), defined here as the height of mean sea level relative to the local land surface at a given time, and (ii) the palaeo-inundation elevation, defined as the vertical value that must be applied to the modern Digital Elevation Model in order to reproduce the position of the palaeo-shoreline, was performed. Both terms were not considered equivalent because the coastal plain of Dubai has aggraded since the mid-Holocene, the modern land surface stands higher than the contemporaneous palaeo-surface, and a modest RSL highstand therefore corresponds to a substantially larger inundation elevation when projected onto present-day topography.

Elevation_inund = RSL + S_agg + T_HAT + U [Eq. 1]

Formally, the value applied to the modern DEM for estimating the palaeo-inundation of each period was expressed as Equation 1.

where RSL is the relative sea-level highstand for the period, S_agg is the thickness of sediment aggraded at the site since that period (measured directly in the sedimentary trenches), T_HAT is the elevation of the upper limit of the tidal frame above mean sea level, and U is the cumulative vertical crustal displacement. Under this formulation the RSL term remains within the range supported by the regional literature (≤ +1 to +2 m), while the composite inundation elevation reproduces the mapped shoreline positions.

The tidal datum was dictated by the nature of the indicators. The geomorphological mapping (Section 3.1) identified the inland marine units as predominantly intertidal (tidal flats, khors, strandplains and coastal sabkha) rather than subtidal. This was material, as an intertidal surface was emergent at low water and submerged at high water, so it was referenced not to mean sea level but to the upper tidal frame. For such surfaces to form, mean sea level not needed to reach their elevation only high water need do so.

The Dubai coast has a mean tidal range of ~1 m (greater at springs), placing the highest astronomical tide (HAT) roughly 0.75–1.0 m above mean sea level. We therefore adopt T_HAT ≈ +1.0 m for intertidal indicators; where subtidal units are mapped, the elevation is referred to mean sea level and the tidal term omitted.

Table 2. *Bibliography on shoreline estimations for 2nd millennium BC. on SE Arabia. Heights related to above present sea level.*

Location	Height	Reference
Marawah Island, Abu Dhabi (U.A.E.)	5 – 4 m	Evans et al., 2002
Al Jubali and Dubai	4.4 – 3.8 m	Wood et al., 2012
Abu Dhabi (U.A.E.)	4.8 – 4.0 m	Evans et al., 2002
Al Jubali (Saudi Arab)	4 m	Ridley and Seely, 1979
Eastern Saudi Arabia	3 m	McClure & Vita-Finzi, 1982
Southern Arabian Gulf	3 m	Kirkham, 1998
Southern Arabian Gulf	3.5 m	Alsharhan Kendall, 2003
Northern U.A.E.	2 – 1 m	Pain & Abdelfattah, 2015
Ghagha island and Ras Khumays	1.67 m	Damien et al., 2020
Umm Al Quwain (U.A.E.)	1.5 m	Bernier et al., 1995

Shoreline estimations were conducted for five intervals, of 1,000 year each, spanning the 3rd millennium BCE to the 1st millennium AD. These are chronological intervals rather than archaeological periods, although their correspondence with the regional cultural sequence (Hafit, Umm an-Nar, Wadi Suq, Iron Age, Islamic) is indicated where relevant. Published sea-level values were compiled by period (Fig. 5) and are here reported as RSL with associated uncertainty rather than as fixed elevations.

The regional literature offers a range of estimates for the mid-Holocene highstand in the southern Gulf (Table 2): Parker et al. (2020) reported 2.8–3.10 m with an upper limit of 3.75 m; Lokier et al. (2015) documented levels exceeding present from 7100–6890 cal yr BP, remaining above +1 m shortly after 5290–4570 cal yr BP, and returning to present levels by 1440–1170 cal yr BP; Mauz et al. (2022) derived a lower figure of 1.6 ± 0.4 m at 6.7–6.0 ka from glacio-isostatic modelling.

An RSL of +2 to +2.75 m was adopted for the 3rd millennium BCE, declining through the 2nd millennium BCE and approaching present by the 1st millennium AD, with the spread between published estimates carried as uncertainty. The 3.5 m of Lambeck (1996) is a modelled prediction centred on ca. 6 ka, not a dated index point. Several elevations in Table 2 derive from storm berms and record extreme-event or highest-tide reach rather than mean sea level, as these are flagged as maximum-reach indicators and, rather than discarded, used for comparison in the discussion.

Once the palaeo-inundation elevation was established for each period (Figure 4), it was projected onto a present-day Digital Elevation Model (DEM). GMTED data (250 m resolution), representing current topography. The DEM was integrated in ArcGIS Pro to estimate past coastline positions. It must be emphasised that this procedure did not assume that the terrain has remained unchanged since the mid-Holocene; on the contrary, the aggradation term in the expression above explicitly accounts for the fact that the modern surface is higher than the contemporaneous one.

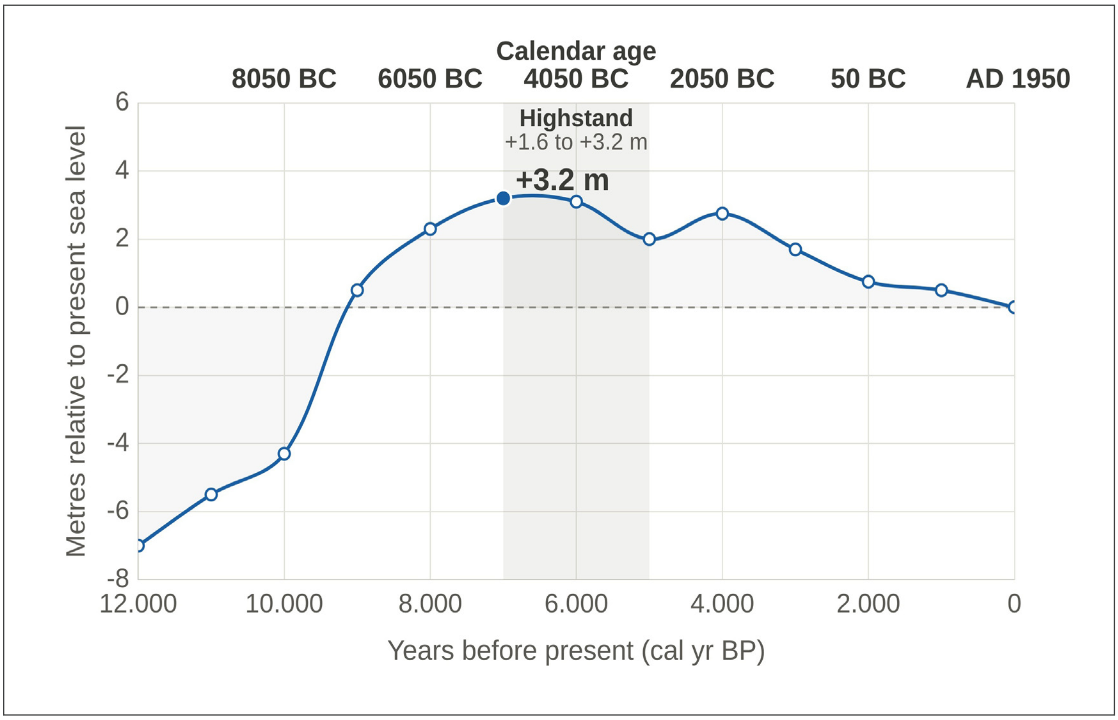

Figure 4. *Averaged heights estimations during the Holocene period for the Southeastern Arabian region, derived from recent published research.*

The resulting cartography should therefore be read as the intersection of a palaeo-water plane with modern topography, which is cartographically equivalent to intersecting a lower water plane with the reconstructed palaeo-surface.

An accommodation space and terrain aggradation estimation was conducted. The southern Gulf coastal plain is a prograding carbonate ramp in which accommodation space created during the post-glacial transgression has been progressively infilled (Lokier & Steuber, 2008; Lokier et al., 2015). The sedimentary trenches described in Section 2 allowed this infill to be measured directly, but only the portion post-dating the horizon of interest was relevant to the reconstruction. Rather than adopting the full depth of each section, an isolation of the thickness deposited above the units correlated with the 2nd–1st millennium BC occupation was performed. Approximately 0.75 m at Al-Soufouh and 0.49 m at Al-Qusais. These figures, and not the total trench depths of 2.5 m and 1.95 m respectively, constitute the aggradation term S_agg. Restoring them returned the contemporaneous land surface to a level roughly 0.5–0.75 m below the present one at these localities.

Therefore, the resulting vertical budget with S_agg of 0.5–0.75 m and T_HAT ≈ 1.0 m, a palaeo-inundation elevation of 3.5–4.5 m relative to the modern DEM (the range used in the cartography) required a sea-level term of about +2 to +2.75 m. This fell within the 2.8–3.10 m (upper limit 3.75 m) reported by Parker et al. (2020) for the southern Gulf. The two levels were not strictly comparable, since the modelled figure was a regional mean whereas the southeastern-Gulf index points included localities affected by differential crustal movement (Wood et al., 2012). However, the essential point was that the required term lied within the published range.

As a "buffer area" in the GIS estimations a potential mangrove and marsh extents were estimated from the current average dimensions of UAE mangrove ecosystems, which fringe coastlines and shallow waters (Bunting et al., 2018). Using GIS and satellite imagery, extents were measured across Umm Al-Quwain, Dubai, Ajman, Ras Al Khaimah and Abu Dhabi. The selected and exact locations for measurements were: Khor Ajman (Ajman), Al Houtah (Umm Alqwain), Al Houtah (Umm Alqwain), Al Seeanneah bar (Umm Al Quwain), Al Seeanneah western island (U.A.Q), Meshara (Umm Al Quwain), East of Umm Al Quwain City, Khor Al Yeefrah (Umm Al Quwain), Umm Al Thuob (Umm Al Quwain) and Al Ghellah Island (Umm Al Quwain).

Lacking Bronze Age values, an average fringe width of 1,074 m (~1.07 km; Table 5) was applied with the ArcGIS Pro Buffer tool. This buffer was a cartographic generalisation, not a claim of uniform development, and should be read as the maximum potential envelope within which these ecosystems could have developed, not their actual continuous extent. The modern-fringe imagery is the Airbus Pléiades Neo HD15 product (15–20 cm, super-resolved from native 30 cm).

3. Results

3.1 Geomorphological Analysis

The first step in reconstructing the past coastline involved the creation of a geomorphological map under minimal anthropogenic influence, based on aerial imagery from a 1965 American reconnaissance survey (CORONA Project). The presence of marine sediments in currently dry, non-aeolian areas is consistent with marine transgressions reaching further inland than the present shoreline (Figure 5). It should be stressed that the age of these photo-interpreted deposits is not independently constrained: no geological dating has been applied to them, and their possible age attribution remains a working hypothesis based on their near-surface position and the absence of overlying aeolian cover, rather than a demonstrated result.

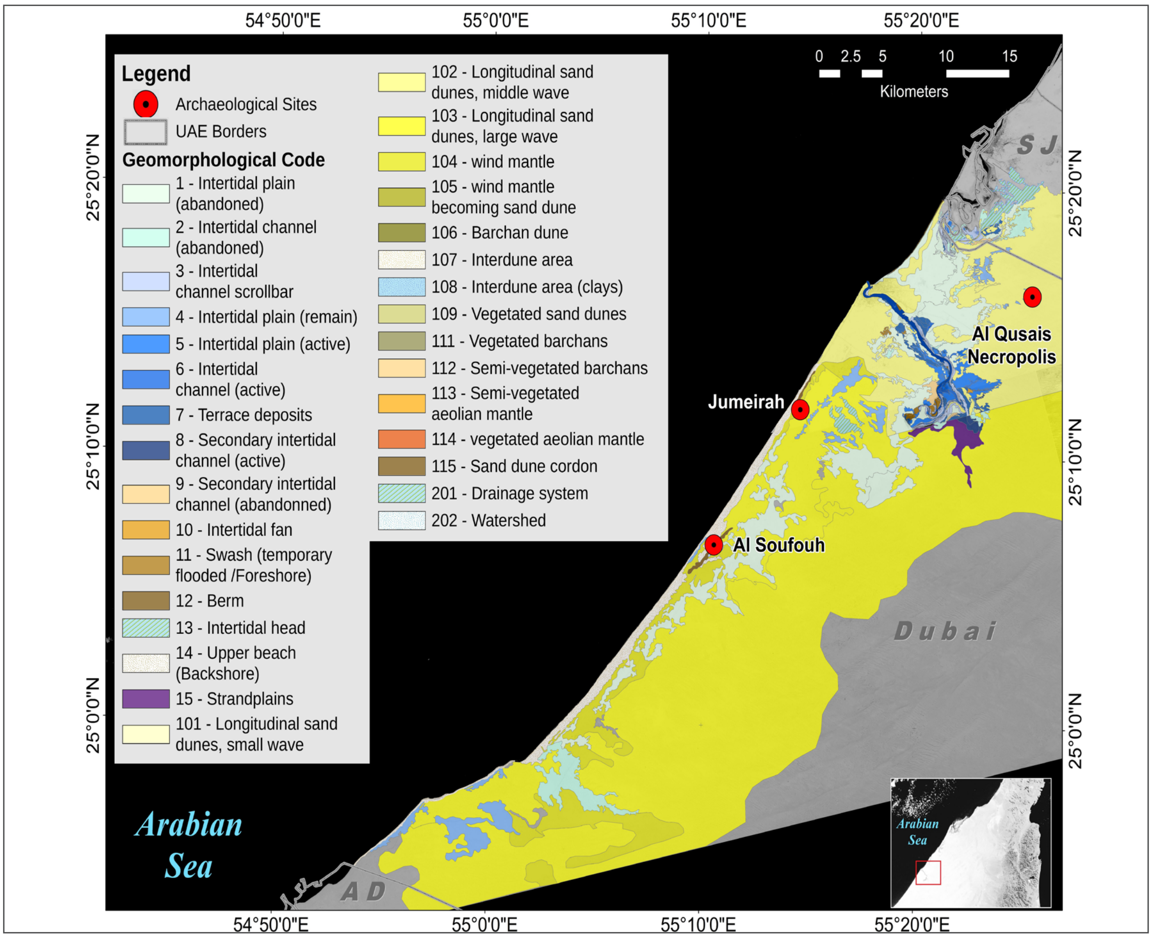

Figure 5. *Geomorphological map of the Dubai coast.*

The resulting map (Annex 1) identified 36 geomorphological units: 14 marine, 15 aeolian, 4 fluvial/lacustrine, and 2 anthropogenic. Aeolian environments dominate spatially, while marine units—mainly former intertidal plains, inlet channels (khors), and strandplains—extend several kilometers inland. Coastal features such as dune ridges, beach berms, and foreshore environments are also present.

The total area of aeolian environments in the entire analyzed area is 1453 km² while marine environments occupy 129 km².

Overall, the results indicate a complex marine dynamic characterized by significant inland penetration of marine environments.

3.2 Stratigraphy and Sedimentological Analysis of Al Qusais and Al Soufouh Trenches

The trench made in Al-Qusais has been analyzed in depth by Fernández-Sánchez et al. (2025). The analyzed trench recorded four main depositional environments across ten strata, reflecting alternations between shallow marine, mangrove, and aeolian conditions. The basal unit (195–132 cm) consisted of massive sands of probable aeolian origin with decreasing root presence, indicating progressive aridification. The overlying interval (132–66 cm) showed a transition from intertidal or estuarine deposits with in situ bivalves and mangrove remains to cross-stratified sands, marking a shift to aeolian conditions following marine regression. Between 66 and 12.5 cm, shallow marine conditions return, with carbonate intercalations and fauna, evolving into a mangrove environment with abundant roots and marsh vegetation. The uppermost section (12.5 – 0 cm) displays an erosional contact and aeolian cross-bedded deposits capped by a silty-clay crust.

The sequence reflects alternating marine–mangrove and arid phases, indicating frequent relative sea-level fluctuations and rapid climatic shifts. Correlation with the Al-Qusais necropolis suggests a consistent regional paleoenvironmental evolution during the 2nd–1st millennium BCE, characterized by mangrove-influenced Sabkha deposits followed by marine regressions and aeolian development, within which human occupation occurred under relatively arid but dynamically coastal conditions.

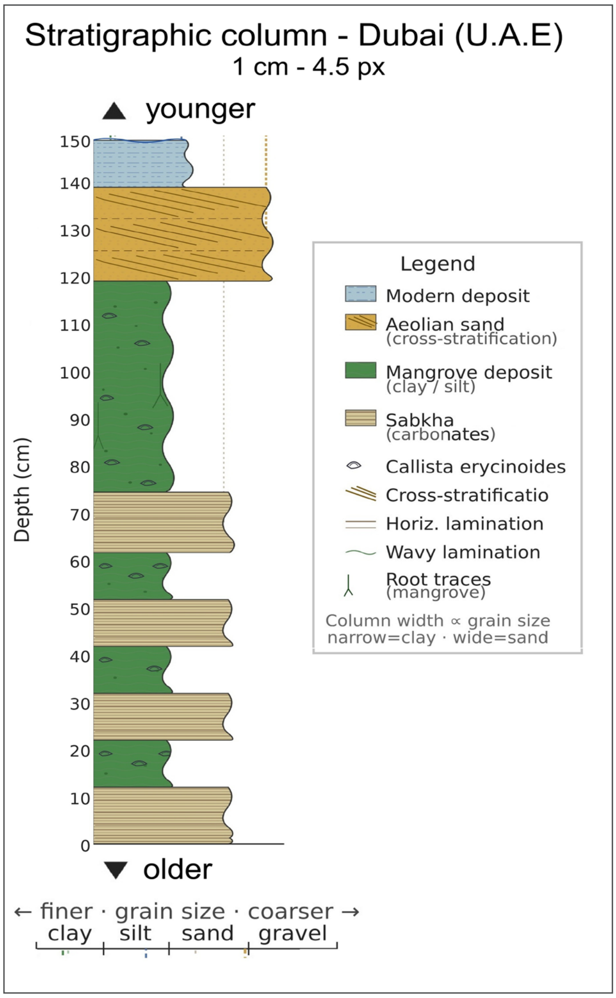

Figure 6. *Stratigraphic column of the trench developed in Al-Soufouh based on images from 2006.*

Another sedimentological trench was revisited in this research. Figure 6 shows the stratigraphic column of the Al-Soufouh trench performed from photographies.

The column as a whole recorded an evolution from conditions dominated by humid coastal systems (mangroves) to drier phases with the development of sabkhas and aeolian deposits, indicating a trend toward greater aridity and subaerial exposure towards the top, interrupted by transgressive pulses.

The succession reflects a cyclical alternation between sabkha environments (supratidal, evaporitic, high salinity), mangrove environments (intertidal, organic, low energy), and aeolian conditions (subaerial, arid, higher energy). This pattern suggests a shallow coastal system subject to frequent sea-level fluctuations along with changes in aridity/humidity. Furthermore, lateral migrations of depositional environments may have occurred.

Ten stratigraphic units or sets have been found, classified with numbers in the column. Unit 1 is a removed and anthropogenically modified material corresponding to aeolian sediments and clay desiccation crusts transported by sheet flow. The second level corresponds to aeolian sands with cross-stratification, forming dune ripples. This set corresponds to the last arid episode of the last 1000–1500 years, corresponding to the Islamic period between 500 AD and 1000 AD. The following sequence corresponds to a thick level containing mangrove deposits, with shells of the *Anodontia edentula* and *Terebralia* Palustris types, indicating a long-lasting episode where this area would have contained mangroves or was a perimeter zone of this mangrove coast.

Subsequently, the sequences found are of Sabkha-type carbonated marine sediments and alternations with Mangrove sediments that presumably had a greater depth and organic matter.

3.3 Malacological Analysis of Al-Qusais

Additionally, two field surveys (one in 2020 and another one in 2024) were conducted in Al-Qusais to identify altered marine shells exposed at the surface around the site. A total of 55 shells were recovered. Most shells are associated with mangrove, lagoonal, or intertidal environments, although some taxa (e.g., Hexaplex kuesterianus) are linked to shallow rocky settings. A modern origin is considered unlikely, as several specimens belong to taxa not recorded alive in the region today (e.g., Callista erycinoides, Terebralia palustris; Fowler, 2005).

The survey identified 5 shells from Hexaplex kuesterianus (common in shallow waters and attached to rocks); 18 specimens of Terebralia palustris, typical of mangrove areas (Fowler, 2005; Sonak, 2017; Yamanaka and Mizota, 2015); 4 shells of Tellinimactra angulata, identified as belonging to a mangrove environment (Jahangir et al., n.d.); 7 of Anodontia edentula, from mangroves (Poutiers, 1998); 9 specimens of Callista erycinoides, also from mangroves but dating to the Miocene period (Flanders Marine Institute, 2025); as well as 12 other species from various ecosystems, primarily mangroves.

The presence of Terebralia palustris is not in itself a chronological marker: its extirpation from the Arabian Gulf coastline correlates with mangrove overexploitation and loss ca. 4,000 years ago (Feulner, 2006; Händel, 2013; Magee et al., 2017), and in the UAE it survives only as a threatened relict population at Khor Kalba on the Gulf of Oman. The chronological attribution rests instead on the anthropogenic breakage patterns below and on stratigraphic correlation with the dated necropolis sequence.

Some specimens correspond to fossil taxa from the Eocene or Miocene; however, their limited presence does not indicate a fully reworked assemblage. Notably, a significant proportion of shells (27 out of 55) exhibited breakage patterns consistent with anthropogenic opening, as described for *Terebralia* Palustris and similar taxa (Uerpmann & Uerpmann, 2003). This suggests human consumption, indicating that the assemblage is broadly contemporaneous with the occupation of Al-Qusais and excluding both a purely geological and a modern origin.

3.4 Shoreline Estimations in Gis from 4,000 BC to 1,000 AD

The evolution of the past coastline has taken into account a possible perimeter zone of the mangrove and marsh ecosystem. Furthermore, the stratigraphic columns of Al-Soufouh and Al-Qusais demonstrate the necessity of a mangrove forest extension around the coastline.

The average length of the measurements was 1,074 meters. Therefore, each map of the estimated coastline was assigned a perimeter corresponding to the area of mangrove ecosystem.

This section provides a concise description of the estimation of the shoreline position. Each period has been defined and described in a separated section.

Figure 7 shows the estimated coastline for the 3rd millennium BC. Overall, the sea would have extended inland approximately 5 km to the south, while in the northern area it would have extended between 10.8 and 4.4 km. Large areas above sea level would have existed, potentially forming islands.

The Al Soufouh site would have been located above sea level on one of these islands in the southern area. One such island above sea level runs parallel to the coast from the south of the Emirate of Dubai almost to the old city.

Downtown Dubai (Shindaga, Al Fahidi, Al Hamriya, and Deira) would also appear above sea level.

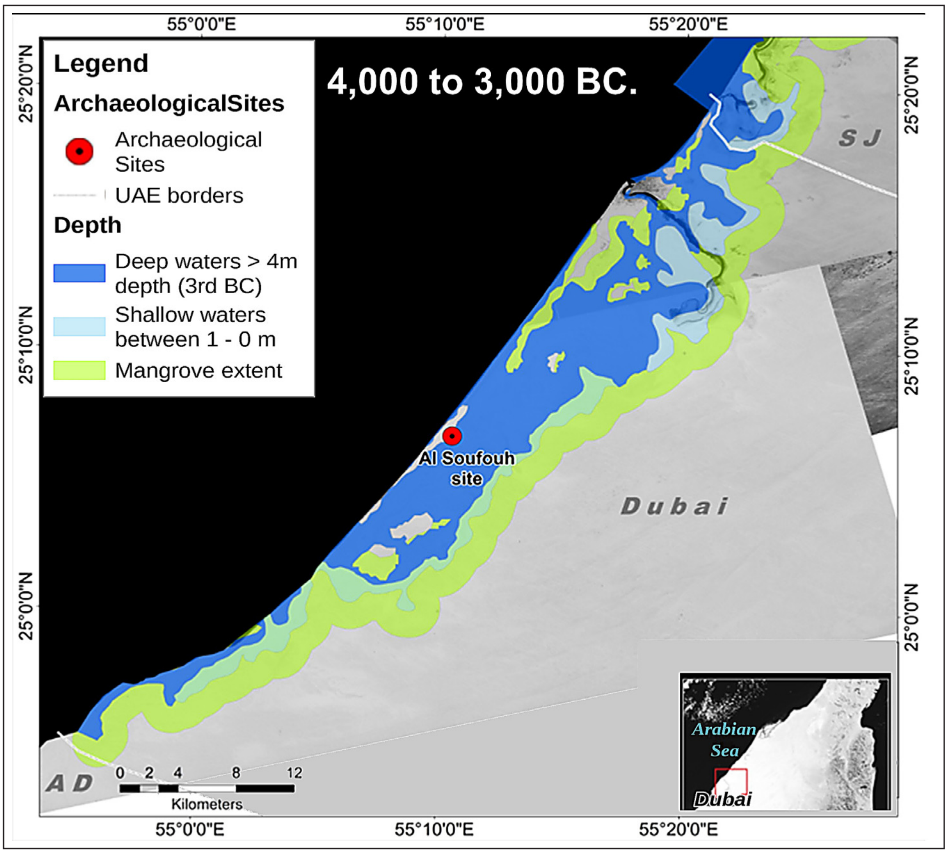

Figure 7. *Shoreline estimation for the years 4,000 to 3,000 BC. 1965 aerial photography as basemap.*

Figure 8 shows the estimated coastline for the 2nd millennium BC. In general, the sea would extend inland approximately 7 km to the south, while in the northern area it would extend between 12.1 and 6.8 km. It can be noted that the sea level would have been only about 700 m away from Al Qusais, and the mangrove line would have been within the nowadays cemetery, at its southwest corner.

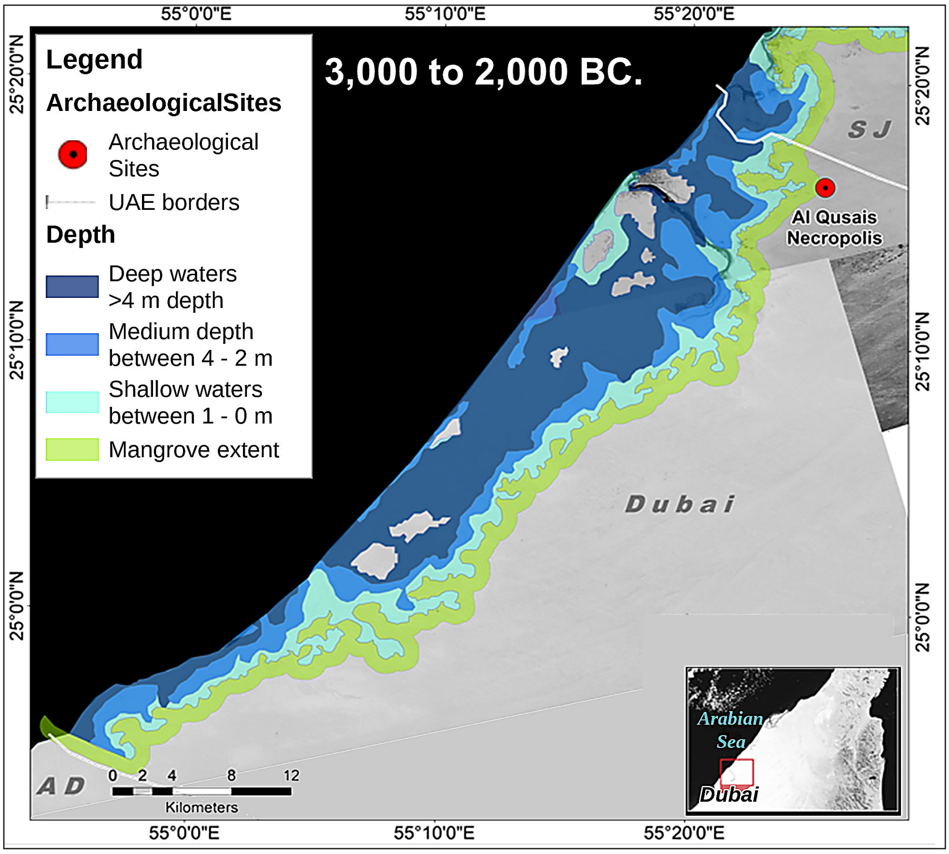

Figure 8. *Shoreline estimation for the years 3,000 to 2,000 BC. 1965 aerial photography as basemap.*

The number of inland islands would be significantly reduced, although the areas of Deira, Shindaga, Al Fahidi, and Al Hamriya would remain above the sea.

In this scenario, the area where Al-Soufouh would be located was still above sea level, but shallow water could be occupying more extent than in the previous millennium. Jumeirah site would still remain under sea level.

Figure 9 shows the estimated coastline for the 1st millennium BC. It can be noted that the sea level would be very similar to that of the 3rd millennium BC, although much lower than in the 2nd millennium BC.

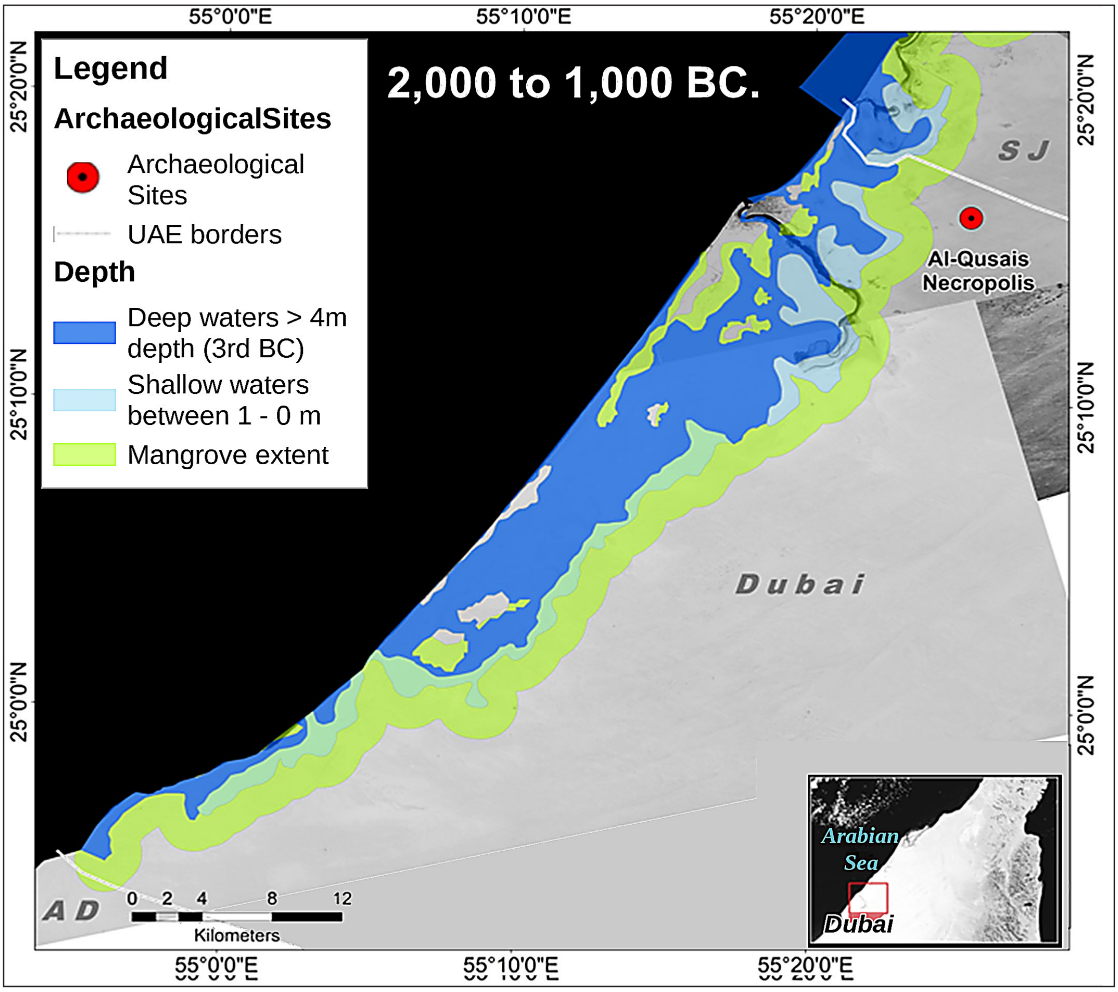

Figure 9. *Shoreline estimation for the years 2,000 to 1,000 BC. 1965 aerial photography as basemap.*

Overall, the sea was receding and would extend inland about 5.2 km to the south, while in the northern area it would extend between 10.8 and 4.8 km.

The same islands (Shindaga, Al Fahidi, Al Hamriya, and Deira) that appear above sea level in the other analyses would also be present, some of them larger than in the 3rd millennium BC. The sea level would be about 3.7 km from Al Qusais, and the mangrove line would be 1.5 km away.

During the years 1,000 to 0 AD, overall, the sea was receding and would extend inland about 5.2 km to the south, while in the northern area it would extend between 10.8 and 4.8 km. The same islands (Shindaga, Al Fahidi, Al Hamriya, and Deira; Figure 10) that appear above sea level in the other analyses would also be present, some of them larger than in the 3rd millennium BC. The sea level would be about 3.7 km from Al Qusais, and the mangrove line would be 1.5 km away.

The sea level would be much lower in the 0 to 1st millennium AD (Figure 11) than in any of the previous analyses, given that the sea would be in a stage of retreat or regression. In general, the sea would have extended inland very irregularly, sometimes only a few hundred meters and at other times several kilometers, but apparently following ancient Khor or intertidal inlets that are now urbanized.

The Jumeirah site appears surrounded by a small intertidal inlet or Khor, which would be consistent with its port-like character and defensive position.

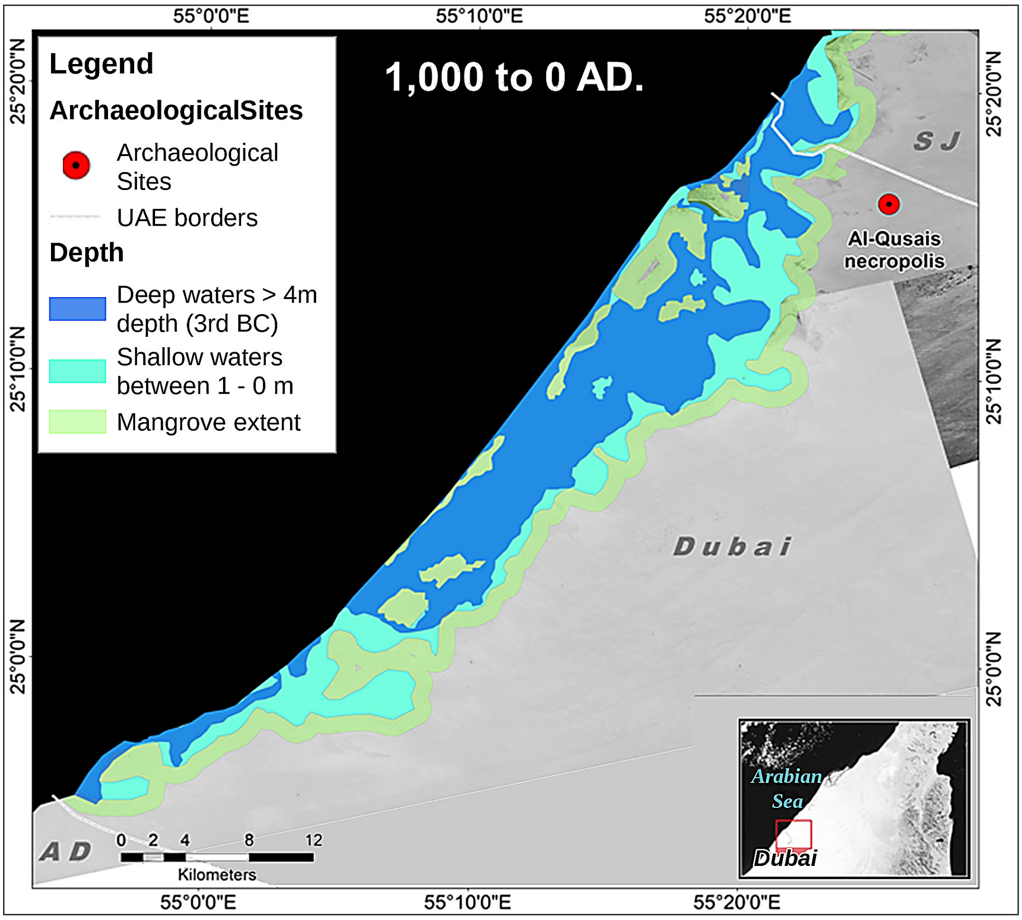

Figure 10. *Shoreline estimation for the years 1,000 B.C. to 0 AD. 1965 aerial photography as basemap.*

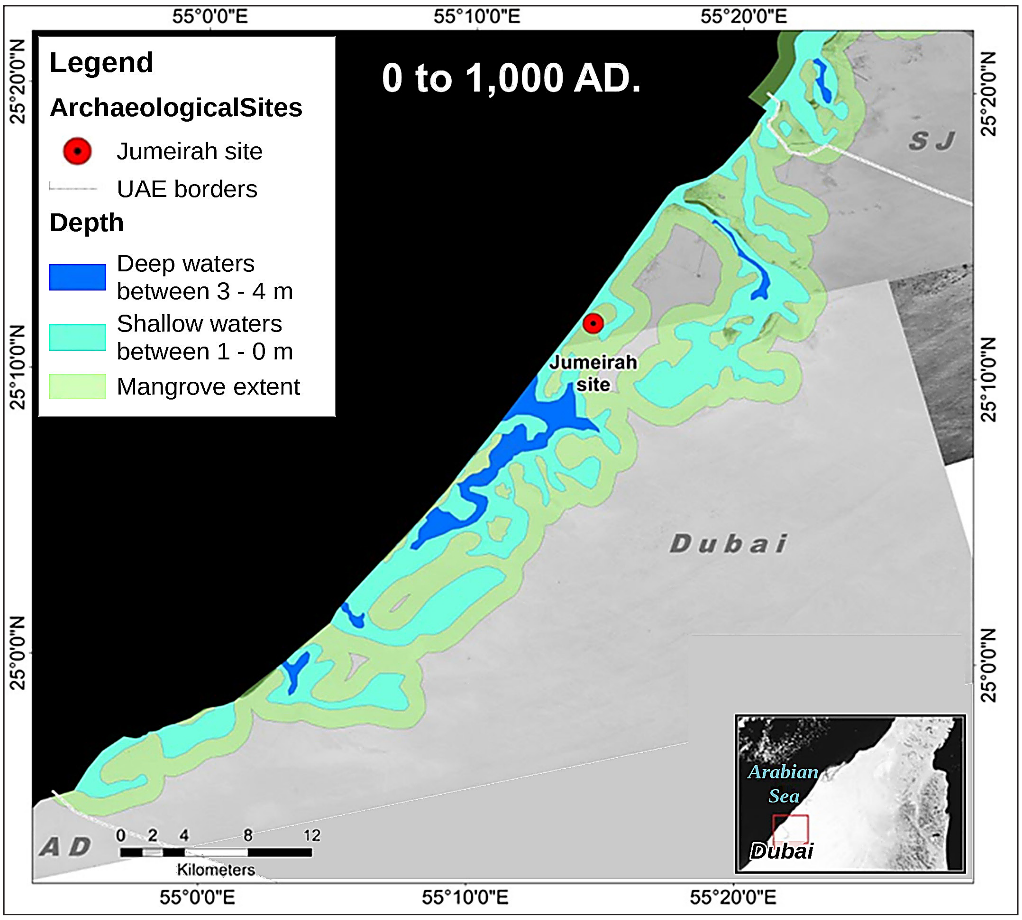

Figure 11. *Shoreline estimation for the years 0 to 1,000 AD. 1965 aerial photography as basemap.*

4. Discussion

GIS has proven to be a very useful tool when it comes to contextualizing archaeological sites with their environmental and social surroundings, as demonstrated by research in recent decades (Brandt et al., 1992; Contreras Rodrigo & Fernández Sánchez, 2022; Tantillo, 2007). The integrated treatment of archaeological documentation, sea level stage variables and topographic variables has made it possible to estimate in GIS the coastal evolution in the 3rd – 1st millennium BC, as well as Islamic periods of the 1st millennium AD.

The shoreline reconstruction placed Al-Qusais, Al-Soufouh and Jumeirah alongside a coastline located substantially further inland than the present one. It is important to specify what this implied: the reconstruction required a palaeo-water plane standing some 3.5–4.5 m above the modern land surface at these localities, not a mean sea level 3.5–4.5 m above its present datum. As set out in Section 2.2.3, roughly 1.5 m of that total is accounted for by aggradation of the coastal plain since the occupation horizon and by the tidal frame, leaving a relative sea-level term of about +2 to +2.75 m — within the range of published index points for the southern Gulf (Parker et al., 2020; Arhan et al., 2021) rather than exceeding it. The proximity of the Al-Qusais necropolis to the estimated shoreline (~700 m) was therefore compatible with the regional sea-level record without invoking an anomalous highstand.

A second consideration explained why the inland penetration was large horizontally yet modest vertically. The Dubai coastal plain is a low-gradient carbonate ramp and sabkha system, with slopes of the order of 1:1000 or lower. On such surfaces the horizontal shift of the shoreline equals the vertical change divided by the gradient, so a 1 m rise migrates the coast about a kilometre and a composite inundation of 3–4 m several kilometres. The 5–12 km of penetration reconstructed in Section 3.4 is thus an expected consequence of the local topography, not evidence of an extreme sea-level event. The same property, noted by Lokier and Steuber (2008), means the lateral uncertainty is high: a vertical error of only 0.5 m propagates to several hundred metres horizontally, which should be borne in mind when interpreting the site-to-shoreline distances reported here.

That the past coastline differed from the present one has been proposed by several authors, though the magnitude of sea-level change has often been overstated in older work and published estimates remain genuinely divergent. Dated index points from the southern Gulf place the mid-Holocene highstand at 2.8–3.10 m, with an upper limit of 3.75 m (Parker et al., 2020); Lokier et al. (2015) record levels above present from 7100–6890 cal yr BP, still exceeding +1 m shortly after 5290–4570 cal yr BP, and returning to present by 1440–1170 cal yr BP; glacio-isostatic modelling yields a lower regional figure of 1.6 ± 0.4 m (Mauz et al., 2022). This spread is not merely analytical scatter: the southern Gulf margin is demonstrably mobile in the vertical plane (Wood et al., 2012), so index points from different localities need not record the same relative elevation, and a single regional value may not be meaningful.

Higher figures in earlier work require careful attribution: the +5 m of Evans et al. (2002) corresponds to the last interglacial (MIS 5e, ca. 125–75 ka), not the Holocene, and the 3.5 m of Lambeck (1996) is a modelled prediction centred on ca. 6 ka, not a dated index point for the 2nd millennium BCE — by which time relative sea level in the southern Gulf was in any case already falling. Our reconstruction is consistent with this: the inland Bronze Age shoreline reflects a highstand within the published range acting on a land surface then standing lower than today and referenced to high water rather than to mean sea level.

The vertical crustal behaviour of the margin is directly relevant, but must be characterised carefully. Wood et al. (2012), working between Al Jubail and Dubai, reconstruct a two-stage history from dated palaeo-dunes (43–53 ka), marine terraces (17–30 ka) and palaeo-shorelines (3.3–5.5 ka): rapid subsidence exceeding 1 mm/a followed by uplift of up to 6 mm/a decreasing through time. The Holocene shorelines within our window belong to the later, uplift-dominated phase, not the earlier subsidence. This carries a specific consequence, contrary to earlier interpretations of these sites: sustained uplift produces a relative fall and a seaward regression, not a transgression, so tectonic uplift cannot be invoked as the driver of the marine incursions recorded at Al-Qusais and Al-Soufouh, and any such attribution should be set aside.

The deeper relevance of Wood et al. (2012) lies in their central conclusion: dating across different timescales points to rapid change in surface elevation, rather than sea-level change, as the origin of many coastal features. That is precisely the framework adopted here — the inland Bronze Age shoreline is explained principally by the lower elevation of the contemporaneous land surface (through unfilled accommodation space, aggradation, or crustal movement) and only secondarily by the modest highstand. Their rates are high relative to most regional estimates and their proposed mechanism (hinge-line migration of the Arabian plate or Hormuz salt mobilisation) remains unresolved, so the reference is used as one constraint among several rather than the sole basis for interpretation. Other authors place the Gulf level in the Umm Al Quwain area only 1.2 m above present for the 2nd millennium BC (Bernier et al., 1995), fully compatible with the framework adopted here.

Maps estimating the position of the coastline have been compared with sites from the Umm an-Nar period (Al-Soufouh, ca. 2700–2000 BC), Wadi Suq (Al-Qusais, 2000–1000 BC) and with Islamic sites (Jumeirah, 1000 AD). It is observed that the coastal position for the Islamic period would fit very well with the location of Jumeirah in a small khor (intertidal channel) that would have been receding towards the present-day coast.

In the case of Al Soufouh, the coastal position for the 3rd millennium BC (Alsharhan & Kendall, 2019) aligns perfectly with the existence of the site. It would be located near the coast, although surrounded by shallow waters interconnected with a surface sediment bar parallel to the current coastline. By the 2nd millennium BC, Al-Soufouh would appear to in the very vincinity of surface waters, sourrounded by sea, what is also noticeable when observing Al-Soufouh in an aerial photograph, as a ridge in the southeast, indicative of a higher topographic position.

In the case of Al-Qusais, the site could correlate perfectly with the shoreline and Mangroves position for the 2nd and 1st millenia BC, and somehow with the 1st to 0 millenia BC period. Only 700 meters would be the distance separation from Al-Qusais necropolis and the shoreline, while the mangrove area would be inserted in the settlement and in the northern analyzed trench. This position could allow Al-Qusais settlers to rely on marine water and food resources, as also relying on the mangrove fauna for feeding purposes.

The coastline would have allowed for the development of ancient populations that today would be several kilometers from the sea (Cerro Linares, 1999). Some human occupations in the emirate of Umm Al-Quwain, predating the Bronze Age, already show traces of cultural adaptation to the changing environments of the past (Boucharlat et al., 1991). The Ubaid site in Saudi Arabia has been described as intimately associated with the paleogeographic environment in which it was situated, which is no longer the same today (McClure & Al-Shaikh, 1993). In fact, recent research suggests that human occupations in the Arabian-Persian Gulf may have survived hyper-arid periods thanks to the “refuge” offered by the coast and its changing margins (Rose, 2010).

The “Arabian Seashores” project explored the Omani coast, discovering that a large number of Paleolithic, Neolithic, and Early Bronze Age archaeological sites were associated with regional coastal evolution (Charpentier et al., 2023).

The 2nd–1st millennium coastline is therefore identified both above the present sea level and, necessarily, near Al-Qusais: a population such as the one buried in the necropolis would have required proximity to natural resources, so the very existence of the site can be treated as a further proxy for sea-level position. This estimated coastline agrees not only with regional research but also with the other analyses carried out in this study.

Sedimentological analyses north of the modern Al-Qusais cemetery reveal a sequence of marine transgressions followed by progressive aridification, with environments evolving from shallow marine and mangrove systems to aeolian conditions. Up to three inland marine incursions have been identified, one of which (ca. 65–55 cm depth) correlates with the sabkha level where the necropolis tombs were excavated (Valente et al., 2023). Stratigraphic comparison between the trench and the necropolis indicates consistent depositional patterns, including comparable layer thicknesses and aeolian influence, supporting a direct correlation between sedimentary and archaeological units.

These results suggest that human occupation occurred during a phase of increasing aridity, while coastal environments remained in close proximity, with the shoreline likely located near the northern sector of the cemetery. Regional palaeoclimatic records indicate wetter conditions between ca. 5.0 and 3.8 ka BP, followed by progressive aridification with intermittent humid phases (Fleitmann et al., 2003, 2007b; Berger et al., 2013), consistent with the sedimentary evidence.

Comparable sequences identified near Al-Soufouh show mangrove environments during the mid-Holocene followed by marine transgressions (Zander & Brückner, 2005), although local variability is suggested by the absence of mangrove indicators in later periods (Driesch et al., 2006). The presence of Anodontia edentula and Terebralia palustris, both associated with mangrove ecosystems, in the Al-Qusais trench and surrounding areas further supports these environmental reconstructions. While some fossil shells are attributed to sediment disturbance, the prevalence of anthropogenically modified specimens indicates human exploitation. The absence of Terebralia palustris along the modern UAE coastline reinforces a non-modern origin for these assemblages.

Geomorphological mapping has helped reconstruct past coastal positions. Although the exact age of photointerpreted sediments from 1965 imagery is uncertain, many are likely near-surface deposits from the 3rd–1st millennia BC. The presence of marine sediments and intertidal morphologies in areas where 2nd millennium BC coastlines were estimated suggests marine transgressions contemporaneous with the occupation of Al-Qusais. Mapping also confirms widespread transgressions along Dubai Creek and the coastline toward Sharjah, indicating that the necropolis was located within a marine-influenced environment, such as mangroves or intertidal plains. At Al-Soufouh, a coastal ridge on an elevated platform was identified, whereas Jumeirah shows intertidal channels but no clear shoreline indicators.

The most significant shortcoming was the absence of absolute dating. Sampling at the Al-Qusais north trench was constrained by the COVID-19 lockdown, and no radiocarbon or OSL ages were obtained from either trench, so chronological control rested on relative correlation with the dated necropolis sequence. Although standard, this propagates into the reconstruction: the aggradation term depends on assigning a specific sediment thickness (0.75 m at Al-Soufouh, 0.49 m at Al-Qusais) to the interval since the occupation horizon, which cannot be verified without direct dating. Because these thicknesses are modest, the vertical model rests proportionally more on the sea-level term, making it sensitive to the choice among divergent published highstand estimates. Obtaining radiocarbon or OSL ages from both sections is consequently the single most important priority for future work.

Topographic uncertainty arose from the use of a low-resolution DEM (GMTED, 250 m), selected to avoid distortions introduced by urban features but reducing elevation accuracy, particularly at Al-Soufouh where the site occupies a subtle topographic rise. The aggradation correction was derived from two point measurements and is assumed to apply across the coastal plain; in reality, sediment accumulation would have varied spatially, and the resulting shoreline positions carry a corresponding lateral uncertainty that is not quantified here.

The tidal correction introduced a further uncertainty. Present-day tidal ranges are used as a proxy for Bronze Age conditions, but tidal amplitude in a semi-enclosed basin is a function of its geometry, and the configuration of the Gulf during the mid-Holocene highstand differed from the present one; palaeotidal modelling for the Gulf remained limited. The assignment of individual mapped units to intertidal rather than subtidal categories rested on photointerpretation and on the sedimentary facies recorded in the two trenches, and has not been verified by systematic facies analysis across the mapped area.

Finally, published sea-level estimates vary considerably (~1.2–5 m above present for the mid-Holocene), partly because they are not always referred to the same datum and partly because several derive from storm berms rather than mean sea-level indicators. Following recent syntheses (Lokier et al., 2015; Mauz et al., 2022; Parker et al., 2020), an RSL of +2 to +2.75 m was adopted, with the remaining vertical difference attributed to terrain aggradation, tidal range and crustal movement (Section 2.2.3). Table 2 should be read with this distinction in mind, and entries flagged as storm-berm indicators should not be read as records of mean sea level.

5. Conclusion

Geographic Information Systems (GIS) have proven to be a key tool for conducting paleoenvironmental reconstructions. Determining past sea-level elevations presents significant limitations if they are not expressed in terms of shoreline position on the landscape. GIS enables geological variables, faunal data, and archaeological records to converge in order to address questions about the past.

This research has demonstrated that the apparent disconnection of the Al-Qusais site from natural resources was not permanent in the past.

Sedimentary deposits analyzed from trench sections located north of the modern Al-Qusais cemetery suggest the occurrence of between two and three marine transgressions (shoreline advances) of shallow waters, which were subsequently replaced by mangrove and marsh ecosystems, and later by arid aeolian conditions. One of the mangrove and marsh ecosystems identified in the northern area may have been contemporaneous with human activity during the Wadi Suq period (2000–1500 BC). Sedimentary analysis from Al-Soufouh likewise indicates the presence of a recent arid phase and multiple marine transgressions associated with mangrove environments.

GIS-based reconstruction indicated that during the 2nd millennium BC the Al-Qusais site would have lain approximately 700 m from the contemporaneous shoreline and been integrated within a mangrove–marsh ecosystem, with geomorphological evidence placing intertidal flats or channels within a few hundred metres of the site. This proximity does not require an anomalously high mean sea level. It follows from a relative sea-level highstand of approximately +2 to +2.75 m, within the range of published index points for the southern Gulf, acting on a land surface then standing some 0.5–0.75 m lower than today owing to subsequent sediment aggradation, in an intertidal setting referenced to high water rather than to mean sea level. On a surface of gradient 1:1000 or lower, these values were sufficient to displace the shoreline several kilometres inland. The apparent isolation of these sites is thus a product of coastal progradation, infilling and sea-level fall acting together.

At Al-Soufouh, during the period between 4000 and 3000 BC, conditions appear to correlate with a marine transgression that would have surrounded the site, effectively forming an island, and coinciding with a geomorphological ridge of possible marine origin. The Jumeirah site, in turn, would have been situated closer to the shoreline due to the presence of a possible khor (a small marine inlet) that may have existed in the area.

Available archaeological documentation from Al-Qusais indicated that settlement remains identified during excavation campaigns in the 1970s (now lost) would have been located even closer to the coastline.

All findings from this research suggested that coastal sites in the Emirate of Dubai followed the evolution of the shoreline, emerging during periods of marine transgression when the coastline was located near their relative position. This would have enabled a reliance on marine resources, consistent with other prehistoric sites in southeastern Arabia.

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