

Environmental Urban Plan for Failaka Island, Kuwait: a Study in Urban Geomorphology

Ahmed Hassan^{1*}, Muhammad G Almatar², Magdy Torab³, Casey D Allen⁴

¹ Ph.D. Geomorphology, Nickname (Ahmed El-kasaby), Ministry of Education, **Kuwait**.

 : [0000-0001-6157-4284](https://orcid.org/0000-0001-6157-4284), ameh812000@gmail.com

² GIS and Urban Planning, Department of Geography, College of Social Sciences, Kuwait University, **Kuwait**, muhammad.almatar@ku.edu.kw.

³ Prof of Geomorphology, Department of Geography, Damanhur University, **Egypt**,

 : [0000-0002-2315-5158](https://orcid.org/0000-0002-2315-5158), magdytorab@hotmail.com

⁴ The University of the West Indies, Faculty of Science and Technology, Department of Biological and Chemical Sciences, **Barbados**.  : [0000-0002-2364-9051](https://orcid.org/0000-0002-2364-9051) caseallen@gmail.com

* Corresponding author: ameh812000@gmail.com

ABSTRACT

Failaka Island, located in the far east of Kuwait Bay, is about 20 km from the State of Kuwait's coast, and represents a focal point for regional geography and history, with pristine beaches and archaeological sites dating to the Bronze, Iron, Hellenistic, Christian and Islamic periods. According to environmental data and in coordination with local authorities to develop an urban plan, the island is set to become the first tourist destination for the State of Kuwait. To achieve the Vision of Kuwait 2035, one of the planning objectives focuses around Urban Planning for the Establishment of Environmental Cities that Achieve (UPEECA) environmental sustainability criteria. The paper then, aims to propose the environmental urban plan for Failaka Island. Based around Environmental Analytical Hierarchical Processes (EAHP), and using the Field Calculator and ModelBuilder functions in ArcGIS, this research centres on the feasibility of carrying out an urban plan using suitability modelling that includes four factors and 13 criteria covering the island's ecological and human composition. This study utilizes both remote sensing (UAVs for 3D imaging) and field study (ground truthing) to identify changes in land use and land cover – such as using sample analysis of the historical sites and soils for tracing evidence and creating/updating a soil map – and create the first GIS database for the island that can lead to generating a suitability model.

KEYWORDS: *Urban Geomorphology, geoarchaeology, suitability Model-GIS, Environmental Analytical Hierarchical process (EAHP), Failaka Island.*

1. Introduction

Global urban population exceeded the rural population for the first time in human history in 2007. Since then, the proportion of people living in urban areas has continued growing and it is expected that by 2050 almost two-thirds of the global population will be urban (UNDESA, 2014). Accordingly, researchers in all fields related to sustainable development – including geoheritage and urban geomorphology – should strive for urban planning based on assessment of environmental potentials that include on-site assessment and land-use suitability analyses, with the aim of identifying the most appropriate spatial pattern for the future land use in order to achieve a sense of sustainable development. In recent years, land-use suitability analysis has been applied to the assessment of agricultural land (Feizizadeh and Blaschke, 2013), determination of land habitats for animal and plant species (Store and Kangas, 2001), landscape evaluation and planning (Girvetz et al., 2008), and regional planning and environmental impact assessment (Marull et al., 2007; Rojas et al., 2013). Carr and Zwick (2005) also employed suitability modelling to identify potential future land use conflicts in North Central Florida.

While suitability analysis focuses on the process and procedures used to establish the suitability of a system according to the needs of a stakeholder (Parry, 2018), in most lesser-developed countries, people often construct residential buildings without considering resources for the new residential areas. Therefore, it becomes the government's problem to provide the required resources for these areas. Occasionally, some countries adopt urban planning strategies that are incompatible with the environment and increase environmental problems that make life difficult for the population.

Site suitability analysis is the process of determining the fitness of a given tract of land for a defined use (Steiner et al., 2000), and to find a suitable site for construction of an amenity or urban area, sophisticated analyses are required that take into account critical components such as technical, environmental, physical, social, and economic factors. Tools for identification, comparison, and analysing multi-criterion decisions for an urban site development require proper planning and management, and often incorporate vital geospatial tools such as remote sensing, GIS, GPS, and AHP (Shukla et al, 2017; Sandipan et al, 2013). Based on these facets, this study suggests building Environmental Analytical Hierarchical process (EAHP), centred around an integrated technique of the AHP and GIS, to support the

assessment and the selection of suitable areas for urban development on Failaka Island in the state of Kuwait.

2. Study Site

The second-largest Kuwaiti island after Boubyan island, Failaka Island is located 20 kilometres off the Kuwait coast between 29°23' and 29°28'16 North and 48°16' and 48°24'10 East, with a size approximately 13.8 kilometres long and varying from 1.8 to 6.5 kilometres in width, creating an area of approximately 46.36 square kilometres (Fig. 1; [worldview 2- 50 cm, 2018; Esri, World Imagery, 2020](#)). Triangular-shaped, its base in the west and its head in the southeast, Failaka Island remains relatively flat apart from a small hill approximately nine-meters high on its western side ([Almatar et al., 2020; Mohamed, 1997](#)).

A focal point of the geography and history for Kuwait, Failaka Island offers unspoiled beaches and archaeological sites dating back to the Bronze, Hellenistic, Christian and Islamic periods. Although the first population figure recorded for Failaka's was in 1839 (150 inhabitants), it represents the only island off Kuwait's coast that has been known to host a population for thousands of years, even increasing during the twentieth century: from 1500 to 2447 to 5832 inhabitants in 1930, 1957, and 1985, respectively ([Ministry of Planning, 1985](#)). Failaka Island is considered a unique urban case study, as it has had no occupation, and therefore no urbanization, since 1990 when the Iraqi army displaced its residents by forcing them to leave the island. After Kuwait's liberation, the population did not return to the island, and it has been abandoned since that time ([Mostafa, 1988; Ministry of Planning, 1985; Al-Zaher & Aziz, 2004](#)).

Based on Failaka Island's regional significance, the State of Kuwait seeks to establish a development plan for the Island. The current circumstances allow the State and other decision-makers an opportunity to implement potential mitigation and planning strategies for the island before its reconstruction, taking into account analyses from specialists in environmental planning, as well as incorporating both human and physical characteristics (e.g., geomorphology, geoarchaeology, soils, coastline types, etc.)

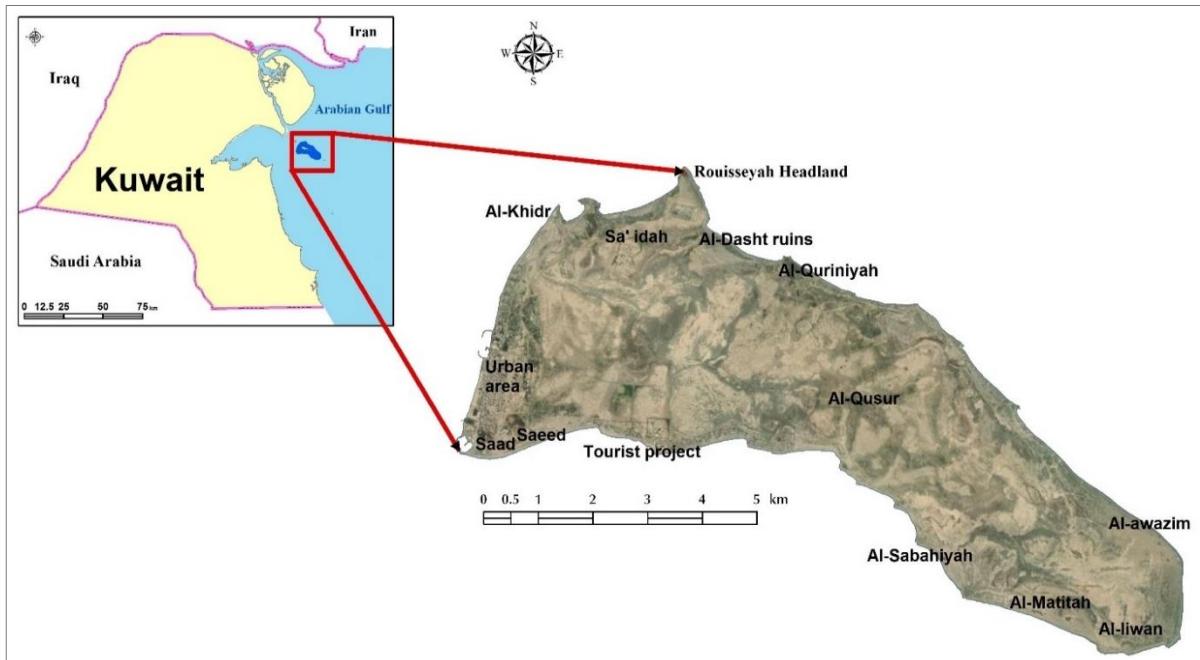


Figure 1. Location of the study area, Source: Esri, World Imagery, 2020.

To achieve these goals, the government of Kuwait has embarked on implementation of several development plans, each of which aims to turn the island into a major tourist destination. Previous plans focused on various development issues such as a tourist attraction center, residential development projects, and urban infrastructure development. In this context, several types of State plans appeared over the past several decades (e.g., [Saba Shiber, 1964](#); [Buchanan Institute Plan, 1971](#); [The Municipality Plan, 1973](#); [Dabbous Engineering Consulting Plan, 2001](#); [National physical plan strategy 2005-2030](#)), as well as plans conducted by researchers with individual efforts and different scientific backgrounds (e.g., [Al-Sarawi et al, 1996](#); [Al-zaher and Aziz, 2004](#)). While each of these previous studies included specific criteria, none integrate them in a significant way, leading to an incomplete assessment of the Island. To remedy these deficiencies, this study proposes a method for environmental planning of Failaka Island by using the ***Environmental Analytical Hierarchical process (EAHP)*** method, incorporated into a geographic information system (GIS), for assessment of multiple factors, including scoring-based scientific literature and local knowledge applied to Multi-Criteria Decision Analysis (MCDA).

3. Materials and Methods

Computer modelling has become one of the most important tools in the field of land use and land cover, as GIS and remote sensing are utilized with increasing frequency to investigate landscape changes such as urban expansion (Herlod et al., 2005). The availability of advanced computer software and tremendous amounts of spatial data encourages GIScientists and remote sensing specialists to implement such technology in modelling land use and land cover classes, and can be a valuable tool for sustainable planning and evaluating social and environmental consequences of landscape fragmentation (Cabral and Zamyatin, 2006; Brown et al., 2002; Henriquez et al., 2006).

Moreover, by implementing models, analyst is provided with information explaining the relationship between one or more factors perhaps associated with a response or the causation of the response. Models then, can be utilized for studying relationships and interactions amongst system elements and for creating testable hypotheses and predictions regarding patterns and mechanisms (Fragkias and Seto, 2007).

Cartographic models are usually analysed to identify suitable locations based on a set of criteria determined by analysts, such as suitability models – initially specified in qualitative conditions such as high, medium, and low – but the actual set of criteria is generated according to quantitative measurements required for the ranking process, with the overall suitability ranking process is generated based on the importance of different classes of criteria (Blostad, 2016). For example, Carr and Zeick (2005) ranked suitability using values ranging from 1 to 9 for each single suitability layer, where 1 presents the lowest suitability and 9 identifies the highest suitability. These layers were then combined based on land use categories into three main suitability criteria: high, moderate, and low.

The next step of the suitability modelling process, and another example of a cartographic model, is what Blostad (2016) calls *weighting among criteria*. This process's final step allows for combining all suitability layers into one single layer that determines the best locations. Blostad (2016) stated that assigning suitability which depends on non-quantifiable measures is usually difficult, and the process is easier when the importance of the diverse criteria is expressed on a common scale (e.g., 1 to 9 or 1 to 5). Still, there are different kinds of weighting processes that can be use in suitability models to generate the final output. For example, Carr and Zeick (2005) used a pairwise comparison methodology called *Analytic Hierarchy Process* (AHP) to determine the weight of the layers to produce the final suitability. Similarly, Blostad

(2016) utilized a weighting process called *importance ranking* to assign the weights for slope effects, soil types, and noises cost in his use of a suitability model to determine the best location for home constriction. In the context of Failaka Island, to perform a multi-criteria suitability analysis for the potential environmental urban plan, four main steps must be included: identifying siting criteria, data preparation, developing a composite suitability index, and selecting suitable site (Fig. 2).

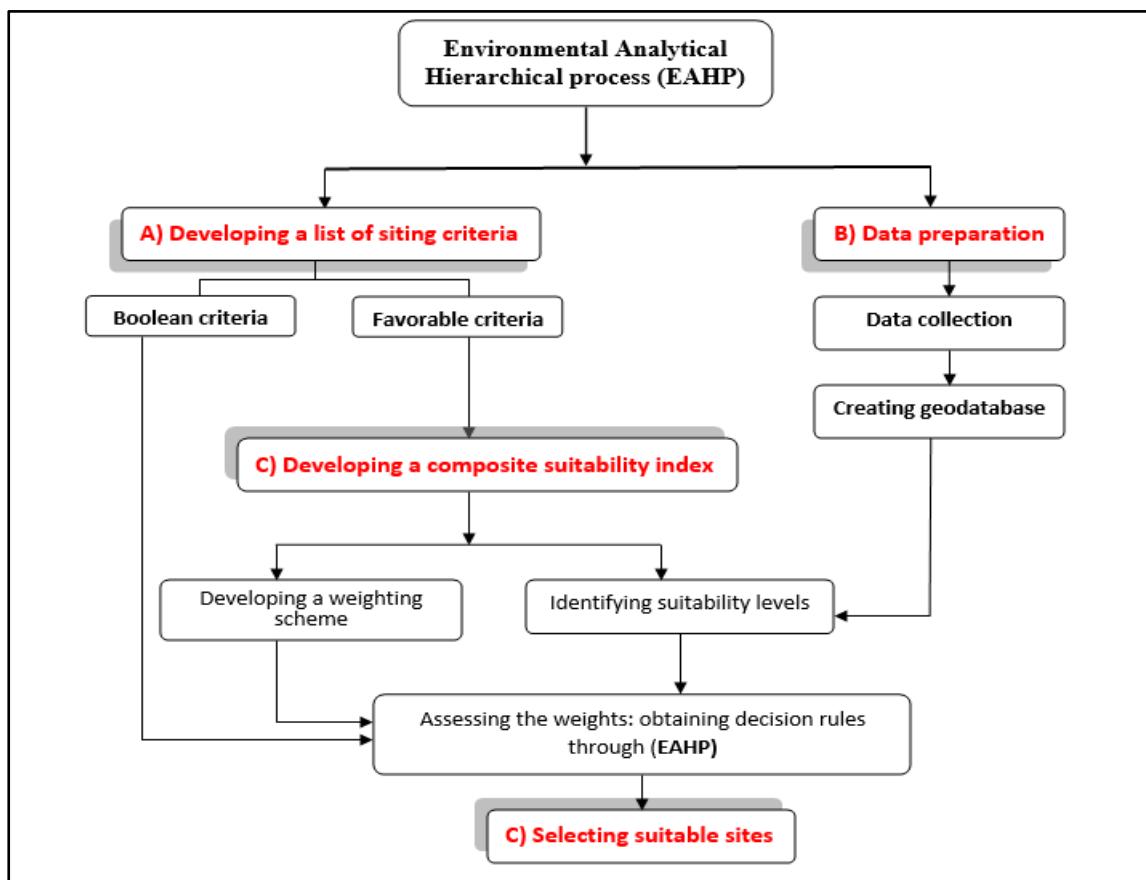


Figure 2. Environmental Analytical Hierarchical process (EAHP) Framework. The four steps involved in calculating the (EAHP) are denoted by letters A, B, C, D.

3.1 Identifying site criteria

Criteria of land-use suitability for urban development are derived from multi-disciplinary scientific theories related to physical, socio-economical, and ecological attributes (Liu et al, 2014). Often, the planners and decision makers use only socio-economic parameters in urban planning, and rarely consider environmental aspects. The criteria in figure 2 can be classified into two main categories: Boolean (exclusionary) and favorable criteria (inclusionary). While Boolean criteria assist in identifying suitability for

a particular purpose in a binary manner, favorable criteria reveal this suitability in gradual levels (Mierzwiak and Calka, 2017; Hassaan, 2020).

3.2 Data preparation

Data preparation represents the first fundamental step in land suitability analysis (Bakhtiar & Thomas, 2013). Upon identifying analysis criteria, datasets of various indicators were collected. These datasets included:

- **Digital Elevation Model** (DEM) from an aerial survey with a spatial resolution of 25 cm, including several topographical analyses such as slope, aspect, and creation of a contour map (Kuwait municipality, 2004).
- **Geomorphological map**, derived from various sources (i.e., satellite imagery such as [Worldview 2-50cm 2010](#) and [worldview2-50cm 2018](#), [Google Earth](#), field study (ground truthing), and aerial photography by a Mavic2 pro UAV).
- **Soil analysis** – including pH, cations, and anions – for 34 samples covering most parts of the island, leading to an updated soil map for the island, and analyses in the Faculty of Science Laboratory, at Alexandria University (Egypt).
- **Coastline types** (as a shapefile, from [Almatar et al. \(2020\)](#)).
- **Land use/land cover**. This represents perhaps the most important dataset for urban and environmental planning, and the most fundamental data of the evaluation model for urban development suitability. It can be derived from multiple sources (e.g., satellite imagery from [Worldview2-50cm 2010](#) and [2018](#), [Google Earth](#), field study (ground truthing), and imagery from [Mavic2 Pro UAV](#)). To obtain data on the history of urbanization on the island in the past century, the study relied on several historical maps from Mohamed (1997 and 2006).
- A 1:50,000 scale **geological map** ([KOC, 1980](#)).
- **Cost-effectiveness criteria**. One of the most important criteria for saving expenses and maintaining the environment with the lowest potential so the island does not lose its distinctive environmental character because of human-caused environmental changes. The island was divided into four sectors from west to east, with sector 1 being closest to the port, and sector 4 being the farthest, the aim being to focus urbanization on the western half of the island.
- **Land availability criteria**. In order to protect archaeological areas and urban areas from human and natural hazards, criteria are selected that provide an urban plan to help preserve historical monuments of the island – especially since the island has several

important archaeological sites dating back more than 5,000 years ago (Al-Duwaysh, 2015; El-Baz and Al-Sarawi, 2000). For archaeological areas, the island was divided into four archaeological categories (see *Land Availability*, number 9, Table 1). With regard to the natural hazards, Almatar et al. (2020) provided a map of the areas exposed to the danger of sea level rise and sabkhas. This also divided the island into four sectors (*Land Availability*, number 10, Table 1).

- **Socio-economic** criteria are divided into two overarching layers: *distance from the main town* and the *productive capacity of the land*. Firstly, the island was again divided into four sectors. Secondly, 34 soil samples were analyzed and compared with the results of a study conducted by Abbadi and El-Sheikh (2002). Furthermore, for understanding soil and land use planning in terms of sustainable development, it was also necessary to define the interactions and competitions which exist between the different uses of soil and land (Blum, 2013).

The collected datasets were integrated into a geodatabase, including many vector feature classes such as land use highlighting various human activities, as well as the geomorphological map, soil type, and archaeological/historical sites. These vector layers were subsequently employed to create several raster surfaces for further analyses.

3.3 Developing a composite suitability index

For the purpose of this study, a composite suitability index was developed considering four factors reflecting the four favorable analysis criteria (Table 1). Establishing the weighting matrix on the other hand, depended on 13 criteria, with higher values of environmental factors given overarching landform features, such as geomorphology, coastline type, and geology (15, 15, and 10, respectively). The relative weighted values of each factor and criteria were then discussed and reviewed by both the authors and experts from different disciplines in the Earth and geosciences (see Table 1 for full discussion).

Table 1: List of criteria and relevant indicators

| Factors | Weight % | Criteria | Weight % | Rank | | | |
|--------------------|----------|---|----------|---------------------------|---------------------|--------------------|------------------|
| | | | | 9 | 6 | 3 | 0 |
| | | | | High | Moderate | Low | Unsuitable |
| Environmental | 60 | 1. Elevation (M) | 8 | 10 – 7.5 | 7.4 – 5 | 4.9-2.5 | 2.4-0 |
| | | 2. Geomorphology | 15 | Old urban | Flat dry land | Sabkhas | Archaeology site |
| | | 3. Soil PH | 8 | 8.43 – 8.87 | 8.19 – 8.42 | 8 – 8.18 | 7 – 7.9 |
| | | 4. Coastline type | 15 | Sandy | Sandy rocky | Muddy & gravelly | Rocky |
| | | 5. Geology | 10 | Cemented coastal deposits | Strand line deposit | Dipdipah formation | Sabkhas deposits |
| | | 6. Slope | 4 | 0.93 – 2.57 | 0.46 – 0.92 | 0.2 – 0.45 | 0 -.19 |
| Cost-effectiveness | 15 | 7. Distance to port | 8 | Very near (west) | Near | Middle | Far (East) |
| | | 8. Distance to water and energy line | 7 | Very near (west) | Near | Middle | Far (East) |
| Land Availability | 10 | 9. Archaeological area | 6 | Rest of land | - | buffer zone 400M | Sites |
| | | 10. Natural hazard | 4 | Zone 1 (6-10M) | Zone 2 (3-6M) | - | Zone 3 (0-3M) |
| Socio-economic | 15 | 11. Land use | 10 | Urban area | Non- urban | Salt deposits | Archaeology site |
| | | 12. Distance from main town | 2 | Zone 1 | Zone 2 | Zone 3 | - |
| | | 13. The productive capacity of the land | 3 | Zone 1 | Zone 2 | Zone 3 | - |

3.4 Selecting suitable sites

Once weighting was applied to the model, a final shape for each criteria and factor classification is the result (Figure 3). Based on these results, and with little modification, the suitability of the 13 criteria for the proposed urban plan was further divided into four types: unsuitable, low, medium, and high.

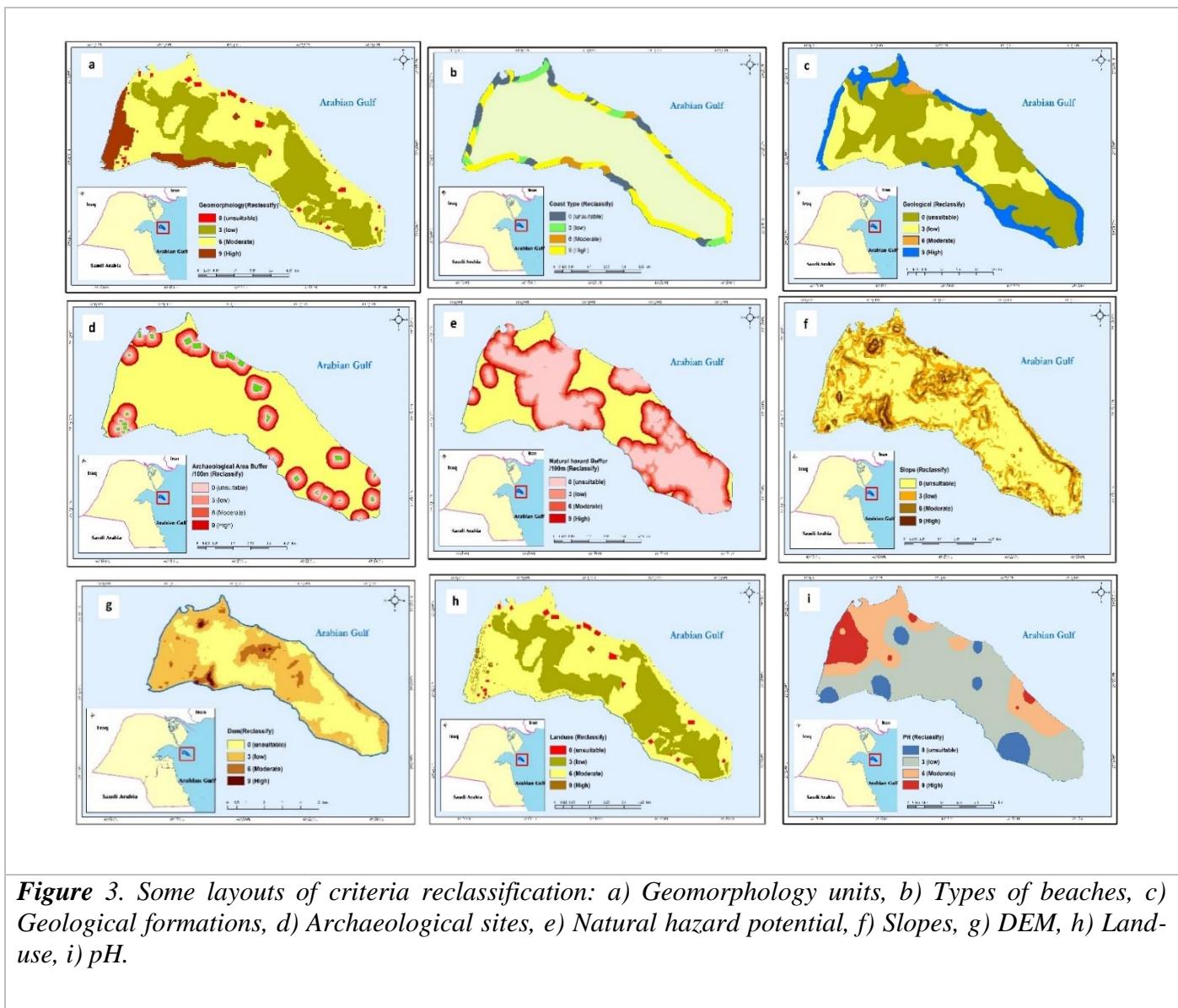


Figure 3. Some layouts of criteria reclassification: a) Geomorphology units, b) Types of beaches, c) Geological formations, d) Archaeological sites, e) Natural hazard potential, f) Slopes, g) DEM, h) Land-use, i) pH.

4. Physical and human geography of Failaka island

Examining the physical and human properties of any location is crucial in understanding ecosystems (Freedman, 2018). In this context, the study of climate, geology, soil, geomorphology, history, and archaeological sites for Failaka Island reveals more of the environmental aspects that characterize the island, which in turn contributes to the development of an urban plan based on environmental *potential*. This potential further contributes to achieving the sustainable development goals (SDGs). Officially known as “Transforming Our World” – the 17 goals set by the United Nations Organization 2015-2016 – the 17 Sustainable Development Goals are included in the 2030 Agenda for Sustainable Development. Especially goals 11, 14, and 15 (UN, <https://www.un.org/sustainabledevelopment/>).

4.1. Climate

The island's climate is hot and arid with moderate winds, and the temperature reaches a maximum of 54.3°C in summer and a minimum of 1.7°C in winter. The average monthly wind speeds on the island range from 3.3-7.3 m/s, while the approximate annual rainfall is 115.4 mm (KMD, 2020; Al-Sarawi et al., 1996). Table 2 displays some climatic characteristics of the study area.

Table 2: Climatic characteristics of Failaka Island 2007-2019

| Month | Temp. Ave. (c) | Temp. Min. (c) | Temp. Max. (c) | Relative humidity ave. (%) | Rainfall amount (mm) | Wind speed ave.(m/s) | Wind speed max. (m/s) | Evaporation ave airport. (mm) |
|-------|----------------|----------------|----------------|----------------------------|----------------------|-----------------------|-----------------------|-------------------------------|
| JAN | 13.5 | 4.6 | 21.7 | 68.4 | 14.9 | 4.6 | 19.1 | 5.4 |
| FEB | 15.9 | 6.5 | 25.4 | 63.3 | 11.9 | 4.8 | 19.9 | 7.2 |
| MAR | 20.4 | 11.1 | 31.7 | 54.7 | 14.3 | 4.8 | 20.8 | 9.8 |
| APR | 25.3 | 15.7 | 37.5 | 49.7 | 6.2 | 4.6 | 24 | 12 |
| MAY | 31.4 | 21.5 | 44.2 | 42 | 5.6 | 4.6 | 20.5 | 15.3 |
| JUN | 35.5 | 25.8 | 48.1 | 30.2 | 0 | 5.7 | 19.1 | 17.8 |
| JUL | 36.7 | 27.4 | 49.2 | 34.5 | 0 | 5.2 | 17.5 | 17.5 |
| AUG | 36.3 | 27.5 | 47.8 | 41.9 | 0 | 4.6 | 15.7 | 16.4 |
| SEP | 33.7 | 23.5 | 45.6 | 42.7 | 0.2 | 4.4 | 16.2 | 14.7 |
| OCT | 28.5 | 18.5 | 41.1 | 52.6 | 10.8 | 4.3 | 19.7 | 11 |
| NOV | 20.9 | 11.7 | 31.1 | 60.6 | 45 | 4.6 | 18.9 | 6.7 |
| DEC | 15.5 | 7 | 24.4 | 66.2 | 16.2 | 4.6 | 17 | 5.2 |

Source: Kuwait Metrological Department (KMD), 2020. All data from Failaka Island Station except evaporation from Kuwait Airport Station.

4.2. Geology

The geological map represents a very important tool for urban planning and, accordingly, understanding geological formations represents an important component for any urban development project. Fortunately, Failaka Island's geological formations are straightforward (Austria, 1968; Mostafa, 1988), and divided into four categories:

- **Cemented coastal deposits or oolitic complexes.** An oolitic complex is a series of part marine and part aeolian ridges. These ridges formed alongside Failaka's barrier beaches and coastal dunes, which are separated from the Gulf by coastal lagoons and sabkhas. Likely deposited during high water stands, they consist of oolitic sand, sandstone, and limestone. The area of this formation is 6.9 km², which constitutes 14.88% of the island's total area.
- **Dibdibah formations.** The area of this formation is 18.81 km², representing 40.57% of the island's total area. These formations belong to the Pleistocene Epoch and appear as coarse-grained, pebbly sand with thin intercalation of clayey

sand and clay. These sediments are sometimes combined with calcium carbonate and gypsum, producing conglomerates.

- **Sabkha deposits.** Most of these coastal mudflats are widespread on the island, and their surface levels vary between 0 and 3 meters in height but are extremely flat and usually barren of any vegetation (Picha & Saleh, 1977). This type of sediment is usually under the constant influence of saline groundwater and susceptible to floods at certain times, often leaving deposits of various evaporite minerals. The sabkha deposits cover an area of 20.1 km², and constitute 43.35% of the total area of the island (WorldView 2 -50 cm, 2018).
- **Strand line deposits:** These shell-sand and shingle sites appear on the coast in the form of beach gravel and minor unconsolidated beach sand. This geological formation covers the lowest area and percentage (0.55 km² and 1.17%, respectively), perhaps due to the formation of these sediments on the northern coast of the island, where strong sedimentation streams that formed during rainy periods of the Pleistocene Epoch were washed away by the currents from the Shat al-Arab region when it collided with the Headland of Rousseyah (KOC, 1980).

4.3. Soil

Soils are a potential source of much information in urban planning studies across scales, from specific archaeological sites to broad regional assessments. Applications of soils in the study of the human past include soil geomorphology, the geoarchaeological principles of site formation processes, and the identification of human impacts (Holliday, 2004). Soil surveys are a useful tool for interpreting landscapes, but with the caveat that they were designed for modern planning and land-use studies. Soils are also an integral component of stratigraphic studies at archaeological sites. Owing to these complexities, it was necessary to compare the soil types of the island with the designated site of the plans (Al-Zaher & Aziz, 2004). This endeavor represented one of the most important criteria of our proposed urban plan, as relying on an updated soil map was key to establishing optimum land use planning efforts.

The soil map was prepared based on 34 samples collected in the winter of 2018 covering most parts of the island (Figure 4). Soil study relied on analyses of such criteria as pH, SAR, electrical conductivity, cation and anion exchanges and ratios, and CaCO₃ (calcium carbonate), and compared its results with a study by Abbadi and El-Sheikh (2002). Soil production capacity was calculated based on soil pH, and cation and anion exchange capacity.

The results, displayed as green areas in Figure 4, were later excluded as urban areas, and were instead proposed as agricultural areas within the island plan.

Chemical analyses of Failaka Island represent a very important indication of the best arable areas and potential archaeological sites. For example, the detailed role of soil calcium as an important component of identifying food preparation areas of the past, its presence in the ash of burning charcoal, and its high content in teeth and bones, makes its investigation a crucial soil research component needed in archaeology. Middens found *in situ* represent the source for some of the site's bone and ash disposal areas and contain significant amounts of calcium (Vranova et al, 2015). To confirm these previous findings, the results of the soil analysis indicated a rise in calcium in the points numbers 5, 10, 22, 28, and 29, and the values ranged from 75-106.

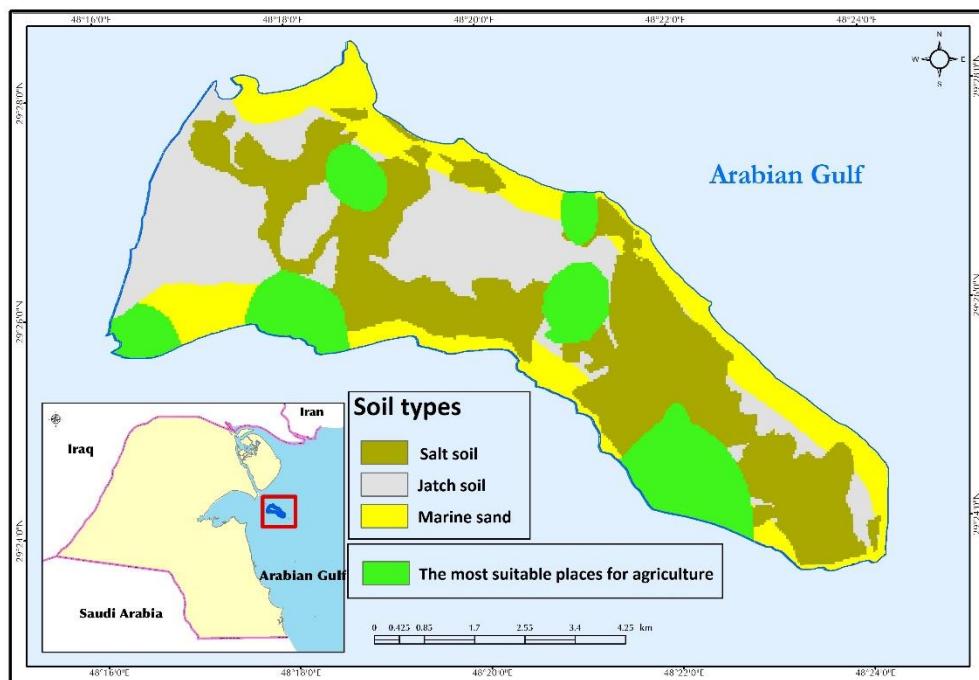


Figure 4. Soil types on Failaka Island and the proposed areas for agriculture

Source: Abbadi & El-Sheikh, 2002 and Al-Zaher & Aziz, 2004, modified for soil analysis samples procured during this study.

4.4. Geomorphology

During the planning of an urban environment, usually only economic and social parameters are considered (Bathrellos et al, 2012). Yet, geomorphology remains an important and effective tool to aid planners and decision-makers in low-cost environmental planning and environmental sustainability. For example, the sabkhas on Failaka Island constitute about 50%

of the landmass, and therefore building a city or extending a road on the sabkhas areas would cost a significant amount. In this case, geomorphology becomes an effective tool to choose the most appropriate and cost-effective route through the sabkhas, as well as the best location for the city.

The study of erosion and sedimentation processes can be related to the rates of change in the beaches. For example, 68% of the coastline of New England and the mid-Atlantic region of the United States has undergone erosion in recent decades for a variety of reasons, but often related to anthropogenic influences (Goudie & Viles, 2016). In contrast, Failaka Island's beaches remain untouched for the past few decades because people have not been allowed to inhabit or visit the island since 1990.



Figure 5. Geomorphology map of Failaka Island. Source: Field study (ground truthing), Worldview 2-50cm-2018, Google Earth 2018, and Mavic2 pro UAV imagery.

Based on these factors then (cf., Bathrellos et al. 2012, Goudie & Viles, 2016), the island can be divided into two types of geomorphological forms: those related to the coastline and those on the landmass proper (Figure 5). The island cannot be planned without taking the coastline type into account, and thus this study also took into consideration shoreline pattern classification along the island's 38.75 km total coastline length.

Coastal landforms can be further classified into two types: erosional landforms and sedimentation landforms (Figure 6). Analysis of satellite images, drone images and field study/ground truthing, reveals five beach types (Figure 5 and Table 3). The classification of beach types remains an essential pillar of the proposed urban development plan, with the island functioning as a tourist destination. Limiting the use of sandy beaches for tourism development areas, therefore, remains an important consideration. As Table 3 demonstrates, half of the island's coasts are sandy beaches, making these areas suitable as urban areas and public beaches.

Geomorphological processes play an important role in balancing the sediment accumulation/loss as well, given that, between 1976 and 2016 the northern beaches *accumulated* sand at 77 cm/year, while southern beaches *eroded* by 78 cm/year (AlSahali & AlMutairi, 2019). Building a city in sand dunes or in areas where some other geomorphic danger such as a foundation being weakened by unstable bedrock, represents a big mistake. Due to this, the study sought to understand the geomorphological characteristics of the island, characterized by four anthropogeomorphological units: depressions (sabkhas), flat drylands, previously-built urban areas, and archaeological sites.

Table 3. Lengths of beach types on Failaka Island

| Type | Length (km) | % |
|-----------------------|-------------|-------|
| Sandy beaches | 19.91 | 51.38 |
| Rocky beaches | 9.6 | 24.75 |
| Shingle & Mud beaches | 3.06 | 7.89 |
| Sandy rocky beaches | 2.3 | 5.96 |
| Cliffs | 2.7 | 6.97 |
| Ports | 1.18 | 3.05 |
| Total | 38.75 | 100 |

Source: (Field study/ground truthing, Worldview 2-50cm-2018, Google Earth 2018, and Mavic2 pro UAV imagery).

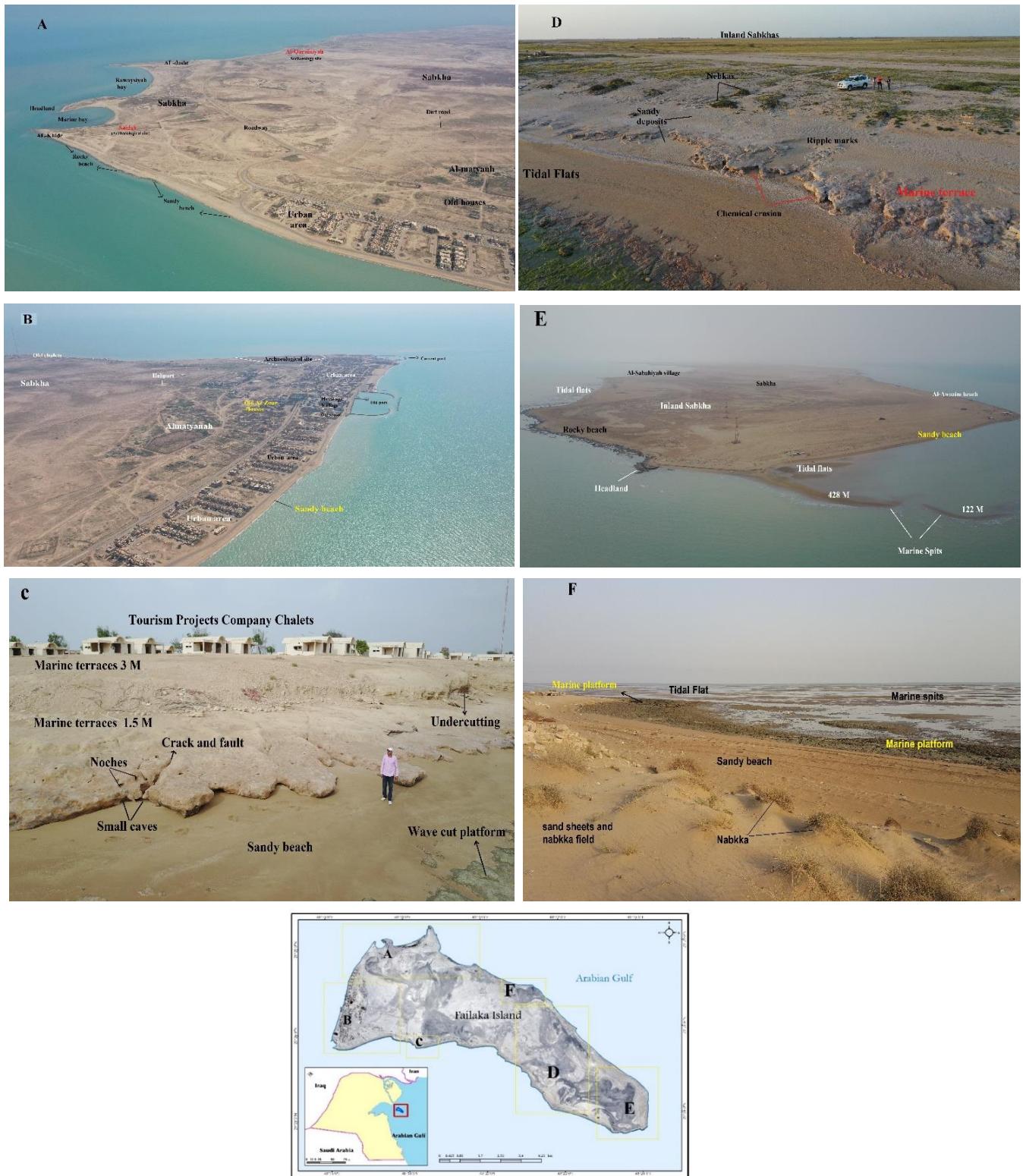


Figure 6. Some of the geomorphological landforms on Failaka island. A) Marine headlands and bays. B) Sandy beaches and urban area. C) Some of the erosion landforms: Marine cliffs and terraces. D) Inland sabkhas, nebkhlas (e.g., coppice dunes), and chemical erosion. E) Marine spits and headlands. F) Sand sheets and coastal sand dunes. Photos captured with Mavic2 pro UAV. A, B, and E from an altitude of 300-456 meters and photos C and D from 52 meters. Photo E was taken from ground level.

4.5. *Historic and archaeological sites*

Failaka Island hosted several factors that made it ideal for the establishment of ancient civilizations: strategic location along trade routes, its suitability as a natural port, and its mediation of other ancient civilizations (Al-Duwaysh, 2015). According to Bibby (1970), the island represents one of the oldest settlements (3000 BC) within marine range of the Arabian Gulf. Bibby also asserts that the island had a distinctive pattern of civilization due to its close contact with neighboring civilizations. Nevertheless, the human settlement of Failaka was not stable throughout history, as it witnessed influxes and exoduses depending on the trade activities in the Arabian Gulf (Mostafa, 1988), as well as periodic epidemics, all of which adversely affected continual habitation on the island. Based on available documents, Failaka civilization can be categorized into three ages: 1) ancient civilization, including the archaeological sites of the Bronze and Iron Age, 2) middle civilizations, represented by the Hellenistic civilization in the southwest of the island, and 3) modern civilizations including Islamic and Christian civilizations (Bibby, 1970; Mostafa, 1988).

The archaeological sites on Failaka Island extend along the shoreline and through the middle of the island (Fig. 7). Most archaeological missions have focused on the southwestern and northwestern parts of the island, and those records support the island's occupation from the late Islamic to the Modern Eras. The Danish archaeological excavations have been operating since 1958, making them the first archaeological excavation in the history of Kuwait (Ashkanani, 2016; Al-matar et al., 2020). Yet, several archaeological sites – such as Al-Dasht, Al-Sabahiyah, Al-Sa'id, Al-Ali, Al-Awazim, and Matitah – have been only surveyed and not studied in any detail. The following sites represent the most important archaeological sites on the island to date.

Al-Khidr. A Bronze Age site, known as the Dilmun-Culture port, located in the northwest of Failaka Island. It was fully excavated in 2004. The survey indicated the presence of numerous sherds, stone structures, metal objects, faunal and floral remains, pearl and fishing hooks, and over 600 Dilmun stamp seals. The site is below a modern Islamic cemetery that stretches along the western shore of the shallow Al-Khidr bay, which served as a port in the past (Benedikova & Barta, 2009; Al-Mutairi, 2017). Today, the Al-Khidr site consists of three visible and two less visible mounds.

The KH-1 mound is a low mound roughly 3 to 3.5 meters above the contemporary seabed of Al-Khidr bay, stretching 150 meters in a north-south direction. It is a sandy dune

with shrubby vegetation. Due to high tides, water erosion (2-4 meters) has influenced/damaged the growth of its vegetation (Benedikova & Barta, 2009).

F3 mound, a Bronze Age mound referenced by the Danish mission in 1958, is known to islanders as Tell Sa'ad. It is roughly 3 meters above sea level. It contains a residential settlement with domestic activities, including archaeological evidence of an elite or temple-like structure, the skeletons of gazelles and goats, 170 round stamp seals, and some kilns for an unknown purpose (Ashkanani, 2016). On the top of this mound, the summerhouse of Ahmad Al-Jaber Al-Sabah, the sheikh of Kuwait, was built during the 1920s (Ashkanani, 2018; Al-Mutairi, 2017).

F5 mound. Also known as Tell Sa'id, it is an Iron Age mound that represents the Seleucid culture, post-Alexander the Great. The site was a subject of the first archaeological mission by the Danes (Fig. 7). It is now understood to be a Hellenistic fortress that consists of multiple residential units, two temples, multiple storage areas, two gates, and a trench. A French archaeological mission has been working on the site since the 1980s (Ashkanani, 2016).

F6 mound, also known as “the palace”, represents a Bronze age mound located near Tell Sa'ad and Tell Sa'id. It is the oldest archaeological site on the island associated with the third Ur dynasty and the Dilmun occupation (~2200 BC). The site consists of a palace-like structure and a Dilmun temple at 4.20 meters above sea level (Ashkanani, 2016).

Al-Qusur. Situated in the middle of the island with elevations ranging from roughly two- to five-meters above sea level and surrounded by sabkhas, Al-Qusur represents the largest archaeological site on Failaka Island, covering roughly 2 x 2.6 kilometres (Pieta at el., 2009). Over one hundred structures have been found by Italian, Slovakian, and French archaeological missions, and include structural foundations of courtyard houses, church buildings, a central building, and an oval building of unknown purpose. The archaeological records support the presence of a Christian community and a monarchy sometime between the 7th to 9th century AD (Almatar et al., 2020; Al-Mutairi, 2017).

The Al-Quraniya mound, located in the west-central part of Failaka Island along the north shore, is roughly 550 meters long and 250 meters wide. With an elevation of roughly 6-8 meters above sea level, Al-Quranyia is one of the highest architectural sites on the island, and it contains an old village with 30 structures, mixed grasses and shrubs, and a deserted modern farm (Shehab et al., 2009). The old village dates to roughly 200-440 years ago, according to the features of the Arabic corner tower, the square courtyard with buildings, the plain and incised pottery, and the glazed ware.

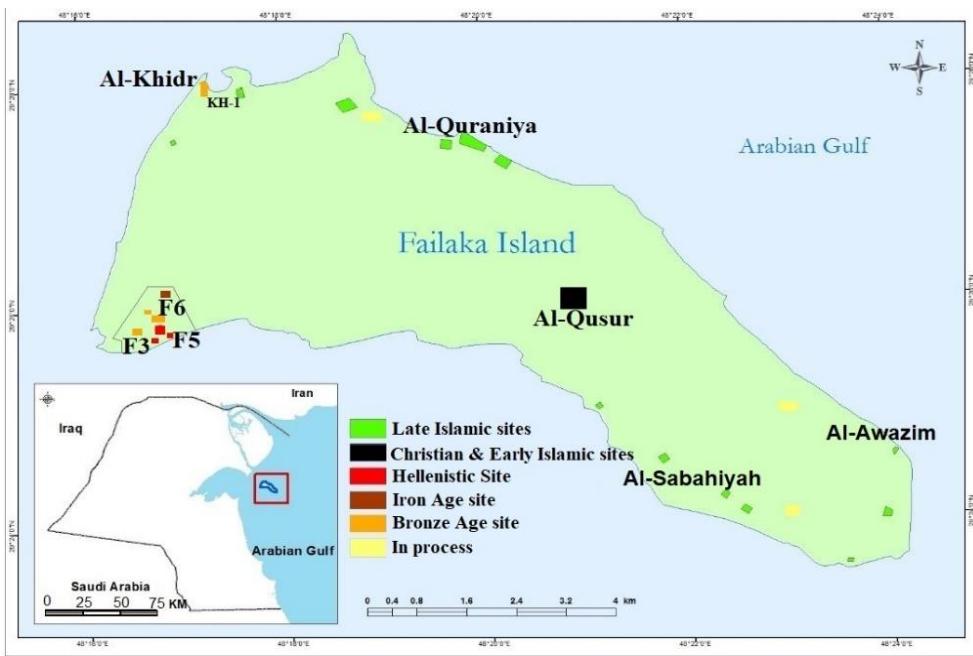


Figure 7. Archaeological sites in Failaka island, Source: (Field study/ground truthing, Worldview 2-50cm -2018, Google Earth 2018, and MavicPro2 UAV imagery).

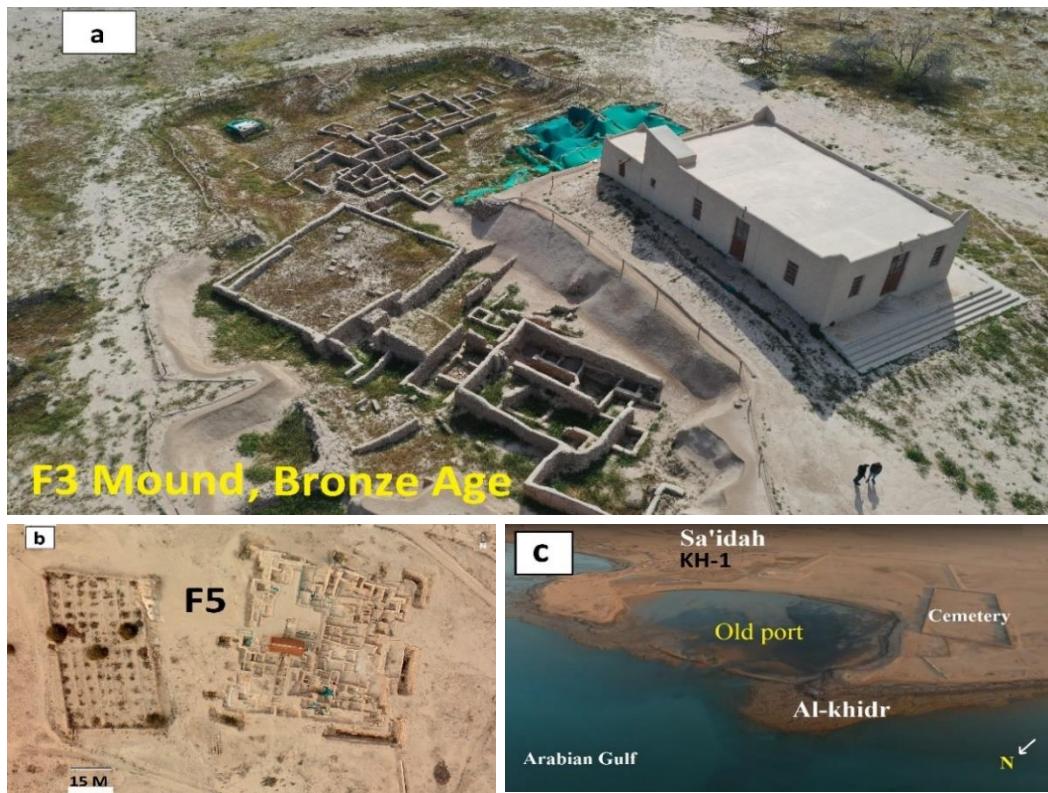


Figure 8. Some of Archaeological sites in Failaka island. a) Oblique photo by UAV, Mavic 2 pro, altitude 41 M, 19 March 2019, b) Mosaic for Hellenistic castle by UAV, Mavic 2 pro, altitude 143 M, 19 November 2019. c) Oblique photo by UAV to Al-khidr, KH-1 and old port.

5. **Results and Discussions**

Failaka Island represents one of the most important heritage areas in the State of Kuwait, and there are plans from the State to construct a nature reserve, a residential area, and a tourist marina (Almatar et al., 2020). Failaka's good environmental condition, freshwater, and fertile soil have contributed to previous initiation of agricultural activities and human settlement as well. Lack of coral reefs on the coastal areas coupled with deep, wide gaps along the coastline have provided for the establishment of several ports on the island in the past (Al-zaher and Aziz, 2004). Many researchers and archaeological missions concluded that Failaka Island was one of the important cultural centers in the Arabian Gulf region, as it has a distinctive cultural character among other places in the region (Mostafa, 1988; Almatar et al., 2020; Al-Mutairi, 2017). The old general plan of Kuwait (see Shiber, 1964) mentioned the possibility of exploiting the island for tourism development, with the aim to make it like the Princess Islands in Turkey, Capri Island in Italy, or the Canary Islands in Spain.

5.1. ***Old urban plans***

On top of socioeconomic characteristics, physical and environmental factors should also play a fundamental role in the site selection of a development plan. Failaka Island, with no exception, has environmental inputs that cannot be ignored in the site selection processes (Al-zaher and Aziz, 2004). While there are multiple other urban plans for Failaka island formulated between 1964 and 2005 (see Fig. 9), many reasons exist that make these plans invalid for implementation. Several examples of why previous urban plans for Failaka Island remain unacceptable include:

- Environmental changes on the island, for instance, an increase in the area of sabkhas and changes in land cover by the length of the island's population abandonment and change in State policy regarding settlement of the island.
- Many previous plans did not concern themselves with archaeological areas and did not consider the importance of archaeological areas that deserve to be left empty and protected or placed within the tourist or urban areas to generate extra income.
- Some previous plans did not consider the spread of sabkha on the island, which now constitutes 43.3% of the land area, and which should be left empty because of the difficulty in road construction. An intelligent environmental plan will reduce costs to the State rather than resorting to continual soil treatments and

raising the level of sabkha, especially considering the effects of sea level rise since 1990 which increased the areal extent of sabkha during that timeframe.

- Most plans do not take into account beach type, even going so far as to put a public beach in the area of rocky beaches, and camping areas in sabkhas ranging in depths from 0-3 meters, creating areas of geomorphological hazards.
- Most plans did not rely on intensive fieldwork to survey the island, especially the most recent study, issued by the Municipality of Kuwait, showing that they did not consider the archaeological and environmental components of the island, or several other scientific standards (e.g., soils, geomorphology, prior land use).
- Some plans overlook the many environmental changes that took place in Failaka in recent years. For example, deserting the island reduced the agricultural areas used, leading to desertified areas where sabkhas have grown to cover 43.3 % of the total land area ([Almatar et al., 2020](#); [WorldView2 -50 cm, 2018](#)).
- Plans focused solely on the land layout of the island without considering the link between the existing land use patterns and those proposed. For example, it is necessary to compare the soil types of the island with the designated site of the plans using a new soil map of Failaka Island based on recent studies ([cf., Al-zaher and Aziz, 2004](#); [Abbadi & El-Sheikh, 2002](#)), and creating a new soil map analysis via soil samples to determine soil production capacity based on total nutrients in the soil.
- Although a few of the old plans of [Shiber \(1964\)](#), [Buchanan \(1971\)](#), and [Municipality \(1973\)](#) suggested site selection decision was heavily affected by soil fertility, these plans utilized a self-contained city model with agricultural areas that cover the population's food needs. The preservation of the agricultural land and allocation of a high proportion of land (50%) of the plan's areas for agricultural utilization is strong evidence of soil fertility's impact on site selection decisions. Even so, the study focused on its proposed urban plan to determine the most suitable places for agriculture *only*.

Urban planning based on engineering without studying the environmental potential, biodiversity, geoarchaeological, and spatial modelling are no longer suitable as they were in the past. Through spatial modelling based on multiple criteria, it is possible to produce urban plans that achieve the goals of sustainable development and employ the potential of the environment correctly to ensure the preservation of environmental diversity. Additionally, numerous discoveries have occurred at Failaka's archaeological sites over the last two decades.

Given these important reasons, the old urban plans are no longer suitable. Indeed, if those older plans were to be implemented, not only would any prior human footprint be erased by damaging/destroying archaeological areas, but the potential for environmental destruction and geomorphological hazards would also increase. Based on these criteria then, there is an urgent need for a new urban plan.

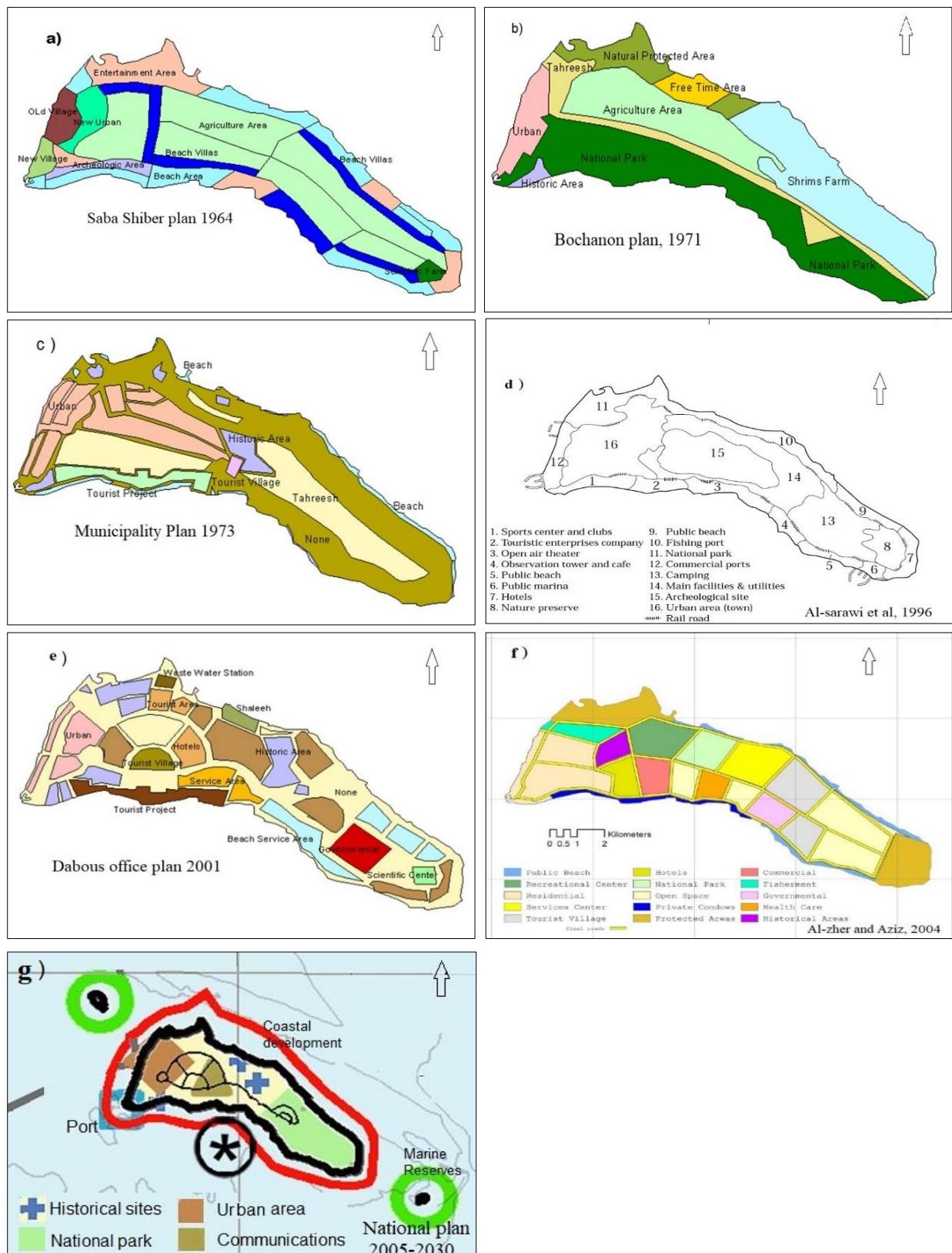


Figure 9. Some of old urban plans of Failaka island. Source (Shiber, 1964; Al-zaher and Azizi, 2005; Kuwait Municipality; Al-Sarawi et al, 1996, Kuwait municipality).

5.2. New urban plan for Failaka Island

The proposed urban plan for Failaka Island presented herein is based on environmental components and natural characteristics, as well as socioeconomic factors. The selection and analysis of sites was dependent on different criteria, as noted in Table 4, and the proposed urban plan utilized both high-precision data and high-resolution topographic surveys that relied on three main data sources that produced 13 individual data layers (Table 4): intensive field work, aerial survey by UAV, and high-resolution satellite imagery – all components neglected by previous plans.

After correlating the multiple layers, environmental, cost-effectiveness, and socioeconomic factors can be considered favorable criteria, while land availability can be considered a Boolean criterion. Upon further analysis of the layers, a set of indicators were identified to reflect criterion in Table 4, and the relationship between each indicator and suitability for a specific urban style that fits each proposed location.

Table 4. List of data sets used in this study

| Factors | Criteria | Type | Data Source & setup |
|--------------------|-------------------------------------|------------|---|
| Environmental | Geomorphology | Favourable | Field work, drone image, World Veiw2, 2010 & 2018 |
| | Coastline type | | Field work, drone image, World Veiw2, 2010 & 2018 |
| | Geology | | KOC,1980 |
| | Elevation (M) | | Aerial photography, 2004, Kuwait Municipality, 25 cm |
| | Slope | | From DEM |
| | Soil PH | | Al-zaher & Aziz, 2004; Abbadi & El-Sheikh, 2002; Analysis of 34 soil samples |
| Cost-effectiveness | Distance to port | Favourable | <i>The island divided into four sectors from west to east, where priority was given to urbanization areas in the west than east</i> |
| | Distance to water and energy line | | |
| Land Availability | Archaeological area | Boolean | <i>Archaeological areas have been added buffer zone to protect it from urbanism</i> |
| | Natural hazard | | <i>Sabkha area</i> |
| Socio-economic | Land use | Favourable | <i>The island is divided into four zones, according to the type of land use</i> |
| | Distance from main town | | <i>The island divided into four sectors from west to east, where priority was given to urbanization areas in the west than east</i> |
| | The productive capacity of the land | | <i>Analysis of 34 soil samples</i> |

Table 5 and figure 10 specify the area of each anthropogeomorphology landform on the island and embodies an essential pillar for understanding the Earth's surface on Failaka Island. For example, the already-existing urban area represents 5% of the island's total area, which means building on it is very important if the island's heritage sites are to remain intact (and perhaps subsequently used as a tourist attraction). In the same context, though the current road network is concentrated in the west of the island with a length of about 15 km, it is old, worn-

out, and in need of maintenance. But with a new plan, all new, proposed road networks could be moved away from archaeological areas and geomorphological hazards.

Table 5. Area of landforms and percentage of Failaka Island.

| Landforms or Land use | km ² | % |
|-----------------------|-----------------|------|
| Sabkhas | 20.12 | 43.3 |
| Archaeology sites | 1.79 | 3.9 |
| Urban area | 2.34 | 5 |
| Non | 22.19 | 47.8 |
| Total | 46.44 | 100 |

Source: (Worldview 2-50 CM- 2018; Google Earth 2020; Field study and aerial survey by Mavic 2 pro UAV imagery.

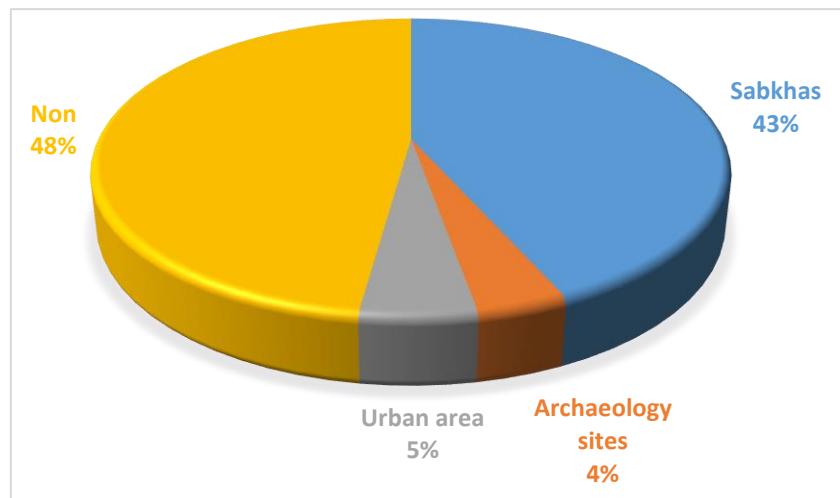


Figure 10. landform percentage of Failaka Island.

Using the methodology of EAHP, the four suitability ranges resulted: unsuitable, low, moderate, and high. From these data, a suitability map for Failaka island was created (Fig. 11). As detailed in Table 6, the areas of high suitability for urban use is 6.87 km² (14.81% of total land area), whereas the moderate urban use areas represented 5.63 km² (12.1% of total land area). Thus, only about one quarter of the island is potentially suitable for urban development based on the 13 criteria proposed by this study (“High” or “Moderate”). The rest of the island remains unsuitable for development because of the increasing sabkhas and/or rocky/muddy beaches.

Table 6. Area and percentage of each category suitable for urbanization.

| Category | Area km ² | % |
|------------|----------------------|----------|
| Unsuitable | 18.38 | 39.64625 |
| Low | 15.48 | 33.39085 |
| Moderate | 5.63 | 12.14409 |
| High | 6.87 | 14.81881 |
| Total | 46.36 | 100 |

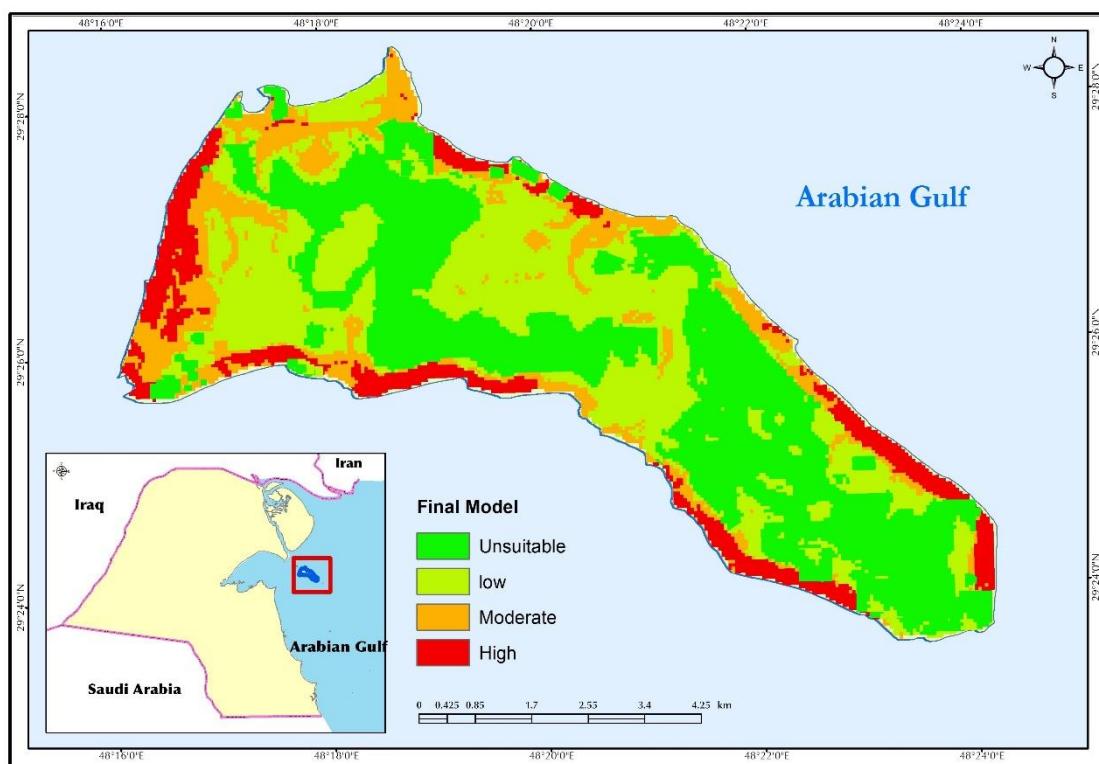


Figure 11. The most suitable areas for the proposed urban plan.

6. Conclusions and Recommendations

Urban planning based on environmental criteria represents an essential pillar for achieving sustainable development for future cities. This study suggested the *Environmental Analytical Hierarchical Process* (EAHP) method and incorporated multiple accompanying factors into a geographic information system (GIS) for further analysis. Out of the 46.36 km² total land area of Failaka Island, only 12.5 km², or 27.9%, was found as “suitable” area for development (“High” and “Moderate”, see Table 6 and Fig. 11). Analysis also showed that sandy beaches of the island represent approximately 51% of the island’s total beaches (totalling about 20 km

in length) and, alongside archaeological sites, these remain an essential pillar for attracting tourists on weekends.

Based on years of intense fieldwork by the current research team and previous expeditions as well as subsequent modelling and analysis by the current research team then, this study suggests several recommendations for moving forward with the planning process of Failaka island as a tourist destination and potential UNESCO World heritage Site. These include:

- Using transportation that does not pollute the environment, such as a solar-powered electric metro line circumnavigating the island to avoid the range of sabkhas and depressions located in the center of the island.
- Preventing vehicles from creating random passages in desert paths, which affects vegetation and living organisms, thus protecting the environment.
- Creating two areas for biodiversity on the island: “Al-Khidr Bay” in the northwest of the island, and “Sabkhas” located in the east of the island between Al-Awazim and Al-Sabahiya.
- Building a road along the coastline that encircles the island (perhaps adjacent to the solar-powered metro line) and two roads that cross the island from north to south, specifically avoiding desert depressions and sabkhas with an elevation of less than 3 meters, to avoid the roads turning into salt lakes during the rainy season.
- Enhancing the natural areas of Failaka Island through increased protection and preservation efforts. These natural areas include archaeological sites, coastal dunes, and the coral reef within the intertidal flat.
- Allowing the inland sabkhas to remain in their natural state, using the coastal dunes as a coastal defense in some locations.

Given all the evidence from ground-truthing and GIS analysis, it is clear Failaka Island has environmental components and diversity in its archaeological sites which require Kuwaiti officials and decision-makers to plan in a way that ensures preservation of these factors for future generations – including Kuwait’s largest heritage site. Failaka Island’s unique physical and cultural diversity has made it a magnet for governmental officials, who want it to become a World Heritage Site, even hosting a recent *UNESCO* delegation visit. The plan presented herein supports the efforts to designate Failaka island a World Heritage Site.

| | |
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