Doi: 10.34120/0080-049-003-014

التوزيع المكاني للظواهر الجيومورفولوجية الساحلية في دولة الكويت باستخدام طرق الاستشعار عن بعد وحلول نظم المعلومات الجغرافية

جاسم البناي

ملخص:

هدف الدراسة: تسعى الدراسة إلى إيجاد خريطة جيومورفولوجية ساحلية متكاملة للكويت باستخدام التقنيات المكانية. تقع دولة الكويت في الجزء الشمالي الغربي من الخليج العربي، ويمكن ملاحظة وجود تفاوت في خط الساحل للبلاد على الرغم من طوله القصير نسبياً. يوفر الاستشعار عن بعد ونظم المعلومات الجغرافية القدرة على تحديد هذه الاختلافات المكانية باستخدام العديد من الحلول؛ مثل المؤشرات الطيفية وتحسين الصور والتحليل البصري باستخدام صور عالية الدقة تم التقاطها بوساطة الأقمار الصناعية أو الطائرات المسيرة. **المنهجية**: في هذه الدراسة، تم رسم خرائط الجيومورفولوجيا الساحلية على طول ساحل الكويت وجزرها باستخدام الحلول المكانية المذكورة، مدعومة بأساليب إحصائية لتحديد دقة النتائج. وتم حساب معاملات كابا بالاعتماد على نقاط (عددها = 80)، تم ملاحظتها بوساطة المسح الميداني، وأظهرت دقة جيدة (0.73). **النتائج**: أظهرت النتائج تنوعاً في الظواهر الجيومورفولوجية على طول ساحل دولة الكويت. **الخلاصة**: شملت هذه الظواهر الشواطئ، والسبخات، والمسطحات المدية وغيرها من الظواهر الساحلية.

المصطلحات الأساسية: الكويت، الاستشعار عن بعد، نظم المعلومات الجغرافية، الجيومورفولوجيا الساحلية، الجغرافيا.

Spatial Distribution of Kuwait Coastal Geomorphological Features Using Remote Sensing Methods and GIS Solutions

Jassem A Albanai*

Abstract:

Goals: The study aims to create a coastal geomorphological map of Kuwait by using spatial technologies. Kuwait is a country located in the northwestern part of the Arabian Gulf, where a disparity in the country's coastline can be noticed despite its relatively short length. Remote sensing and GIS can help identify these spatial differences by using several solutions, such as spectral indicators, images enhancement, and visual analysis using high-resolution images captured by satellites or drones. **Methods**: In this paper, coastal geomorphological features were mapped along the coast of Kuwait and its islands using these spatial solutions, supported by statistical methods to determine the accuracy of the results. Kappa coefficients were computed at ground truthing points (n = 80) observed from field survey which showed good accuracy (0.73). **Results**: The results showed a wide variety in geomorphological features along Kuwait coast. **Conclusion**: The features included beaches, coastal sabkhas and tidal flats among other coastal features.

Keywords: Kuwait, Remote Sensing (RS), Geographic Information System (GIS), Coastal Geomorphology, Geography.

* Marine Monitoring Section, Water Quality Monitoring Department, Environmental Public Authority, Kuwait.
Email: albanay.com@gmail.com

1. Introduction

Almost two-thirds of the world's population lives on a narrow part of the land, and such pressure is easily noticeable when looking at coasts. All these pressures illustrate the present widespread interest in coasts. Because the coastal system is very sensitive to any variable of the system elements, coasts are affected and formed in different ways; they are controlled by relations between the four spheres of the same region, rendering the coastal system one of the most open and complex on Earth. The coastal areas of the State of Kuwait are part of the shallow depression extending from the Shatt al-Arab, which is considered a repository rich in soft materials that flow into the northern Arabian Gulf. The length of the coastline of the State of Kuwait stretches more than 1000 km (including recent reclamation projects). The longitudinal extension of the Kuwaiti coast gives rise to a difference in coastal appearance, as it contains a variety of formations, such as sea terraces, mudflats, marshes and sabkhas, rocky headlands, artificial coasts, sandy coasts, coastal dunes and cliffs among others. Most of these features came as a result of the rise and fall in sea level (immersion and recession); others, such as cliffs and plateaus, mostly resulted from the tectonic movements around the coastal region (El-Baz & Al-Sarawi, 2000). In addition to the waves and currents generated by the wind, tidal operations affect the shape of the coast through erosion, transportation and deposition; Kuwaiti coasts are classified as complex coasts that are brought about by a combination of more than one factor.

Remote sensing and geographic information systems (GIS) are of great importance in coastal studies; satellite imagery is characterized by its comprehensive ability to explain coastal geomorphological differences, especially with high-resolution images and drone photos. Besides, the spectral resolution of the sensors can be used effectively to calculate some spectral bands, through which some coastal features, such as sabkhas and tidal flats, can be identified according to their different properties which affect their radiative behaviour. GIS software represents the optimal environment to take advantage of remote sensing sources, as these systems include many tools through which raster and vector models can be analysed and validated. Therefore, remote sensing and GIS, in addition to the global position system and field survey, all work in tandem to help us understand the coastal environment.

Geographic studies of coasts can be found in a large body of academic work, which mostly relied on field surveys, while a handful of other studies relied on laboratory measurements, such as the ones that investigated the coastal sabkhas (Al-Ajmi, 2008; Al-Zamel & Al-Sarawi, 1998). Some dealt with specific areas within the coastal region of the State of Kuwait, such as studies of the northern coastal sabkhas and nabkhas (Kiluo, 1986, 2006; Saleh, Al-Ruwaih, Al-Reda, & Gunatilaka, 1999), while others focused on those found on the southern coast of Kuwait (Gunatilaka & Mwango, 1987). However, the geomorphology of Khiran region was comprehensively discussed by Al-Hussanin (1988). Al-Zamel & Al-Sarawi (1998) studied the sabkha sedimentation of quaternary north Kuwait Bay geologically, while Kleo & Al(2010) focused on sabkhas development geographically. Some studies presented the geographical distribution of coastal geo-features in Kuwait (Al-Obaid & Al-Sarawi, 1995; Alyamani et al., 2004; Kasaby, 2014). Moreover, a good number of studies dealt with coral reefs (as shown in Karbinter et al., 1998). However, studies relating to the geographical distribution of coastal geomorphological features using spatial technologies are somewhat limited, which opens the opportunity up for the present work. This study aims to show the spatial distribution of Kuwait coastal geomorphological features using the quantitative and descriptive approaches supported by the geo-technologies.

2. Material & Methods

2.1 Study area

2.1.1 Physical Geography

Kuwait lies between latitudes 28º30’ and 30º05’ North, and between longitudes 47º30’ and 48 º36’ East; this means that it is lies on the northwest of the Arabian Gulf. The total area of is around ̆ ñ¡ square km (Misak, Mahfoz, & Alasfour, 2003). In 2020, the length of its maritime borders, including its islands, was estimated to be more than 1000 km. Kuwait includes nine islands: (from north to south) Warba, Bubyan, Awhah, Failaka, Miskan, Kubber, Qaruh, Umm Al-Maradim, and Um Al-Namil, which is located inside the Kuwait Bay. Kuwait Bay is a relatively shallow bay and is of great economic, historical and geographical importance for Kuwait.

Due to its geographical conditions, Kuwait has a desert climate, which is characterized by the presence of a hot and long summer and a cold and short winter (Albanai, 2017). Kuwait is characterized by wide temperature range (Fig. 1) and a dearth of rain (Fig. 2) and low relative humidity. In the summer, the prevailing north-westerly winds often increase the frequency of the dust storms known as Tooze (Fig. 3) - in conjunction with climate change, for the increasing temperature affects the topsoil which leads to a lack of vegetation (Albanai, 2019). As a result of these climatic conditions, vegetation in Kuwait is scarce and often found as separate shrubs, perennial and annual plants. Plants are usually seen in depressive areas and on the edge of torrential streams where water accumulates in the rainy season (Fig. 4). As a logical result of the lack of vegetation, animal life is also rare and is almost totally confined to nature reserves.

Kuwait is characterized by its flatness, where there are no peaks or heights. The elevated regions in Kuwait are limited to those located north of Kuwait Bay, known as Jal Al-Zour. The height of this region reaches about 145 meters above sea level. Kuwait's land is graduated from sea level in the east to more than 270 meters above sea level in the southwestern part (Fig. 5).

Two important factors are controlled by the surface geomorphology of the State of Kuwait: the river sediments coming from the waters of the Shatt al-Arab in the northern Arabian Gulf, which the prevailing currents in the Gulf contribute to transporting to Kuwait, and the historical sediments coming from Wadi Al-Batin, which is a dry valley believed to have been a river about 5,000 years ago when the weather conditions were more suited (El-Baz & Al-Sarawi, 2000). As for the coastal geomorphology of the State of Kuwait, it is noticeable that most of the coastline is covered by muddy beaches, sandy beaches, tidal flats and sabkhas.

Kuwait's regional waters cover an area of 8 square km, and Kuwaiti water is characterized by its relatively high temperature and salinity. With the location of Kuwaiti water - south of the Tigris and Euphrates rivers in the north of the Arabian Gulf - in addition to the trend of the currents prevailing in the Arabian Gulf from east to west, the concentration of nutrients in the region is relativity high. (Al-Matar, Yousef, & Alsafar, 2009; Ali, Mustafa, & Alhasan, 2001).

Figure 1.
Air temperature average from 1990 to 2015. Data: station: KIA (Kuwait Meotrlogical Department, 2020).

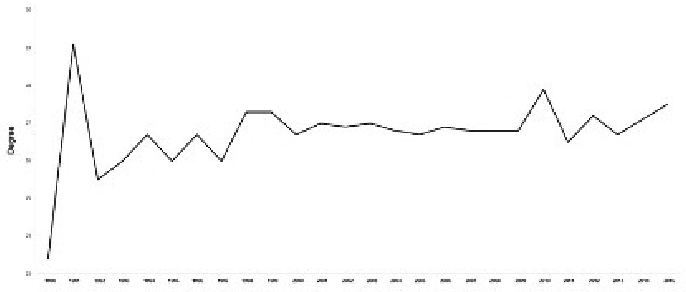


Figure 2.
Rainfall, yearly total amount and monthly average, from 1990 to 2015. Data: KIA station (Kuwait Meteorological Department, 2020).

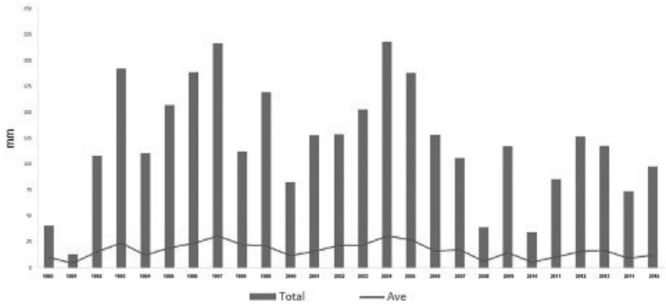


Figure 3.
MODIS images show the dust storm that comes to Kuwait from the Arabian deserts (Parstimes, 2020).

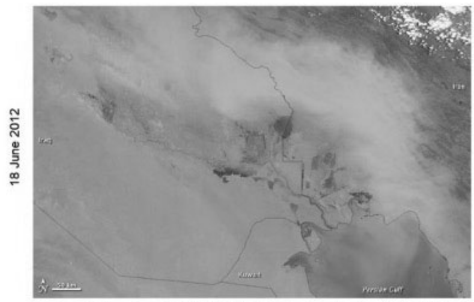
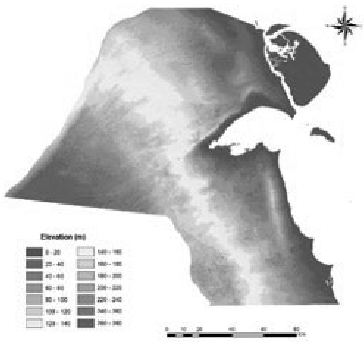


Figure 4.

Geographical distribution of vegetation in Kuwait shown by near-infrared reflections. Data: Landsat images mosaic, taken January 2020.

Figure 5.

Kuwait elevations using the SRTM digital elevation model.



2.1.2 Human Geography

With the discovery of oil in Kuwait, immigration increased to the country, which led to the urban growth of the State of Kuwait vertically, horizontally, and in a semi-circular manner south Kuwait Bay. Today, and after more than 250 years of its foundation, Kuwait City has turned into a modern and sprawling metropolis with seven circular roads surrounding it and connecting it with huge roads. The one-city-state has not been able to accommodate the high population density resulting from natural growth rates and the increase in expatriate labour, which led to the vertical expansion (Albanai, 2017). Population in Kuwait is concentrated in the urban area, which consists of six governorates extending from the north and northwest, where Jahra, the capital, and Farwania, can be found. Hawali, Mubarak Al-Kabeer and Al-Ahmadi are further south. The urban area is the main part of the country in terms of population densities (Fig. 6), different services, main and branch road networks, industrial and residential areas and other activities (Fig. 7).

There are currently only two non-urban areas in Kuwait, which are Al-Abdali and Al-Wafra agricultural areas on the northern and southern borders of the country. The Sheikh Jaber Al-Ahmad Bridge is considered one of the most prominent long sea road projects in the world. This bridge connects the southern region and Kuwait City with the northern region; its prime purpose is to facilitate expansion and investment in the northern regions, and the inauguration of a new northern city comparable to the current size of Kuwait City. As part of this project was completed in 2019, two industrial islands - the South Island and North Island of Jaber Bridge - were established as rest areas and services for road users. These artificial islands are the first examples of such a reclamation process in Kuwait's marine environment (Albanai, 2017). Kuwait's population is estimated today to be around 4.7 million (PACI, 2018) (Fig. 8).

Figure 6.

Population distribution of Kuwait (Kuwait Central Statistical Bureau, 2015).

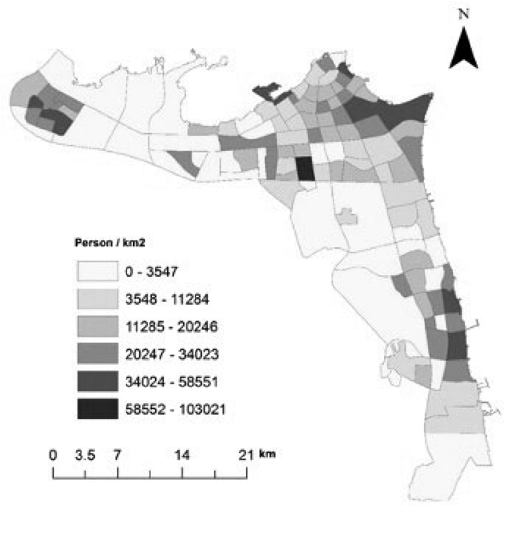
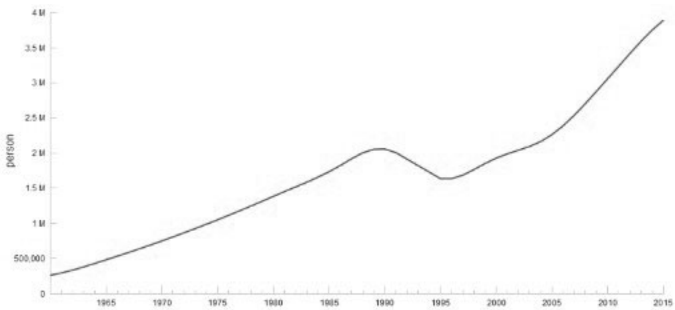


Figure 7.

The c-band sentinel 1 radar image captured on 17 February 2019 clearly shows the extension of Kuwait's urban area.

Figure 8.

Population growth of the State of Kuwait from 1965 to 2015 ("Worldometer," 2018).



2.2 Data description

A network of satellites was used to monitor the Earth's surface. Landsat 8 images were used to calculate the spectral indices, while Sentinel-2 was used for displaying some geomorphological phenomena in Kuwait as well as for visual analysis. High-resolution images provided by Google Earth and ArcGIS Online base maps were used to track and understand the nature of the various coasts. A DJI drone was used as part of the field survey, for the same purpose but for smaller areas.

Moreover, SRTM radar data were also used to extract the elevation values of Kuwait and the coastal plateaus.

Landsat 8 is the latest and most recent satellite of the Landsat program, which was launched in 2013 and has been orbiting the earth since; it contains two sensors (OLI and TERRA) with 11 bands, and it has a temporal resolution of 16 days (USGS, 2020b). Landsat 8 data is freely available on the US Geological Survey website (USGS, 2020a). NASA and USGS also made it possible to use SRTM data for free, a project implemented in 2000 to obtain a digital elevation model that covers the Earth at three levels: spatial resolutions of about 90 square meters, 60 square meters, and 30 square meters (USGS, 2020a).

The European Space Agency launched Sentinel 1A and Sentinel 2A satellites to monitor and study the Earth's surface, and more recently it also launched Sentinel 1B and 2B as a sequel to the project. The temporal resolution is up to 5 days for both 2 A and B satellites. As for the Sentinel 1 satellites, the temporal resolution is up to 6 days for both 1A and 1B satellites. Sentinel images can be downloaded freely from the ESA website (European Space Agency, 2020).

Digital Globe has a network of high-resolution satellites commercially; the satellites' spatial resolution reaches to limited centimetres and the temporal resolution ranges from one to two days. A range of satellites work as a network, including AKONAS, Quick Bird, Word View satellites and GeoEye. These satellites have 4 to 16 bands, and their images can be ordered via Digital Globe (Digital Globe, 2020a). Aside from the satellite images, drones are also used to photograph the Earth's surface at high resolution and from low altitudes relative to the satellite images. The spatial resolutions of the drone photos reach to less than 1 square centimetre, and the drones can avoid atmospheric obstacles. Table. 1. Shows some properties of all remote sensing instruments (satellites and drone) that were used in this study.

Table 1.

The properites of remote sensing instruments that have been used in this study.

Satellite(s)	Sensor(s) Category	Spectral reslution	Spatial resolu-tion	Temporal reso-lution (day)
Landsat 8	Mulispectral, thermal, panchromatic	11	15-100m	16
Sentinel 1 (A-B)	Microwave c-band (radar)	2	10m	5
Sentinel 2 (A-B)	Multispectral	13	10-60m	5
Digital Globe	Multispectral, panchromatic	4-16	31-64cm	1-2
Drone	Visible light	3	10 < cm	-

2.3 Data pre-processing

Satellite imagery must undergo preliminary processing before being analysed. The images usually are stored in a digital number format, which is the primary format where the image files are saved. This format gives rise to the radiance, which enables us to benefit from the image. This process is useful for creating a uniform scale for all pixels so that they can be compared and analysed. The process is called radiometric calibration and needs to be applied in most cases as a pre-processing stage. Some satellite images are stored without coordinates, which need to be georeferenced. This process is applied either by ground control points or by using a georeferenced map so that the images refer to their correct geographical coordinates. This matter is important in analysing the image and making use of it in the best possible way. For example, it is not possible to calculate distances and measurements on an image with unknown coordinates. Every satellite covers a specific geographic range in a single image, but it does not often match with the study area dimensions and the study goals. For example, the State of Kuwait is covered in four Landsat 8 plates, meaning that four images of Landsat should be downloaded to obtain a complete satellite view of Kuwait.

These images need to be combined for analysis. This merging process is called mosaic, and there are several types of mosaics, whose choice varies according to the suitability of the study. Images often need to be enhanced to identify the geographical feature, as some formations in the images can only be seen after enhancement. Scientific foundations and principles are behind the different methods for image enhancement, and the most important types are Linear 1%, Linear %, equalized histogram, among others. All these processes have been carried out on Landsat 8 and Sentinel images using ENVI 5.3 software.

Satellite images were used to create the vector layers. The near-infrared band of Landsat 8 was used to map Kuwait's shoreline, as it is characterized by a strong reflection of land and absorption of water, making it a typically well-suited method to delineate the shoreline.

2.4 Spatial analysis and data validation

Spectral indicators were calculated to determine some coastal features, such as sabkhas and tidal flats. The sabkhas are distinguished by their various sedimentary properties, which give them a distinctive radiological behaviour that enables us to monitor and locate them on maps. The Normalized Difference Moisture Index (NDMI) was applied to the Landsat 8 images captured in January 2020 using a band math tool in ENVI 5.3. The NDMI shows the crop's water stress level and is calculated as the ratio between the refracted radiations of near-infrared and SWIR bands (Jensen, 2016). This resulted in the extraction of the coastal sabkha category using reclassification and raster calculator tools in ArcGIS 10.4.1 (Fig. 9). The index was computed using the following formula:

$$NDMI = \frac{(band_{NIR} - band_{SWIR})}{(band_{NIR} + band_{SWIR})} \qquad Euation\ 1$$

Where refers to the Near-Infrared band at 0.85 - 0.83 wavelength (μm) and refers to the Short-infrared band at 1.57 - 1.65 wavelength (μm) and of Landsat 8 OLI sensor.

On the other hand, the Normalized Difference Water Index (NDWI) was applied to determine the tidal flats using the same Landsat 8 images used to calculate NDWI through the same tool (Fig. 10). The NDWI is related to water stress and water differences. It is calculated as the ratio between the refracted radiations of the near-infrared (NIR) and the short-wave infrared (SWIR) bands. The NDWI has been used successfully in intertidal zone mapping in Australia in several studies (Sagar et al., 2017). The required category of both indices was retrieved based on a visual analysis of high- and medium-resolution satellite images. The index was calculated using the following formula:

$$NDMI = \frac{(band_G - band_{NIR})}{(band_G + band_{NIR})} \qquad Euation\ 2$$

Where G refers to the green band at 0.53 - 0.59 wavelength (μm) and refers to the Near-Infrared band at 0.85 - 0.83 wavelength (μm) of Landsat 8 OLI sensor.

As for the classification of Kuwaiti coasts and beaches according to their geomorphological nature, the country's beaches can be classified into four main sections: sandy beaches, muddy beaches, rocky beaches, and artificial beaches and coasts. These categories were approved by applying them to beaches across almost all the coastline, either individually or combined. The categories were defined by reviewing several studies mentioned in the introduction, field observation using a drone (Fig. 11), as well as visual analysis of high-resolution images, and enhancement of medium-resolution images (Fig. 12). This enabled us to identify the variation of the radiological characteristics of the coastal differences. Accordingly, the shoreline was manually edited along its coastline using ArcGIS.

As for other features, some have been mapped according to their geomorphological forms by space images and aerial photographs taken during the field survey (Fig. 13) - these include bays, spits, rocky headlands and creeks (Fig. 11). As for the sites of coral reefs, their location and distribution in Kuwait are already known from several sources (Alyamani et al., 2004; Environment Public Authority, 2020; Karbinter et al., 1998).

The accuracy of the classified coastal features was evaluated using ground truthing points (GTPs). The ground truthing points (n = 80) were selected randomly from field observation (Fig. 11) and were taken for each of the following features equally: sabkhas, tidal flats, muddy beaches, sandy beaches, rocky shores, reclamation and artificial beaches, and coral reefs. The other features such as rocky headland, spits and bays were avoided in validation because they were identified from their morphologically significant forms. ArcGIS was used for matching between the final classified coastal features map and GTPs using Cohen's Kappa coefficient. All the mentioned coastal features layers were overlaid as one classified raster model for this purpose, and then the ground truthing points were entered into the software as a projected shapefile and overlaid on the classified map. The points were transferred to raster for matching. The cell size for both the classified map and GTPs were specified to be equal to 30 square meters, which is the lower resolution used in this study. Then both were combined to extract values and calculate a Kappa. The result showed good accuracy of the model where the Kappa coefficient was 0.73, which was calculated using the following formula:

$$K = \frac{N\sum n_{ij} - N_i + n + j}{N^2 - \sum n_i - n_j} \qquad \textit{Euation } 3$$

Where n is ground truthing point value and n_j is the classified map value in the same location.

Figure 9.

The geographical distribution of sabkhas in North Kuwait by applying NDMI (high values) on Landsat images taken on January 2020. Sabkha can be found in Ras Julai'a, Ras Al-Zour and Bubyan.

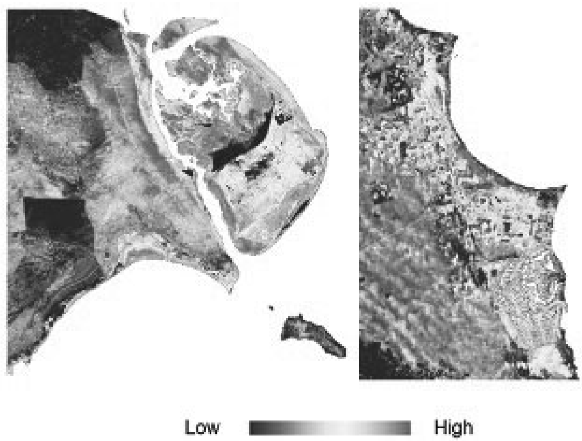


Figure 10.

The geographical distribution of tidal flats in Kuwait by applying NDWI (high values) on Landsat images taken on January 2020. The main tidal flats can be seen around Bubyan and Warba islands, on the north-western side of Kuwait Bay and South Al-Khiran.

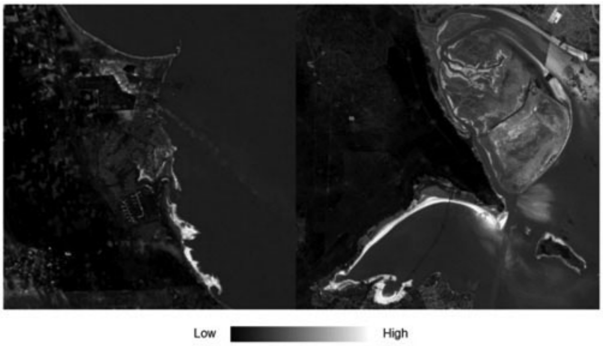


Figure 11.

Some drone & field images taken in the period from 2018 to 2020 during the field survey for validation.

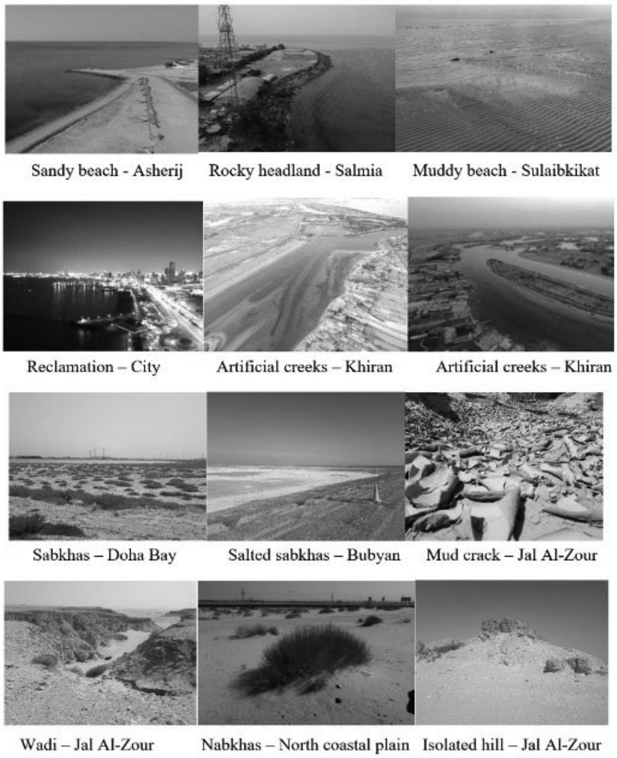
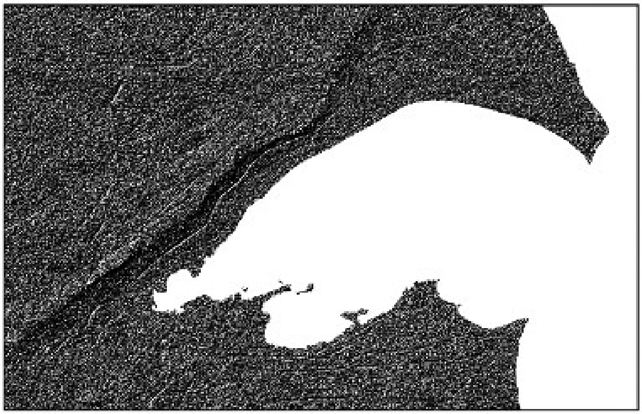


Figure 12.
Enhanced Sentinel 2 image taken on 6 January 2020 showing Kuwait Bay.

Figure 13.
Hill shadow analysis of Jal Al-Zour shows the terrain (SRTM).



3. Results

Kuwait contains one of the most distinctive bays in the world, locally called Kuwait Bay, and it is considered a geographic feature rich in biodiversity and unique in geological and geomorphological terms. Kuwait Bay occupies an area of about 715 sq km, with sub-bays like the Doha and Sulaibikhat Bays in the far western islands (Fig. 12).

Coastal sabkha is considered one of the major geomorphological manifestations in the State of Kuwait, as it is seen in the form of separate and intermittent sabkhas in large parts of the coast of Kuwait along both the north and south. Bubyan island is believed to contain the most sabkhas, but elsewhere, the sabkhas extend over various parts of the northern coasts and north Kuwait Bay. Moreover, sabkhas are located south of Kuwait from Ras Julai'a heading south to the extremity of Kuwait borders; however, human intervention in the Khiran region has had an impact on the sabkhas by reducing their geographical distribution (Fig. 14). Coastal sabkhas can be found in Kuwait at different altitudes, as these altitudes decrease in the northern coast and increase in the southern areas (Fig. 15). Many coastal features can be seen in sabkhas, such as nabkhas as extensively discussed by Al-Ajmi (2008). Nabkhas can be found with great frequency along Kuwait's coasts that were not exposed to human influence.

Tidal flats are one of the major geomorphological manifestations in the State of Kuwait; the largest and most important are those that permeate the Warba and Bubyan islands north of Kuwait, the tidal flat north and west of Kuwait Bay at the Sulaibikhat and Doha bays, and the tidal flat located south of Khiran (Fig. 10). The range of intertidal flats in Kuwait starts from about 50 meters and may reach to 1 kilometer or more in some areas. Many temporary geomorphological features are formed in tidal flats, such as spits, barriers, tidal inlets and tidal ripples. Morphological measurements about tidal flats and other major geomorphological can be found in Table. 2.

The presence of sandy beaches can be observed in different parts of the Kuwaiti coast, where such beaches are considered one of the major geomorphological features in the State of Kuwait. Sandy beaches are found along the area from Ras Al-Ard to Ras Al-Zour to the south. Many of them have been backfilled and erected for development projects. On the other hand, muddy beaches exist in separate areas in Kuwait; the most important are those on the islands of Bubyan and Warba north of Kuwait, Doha Bay, and south of Khiran. The muddy beaches are considered the longest in Kuwait due to the nature of the northern beaches located south of the Shat Al-Arab delta, and the long and winding creeks north of Bubyan. Moreover, rocky beaches can be found on the southern coast of Kuwait where they can be noticed at the rocky headland regions. They are found in separate places on the southern coast of Kuwait from Ras Al-Ard towards the south (Fig. 16). Fig. 19 shows the length of each beach along Kuwait coast.

The area that extends from Ras Ajozah (Kuwait City) to Ras Al-Ard "Salmiya" is one of the oldest coastlines to have been man-changed in Kuwait, where much evidence can be found in the reclamation projects such as those in the Green Island, Yacht Club, Marina Beach, Kuwait Towers, Al-Shaab Sea Club, among others. Also, many changes can be found on the coast in the southern region, where people have taken steps to establish seaports (Fig. 16; Table. 3). The free zone is one of the projects that highlights the impact of geomorphological changes in the coastline on water hydrodynamics and maritime operations. Here, Harer Island, which was previously considered the tenth island in Kuwait, was linked to land to form the free zone as we know it today. This backfill caused a clear obstruction to water hydrodynamics, as the general direction of currents in Kuwait Bay is counter-clockwise, which means that the land area constitutes a barrier to the water, which previously flowed to release its contaminants from Kuwait Bay. Besides, the interference of humans in changing the nature of Khiran is the largest at the state level; here, complex creeks were created for recreational purposes, thus increasing the length of beaches from 36 km in 2004 to 163 km in 2020 (Fig. 14).

It is observable that there is a complex network of creeks in the northern part of the coast of the State of Kuwait, especially on the Bubyan and Warba Islands, where it can be seen in the north of Bubyan Island and separate parts of the coast from Warba Island. More recently, the southern region has witnessed the conversion of the natural creeks into a complex network of industrial creeks. The presence of coastal Questa north of Kuwait Bay is noted, particularly in the Jal Al-Zour region.

Kuwaiti islands are distinguished by the presence of marine (sandy) spits. Umm Al-Namil Island has the longest such feature in Kuwait. It is also noted that there are relatively small and sandy spits on the islands of Ouhah, Miskan and Umm al-Maradim. The southern coast of Kuwait contains two sandy spits located specifically in the south of Khiran, forming coastal lagoons which are currently used for recreational purposes. The two spits are part of the Khiran project, which means that their shapes are changing. Aside from this, Kuwait also contains seven rocky headlands (Fig. 15), of which the majority are found in Kuwait Bay - the largest is in Ras Subiah at the northern entrance of the bay. In the southern entrance of the bay, Ras Al-Ard and Ras Al-Ajozah can be found. In the western region of the Bay, Ras Ashairej can be seen, located in the middle of Sulaibikhat and Doha Bays, and Ras Kazma lies in the far west of Kuwait Bay. In the south of Kuwait, there are two rocky heads, Ras Julai'a and Ras Al-Zour. It is also noted that there are relatively small heads on Failaka Island.

Looking to the other side, coral reefs spread in Kuwait around the southern islands (Umm Al-Maradim, Qaruh, Kubber) and form patches in the deep waters; they create separate platforms along the southern coast of Kuwait in shallow areas (Fig. 15). The largest and most developed coral reef populations are found around the islands (Fig. 18), at depths of more than 10 meters. Fig. 19 shows the overall geomorphological features along Kuwait coast.

Table 2

The total area of Kuwait's main coastal features along the coastline in square km.

Sabkhas	1061
Tidal flat	292
Kuwait bay	715
Urban Area	660

Table 3.

The length of Kuwait coasts along the coastline in square km.

Sand beaches	181
Muddy beaches	545
Rocky beaches	35
Artificial beaches and reclamation	421
Jal Al-Zour	45

Figure 14.

Change detection of Khiran region from 2004 to 2013 (ArcGIS Online, 2020; Digital Globe, 2020b). The creeks' length has been increased from 36 km in 2004 to 163 km in 2020.

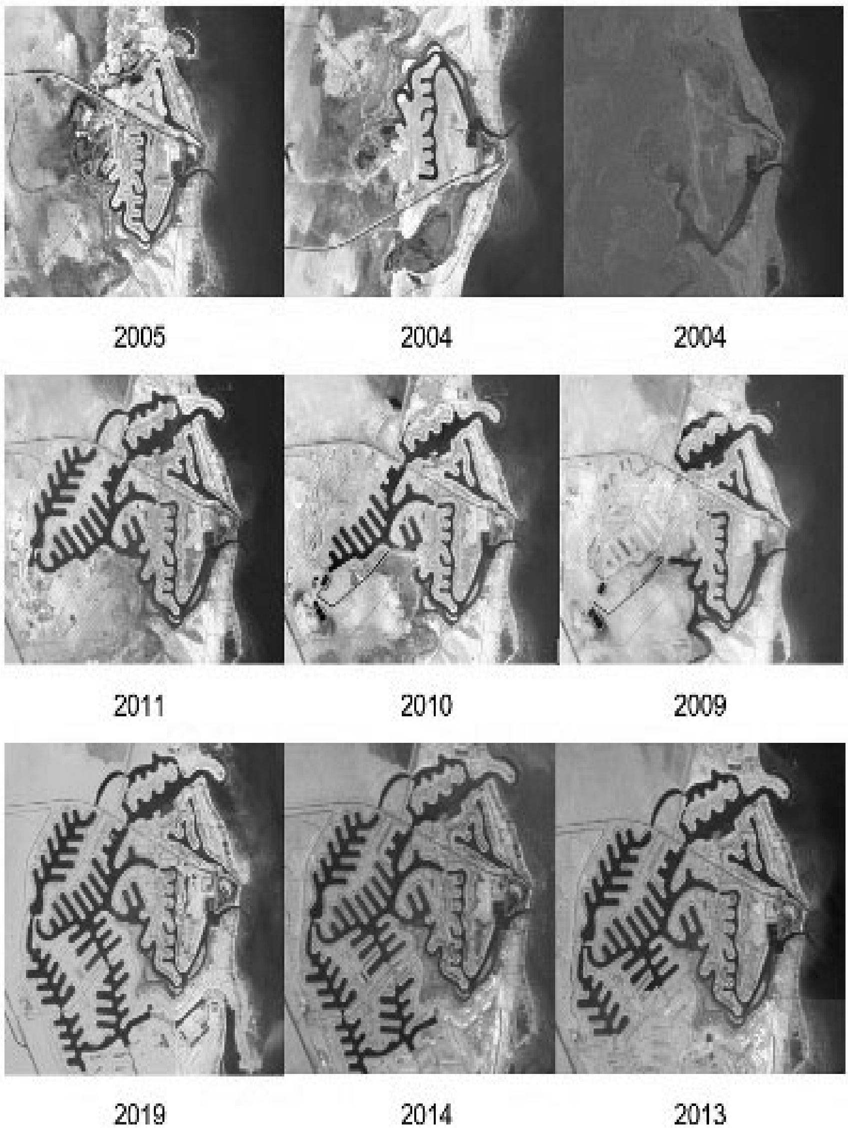


Figure 15.

The geographical distribution of some coastal features in Kuwait.

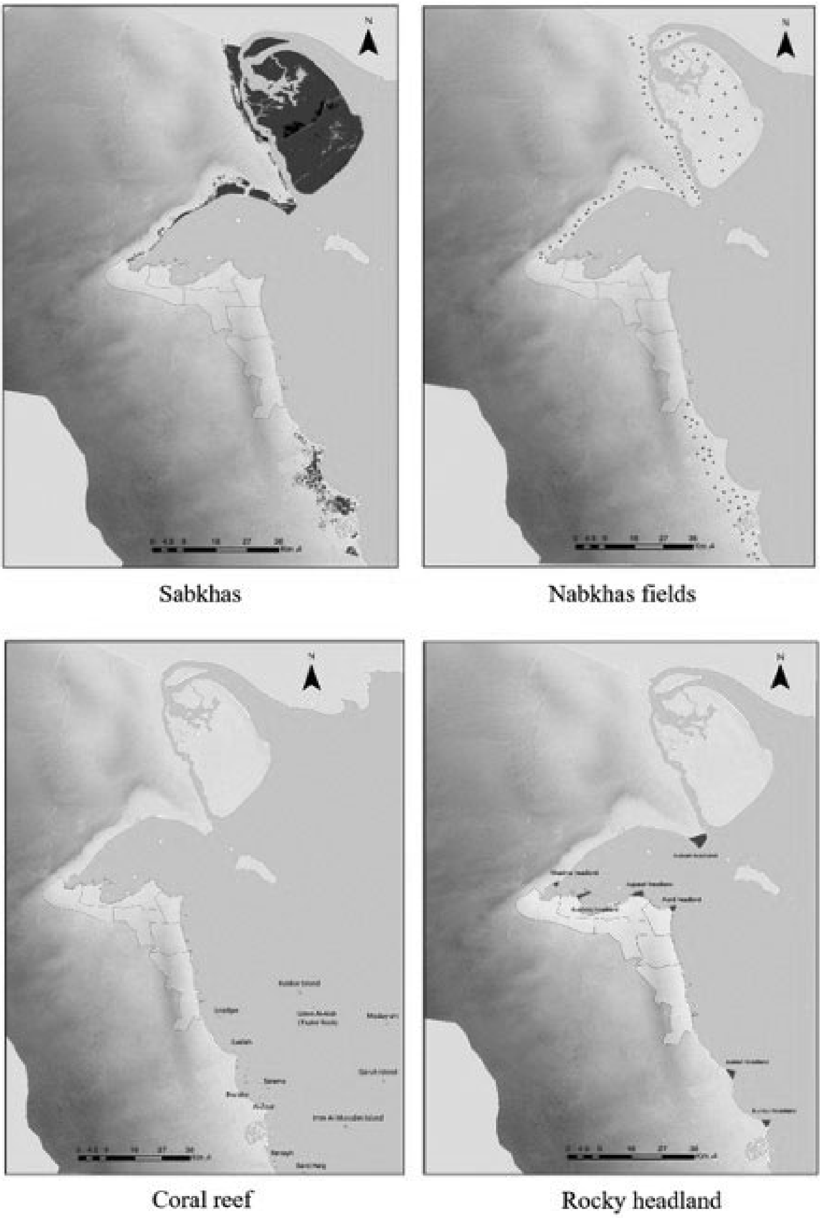
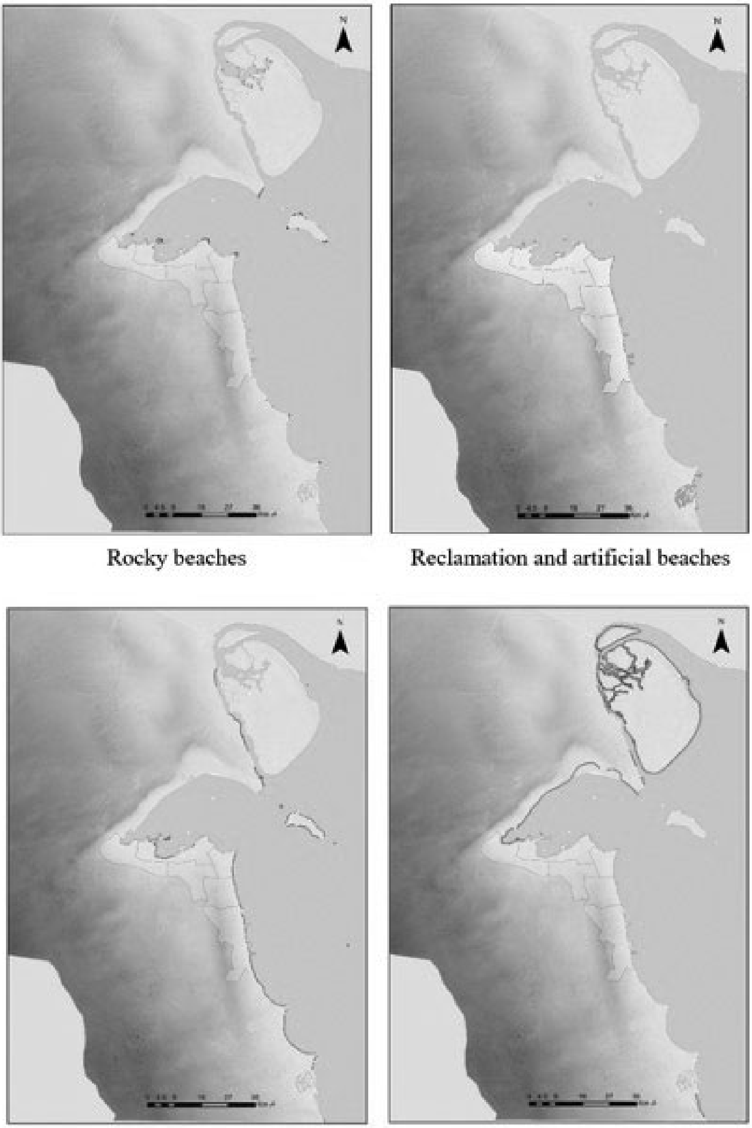


Figure 16.

The geographical distribution of beaches (Including artificial coasts) along the shoreline of Kuwait.



Rocky beaches

Reclamation and artificial beaches

Sandy beaches

Muddy beaches

Figure 17.

The length of Kuwait coasts along the coastline in percent.

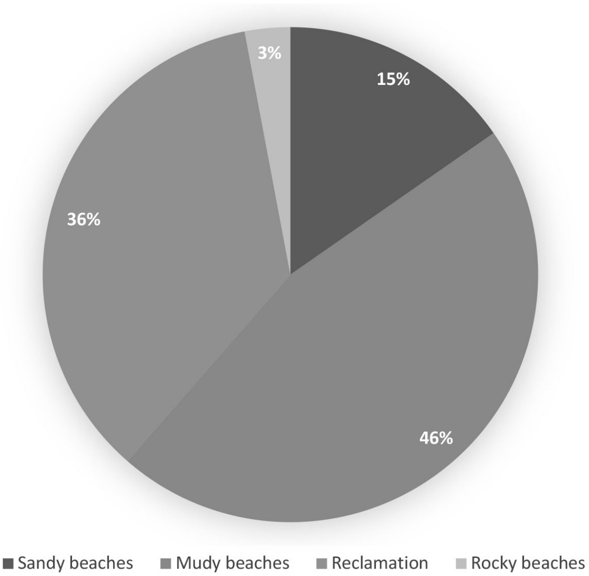
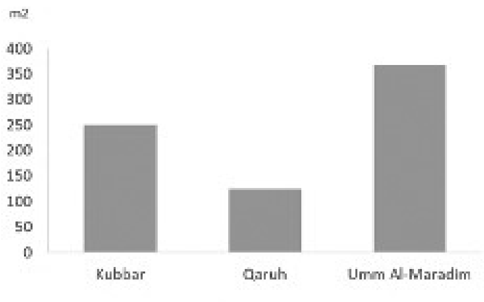


Figure 18.

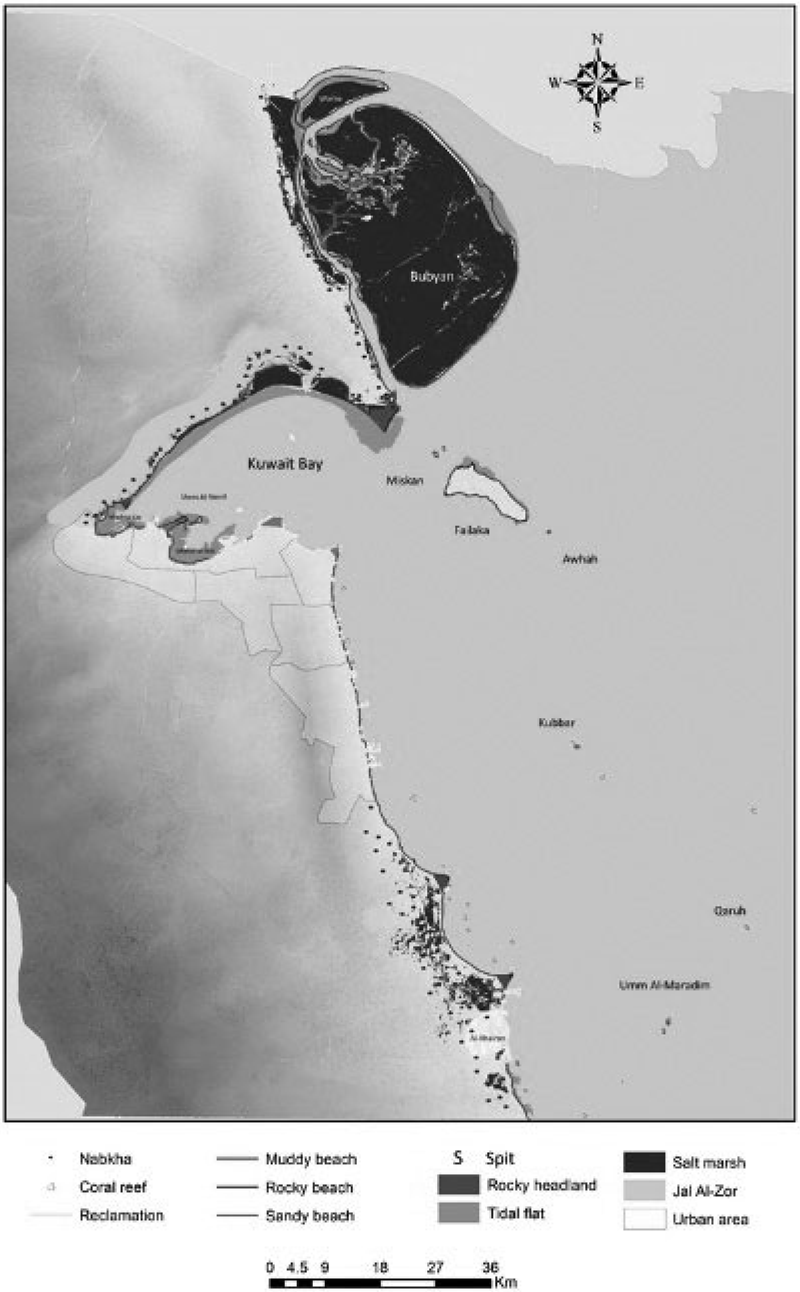
The area of coral reef around the Kuwaiti islands in square meters and the descriptive statistics of the coral reef around Kuwait islands.



Descriptive statistics	
Mean	247.3333
Median	250
Standard Deviation	122.0219
Skewness	-0.0983
Range	244
Sum	742
Count	3

Figure 19.

The coastal geomorphological feature map of the State of Kuwait.



4. Discussion

Spatial technology provides solutions in mapping coastal features based on their radiative behaviour and morphological forms, especially with modern technology and the relative availability of methods to measure the accuracy of results. It thus saves effort, time and money spent on researchers as effective tools in studies related to the classification of surface features. However, sabkha, tidal flatbeds, sandy beaches, muddy beaches, reclamation and artificial beaches were identified as major manifestations on the coast of Kuwait. The importance of knowing the nature of the northern coast (mostly muddy beaches) increases with the expansionary plans of the State of Kuwait to achieve the vision of Kuwait 2035.

The results showed a convergence of the shoreline coastal geomorphological map to Alyamani et al.'s (2004) study, except for some differences in considering that the area extending from Ras Al-Ard to Ras Al-Ajozah is classified as artificial beaches and reclamations in addition to some details in the sandy muddy northern coasts distribution. On the other side, the geomorphological map converges with that presented in Kasaby's (2014) study with some differences in the extension of the tidal flats north of Kuwait Bay, and the classification of the area from Ras Al-Ard to Ras Al-Ajozah. As for Sabkha, this study shows a similarity in its geographical distribution with Al-Ajmi's (2008) study, considering an increase in the estimate of the total area mostly due to the inclusion of larger areas of Sabkha in Bubyan Island.

This study added the quantitative dimension of coastal geomorphological features of Kuwait, monitored the changes that have occurred to this date, especially concerning artificial beaches and reclamation actions, in addition to including the Kuwaiti islands as part of the coastal geomorphology of the State of Kuwait, which was not comprehensively discussed in previous studies.

The geographical distribution of coastal geomorphological features in the State of Kuwait reflects the natural and human factors and forces that affected them. Sabkhas and muddy beaches tend to be concentrated in the north of Kuwait and in Bubyan and Warba Islands. The northern coast of Kuwait was formed mainly by the fluvial deposits coming from the Tigris and Euphrates rivers (Shatt Al-Arab) in the northern Arabian Gulf (Alyamani et al., 2004). The distribution of nabkhas is linked to sabkhas distribution, as they found are in frequency along sabkhas (Al-Ajmi, 2008). However, the northern coast of Kuwait Bay is subjected to tidal forces, where it is found that the tidal flats are more evident in Kuwait Bay than on other coasts (El-Baz & Al-Sarawi, 2000). As for the southern coast, it is characterized by its sandy sediments, and the man-made changes of the original environment in this area through reclamation actions and development of the urban area in the southern part of the country, where artificial beaches, ports, and coastal facilities abound. The artificial beaches - especially with the expansion of the Khiran project, have become comparable to the sandy beaches in their lengths. Most of the rocky headlands are located in Kuwait Bay and the southern coast of the state, and they are affected by hydrodynamic factors, where the waves play a major role in their formation in terms of hydrodynamic gathering on the rocky headlands (erosion), and sculpting along bays (deposition). The rocky headlands accompany rocky beaches that are less than the sandy and muddy counterparts along the coast of the State of Kuwait. However, the southern waters of the State of Kuwait contain coral reefs as result of the factors that lead to their prosperity in terms of water clarity and level of depth.

5. Conclusion

In this article, the spatial distribution of coastal geomorphological features in the State of Kuwait has been explained, mainly using remote sensing and GIS solutions. The accuracy of the final model was validated by calculating the Kappa coefficient using GTPs ($n = 80$) as a part of the field survey. Kappa shows good accuracy, where the correlation is 0.73. The study shows the importance of remote sensing and geographic information systems in planning, classifying the coasts and their suitability for development projects, and creating an accurate and comprehensive coastal database. The study integrative approach can be used in many fields related to environmental and physical studies.

The study recommends further field and laboratory analysis integrated with remote sensing and GIS methods to understand the geographical distribution of coastal geomorphology of Kuwait. However, this study relied on a satellite image taken in the rainy season (January 2020) to clarify the geographical distribution of sabkha as its spectral signature becomes clear. Therefore, further studies are needed to extract the sabkhas distribution from satellites in the dry seasons and compare the two results.

Acknowledements

The author would like to thank: the European Space Agency, NASA and the USGS for the freely available images of Sentinel 1, Sentinel 2, Landsat 8, MODIS and SRTM; the Google Earth and ArcGIS teams for the high-resolution base maps; and the authors whose studies were cited and used in this article.

References

Al-Ajmi, J. A. S. (2008). *Sabkhas of the northern coast of Kuwait "A geomorphological study."* Kuwait: Center for research and studies on Kuwait.

Al-Hussanin, A.-S. (1988). Geomorphology of Al-Khiran Region - South Kuwait. *Research and translation unit - Geography dept at Kuwait university and Kuwait Geographical Society, 19*.

Al-Matar, S., Yousef, A., & Alsafar, A. (2009). *Life on sea and Arabian Gulf*. Kuwait Institute for Scientific Research.

Al-Obaid, E., & Al-Sarawi, M. (1995). Artifical beaches along the Kuwait water front, Kuwait. In *Coastal Change 95* (pp. 603-609).

Al-Zamel, A., & Al-Sarawi, M. (1998). Late quaternary sabkha sedimentation along Kadhamah bay coast, Kuwait, Arabian Gulf. *Arab Gulf J. Scient. Res*, *16*, 471-495.

Albanai, J. (2017). *Urban life development in Kuwait*. Kuwait. Unpublished.

Albanai, J. A. (2017). *The four spheres "An introdacution to physical geography and geosystem"* (2nd ed.). Dar Kalemaat.

Albanai, J. A. (2019). *A GIS science simulation for the expected sea level rise scenarios on Failka Island in the State of Kuwait*. Kuwait: Center For Research and Studies on Kuwait.

Ali, L., Mustafa, A., & Alhasan, R. (2001). *Oil pollution*. Kuwait: Center For Research and Studies on Kuwait.

Alyamani, F., Bishop, J., Ramadhan, E., Al-Husaini, M., & Al-Ghadban, A. (2004). *Oceanographic Atlas of Kuwait's waters*. KISR.

ArcGIS Online (2020). Digital Globe. Retrieved February 19, 2020, from arcgis.com

Digital Globe (2020a). Digital Globe. Retrieved February 20, 2020, from digitalglobe.-com

Digital Globe (2020b). Google Earth Pro. Retrieved February 20, 2020, from google.com/maps

El-Baz, F., & Al-Sarawi, M. (2000). *Atlas of State of Kuwait from satellite images*. Kuwait Foundation for the Advancement of Sciences (KFAS).

Environment Public Authority (2020). eMISK. Retrieved April 10, 2019, from epa.org.kw

European Space Agency (2020). ESA. Retrieved February 20, 2020, from https://www.esa.int/

Gholoum, M. (2016). *Mapping coral reef density using high spatial resolution satellite imagery: a case study in the State of Kuwait*. University of South Australia.

Gunatilaka, A., & Mwango, S. (1987). Continental sabkha pans and associated nebkhas in southern Kuwait, Arabian Gulf. *Geological Society, London, Special Publications, 35*(1), 187-203. https://doi.org/10.1144/GSL.SP.1987.035.01.13

Jensen, J. R. (2016). *Introductory digital image processing "A remote sensing perspective"* (4th ed.). Prentice Hall Press.

Karbinter, K., Hareson, P., Hegson, G., Alsafar, A., Alhazeem, S., & Randel, J. (1998). *The Coral and coral reef Fishes of Kuwait*. Kuwait: Kuwait Institute for Scientific Research.

Kasaby, A. M. E. sayed El. (2014). *Human effects on the geomorphology of Kuwait State's Coasts*. Kuwait: Center For Research and Studies on Kuwait.

Kiluo, A. (1986). Sabkhas of the northern coast in the State of Kuwait - A geomorphological study. *Research and Translation Unit - Geography Dept at Kuwait University and Kuwait Geographical Society, 12*.

Kiluo, A. (2006). Sabkhas of the northern coast in the State of Kuwait. *Research and Translation Unit - Geography dept at Kuwait University and Kuwait Geographical Society, 318*.

Kiluo, A., & AlO. (2010). The Sustainable Development of Kuwaiti Sabkhas. *Digest of Middle East Studies, 20*. https://doi.org/10.1111/j.1949-3606.2011.00064.x

Kuwait Central Statistical Bureau (2015). Kuwait polulation report. Retrieved February 12, 2020, from www.csb.gov.kw

Kuwait Meotrlogical Department (2020). Kuwait Meotrlogical Department. Retrieved February 11, 2020, from met.gov.kw

Misak, R., Mahfoz, S., & Alasfour, T. (2003). *Desert environment on the State of Kuwait*. Center For Research and Studies on Kuwait.

PACI (2018). *Kuwait Statistics*. Retrieved December 1, 2018, from https://www.paci.-gov.kw/stat/

Parstimes (2020). Satellite images of Persian Gulf. Retrieved February 11, 2020, from http://www.parstimes.com/spaceimages/persian-gulf/

Sagar, S., Roberts, D., Bala, B., & Lymburner, L. (2017). Remote Sensing of Environment Extracting the intertidal extent and topography of the Australian coastline from a 28 year time series of Landsat observations. *Remote Sensing of Environment, 195*, 153-169. https://doi.org/10.1016/j.rse.2017.04.009

Saleh, A., Al-Ruwaih, F., Al-Reda, A., & Gunatilaka, A. (1999). A reconnaissance study of a clastic coastal sabkha in Northern Kuwait, Arabian Gulf. *Journal of Arid Environments, 43*(1), 1-19. https://doi.org/https://doi.org/10.1006/jare.1999.0529

USGS (2020a). Earthexplorer. Retrieved February 11, 2020, from earthexplorer.usgs.gov

USGS (2020b). Landsat Mission. Retrieved February 20, 2020, from https://www.usgs.-gov/land-resources/nli/landsat

Worldometer (2018). Retrieved January 25, 2020, from https://www.worldometers.info/world-population/kuwait-population/

Submitted: July 2020

Accepted: Decmber 2020