Climate Change and Morphological Stability

Batroun scale, Lebanon

Co-Evolve4BG

Analysis of Threats and Enabling Factors for Sustainable Tourism at Pilot Scale

Climate Change and Morphological Stability

Batroun scale, Lebanon

OVERVIEW

The present document was issued within the framework of **Co-Evolve4BG** project "*Co-evolution of coastal human activities & Med natural systems for sustainable tourism & Blue Growth in the Mediterranean*" in relation to Threats and Enabling Factors for maritime and coastal tourism development on a national scale" Co-funded by ENI CBC Med Program (Grant Agreement A_B.4.4_0075).

This document consists of the **Deliverable 3.1.2.29** (Climate Change and Morphological Stability –Batroun scale, Lebanon) of the **Activity 3.1.2** (Threats and Enabling Factors at local scale: Pilot Areas analysis) under the **Output 3.1** (Integrated analysis of Threats and Enabling Factors for sustainable tourism at MED scale) of the project.

REVIEW

Contributors

Talal DARWISH, Pr.
National Center for Remote Sensing– CNRS, Lebanon
Amin SHABAN, Pr.
National Center for Remote Sensing – CNRS, Lebanon

Reviewers

Sihem BENABDALLAH, PhD
Center for Water Research and Technologies – CERTE, Tunisia

Supervisors

Béchir BEJAOUI, PhD
National Institute of Marine Sciences and Technologies, Tunisia
Nahed MSAYLEB, PhD
Lebanese University, Faculty of Agriculture and Veterinary Sciences, Lebanon

LAYOUT

Khouloud ATHIMEN, Engineer, Technical Coordinator
National Institute of Marine Sciences and Technologies, Tunisia
Houaida BOUALI, Engineer
National Institute of Marine Sciences and Technologies, Tunisia
Mohamed Ali BRIKI, Engineer
Coastal Protection and Planning Agency, Tunisia

Index

List of figures

List of tables

List of abbreviations

CCKP	Climate Change Knowledge Portal
MoPWT	Ministry of Public Works and Transport
GDCA	General Directorate of Civil Aviation
CAL	Climatic Atlas of Lebanon
LARI	Lebanese Agriculture Research Institute
CNRS-L	National Council for Scientific Research-Lebanon
TRMM	Tropical Rainfall Measuring Mission
CHIRP	Climate Hazards Group Infrared Precipitation with Stations
NOAA	National Oceanographic Data Center
UNDP	United Nations Development Program
GDP	Gross Domestic Product
SIRA	Strategic Research and Innovation Agenda
DRR	Disaster Risk Reduction
FAO	Food and Agriculture Organization

I. Introduction

Located along the Eastern Mediterranean Basin, Lebanon is a small country with about 10,452 km^2 having attractive natural features, where its rugged topography encompasses two mountain chains that extend parallel to the Mediterranean Sea, separated by a wide plain. Therefore, the mountainous Lebanon topography makes it a meteorological barrier that confines all cold air masses derived from the west and condensates them as masses of rainfall and snow. This is the reason behind the high precipitation rate in Lebanon which averages to about 900 mm, and this is manifested in the availability of water resources, and thus the dense vegetation cover.

Lebanon enjoys the Mediterranean climate, which is generally moderately cold and rainy in winter, hot and humid in summer, and mild in spring and autumn. The average temperature ranges between 14 °C in winter and 27 °C in the summer, which is in general moderate. Therefore, Lebanon is a remarkable place in the entire Middle East Region, and this can be attributed to: the mild climate, the proximity between the sea and mountains, snow cover on the adjacent mountain, long coastline (240 km), rivers, springs and wetlands, forests; in addition to the presence of archeological and heritage sites. These characteristics made Lebanon the first touristic destination in the 1970s.

Despite its diverse topography, almost all Lebanese regions enjoy similar natural characteristics, but they differ in that some are mountainous, and others are coastal regions, and each has its own natural attraction. Another advantage is that all attractive sites in Lebanon are close to each other due to the small area of the country and then they can be visited within short time intervals.

Batroun is a coastal city along the Lebanese coastline, and it represents a typical aspect of the Lebanese touristic (coastal) cities. It belongs to Batroun District which has a surface area of about 287.5 km^2, while the City of Batroun is about 468 ha, and it has more than 10,500 people. Its gradational elevation from the sea goes up to 120 m.

The City of Batroun encompasses several touristic advantages including a big number of hotels, restaurants and coastal resorts, a port with touristic commercial and fishery activities, traditional markets and handcrafts, heritage, and archeological sites. It is considered as one of the best tourist destinations in North Lebanon. It includes many landmarks characterized by religious, heritage and archeological aspects, such as the historic Roman Catholic and Greek Orthodox churches, “Makaad El Mir” ruins by the rocky beach in Batroun, the Ancient Phoenician Wall, Mseilha Fort, and Old Souk.

Many challenges were raised lately in Lebanon including mainly the economic crisis and the unstable security situation, and more recently the impact of the Covid-19 pandemic added more constraints to the economic circulation in the country. This has influenced the tourism sector in Lebanon, which has been unstable for a few decades due to the recurrent events and geopolitical conflicts, and lastly the event of Beirut Port Blast which occurred in August 2020.

However, these are not the only challenges influencing the tourism sector in Lebanon, since there are additional challenges manifesting from the change of climatic conditions and its consequences (*e.g.*, mass movements, coastal erosion, sea level rise, *etc.*); plus, several negative human interferences, such as uncontrolled works whether on land (*e.g.*, quarrying, wildfire, *etc.*) or along the coastline where the destruction of shoreline and urban encroachments are well pronounced.

In this regard, there is a great need to investigate two main natural components that affect the tourism sector in Lebanon in general and Batroun City in particular. These are the climate change and the morphological stability of Batroun City and the surroundings; notably that climate and morphology have a major effect in the evolution of natural ecosystems. Hence, any imbalance in these two components will threaten the enabling factors for the development of coastal and maritime tourism at the national scale.

This deliverable (related to Tender CoE4BG-LB-ENI-03/2020, #1: ID-PA6-01) is dedicated to study and analyze the available climatic records for the Batroun City and the surroundings, emphasizing on rainfall and temperature as the main two meteorological parameters. These will be primarily considered to investigate the changes in climatic trends. Climatic data will be retrieved from the obtained studies and research projects adopted from ground measurements and from data acquired from remotely sensed tools whenever gaps in ground measurements are absent. Moreover, this deliverable will analyze the morphological features (terrestrial and coastal) of Batroun City and its surroundings. Therefore, the main physical characteristics of the coastline and the adjacent mountains will be diagnosed, and this will be achieved using all thematic maps required accompanied by field surveys to assure reaching creditable morphological data and information.

II. Climatic Characteristics

Batroun City has a small surface area however, it is influenced by the overall climatic conditions of Lebanon, which is described by the Climate Change Knowledge Portal (CCKP, 2021) as hot-warm to cold summer Mediterranean climate that gradually changes with elevated topography. Therefore, Batroun City has a hot to warm summer Mediterranean climate; however, the closeness of the elevated regions to Batroun City affects its humidity, notably the wind blowing from the sea into the adjacent mountains resulting with climatic turbulence. According to Shaban and Houhou (2015), almost all the coastal zone of Lebanon, including Batroun, is classified as semi-arid to sub-humid climate.

The most significant climatic parameters to be investigated are the precipitation and temperature, which are affecting other climatic parameters such as humidity, sunlight radiation, wind, *etc.* In this respect, the surrounding regions of Batroun City will be assessed in the climatic analysis since they are geographically within the same climatic zone, and they have a common impact on each other. Therefore, rainfall, snow cover, and temperature will be analyzed in this report to draw accurate conclusions. Hence, climatic data availability has a role in the analysis, notably, several gaps exist in the climatic records of Lebanon.

II.1. Data sources

Lebanon is lacking sufficient and uniformly distributed meteorological stations. It had 70 meteorological stations till the 1990s, but most of them were destroyed and very few remain functional. The number of these stations has increased lately especially when climate change was exacerbated and affected water resources and agricultural productivity. Thus, there are about 125 operational meteorological stations distributed over the entire Lebanon, where 75 are in the coastal zone and the adjacent (moderate altitude) mountain chains. More specifically, there are 41 stations located along the coastal strip.

The meteorological stations in Lebanon are equipped to measure the principal climatic parameters, where three of these stations are also measuring snow-water equivalent. The meteorological stations of Lebanon are under the mandate/operated by different public and private institutions, including mainly:

- Ministry of Public Works and Transport (MoPWT), operated by the General Directorate of Civil Aviation (GDCA), and disseminated the Climatic Atlas of Lebanon (CAL).
- The Lebanese Agriculture Research Institute (LARI).
- Miscellaneous climatic records disseminated by several research bases (*e.g.*, CNRS-L, AUB, Saint-Joseph, *etc.*).

There are constraints in climatic data preparedness, notably the lack of continuous datasets, non-uniform geographic distribution, and insufficient number of stations, plus the lack of data sharing between different institutions. In this case, remotely sensed products are significant to gather the needed dataset for analysis. Therefore, substantial datasets on rainfall and temperature were extracted from these products. This includes data retrieval from the:

- Tropical Rainfall Measuring Mission (TRMM) which is operated by NASA and JAXA, and it has been disseminating data since 1998.
- Climate Hazards Group Infrared Precipitation with Stations (CHIRPS, 2020).
- NOAA climatic data system - National Oceanic and Atmospheric Administration Data Center (NOAA, 2013).
- A miscellany of World weather and local weather forecast portals (*e.g.,* Weather Atlas, World-data, Tu-tiempo, *etc.*).

In this report, and based on the data sources, climatic data for Batroun City and its surroundings were prepared for detailed climatic analysis. This includes the coastal strip of Batroun from the west until the most facing mountainous regions to the east, comprising the Batroun District, where altitudes attain 2,200 m.

II.2. Precipitation

In a country like Lebanon, precipitation encompasses both rainfall and snow, which are significant sources of meteoric water, knowing that water is the most vital resource where vital sectors depend on, notably agriculture and the whole ecological system, and this is fully applied to Batroun City and its surrounding. Thus, the precipitation rate in Lebanon is characterized by good water availability.

The diverse topography in Lebanon makes precipitation with uneven distribution even between neighboring areas; however, it is mainly altitude controlled as it increases upward, starting from the coastal zone until the mountainous region. Batroun City, as located in the coastal zone, receives a relatively low rainfall rate compared with its neighboring regions, and this is also the case for temperature.

II.2.1. Rainfall

Rainfall measurements for Batroun City and its surrounding has been adopted from several available sources due to the lack of complete time series for the city, which is like many Lebanese regions. Therefore, climatic data for Batroun was derived from the source mentioned in Section 2.1, and more specifically from: Plassard (1971), CAL (1982), CNRS-L (2015), and UNDP (2016), where many datasets were adopted from the remotely sensed products when gaps occur. In this regard, climatic data was also considered from the surrounding station to Batroun City, and certainly from Tripoli and Qartaba stations which are located to the north and south of Batroun and with a distance less than 25 km for each. Collectively, the available rainfall data is reported in Table 1.

Table 1. Rainfall data source for Batroun City and the surroundings.

Time series	Data source	Area
1940-1971	CAL (1982)	Batroun
1990-2000	UNDP (2016)	Batroun
1970-1980	NOAA (2013)	Tripoli
1950-1972	CAL (1982)	Tripoli and Qartaba
1960-1970	Plassard (1971)	Lebanon
1998-2013	CNRS-L (2015)	Lebanon
1999-2005	TRMM	Batroun
2008-2020	CHRPIS (2020)	Batroun

The overall trend of the rainfall data is illustrated in Figure 1, where it shows that the average annual rainfall rate in Batroun City and the surrounding areas ranges between 8 mm as the lowest value in June to 154 mm as the highest value reported in January. The average annual rainfall for Batroun City and the surroundings is estimated at 725 mm, while the annual number of rainy days is about 62 days where they are above 8 days during January, February, March, and December (Figure 1).

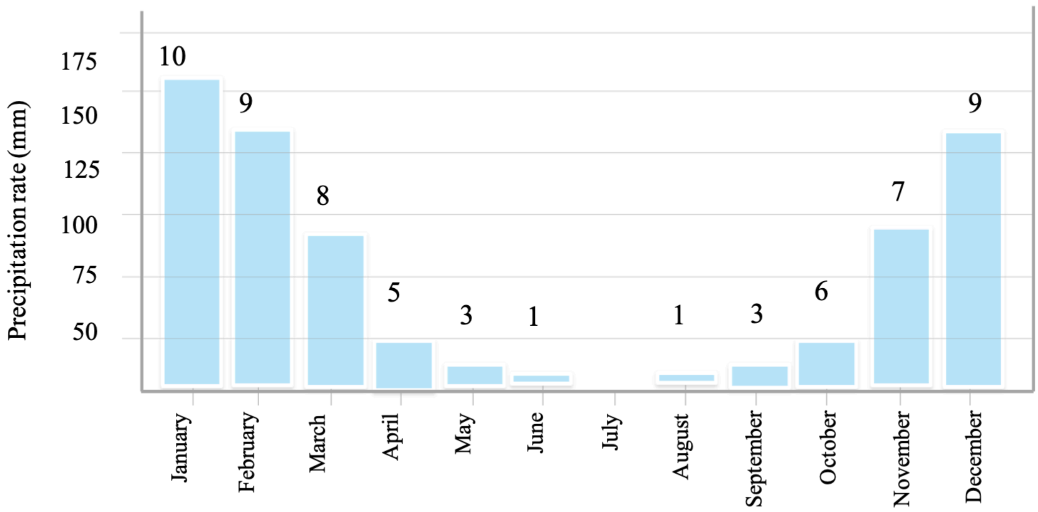

Figure 1. Average annual rainfall rate in Batroun City and the surroundings. Numbers (on columns) represent the number of rainy days per month.

In this regard, it was obvious that the rainfall rate is gradually increasing with altitude, where it ranges between about 725 mm on the coast of Batroun, to about 1110 mm in the Tannourine area at the most elevated part of Batroun District (about 1970 m in altitude). Therefore, the estimated rainfall rate-altitude gradient is about 19.5 mm per 100 m altitude.

II.2.2. Snow cover

Another form of precipitation is the solid precipitation (represented by snow), which annually covers the adjacent mountains of Batroun City to the east. It represents a major source of water in the region where it feeds groundwater and surface water resources. However, snow rarely exists in/nearby the City of Batroun, but it has been reported that the number snow days are altitude-related, and they are distributed as follows (Mhawej *et al.*,, 2013):

Table 2. Variation of rainy days with altitude for Batroun City and the surroundings.

Altitude	Number of rainy days
> 2,500 m	65 days
2,500-2,000 m	37-38 days
2,000-1,500 m	15-16 days
1,500-1,000 m	3-4 days
1,000-500 m	1-2 days
< 500 m	< 1 day.

This means that Batroun District (up to about 2000 m altitude) is witnessing up to more than about 35 days of snow annually. However, less than one day of snow exists in the City of Batroun, and it is well known that the snow occurs once each five years along the coastal strip of Lebanon.

Regarding the thickness of snow, which is an indicator for snow cover, it has been estimated that the average snow thickness in December is 20 cm, 35 cm, 50 cm, 1 m, and 1.2 m for the altitudes 1,200, 1,400, 1,600, 2,000 and 2,200 m, respectively (Shaban, 2020).

II.3. Temperature

Temperature is a significant meteorological factor analyzed for different applications; however, records of temperature in Lebanon are like those of rainfall, incomplete, for limited geographic regions or for intermittent time periods.

Batroun City and the surrounding, similarly to the whole Lebanese territory, is subjected to changes in its air temperature that is traditionally moving in an ascending trend, and this in turn affects several vital sectors, notably water, agriculture as well as other socioeconomic sectors. In general, the average annual temperature in Batroun ranges between 11.2 °C in January and 27.1 °C in August, while the average annual temperature rate in Batroun City and its surrounding is about 19.8 °C (Figure 2).

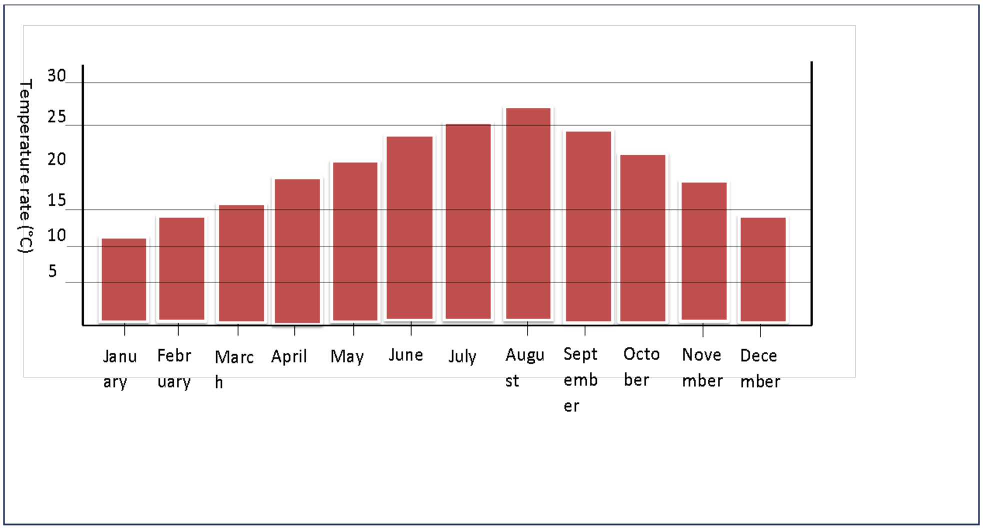

Figure 2. Average annual temperature rate in Batroun City and the surroundings.

On the contrary to precipitation, temperature is gradually decreasing with altitude; and thus, the average annual temperature is 19.8 °C along the coast of Batroun and reaches about 14.4 °C in Tannourine area, at the mountainous part of Batroun District (about 1970 m altitude). Hence, the estimated temperature gradient is about 0.27 °C per 100 m of altitude.

II.4. Relative humidity

Usually, relative humidity is ranked as the third significant climatic parameter after precipitation and temperature, whereas it is generally a function of temperature rate. It is a variable of how much water vapor is in a water-air mixture, compared to the maximum amount possible. The average relative humidity in Lebanon was calculated to around 70% in the coastal zone. While in mountainous regions, relative humidity usually fluctuates between 60% and 80% in winter; and between 40% and 60% in summer (Shaban, 2020).

For Batroun City and its surrounding, the relative humidity ranges between 66% and 72%, where it is distributed as follows: 71, 71, 69, 70, 69, 69, 70, 72, 71, 69, 66, and 70% for the year months starting from January to December; respectively.

II.5. Aridity index

The aridity index characterizes the type of climate with respect to water availability. Therefore, the higher the aridity index of a region, the greater the water resources. It represents a climatic formula where precipitation and temperature are the principal calculated variables. It is a significant component to describe the general climate and water-related availability, notably when climatic zoning is not well defined such as in

Lebanon, which is often contradictory described, such as a semi-arid during the dry season to humid to sub-humid in the wet season (NC, 2011), typically Mediterranean with heavy rains in winter and dry with arid conditions in the remaining months of the year (FAO, 2009).For Batroun City and its surrounding, Aridity Index was calculated using De Martonne Aridity Index (De Martonne, 1926). This Index depends mainly on rainfall and temperature measurements, and thus De Martonne Aridity Index (DAI) is expressed by the following formula:

$$D_{Ai} = [P/(T+10)] + [12þ/(t+10)]/2$$

Where P is the average annual rainfall rate (in mm), T is the average annual temperature rate in degree Celsius (°C), þ is the average rainfall in the driest months and t is the average temperature in the most temperate months. Therefore, De Martonne categorizes the elaborated index as: < 5, 5-10, 10-20, 20-30 and > 30 for arid, semi-arid, semi-humid, humid and very humid; respectively. For Batroun City and the surrounding, De Martonne Aridity Index (DAI) was calculated between 2010 and 2020, and it was obvious that the general climate of Batroun is semi-humid where it this aridity is represented by 56%, and then flowed by 20% and 17% for the semiarid and humid climate; respectively (Table 3).

Table 3. De Martonne Aridity Index for Batroun City and its surroundings (2010-2020).

Arid	Semi-arid	Semi-humid	Humid	Very humid
4%	20%	56%	17%	3%

II.6. Indicators of climate change

Globally, climate is changing, and the changed parameters are different between geographic regions, as well as the degree of change is not the same in these regions. According to the ND-Gain Index, Lebanon is categorized at 106 out of 181 countries that are vulnerable to climate change and its impact.

The two main climatic parameters (*i.e.,* precipitation and temperature) often come on the top for any climatic analysis to deduce any change in climatic conditions for any region, and this is usually viewed over the long term. In this respect, data availability is often a major concern to make climatic analysis and trends. In Lebanon, climatic data availability is still an issue and many studies have been elaborated either for short time series or applied to limited geographic regions, because of lacking data. One of the most comprehensive studies has been done by CNRS-L where a long time series (*i.e.*, almost between 1950s and 2018) was elaborated from utilizing remotely sensed datasets. However, the study covers the entire Lebanon where climatic diversity was obvious for different Lebanese regions including Batroun.

For Batroun City and its surroundings, the available climatic datasets are illustrated in Table 1, which are adopted from remotely sensed products and elaborated by applying simple graphical trends. The overall climate conditions for Batroun Region were inspired from previous studies, such as that realized by the CNRS-L.

II.6.1. Rainfall Indicator

As a liquid aspect of precipitation, which is also considered as the primary meteorological parameter, rainfall was analyzed for Batroun City and its surroundings. The analysis includes long-term rainfall datasets ranging between 1950 and 2020, depending on the available data records which were, as mentioned previously, adopted from different climatic sources and from the remotely sensed products when gaps exist, namely NOAA (2013), and CHIRPS (2018). The analyzed records represent the average monthly rainfall rates (in mm). while, it has been plotted on yearly basis to figure out the general trend of rainfall (Figure 3).

It is obvious from Figure 3 that the general trend of rainfall is in a descending trend, where it shows many rainfall peaks. Therefore, it has been concluded that the average annual rainfall in Batroun City and its surrounding has decreased from 804 mm to 765 mm, with an average of about 22 mm over the past 7 decades. This is almost a rough change in the volume of rainfall water and not very remarkable. At the present time, there is a clear change in the rainfall patterns over the entire Lebanese territory, which has recently moved towards torrential rain patterns, accompanied by several spells of extreme rain and snow; in addition to the shifting in the seasons' dates, as reported by Shaban (2011 and 2020). Currently, the climatic periodicity in Batroun City and its surrounding was estimated to be between 10-12 years (Telesca *et al*.,, 2018).

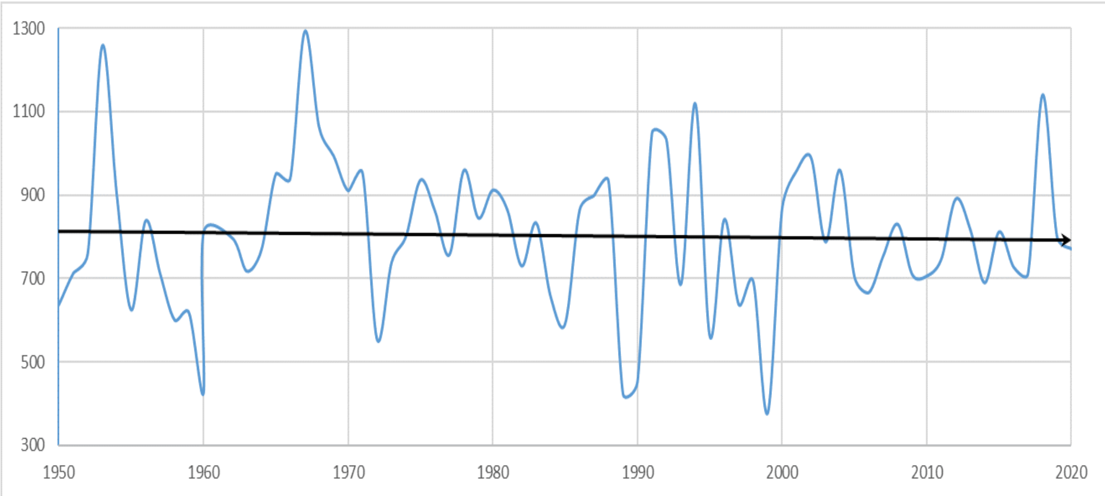

Figure 3. Trend of the average annual rainfall in Batroun City and the surrounding area between 1950 and 2020 (Data adapted from different sources).

The changing rainfall conditions in Batroun City were also inspired from climatic data in the neighboring station, and typically from Tripoli to the north and Qartaba to the south, to figure out the general rainfall conditions for Batroun City and the surrounding mountains facing the Mediterranean, where a decrease in rainfall was noticed even though it was not very remarkable (Figure 4).

II.6.2. Snow cover Indicator

As mentioned previously, Batroun City rarely witnesses snow events, and was estimated at one event per 5 years. However, snow begins to accumulate on the adjacent mountainous regions to Batroun, while there is a wide distribution of snowpack on the elevated regions to the east, where considerable snow thickness and cover have been reported (Telesca *et al.*, 2014; Shaban, 2020). This is well pronounced in Tannourine, Hadath Al-Job, Bcharre and the surrounding mountains of Kornet Essawda (*i.e.*, above 2,800 m). Therefore, the accumulation of snow in these regions affects coastal water resources. In addition, the proximity of snow to Batroun City contributes to tourism attractions and it is worth investigation and involvement while analyzing climatic conditions.

In this respect, the recorded snow measurements in the adjacent mountainous regions to Batroun show no remarkable changes over the studied period which has been carried out between 2010-2018. The thickness and the snow cover area were almost oscillating over different years. Nevertheless, there is a noticeable increase in the melting rate and sublimation of snow cover; thus, the accumulated snowpack is disappearing within a shorter duration than before, and it was estimated at about 3-4 months in the past, while it lasts for 1.5-2 months at present (Shaban, 2020).

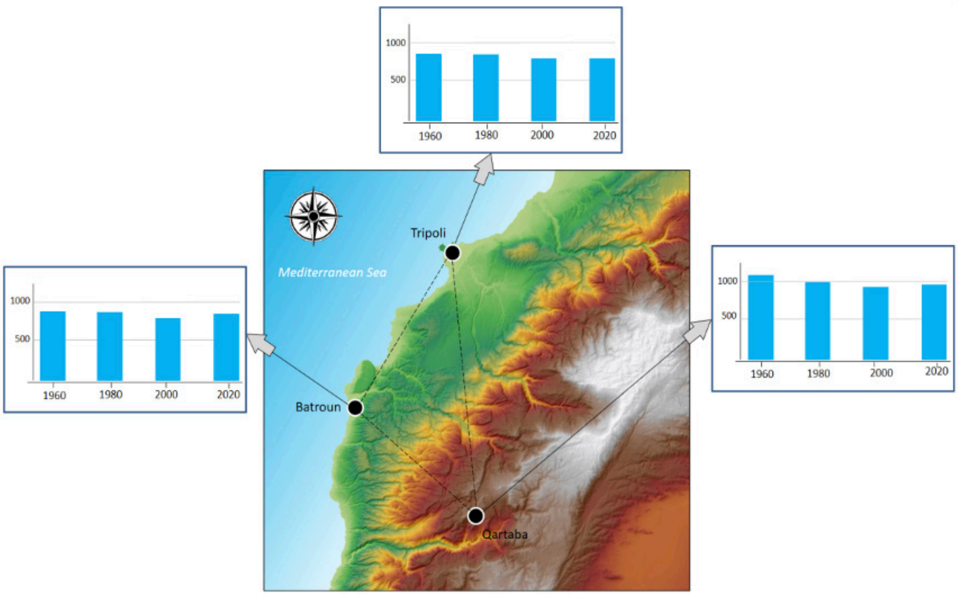

Figure 4. Overall change in the average annual rainfall in Batroun City and the surrounding regions of Tripoli and Qartaba.

II.6.3. Temperature Indicator

Available records for temperature in Batroun City and its surrounding are almost incomplete and sometimes different between data sources. However, the analyzed datasets to deduce the trend of temperature in the region were adopted from different sources to have the most complete time series.

Therefore, the general behavior reveals an ascending trend (Figure 5), where the average temperature increase was estimated at 1.7 °C. However, this figure shows several temperature oscillations, whether in the increase or the decrease in temperature rates over different time periods, which can be attributed to the influence of the recent meteorological fluctuations that occurred lately in the whole Middle East Region (Telesca *et al.*, 2018).

II.7. Evidence of climate change

It is well noticed by locals that the climate has changed in the Batroun area similarly to the entire Lebanon. However, this is just a general consideration by locals, without factual evidence on the temporal/or geographic dimensions. Such evidence is often noticed during field surveys carried out by researchers, where many features have been reported, and they point out to the changes occurring over the past time in the climate of the coastal zone in general and in Batroun City and its surrounding.

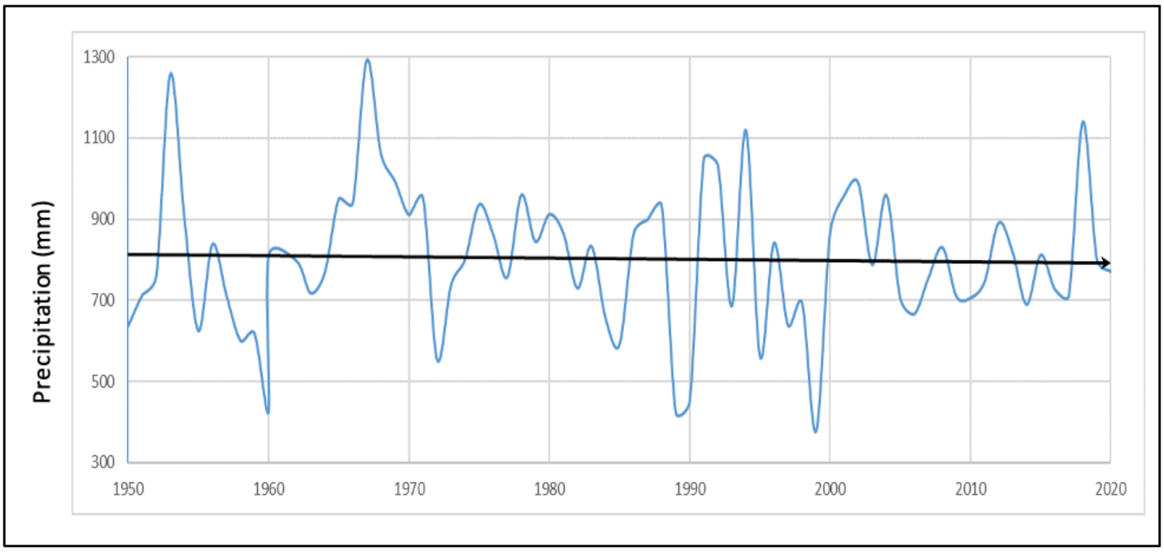

Figure 5. Mean annual temperature of Batroun City and the surroundings between 1974-2020 (Data adapted from multiple sources).

Even though the recognized climate change features (evidence) do not specify the exact changed parameter, they could be used for declaring changes that occurred in the terrain characteristics because of the changing climate. Other than the previous measurable datasets obtained on precipitation and temperature, there are observations supporting ancient and recent climate change in the Batroun area as follows:

1) Paleo-sedimentation: This is a common feature observed along the coast of Batroun and it extends southward to the Madfoun area. There is an obvious ancient sedimentation sequence with different grain size of alluvial sediments evidencing abrupt changes in the riverbed loads due to the diverse climatic conditions in the region (Figure 6a). The abrupt difference in the grain size and their shape of alluviums indicates the diverse energy in the ancient stream flow over different time periods, and this implies paleo-climatic conditions. Thus, larger size grains (*e.g.*, pebbles and cobbles) required high flow energy and then intensive rainfall, and vice versa (Figure 6a).
2) Sand bars: These are accumulation of beach sand constituting elongated sand bars where the sweater extends beyond these bars. This proves the changing sea water level because of changing climatic conditions (Figure 6b).
3) Old agricultural terraces: The change in rainfall rate, plus many other socioeconomic factors, resulted in the disregard of farmers to their agricultural lands. This is well pronounced in the Batroun area; and certainly, in the surrounding mountain where several neglected terraces were observed (Figure 6c).

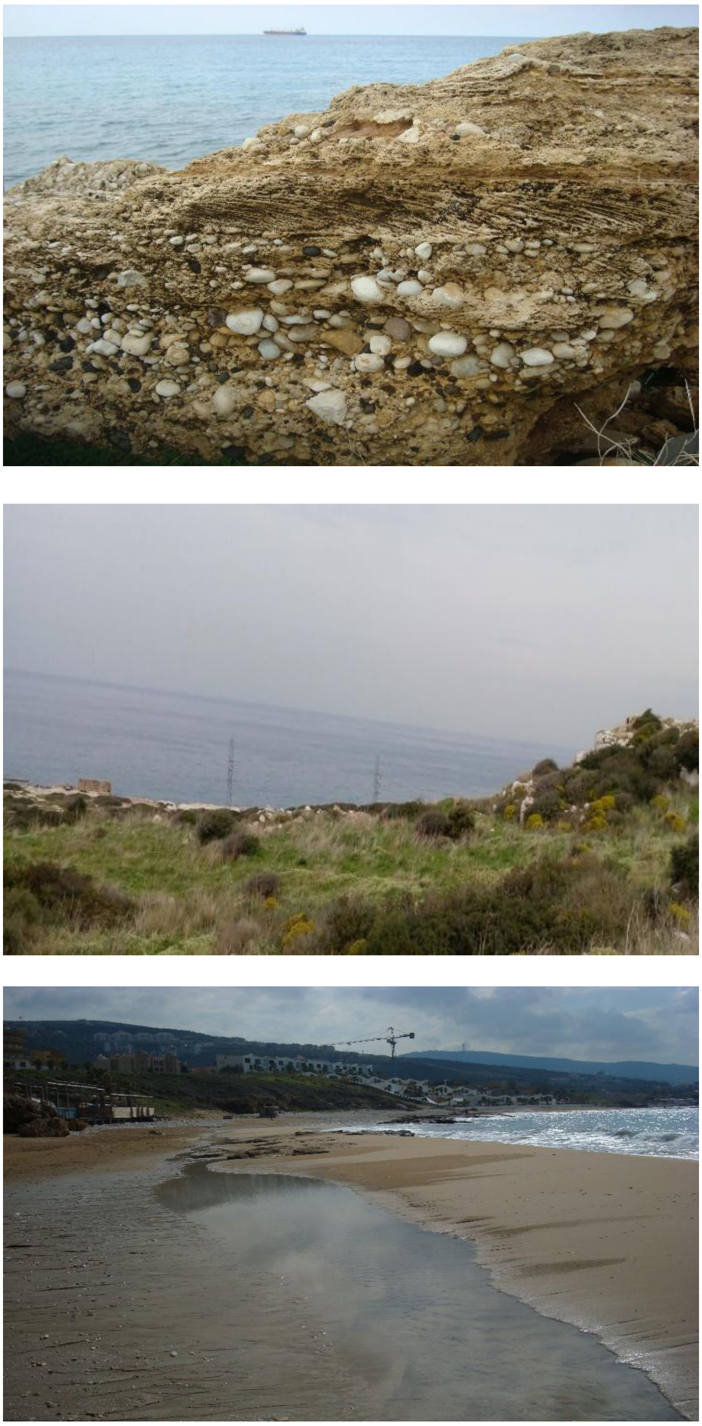

Figure 6. Evidence on climate change in Batroun City and the surrounding. a) Paleo-sedimentation with diverse grain size of alluviums; b) sand bars; c) old agricultural terraces

III. Blue Economy and Climate Change

Resources of the coasts and the maritime regions provide about USD 1.345 billion annually (Roberts, 2015). However, there is rapid and uncontrolled economic development in the maritime region which manifests substantial risks for people and for the maritime environment (Bennett *et al.,* 2021). However, there are several key challenges affecting the blue economy worldwide, and more particularly in the Mediterranean Region. This Includes the impact of climate change on several sectors including tourism, fishery, ecosystem, *etc.* Therefore, the optimal blue economy is controlled by many factors where climate change has been lately raised as one of the most influencing. Besides, the blue economy offers opportunities for climate change adaptation and mitigation. This can be applied to the entire coast of Lebanon where Batroun City is a typical example as follows:

1. There is significant dependence on the wealth of resources within the coast of Batroun and its maritime region to support the income for many locals and this contributes also to the country's GDP. It represents the main form of blue economy in the studied area which presents opportunities to new jobs and activities such as commerce, livestock, industries, aquaculture, transport, *etc.* This will assist in building climate resilience, reduce the region's dependency on energy imports, and address the achievement of food security. In this regard, tourism remains a steadfast and important aspect of the blue economy in this region.
2. Blue economy has a significant role in conserving shallow coastal water ecosystems, tidal marshes and sea grass beds which are critical to regulate natural carbon sinks. In addition, the coastal habitats have been found to fix carbon. In this respect, there is an obvious concern in Batroun City to conserve these components which contribute to climate change mitigation.
3. As a target policy to develop blue economy, the involvement of Lebanon with regional strategies such as Blue-Med Strategic Research and Innovation Agenda (SRIA, 2018), is important in the adaptation to climate change; especially in Disaster Risk Reduction (DRR) which requires capacity building and readiness of coastal populations to adapt.
4. the adverse impacts of climate change. This is well pronounced in Batroun City where several protection measures are applied along the coast.

If it is applied properly with the consideration of environment and ecosystem conservation, the blue economy can boost tourism along the coastal zone and even in the maritime region. Hence, the coastal and maritime regions proved to be geographic spots for the tourism industry, especially that the coastal zones are always the main hubs for smart cities where tourism is well developed, like the case in Batroun city. Therefore, adoption of the blue economy will master human implementations and increase their regulated activities along the coastal zone and the maritime region, as well as create protection measures and develop new civilized methods and urban clusters. This will help develop new tourist industries, and Batroun City is a good example of the blue economy, which still needs to be enhanced.

IV. Coastal Geomorphology

The coastal zone of Lebanon is the most vital part of the country where the largest number of human activities are located with its dense urban development. In particular, the shoreline of this zone is highly vulnerable to natural and man-made changes which are well developed along the coastal strip. However, this strip is still a part of the in-land areas where from loads (*e.g.,* sediments from rivers and streams, backfilling, wastes dumping, *etc.*) are dumped from one side and the interaction/impact with the maritime region from the other side (*e.g.,* waves impact, coastal erosion, *etc.*). Therefore, it is essential to characterize the geomorphology of the coastal zone including specifically the shoreline morphology and coastal materials distributed along the coast; especially for the main cities with developed touristic aspects such as Batroun City.

IV.1 Shoreline morphology

The studied shoreline of Batroun extends between Koubbeh (along Al-Jawz River) in the north to El-Borj in the south, with a total curved length of about 4.53 km. It spans in NNE-SSW direction, and it is situated between the following geographic coordinates:

34° 16’ 05” N & 35° 39’ 28” Eat Al-Jawz River outlet.

34° 14’ 03” N & 35° 39’ 18” E at El-Borj.

The main components of Batroun shoreline are almost irregular, where there are several rocky intrusions into the sea forming land portions, besides several small-scale bays. The most dimensional ones of these components can be classified as in Table 4.

Table 4. Main shoreline components of Batroun City.

Rocky intrusion	Coordinates		Small-scale bays	Coordinates	
	Latitude	Longitude		Latitude	Longitude
MARSATI locality	34°15’36”	35°39’26”	Batroun Port	34°15’28”	35°39’28”
Batroun old Sook and Phoenician Wall	34°15’19”	35°35’20”	Bay of Maqaad El-Meer	34°15’08”	35°39’25”
Portion between Aquarium and Kite Batroun Spot	34°15’03” 34°14’48”	35°39’25” 35°39’32”			
Batroun rocks	34°14’20” 34°14’02”	35°39’32” 35°39’19”			

Therefore, the meandering ratio (M_r), representing the irregularity for the shoreline of Batroun was calculated to deduce its overall irregularity, and this has been applied using the following equation:

$$Mr = \frac{\Sigma\ Ls\ (straight\ shoreline\ length)}{\Sigma\ Lc\ (curved\ shoreline\ length)}$$

$$M_r = 3.18/4.53 = 0.70$$

Hence, if M_r equals 1 that means the shoreline is totally straight; however, the resulting M_r for the shoreline of Batroun (0.70) indicates a slight meandering coastal strip.

For the shoreline of Batroun City, the change detection in its alignment has been investigated for the period between 1963 and recent using topographic maps (1:20,000), which were generated from aerial photos, and high-resolution satellite images (IKONOS). Figure 7 shows the two alignments of 1970 and recently 2021, where the irregularity (meandering ratio) in the shoreline has been increased due to many human activities including mainly backfilling of the sea and the urban sprawl and chaotic constructions towards the maritime region. This should also be affected by natural coastal processes, such as coastal erosion and the etching of coastal materials.

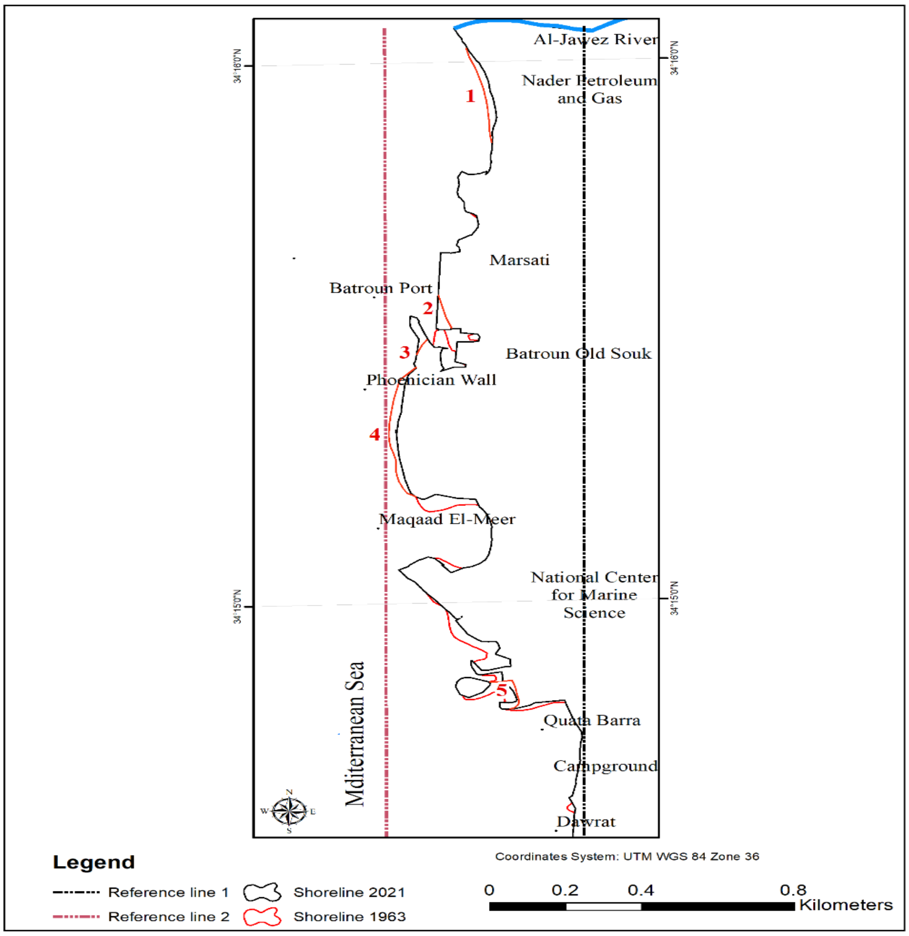

Figure 7. The shoreline of Batroun City in 1963 (from topographic maps) and in 2021 (Detected from satellite images).

As a result, the meandering ratio M_r of Batroun shoreline was 0.6 in 1963 and it increased lately (2021) to 0.7. Therefore, a Reference Line (virtual Line) was plotted to determine any increase or decrease in the shoreline (from/ or into the sea) of Batroun City. Based on the map given in Figure 7, the changing shoreline dimensions are shown in Table 5.

Figure 8. Changes in the shoreline of Batroun City between 1963 and 2021.

Coastal Stretch No	Change	Length (m)	Width (m)	Area (m²)
1	Decrease	339	40	13,560
2	Increase	99	31	3,069
3	Increase	91	20	1,820
4	Decrease	425	49	20,825
5	Increase	318	18	5,724

**According to the map in Figure 7.*

The decrease in the shoreline area is about 34,385 m^2, beside an increase of about 10,613 m^2, which reflects a total decrease of about 23,772 m^2, and this means that the average decrease in the shoreline of Batroun City over the last 6 decades (1963 and 2021) is about 410 m^2/year. The decreased area in the shoreline is attributed mainly to coastal erosion and the etching processes of coastal material.

IV.2. Coastal materials

Even though the coast of Batroun City is relatively small (4.53 km); however, it occupies diverse materials composed largely of fluvial and alluvial deposits and marine and terrestrial sediments, which are sometimes located within the same site (Figure 8).

Figure 9. Example of mixed coastal materials along Batroun coast.

These materials are intruded and mixed with each other due to natural and man-made conditions. Therefore, the origin and geographic distribution of these materials is controlled by many factors including mainly from the coast by the geomorphology of the in-land, lithology and geologic structures, and hydrology from terrestrial side; bedsides the littoral processes from the marine side, with the meteorological regime and processes which are always influencing both sides.

To characterize the geographic distribution of the coastal materials located along the shoreline of Batroun City, a detailed field survey has been carried out where the geospatial databases retrieved from the processed satellite images were used for further field investigation. For this purpose, Sentinel-2 satellite images (10 m spatial resolution, with 13 spectral bands) were analyzed using ERDAS-Imagine software, version 10 software by which digital advantages and enhancement processes (*e.g.,* band combination, filtering, color slicing, edge detection, *etc.*) have been applied to identify terrain features that evidence the located materials along the studied shoreline. In addition, the relevant topographic and geologic maps used are as follows:

1) Topographic maps 1:20,000 (MoND, 1963)
2) Geologic maps 1:50,000 (Dubertret, 1953)
3) Geomorphologic maps 1:50,000 (Sanlaville, 1977).

The studied coastal materials were found with different lithological characteristics including the soft, hard rock with mixed sediments and rock debris, which are observed either as slightly straight coasts with friable sediments or as irregular coasts with massive and consolidated rocks, and both coasts are influenced by urban sprawl. In addition, there are several coastal platforms and vermetid reefs along the coast of Batroun forming small rocky islands. They also represent an integral part of the coastal materials and geomorphology (Figure 9).

Figure 10. Coastal platforms and vermetid reef along the shoreline of Batroun City.

The identified geomorphological features are located on the shoreline and the adjacent lands to the east. Some of the identified elements were adopted or modified after the geomorphological maps obtained by Sanlaville (1977) and the geological maps of Dubertret (1953). Hence, a map showing the coastal materials for the coast of Batroun was produced (Figure 10).

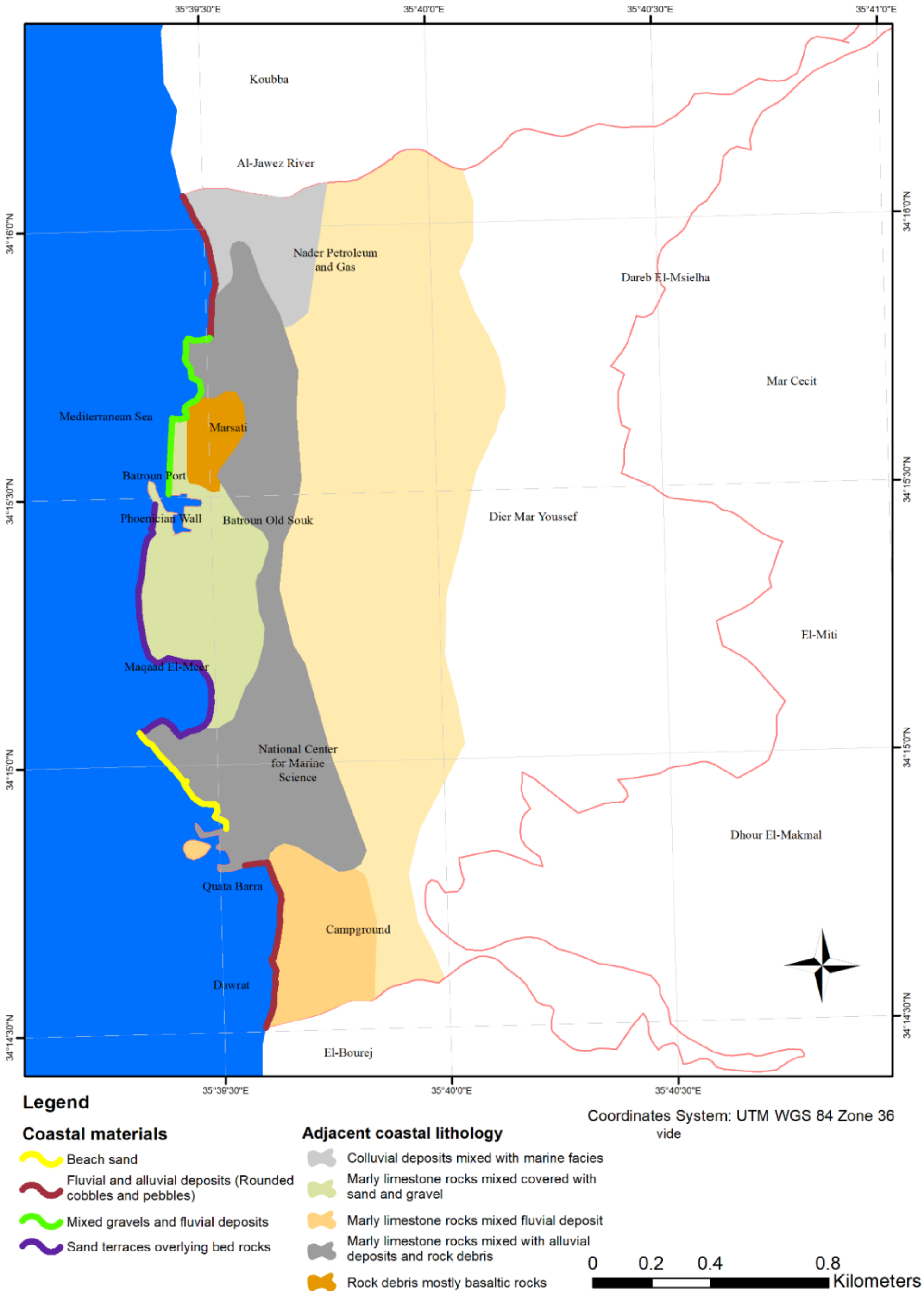

Figure 11. Coastal materials located along the shoreline of Batroun City.

Table 6 shows the identified coastal materials along the shoreline of Batroun City and in the proximity of the shoreline which extends to a range on-land. This was verified in a field survey in the area of concern. Therefore, the detailed characteristics of these materials were reported from the field notes and from the topographic maps following the geological and geomorphological classifications. Thus, the identification of these materials and their distribution help in assessing their vulnerability to coastal processes as well as for the proposition of protection measures required.

Table 6. Identified coastal materials and their characteristics along Batroun City.

#	Proximity to the sea	Coastal materials*	Description	Shoreline uniformity	Total length (m)	%
1	Exactly along the shoreline	Fluvial and alluvial deposits (Rounded cobbles and pebbles)	Boulders, Cobbles, and pebbles mixed with sand and gravel derived mainly from Al-Jawz River and from the located streams	Slightly straight coastline	1,257	27.7
2		Mixed gravels and alluvial deposits	Gravels is dominant, as well as Cobbles and pebbles mixed with different size sediments	Moderately irregular shore	779	17.2
3		Sand terraces overlying bed rocks	Elongated rock pavement overlain by consolidated, and cross-bedded sandstone	Mainly irregular and collapsed shoreline with obvious coast etching	1,276	28.2
4		Beach sand	Friable sand with several indications of sea washing	Smoothly curved shoreline	537	11.8
Construction		Batroun Port and touristic resorts			681	15.0
Adjacent to the shoreline		Colluvial deposits mixed with marine facies				
	Marly limestone rocks mixed with alluvial deposits and rock debris					
	Rock debris mostly basaltic rocks					
	Marly limestone rocks mixed covered with sand and gravel					
	Marly limestone rocks mixed fluvial deposit					

*According to Figure 9.

**Percentage with respect to the total length of Batroun City shoreline.

V. Conclusions

The studied coast of Batroun City is a typical example for many of the Mediterranean coasts, in particular to the Lebanese coast, whether for its climatic conditions and the changing climate evidence, or for its geomorphological aspects. However, the coast of Batroun City is distinguished by a variety of natural and man-made coastal characteristics where urban sprawl hides many of the natural components of this coast, as well as the ecosystem is apparently under big stress due to human activities whether they are located directly on the coast or derived from the neighboring mountainous regions.

The climate of Batroun represents the Mediterranean climate and the mild aspect of Lebanon's climate with four distinguished seasons, and it is, in general, a sub-humid climate as it was calculated in this report. However, an obvious change in the main climatic parameters has been found whether in the rainfall patterns or in the temperature and this could have a significant impact on the tourism industry in the city.

Climate change has also had an impact on the blue economy in the city and the surrounding, since there is a big dependence of locals on the coastal and maritime regions adjacent to the city. There are no clear measures adopted yet to reduce the impact of the changing climate. This is well pronounced from the neglected coast with a special emphasis on the coastal materials which are almost exhausted from uncontrolled human activities including chaotic urbane encroachment. Therefore, the natural setting of the coast of Batroun City is almost lost and even their coastal materials are subjected to unfavorable works.

This report shows an in-depth diagnosis for the climate of Batroun City and its surroundings, as well as evidence for the changing climate in this region. It also presents, for the first time, a detailed classification and mapping of the shoreline of the city and the materials located on the coast. Therefore, it provides significant information for decision-makers to adopt their environmental strategy, especially when mainstreaming the tourism sector.

References

Bennett, N., Blythe, J., White, C., Campero, C., 2021. Blue growth and blue justice: Ten risks and solutions for the ocean economy. Marine Policy. 125.

CAL, 1982. Atlas Climatique du Liban, Tome II. Service Météorologique, Ministère des Travaux Publics et Transports. 40.

CCKP (Climate Change Knowledge Portal), 2021. Climate Change Knowledge Portal for development and practitioners and policy makers. Climate change overview. country summary: Lebanon. Available at: https://climateknowledgeportal.worldbank.org/country/lebanon

CHIRPS, 2020. Climate Hazards Group InfraRed Precipitation with Station data. Available at: http://chg.geog.ucsb.edu/data/chirps/

CNRS-L (National Council for Scientific Research, Lebanon), 2015. Regional Coordination on Improved Water Resources Management and Capacity Building. Regional Project. Technical Report. GEF, WB.

De Martonne, E., 1926. Aréisme et indice aridité. Comptes Rendus de L'Académie des Sciences. 182: 1395-1398.

Dubertret, L., 1953. Cartes 1953 de la Syrie et du Liban au 1/50000me. 21 feuilles avec notices explicatrices. Ministère des Travaux Publics. L'imprimerie Catholique, Beyrouth, 66.

FAO, 2009. AQUASTAT. Water Report 34. Available at: http://www.fao.org/nr/water/aquastat/countries_regions/LBN

Mhawej, M., Faour, G., Shaban, A., 2013. Towards an enhanced method to map snow cover areas and derive snow-water equivalent in Lebanon. Submitted to the Journal of Hydrology.

MoND (Ministry of National Defense), 1963. Topographic maps of Lebanon. Lebanese Army, Geographic Affairs. Batroun Sheet, scale. 1: 20.000.

N.C., 2011. Lebanon's Second National Communication to the UNFCCC. Ministry of Environment. GEF. UNDP.191.

NOAA (National Oceanographic Data Center), 2013. Lebanon Climatological Data. Library. Available at: https://library.noaa.gov/Collections/Digital-Docs/Foreign-Climate-Data/Lebanon-Climate-Data

Plassard, J., 1971. Carte pluviométrique du Liban au 1/200 000. Lebanon: Ministry of Public Works and Transport.

Roberts, J., 2015. The Blue Economy: From Concept to Reality in the Caribbean Region.

Discussion Paper for the Caribbean Regional Dialogue with the G20 Development Working Group.

Sanlaville, P., 1977. Etude géomorphologique de la région littorale du Liban. Publications de l'Université Libanaise. Section des études géographiques, Beyrouth, tome I, 405.

Shaban, A., 2011. Analyzing climatic and hydrologic trends in Lebanon. Journal of Environmental Science and Engineering. 3: 5.

Shaban, A., 2020. Water Resources of Lebanon. Springer Nature Switzerland. 229 pp.

Shaban, A., Houhou, R., 2015. Drought or humidity oscillations? The case of coastal zone of Lebanon. Journal of Hydrology. 529:1768-75.

Shaban, A., Drapeau, L., Telesca, L., Amacha, N., Ghandour, A., 2020. Influence of Snow Cover on Water Capacity in the Qaraaoun Reservoir, Lebanon. Arabian Journal of Geosciences. 14: 15.

SRIA (The Blue-Med Strategic Research and Innovation Agenda), 2018. Blue growth. Available at: http://www.bluemed-initiative.eu/strategic-research-and-innovation-agenda/

Telesca, L., Shaban, A., Awad, M., 2018. Analysis of heterogeneity of aridity index periodicity over Lebanon. Acta Geophysica. 67: 167-176.

UNDP (United Nations Development Program), 2016. Liban-Etude des Eaux Souterraines. New York. United Nation.

DISCLAIMER

PARTNERS

ASSOCIATES PARTNERS