Climate Change and Touristic Area Morphological Stability

In Lebanon

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Co-Evolve4BG

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

Climate change and touristic area morphological stability in Lebanon

الجمهورية اللبنانية
وزارة الاشغال العامة والنقل

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OVERVIEW

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REVIEW

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AUB	American University of Beirut
GDCA	General Directorate of Civil Aviation
LARI	Lebanese Agriculture Research Institute

Abstract

This document is about the various threats linked to the touristic area morphological stability in Lebanon. It gives an overview of the coastal morpho-dynamics in touristic areas in Lebanon, considering climate change. The current report researches as well the relationship between coastal development, urbanisation, and the types of coastal touristic activities.

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I. Introduction

Lebanon is located along the Eastern Mediterranean Sea with a total surface area of 10,452 km^2. Lebanon's regional geographic location as an intersection between Asia, Europe, and Africa, makes it the crossroad of different cultures thanks to the easy access to both transportation and communication between the different continents and regions. Thereby, describing it as a mountainous region with highly impressive climate, vegetation land cover and landscape making it one of the most significant touristic areas in the Middle East region.

The entire Lebanese territory has a moderate Mediterranean climate. It is generally cold and rainy in winter, hot and humid in summer, and mild both in spring and autumn. In addition, Lebanon's geographical location as well as its rugged geomorphology with elongated mountain ridges facing the Mediterranean, they all stand together to build a climatic barrier. In fact, this barrier captures cold air masses from the west and then condensates them to be turned into rainfall and snow. Lebanon is well known by its considerably high precipitation rate (roughly an average of 900 mm). This is obvious through the water resources abundance in the country, and its vegetation cover, too.

It is obvious that Lebanon's both climate and geomorphology are the most important components that have made the country widely known with its remarkable environmental conditions. In fact, the tremendous water resources (*e.g.*, rivers, springs, lakes, *etc.*), mild climate, with two-month snow-covered mountains, together with mountainous landscape, dense forest charming views, as well as the proximity between mountain and sea (*i.e.*, few kilometres), all the above features have turned Lebanon into the most outstanding touristic region that is ranked top one of the lists among other touristy countries.

Moreover, the natural ecosystem development, the natural threats as long as the enabling factors have played a crucial role in the evolution and development of coastal maritime tourism at the national scale. Nevertheless, the constant climatic changes as well as the morphological component distortion due to human physical interference are major threats for the existing ecosystem. This has been lately obvious in Lebanon, where both climate parameters oscillations and changes have occurred. What has widely worsened the situation is the human footprint negative impact because of urban encroachments that are spreading at a very fast pace, making the whole natural ecosystem under risk which in turn threatens the country's touristic areas.

The current document (related to Tender CoE4BG-LB-ENI-03/2020, #1: ID-LB-01) will primarily demonstrate and analyse Lebanon major climatic parameters while emphasising on precipitation and temperature. In fact, they represent a prerequisite step for both the climate change analysis and the existing climatic trends. This will be based not only on creditable applied studies but also on research projects depending both on the ground measurements and datasets acquired from remotely sensed products.

Secondly, this document will illustrate the geomorphological features on mappable forms, their classifications, and the geographic surficial material type distributions. This in its turn will support identifying the natural components that are either influencing or threatening the natural ecosystems and their reflectance on Lebanon coastal touristic areas.

II. Climatic Characteristics

Lebanon rugged topography is characterised by diverse climatic regime, while the precipitation and temperature are unevenly distributed which ultimately lead to different microclimatic zones (Shaban, 2020). In addition, there are blowing-air meteorological turbulences, thereby, causing rain shadow which has an important impact on Lebanese mountains topography. Therefore, cold air masses rise on the mountains from the west. Then, the descending air not only warms but also picks up available moisture to take it to the east of the mountain ridges, to trigger as a result different climatic turbulence (Shaban and Houhou, 2015).

There are two major climatic parameters (*i.e.*, precipitation and temperature) that control most of the climatic conditions (*e.g.*, humidity, sunlight radiation, wind, *etc*.), thereby, governing the entire environmental conditions, which is clearly reflected on Lebanon citizens daily life. Precipitation, including rainfall, snow, and Temperature are the crucial components for the climatic trend analysis and the oscillating meteorological conditions. This often depends on the climatic data availability which are collected either from in-situ measurements or from remotely sensed products.

II.1. Climatic data sources

Till early 1990s, there were about 70 meteorological stations in Lebanon, 2/3 were fixed on the coastal zone and the adjacent occidental mountains of the country. Unfortunately, the largest number of these stations was not operational and not regularly maintained due to the internal political conflict in the country.

Recently, there have been about 125 operational meteorological stations covering all Lebanon, with more than 75 ones located both in the coastal zone and the adjacent mountain chains. Around 41 stations are installed along the coastal strip (Figure 1) and are mandated by several concerned institutions, namely the Ministry of Public Works and Transport (MPWT). They are also specifically operated by the Civil Aviation General Directorate (GDCA), along with the Lebanese Agriculture Research Institute (LARI), while some other climatic records are provided on individual research basis (*e.g.*, universities, research centers, *etc*.).

Both The lack of meteorological measurements and intermittency in the available records in Lebanon, as well as the geographic distribution non-uniformity of the current meteorological stations, have all motivated the use of remotely sensed products. Therefore, a considerable number of precipitation and temperature datasets were easily recorded, with the emphasis on the Tropical Rainfall Mapping Mission (TRMM, 2015) extended by NASA (NASA, 2015) since 1998, Climate Hazards group Infrared Precipitation with Stations (CHIRPS, 2018); and from NOAA climatic data system - National Oceanographic Data Center (NOAA, 2013).

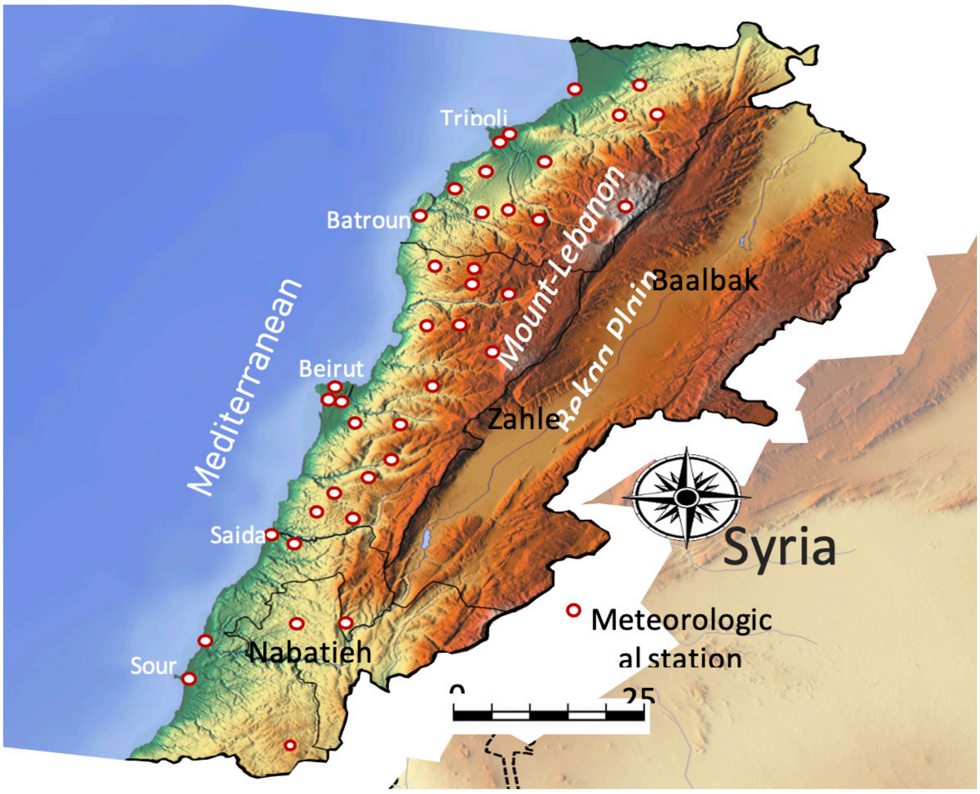

Figure 1. Location of the coastal meteorological stations in Lebanon

The climatic data integration from different sources and products has led to the comprehensive time-series of Lebanon climatic records, thanks to which detailed climatic analysis and mapping were elaborated, such as the conducted research by the National Council for Scientific Research in Lebanon (Rey, 1954).

This document (I-LB-01) focuses mainly on the Lebanese coastal strip which consists of both the coastal plain and the adjacent mountains, which will serve in analyzing the strip’s climatic parameters. This is because there is a clear and tight meteorological interrelation between both geographic areas.

II.2. Precipitation

Precipitation, including rainfall and snow, is a substantial physical component that plays a vital role in several sectors in Lebanon. Thus, the green cover, cultivated lands, fertile plains, water bodies, wetlands and the remarkable biodiversity are all involved and interrelated within the considerable precipitation rate in Lebanon.

The rugged topography in Lebanon has resulted in a wide diversity in precipitation rates, which has led to controlled attitude. Hence, rainfall rate ranges from 650 mm to 1,500 mm throughout both the coastal zone and the crests respectively. This explains the scarcity of little rainfall changes in Lebanon between different regions (Figure 2).

The average rainfall rate Estimations in Lebanon remained unspecified in the few years ago. Thereby, recording contradictory estimations. For instance, it was estimated that the average rainfall rate was: 982 mm, 940 mm, 820 mm, 873 mm, 825 mm, 823 mm, and 800 mm just relying on the preparation and interpolation of the Estimations rainfall available measured data series in Lebanon between 1950s and 2018. In fact, this has been accomplished by integrating the remotely sensed data.

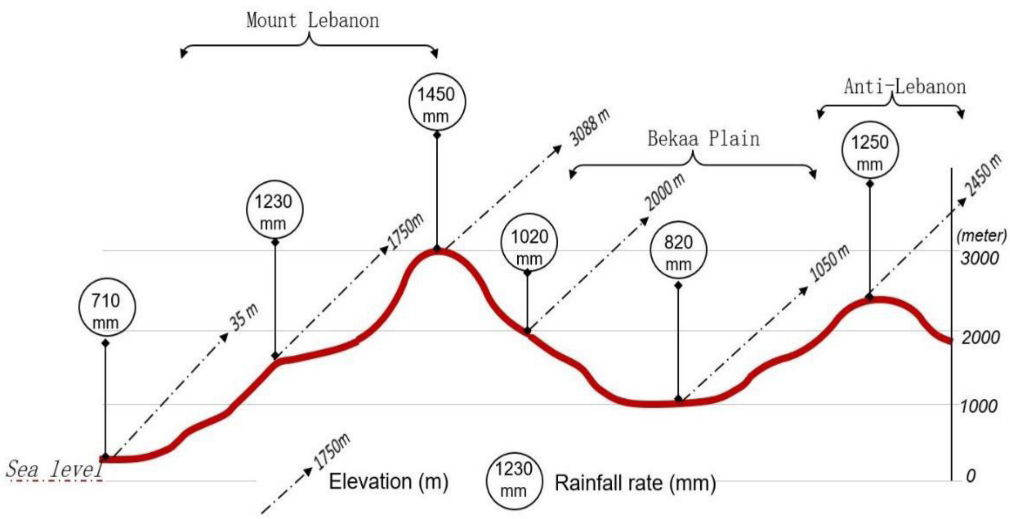

Figure 2. Schematic representation of the rainfall distribution rate along different topographic surfaces in Lebanon

Lebanon's climate is mainly characterized by an abrupt oscillating rainfall trend, which appears as rainfall peaks. These peaks are obvious in the period between November and February when the monthly average rate reaches roughly 200 mm. However, the lowest rates are recorded between May and August.

A recent study using advanced statistical methods, has calculated Lebanon average rainfall rate since the 1950s using records from both different ground stations and remote sensing measurements of several different zones in Lebanon. Then, the collected records were interpolated, and existing gaps were covered thanks to different approaches. In fact, the average rainfall was calculated at 910 mm for the entire country. While the estimated raining days ranged between 60 and 70 (± 15) days per year mainly between October and April.

The topographic surfaces overlapping equally with the rainfall spatial distribution were conducted. Thereby, obtaining six climatic zones (Table 1). In fact, the coastal zone occupies the lowest rainfall rate in Lebanon, which was estimated between 550 mm and 850 mm for the altitude below 100 m, then it raises to 1,050 mm while moving up to about 1,100 m of altitude. Hence, it has been estimated that the altitude is totally interrelated with the rainfall rate, where each 100 m increase in altitude results in almost 30 mm increase in rainfall rate.

Table 1. The major climatic zones of Lebanon (Shaban, 2020)

Climatic zone	Altitude range (m)	Rainfall rate (mm)	Main geography*
The Coastal ribbon	<100	550 - 850	Coastal plain (<5 km wide)
The Plateau	100 – 1,100	750 – 1,050	Diverse, moderate heights
Western Heights	>1,100 – 3,088	1,000 – 1,550	The maximum at Kornet Es-Sawda of 3,088 m (Mount-Lebanon)
Bekaa Plain North	900 – 1,200	200 - 450	An open land between two mountain chains
Bekaa Plain South	800 – 1,200	600 – 1,100	An open land where several hills occur
Eastern Heights	>1,200	700 – 1,250	The maximum at Tallet Mousa at 2,620 m (Anti-Lebanon)

Both the distribution and rainfall pattern on the Lebanon coastal zone show clear diversity between different months. In fact, it has been reported that the rainiest months are November, December, January, and February. Yet, the period from May to August is often considered as the least rainy or almost not rainy or the driest.

Snow (solid precipitation) is another aspect of precipitation in Lebanon where it is regarded as a principal water-feeding source for surface water and groundwater. It is remarkably known that Lebanon is one of the rarest Middle East regions where snow-cover remains for a couple of months on the mountains, occupying about 2,000 km^2 (Figure 3).

Figure 3. Snow cover on the Lebanese mountains, a typical landscape of Lebanon

Snowfall in Lebanon is an annual and permanent meteorological process flowing from either regional local weather and wet storms that strike Lebanon either from the European, Scandinavian, or Siberian areas (Shaban, 2020). Hence, the annual snow-cover average in Lebanon, detected from satellite images, was of an average near to 1,810 km^2 throughout the period between 2000 and 2019. Whereas the maximum average was 6,707 km^2, which is equivalent to 64% of the total area of Lebanon.

In fact, snow-cover on altitudes above 1,500 m is a common feature, where snowpack usually remains between 4 and 8 months throughout the year while snow cover may be varying during the rest of the year. In this respect, snowmelt often starts in the second half of March. However, the number of snowing days according to different altitudes in Lebanon, including its coastal zone may be varying, and it can be illustrated as follows:

- <1 day for altitudes below 250 m
- 2-10 days for altitudes between 250 and 750 m
- 10-20 days for altitudes between 750 and 1,500 m
- 20-40 days for altitudes between 1,500 and 2,250 m
- > 40 days for the altitudes above 2,250 m

II.3. Temperature

Temperature is usually considered as the primary measurement tool in each meteorological station, and it is also the most significant meteorological factor in different applications. However, temperature records in Lebanon are similar to those of rainfall, which are almost unavailable or available only for specific regions or for limited time intervals.

In Lebanon, temperature has obviously increased in recent years, and this has been clear in several sectors, notably in agriculture. Generally, Lebanon is characterized by moderate temperatures, and it may not be considered as very hot or very cold, even during extreme weather. Like rainfall, temperature is an altitude-related climatic variable, thereby, slightly changing between different Lebanese regions.

The plotted estimations of temperature in Lebanon are acquired with big discrepancy. The most creditable estimation of the average annual temperature in Lebanon ranges between 14 °C during winter and 27 °C during summer in the coastal zone with an average of 21 °C.

Whilst the average annual temperature in the mountainous areas is below 12 °C, it often ranges from 2 °C to 18 °C in winter and summer respectively. The calculated time series for the temperature between 1950 and 2018 in the coastal zone of Lebanon revealed that the hottest temperature is scored in the period between June and August, whereas the coldest months are December and January and sometimes February (Figure 4).

According to Shaban the analyzed temperature trends over long time series for the entire Lebanon, it has been reported that the lower calculated average temperature ranges between 5 °C and 10 °C in regions above 1,800 m of altitude; around 15 °C in areas higher than 1,100 m; and about 20 °C in the coastal zone (Shaban, 2020). Therefore, the distribution of annual temperature with different altitudes can be illustrated as follows:

- Coastal strip (<250 m) = 24 °C
- Plateau (250 – 750 m) = 22.5 °C
- Moderately elevated areas (750 – 1,500 m) = 19.5 °C
- Heights (1,500 – 2,500 m) = 18.5 °C
- Crests (>2,500 m) = 14 °C

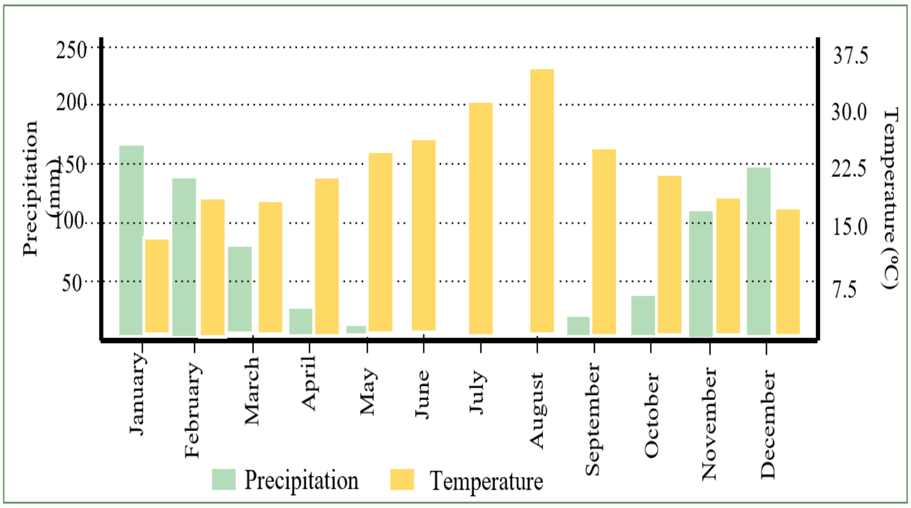

Figure 4. Average annual rainfall and temperature rates along the coastal zone of Lebanon

II.4. Evapotranspiration and Relative Humidity

Evapotranspiration (ET) is considered as the most significant physical factor which is interrelated strongly with the other climatic parameters. However, several inadequate records of measurements for ET in Lebanon have been recorded. Besides, the available records are very limited in space and time. However, the plotted estimations adopted from different sources via lysimeters, showed that the average Et in Lebanon is between 48% and 53% of precipitation (MoE/ECODIT, 2002; MoEW, 2010; Shaban and Hamzé, 2017).

The annual potential evapotranspiration average, as reported by FAO ranges between 1 100 mm in the coastal zone and 1 200 mm in the inner zone (the Bekaa Plain) (FAO, 2009). Besides, the annual potential evapotranspiration was estimated at 936 mm for the entire Lebanese territory (Karam *et al.*, 2003).

Regarding the relative humidity, which is mainly a temperature function involved in several records with temperature and rainfall measurements, the overall relative humidity value in Lebanon is almost conducted within the study range and was estimated around 70% in the coastal zone. While in mountainous regions, the relative humidity usually fluctuates between 60% and 80% in winter; and between 40% and 60% in summer.

II.5. Aridity

There are many contradictory descriptions for Lebanon climate zoning, which is often described as a semi-arid during the dry season to humid to sub-humid in the wet season (NC, 2011). Besides, stated that Lebanon's climate is typically Mediterranean, with heavy rains in winter and dry with arid conditions the rest of the year (Telesca *et al.*, 2014). Therefore, it is necessary to determine Lebanon climatic zoning which can be well demonstrated by the aridity index calculation, which is a rainfall and temperature function. In fact, the aridity index describes a long-term lack of rainfall/or moisture, resulting in relatively high levels of dryness.

Recently, a study has been conducted to determine the Aridity Index of Lebanon coastal zone (Shaban and Houhou, 2015). In fact, to achieve this goal, De Martonne Aridity Index (DAi) and Emberger Aridity Index (EAi) were calculated to emphasize both Lebanon climatic attribute and its climatic factors geographic distribution by investigating ten coastal (& representative) climatic stations. In fact, the DAi and EAi calculations included both rainfall and temperature. Apart from the investigated time series limited to the period between 1985 and 2016 (32 years), there were other investigated stations which have got time series since 1947 such as the meteorological station fixed at the American University of Beirut (AUB). The outcome of DAi calculation showed that Lebanon's climate varies from semi-humid to humid climate zones (Figure 5).

Shaban *et al.* (2019). Stated that Lebanon would not be remarkably affected by drought, which is a common phenomenon for the entire Middle East Region. In fact, it is thanks to its geomorphological setting characterized by the dominant mountainous topography that Lebanon is not threatened by droughts.

According to the calculated EAi, the aridity index was classified into five categories from pre-arid to hyper-humid. The results were illustrated on a digital map showing the geographic distribution of different coastal climatic zones (Khawlie and Shaban ,1998). It is obvious that the Lebanese coastal zone encompasses mainly four climatic zones (*i.e.*, semi-arid, semi-humid, humid, and hyper-humid), and slightly hyper-humid (Figure 6). Therefore, the climatic zoning of the coastal Lebanon can be classified as follows:

- *Semi-arid* = 18% (the coastal stretch between Saida and Tripoli with a maximum extent of about 300 m in-land).
- *Semi-humid* = 35% (between the most southern and northern borders of Lebanon with variable altitude reaching up to about 500 m in-land).
- *Humid* = 38% (It extends from Jezzine to Al-Qbayat, with a variable altitude-reach of roughly 2,100 m in-land).
- *Hyper-humid* = 8% (between the northern part of Keserwan region to the highest altitude in Lebanon near Qurnet Al-Sawda which exceeds 3,000 m).

Based on the above classification, the Lebanon coastal zone could be described as a semi-humid climatic zone, and the entire Lebanon can be described as a semi-arid to semi-humid climatic zone.

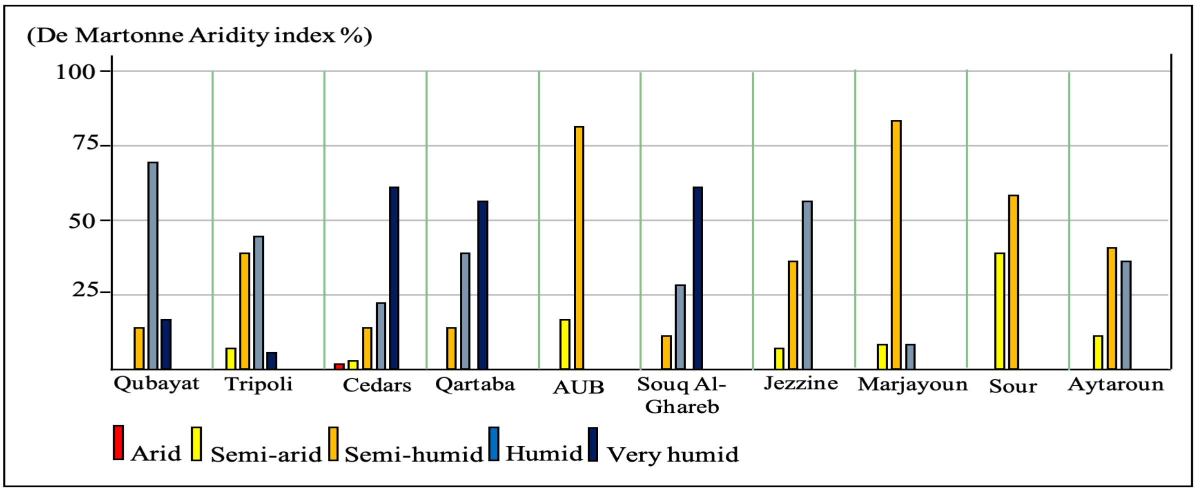

Figure 5. De Martonne Aridity Index for selective meteorological stations along the coastal zone of Lebanon

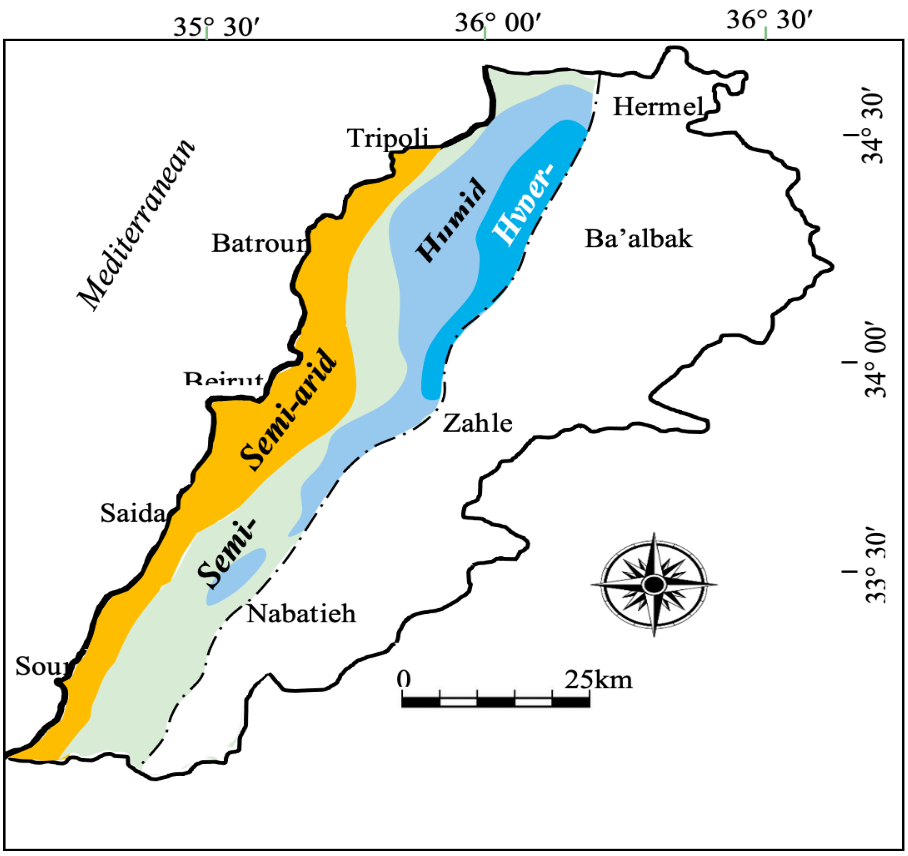

Figure 6. The climatic zone geographic distribution in the coastal zone of Lebanon (Khawlie and Shaban, 1998)

II.6. Indicators of climate change

Climate never remains stable, especially in regions with diverse topography like Lebanon, which is characterized by a mild climate that ranges from semi-arid to semi-humid (Khawlie and Shaban, 1998). Recently, with the changing climatic conditions occurring all over the world, Lebanon has been ranked, according to ND-Gain Index, at 106 out of 181 countries that are vulnerable to climate change and its impact (GAIN, 2017).

The two principal climatic parameters (*i.e.,* precipitation and temperature) are crucial factors to be taken into consideration when analyzing the change in climatic conditions for any region. Besides, they can be well analyzed if long-term datasets are available. In this respect, there are many studies conducted in Lebanon to spot any change occurring in the country's climate. However, most of these studies were both based on regional projections and modelling, or they were analyzed with incomplete time series of datasets. Nevertheless, the CNRS-L has conducted several studies using long time series (*i.e.*, almost between the 1950s and 2018) in which the remotely sensed data were adopted, and then integrated thanks to the implementation of both the advanced statistical and interpolation methods.

1. Precipitation: This includes liquid and solid precipitation (snowpack) which is the primary meteorological parameters. In fact, precipitation in Lebanon has been obviously subjected to changes/oscillations over the last few decades, with many meteorological periodicities (cycles).

Rainfall: The analyzed long-term rainfall datasets were between 1950 and 2018 thanks to the climatic records that have been adopted both from different climatic sources and from the remotely sensed products, namely (TRMM, 2015; NOAA, 2013). In fact, the records illustrated the monthly rainfall average rates (in mm). As a result, the general illustration has been applied for the data retrieved from 37 stations covering the entire country (Figure 7).

According to Shaban, the following can summarize the indicators of the caning rainfall behavior and rates (Shaban, 2020):

The rainfall general trend can be considered as common, with almost normal oscillations as obviously seen in (Figure 7). However, there is an overall decrease in the rainfall rate over the period between 1950 and 2018 (68 years), which was estimated between 12 and 15 mm over the last seven decades. Hence, this change cannot be considered as a remarkable decrease, but rather considered as relatively moderate. Besides, it is clear from the figure that the coastal zone rainfall trend is important for the entire country, yet the rate is quite higher (Figure 7).

There is a very clear change in the rainfall patterns, which have lately turned into strong torrential rain in which several extreme rainstorms have been frequently occurring. In addition, there has been an obvious shift during seasons, which affects in turn other vital sectors like water resources and agriculture.

The elaborated maps for the rainfall rate geographical distribution (between 1950 and 2018) shows that there is a decrease in the rain fall rate spatial extent estimated at about 52% of Lebanon's territory, as well as a 48% increase in the rainfall rate. This was further proved through the studies elaborated by GAIN which indicate the visible, yet moderate change in the amount of rainfall water (GAIN, 2017).

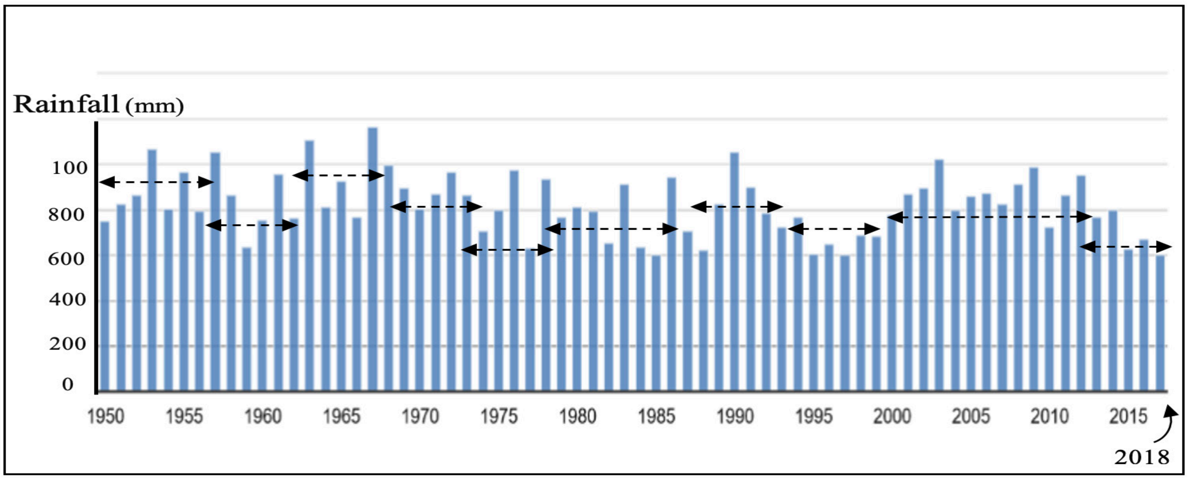

Figure 7. Average annual rainfall rate (1950-2018) for Lebanon and for the coastal zone (black, dashed arrows)

<u>*Snow:*</u> There are several studies conducted on snow cover and its spatial distribution over the Lebanese mountains as well, including both its aerial extent and melting/accumulation regime and periodicity. In fact, snow has always been a worry because it contributes to more than 60% of water feeding rivers, springs, and groundwater in Lebanon.

Therefore, the factors influencing snowpack and its hydrologic behavior were determined mainly by including the climatic impact. Furthermore, the most recent study was applied to the time interval between 2000 and 2019 (Shaban *et al.*, 2020; Telesca *et al.*, 2014), as shown in Figure 8.

From the illustrated snow cover trend in (Figure 8), we notice generally that there were no obvious changes noticed on the snow cover area over the investigated period in the entire country, particularly the coastal zone. Nevertheless, it was noticeable that the duration of snowpack melting has become shorter. In other words, the accumulated snowpack is disappearing more and more in a shorter duration than before. In fact, in the past years it was estimated at about 3-4 months, while currently it lasts only for 1.5-2 months.

Accordingly, it was estimated that the percentage of snow cover area spreading on the mountains overlooking the coastal zone, represents about 62% of the total Lebanon snow cover. This can be caused by the fact that there are higher altitudes in the West Mountains' zone of Lebanon (*i.e.*, Mount-Lebanon) than those in the Anti-Lebanon.

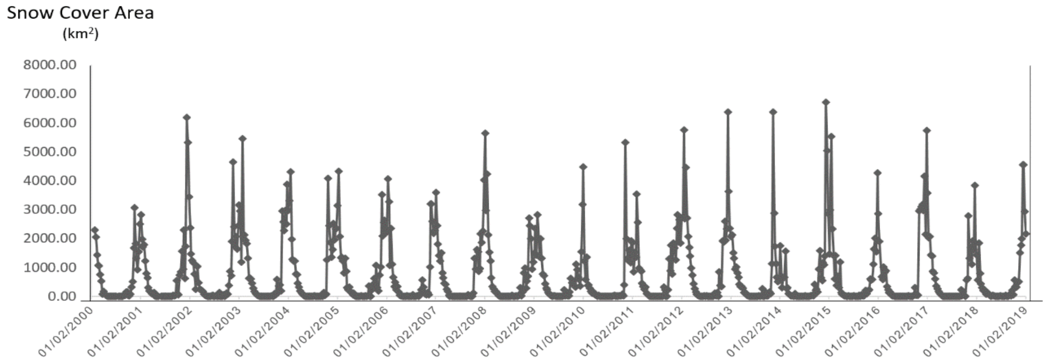

Figure 8. Average annual snow cover is over Lebanon's mountains (2000 and 2019)

2. Temperature: The available temperature records (T) in Lebanon were analyzed and thereby, reporting an abrupt change both in the maximum and the minimum recorded temperatures. In fact, it was shown that the maximum temperature (T_{max}) is increasing towards higher values, while the minimum (T_{min}) is shifting towards lower values. This in its turn has led to a wider difference between both values, which influenced many sectors namely water and agriculture (Telesca *et al.*, 2014).

All conducted studies on Lebanon temperature records proved that the country has a constant increasing trend in temperature. While an annual increase of about 1.8°C has been reported by Shaban for the period between 1970 and 2018 (Shaban, 2014), another value was calculated by Bou Zeid *et al.* which estimated that the increased temperature ranges between 0.6 and 2.1°C (Bou Zeid and El-Fadel, 2002). Besides, the increase in annual mean temperature was calculated also by USAID and a value of 0.11°C per decade in Lebanon was adopted (USAID, 2016).

The recent illustration of the dataset for the mean annual temperature in Lebanon has been elaborated by (Shaban, 2020). This was applied for the period between 1970 and 2018 (Figure 9); thereby, revealing an ascending curve in the general trend, in which the average increase was estimated at 1.8°C. However, this figure shows several temperature spells in both cases of temperature increasing and decreasing values over different periods. This may be caused by the influence of the recent meteorological oscillations that have occurred lately in the whole Middle East Region.

Consequently, the estimated mean annual temperature in the Lebanon coastal zone, notably along the coast, can be higher by 2 to 4°C than the mean annual temperature of all Lebanon. This has been the outcome of different temperature trend calculations

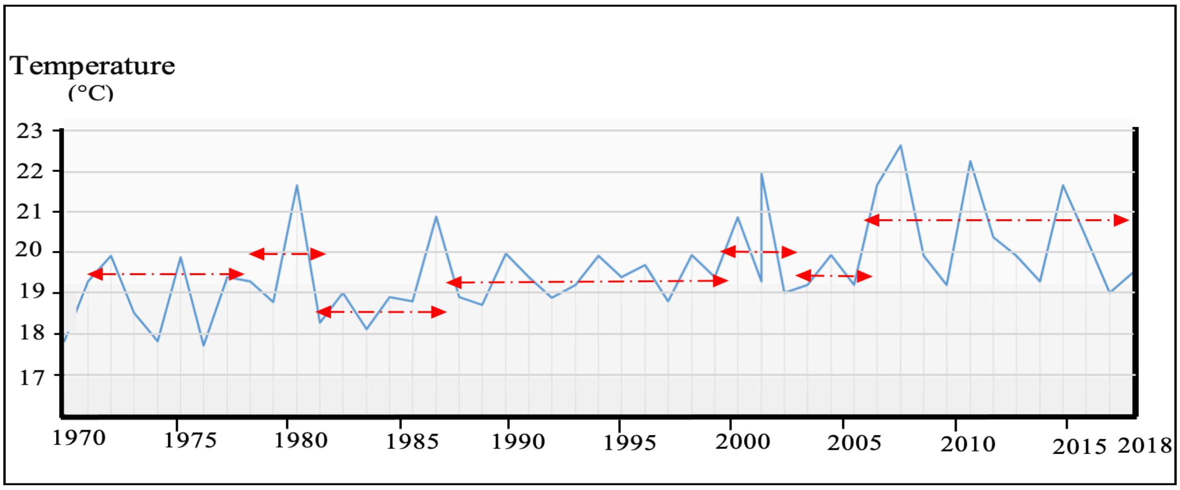

Figure 9. Mean annual temperature of Lebanon (1971-2018) - The temperature spells are shown with red arrows.

II.7. Climate change impact

As to climate change impact, it seems highly significant. It is also more likely to be achieved than just controlling the factors resulting from climate change. However, identifying the different impact aspects is a prerequisite step for further assessment to be able proposes adaptation and mitigation measures. In this regard, an assessment of the changing climate impact on different sectors in Lebanon has been carried out in the 3rd National Communication (TNC, 2016).

The most remarkable climate change impacts could affect primarily Lebanon water resources, which have ultimately influenced other vital sectors, such as agriculture, food security, energy, *etc*. Furthermore, this has been exacerbated with high population growth, increased water demand for irrigation and industry, and water quality deterioration.

In fact, the rain falls oscillation patterns, and specifically the recurrent torrential rain, the shift in seasons' timing, as well as the noticeable temperature change, even on the same day, together with the overall mean annual temperature increase have all played an important part in influencing water storage and availability. Thereby, severely impacting the agricultural sector, this remains highly vulnerable to climate change. Moreover, the current situation has influenced both the demographic and social aspects of the country.

An assessment of the economic climate change costs in Lebanon, estimates that the total cost of climate change in 2020, might be equal to roughly USD 4,000 per household. In fact, this is representing around a third of the average household annual earning, which is estimated currently at about USD 12,000. As a result, many households would become impoverished.

III. Lebanon Coastal Geomorphology

As part of the Middle East Region, Lebanon is characterized by a unique topography where elongated mountain chains are laying in parallel with the Mediterranean Sea. These mountain ridges represent a climatic fence, which makes Lebanon with a specific climate if compared to the rest of other regions.

III.1. Geomorphological surfaces

In a broader sense, Lebanon territory topography encompasses three geomorphological blocks as follows:

1) The western uplifted mountain chains entitled Mount-Lebanon extends adjacently to the coast. In fact, this geomorphologic block is often described as the coastal zone of Lebanon.

2) The eastern compressed mountain chains are described as Anti-Lebanon.

3) A wide depression called the Bekaa Plain, which extends between the two mountain chains. In fact, these units are oriented towards the NNE-SSW direction (illustrated in Figure 1).

With emphasis on the coastal zone, Lebanon includes four geomorphologic units represented mainly by the coastal plain and the adjacent mountain chains. In fact, this zone geomorphology is mainly a combination of several factors as follows: the topographic surfaces and geological features as well as the dominant mountainous nature; the lower slopes plateau; the upper slopes plateau; and the crests. The coastal zone can be divided as follows:

1. *The coastal plain (< 100 m altitude):* It is a littoral ribbon, with friable sediments and loess that extend in parallel with the Mediterranean Sea (NE-EW). It is characterized by a relatively narrow width (less than 10 km). The average width of this plain is about 2.5 km, with an average slope gradient of about 20 m/km. However, in some areas, the coastal plain (low land) has totally disappeared and as a result, rocky masses have invaded and spread directly along the shoreline as in Beirut the capital. Besides, the plain may sometimes reach 10 km in-land as in the case of Akkar Region, north Lebanon.

2. *Lower Slopes Plateau (<500m):* it is the slightly elevated area which is in direct contact with the coastal plain. It has diverse extensions into the land area, which start from the coastline and extend up to 20 km as the case of south Lebanon region. This geomorphologic unit consists mainly of carbonate rock masses that were gently sculptured by valleys to moderate slope channel. This geomorphologic unit has an average slope gradient of 40 - 50 m/km.

3. *Upper Slopes Plateau (500 – 1500 m):* This unit represents a transitional zone between the littoral mountainous facies. It extends to an altitude of 500 m with an average width of about 10 - 15 km. This unit consists mainly of carbonate, argillaceous and clastic rock masses which are intersected by steep-channel valleys. This geomorphologic unit has an average slope gradient of 60 - 65 m/km.

4. <u>Crests (>1,500 m):</u> On a wider regional scale, this geomorphologic unit is a unique landscape where a number of several crests exists. The most elevated crest is located at 3,088 m (so-called: Kornet Essawda or the Black Peak) representing the highest crest in the Middle East Region. This unit, which has similar plateau upper slope rock types, has also a diverse width ranging between 5 and 15 km, while the slope gradient averages between 120 and 140 m/km.

III.2. Shoreline morphology

Lebanon's coastal zone shoreline is about 225 m and extends between Al-Arida in the north and Ras An-Naqoura in the south. Hence, it extends between the following geographic coordinates:

- 34° 37' 58" N & 35° 58' 35" E, at Al-Arida
- 33° 05' 39" N & 35° 06' 14" E, at Ras An-Naqoura.

The general alignment of the Lebanese shoreline is heading towards the NNE-SSW direction, shaping the overall direction of the Mount-Lebanon ranges. Whereas there are several land portions that can be classified as follows:

1. <u>Incident portions:</u> These are land extensions which are either perpendicular or positioned at an acute angle with the shoreline. These are located at (from north to south): Tripoli (4 km), Ras Chekka (2.5 km), Kaslik (1.2 km), Greater Beirut (8.5 km) and Sour (2 km).

2. <u>Curved portions</u>: These portions are characterised by slight intersection along with the shoreline alignment with almost obtuse angle. They are located at (from north to south):

Al-Abdeh (1 km), Tell Ammar (0.8 km), El-Haraich (1 km), Enfe (0.3 km), Sela'ata (0.7 km), Madfoun (0.35 km), Ba'achta (0.3 km), Tabarja (0.3 km), Sa'adyat (1.5 km), Jyeh (1.4 km), Er-Rmayleh (0.6 km), Saida (0.7 km), A'aqbieh (1.2 km), Iskandarouna (1 km) and An-Naqoura (1.2 km).

In addition to these land portions in the country, which are the outcome of geological deformations (*i.e.*, faults), there are a few coastal bays, among which Jounieh Bay is the largest with about 7 km^2.

The calculated meandering ratio (Mr) for Lebanon shoreline was applied for the entire coastal strip. It was calculated via the equation below:

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

Mr = 190/225 = 0.84

When M_r equals 1, it means that the shoreline is totally straight. However, the resulting M_r for the shoreline of Lebanon (0.84) indicates a slight meandering.

The general direction (*i.e.*, sum of trends) of several shoreline segments along Lebanon coastal zone can be illustrated in a Rosette Diagram (Figure 10) that is built both from the calculated geomorphologic measurements (*i.e.*, direction and length) and the topographic maps (scale: 1:50,000) that are applied on Lebanon coastal zone. These measurements were selected among a variety of other identified land portions.

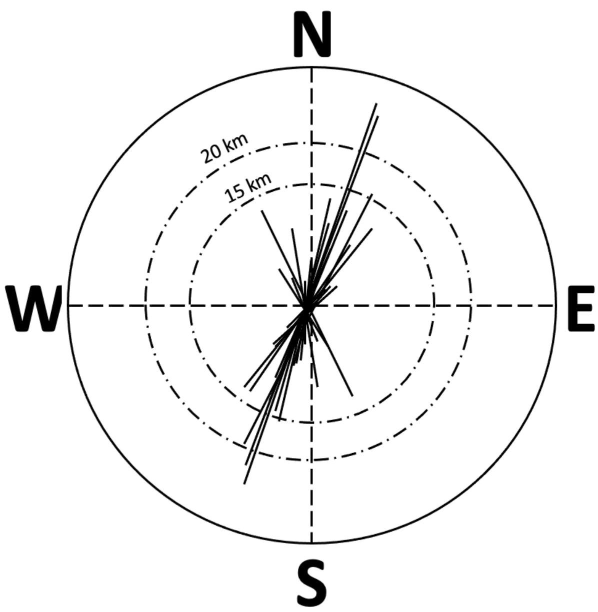

Figure 10. Rosette diagram showing the overall trends and lengths of the shoreline segments along Lebanon shoreline.

The existing physical processes along with human interventions and encroachments along the Lebanon coastal strip has resulted in significant changes. Most of these changes proved to be negative. In fact, they strike both the terrestrial landscape and the marine environment, as well as the natural resources along the coast. The physical processes imply mainly: coastal flooding, erosion, and coastal material etching. Human intervention is represented mainly by the excavation, chaotic constructions, marine backfill and other threatening activities that impact the ecosystem and the environment as a whole.

A study was conducted applying a diachronic analysis of aerial photographs, satellite images and Lebanon topographic maps for the period between 1962 and 2003 (Faour and Abi Rizk, 2005). The results showed that significant changes have occurred throughout the period of investigation, in which almost 41% of the shoreline has been artificially made and 45% of the sandy shoreline has been degraded.

III.3. Coastal material Classification and distribution

The naturally exposed materials allocated along the shoreline (sometimes named “coast type”) include mainly a miscellany of rocks and soil, as well as a mixture of both, with rock and organic matter debris. For the Lebanese coastal strip, the exposed materials are totally controlled by both several natural factors and man-made influencers. The geomorphology, geology, and hydrology from the terrestrial side, as well as the littoral processes from the marine side, along with the meteorological characteristics are always influencing both sides (Figure 11).

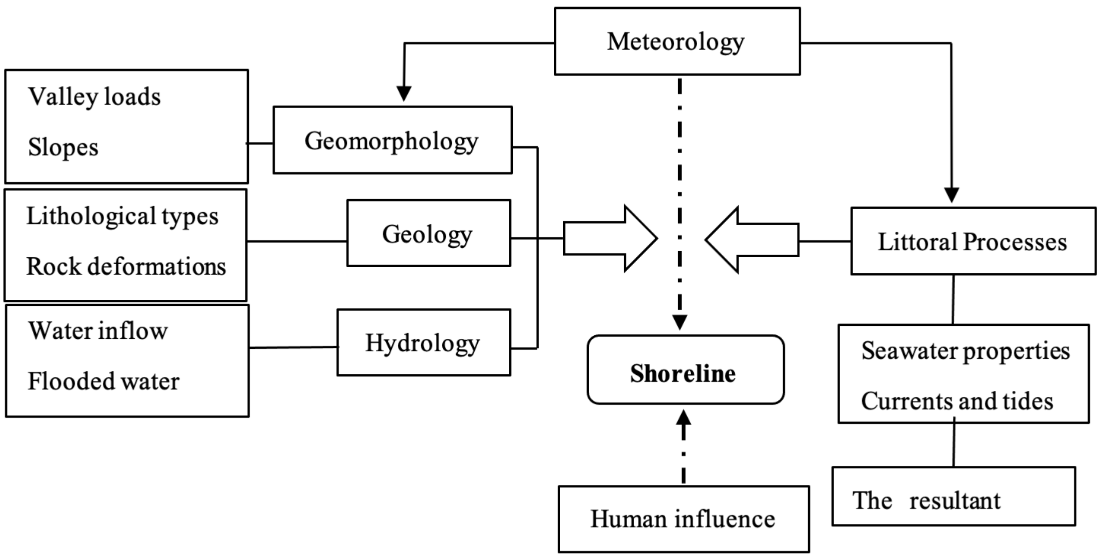

Figure 11. Schematic figure for the major influencers on shoreline morphology and materials

Along with the natural influencing factors, human beings play a major role in the changing of shoreline materials and shape. In fact, this was the outcome of several human activities, with a special emphasis on the established constructions, urban encroachments, and other negative activities (*e.g*., excavation, marine backfill, *etc.*). This is obvious in the Lebanon coastal zone where environmental legislations and urban planning roles are not available or insufficient, or they are disrespected if existing.

A map for the shoreline materials (i.e., shoreline type) has been elaborated relying on many tools such as topographic maps (1:20,000 scale), geologic maps (1:50,000 scale), high spatial resolution satellite images (Ikonos, quick bird), along with field observations. Thereby, identifying six major types of shorelines as illustrated in (Table 2 and Figure 12).

Table 2. Classification of coastal materials (shoreline type) along the coastal zone of Lebanon

	Materials	Description	Shoreline uniformity	Total length	%
1	Marine terraces and sandy beaches	Sandy beaches (friable sand, and sometimes with gravels) almost facing consolidated sand terraces, with almost very gentle slope lands	Smooth and almost straight	31 km	13.7
2	Rock debris, gravel, and alluviums	It is usually found near floodplains and the shoreline where a mixture of fragmented rocks (*e.g.,* gravels and pebbles) and alluvial deposits exist	Moderately irregular to irregular shorelines	33 km	14.6
3	Massive and rocky	Consolidated carbonate rocks (mainly karistified limestone and dolomite). The existing rocks are almost facing the shoreline with a few meters' height (< 5 m).	Rugged and irregular shoreline	61 km	27.1
4	Littoral sand and sand dunes	Soft and friable sand beaches facing land with dunes here the latter occupy clayey and sandy sediments	Smooth and almost straight meandered	45 km	20.0
5	Cliffy, massive carbonate	Hard and consolidated carbonate rocks, almost with high dolomitic friction. They usually show collapsed rocks and cliffs considerable height that may exceed 50 m	Rugged and irregular and destructed shoreline	29 km	12.8
6	Alluvial deposits mixed with sand and clayey soil	These are usually found by the rivers outlets that spread on sandy coasts, and therefore, a mixture of alluvial deposits intervening with sandy and clayey soil	Moderately irregular to undefined shorelines	26 km	11.5

**Percentage of total length with respect to the entire shoreline of Lebanon.*

It is obvious that there is a remarkable segmentation of the shoreline which is interrelated with a diversity of material types. This segmentation represents a function of the previously mentioned influential factors that are clearly observed in the drawn map in (Figure 12). In the map the different types of shorelines are intersected and interrelated, even along the same shoreline direction. Therefore, most of the Lebanese shoreline implies three main aspects, including:

- Soft materials (# 1 & 4, equivalent to 33.7% of the shoreline as shown in Table 2).
- Mixed sediments and materials (# 2 & 6, equivalent to 26.1 % of the shoreline as shown in Table 2).
- Hard and consolidated rocks and cliffs (# 3 & 5, equivalent to 39.9 % of the shoreline as shown in Table 2).

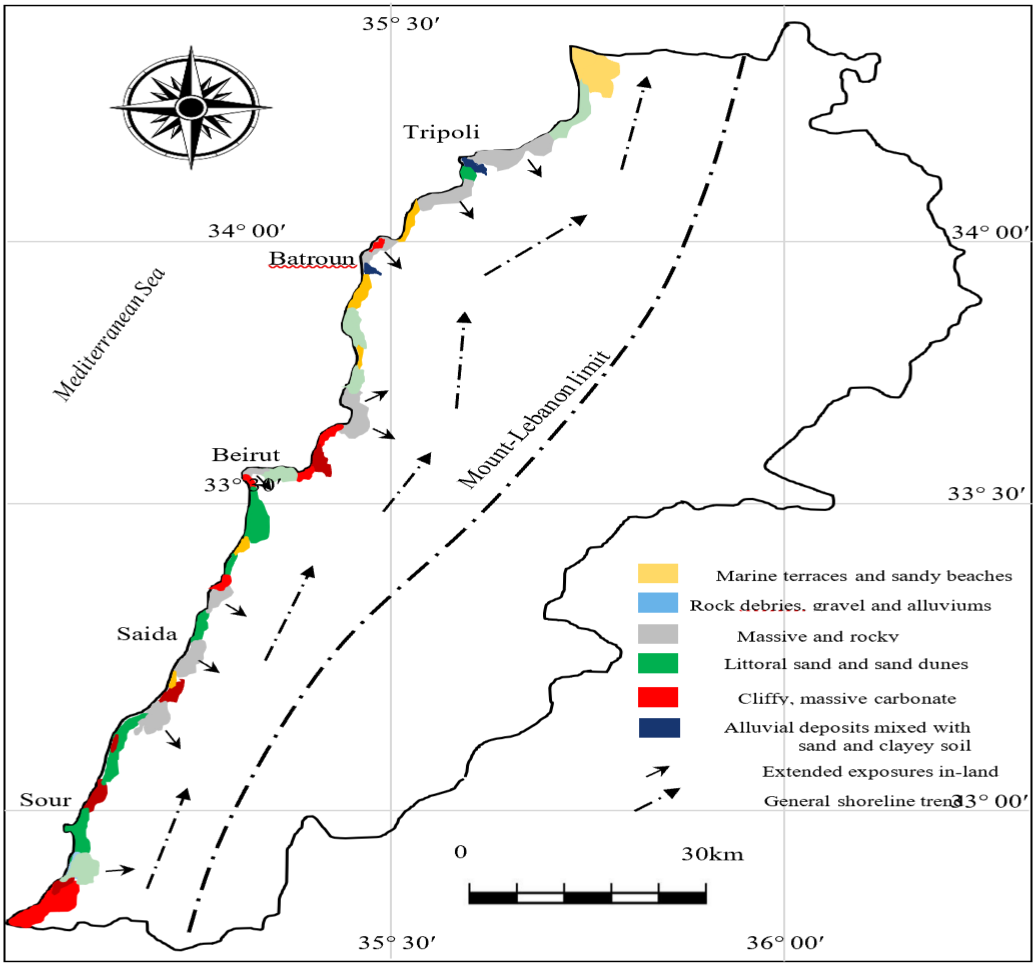

Figure 12. Types (& materials) of shoreline along the coastal zone of Lebanon

IV. Natural Threats on the Coastal Zone of Lebanon

Many threats exist along the coastal zone of Lebanon in general and the coastal strip (shoreline) in particular. These threats are not assumptions, but they are already occurring and over different spells over time. Hence, the existing natural threats have different scales starting from a few square meters up to ten square kilometers. They also threaten the terrestrial and marine environment resulting in abrupt changes in the environment, ecosystems, and human livelihoods, including the tourism sector. In this report, a comprehensive discussion will be presented on the major natural threats (or hazards) occurring along the coastal zone of Lebanon emphasizing those on the coastal strip.

IV.1. Aspects of coastal erosion

Erosion, where surface materials are transported by water, wind or along slopes, is well pronounced in Lebanon. This is largely controlled by the type of surface materials (rock and soil), surface topography and climate, and sometimes due to human interference on stable bodies of surface materials. However, erosion is also taking place along the coastline, but with different mechanisms, factors, and aspects. Therefore, the main five aspects of coastal erosion along the shoreline of Lebanon are illustrated in (Table 3), and can be summarized as follows:

1. Rock Etching and abrasion, especially along friable and moderately consolidated rock, and sediment types (Figure 13).
2. Drifting of surface materials from land to the sea where unconsolidated exposure exists.
3. Channel erosion, where huge amounts of terrestrial materials (soil and rocks) are carried along streams and rivers, forming plumes of turbid water (Figure 14).
4. Sheet erosion and surface materials washing take place mainly when there is rainfall.
5. Collapsing and rock failure happen notably when consolidated rock exposures exist.

Table 3. Major aspects of erosion along the Lebanese shoreline

Erosion aspect	Description	Scale	Probable localities*	Impact
Rock etching	Abrasion at the bottom side of sediments and rock exposures and cliffs	Limited (Few tens of meters)	Littoral sand, sand terraces, alluviums	Local damage
Drifts	Overturning of upper materials along slopes and due to hydraulic processes	Elongated drifts that many reach hundreds of meters	Sandy and shores with fragmented rocks and sediments	Minor and local harm
Channel erosion	Transporting huge amounts (hundreds of tons) along channels remote areas on-land resulting large plumes in the sea	Elongated with Large scale of several kilometers long (may reach 50 km) and few kilometers width	Along the outlets of streams and rivers	Harmful for the marine ecology
Sheet erosion	Shaving the friable surface materials due to rainfall	Hundreds of meters long and parallel to the shoreline	Flat area sloping towards the sea	Negligible harm except for some arable lands
Collapsing and rock failure	Toppling, rolling, and mass wasting of hard carbonate rocks along slopes and cliffs	Local with few tens of meters	Massive and rugged rock exposures	damaging for the beneath terrain of rock masses

**Along the Lebanese shoreline.*

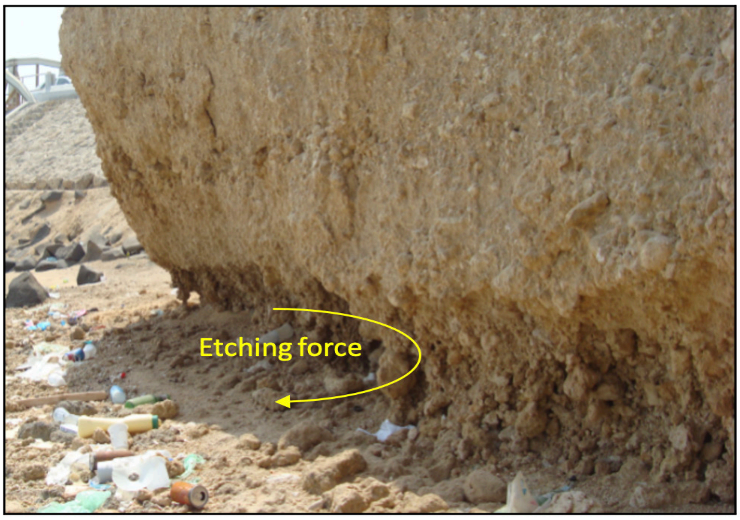

Figure 13. Example of rock and sediments etching along the coastal strip of Lebanon

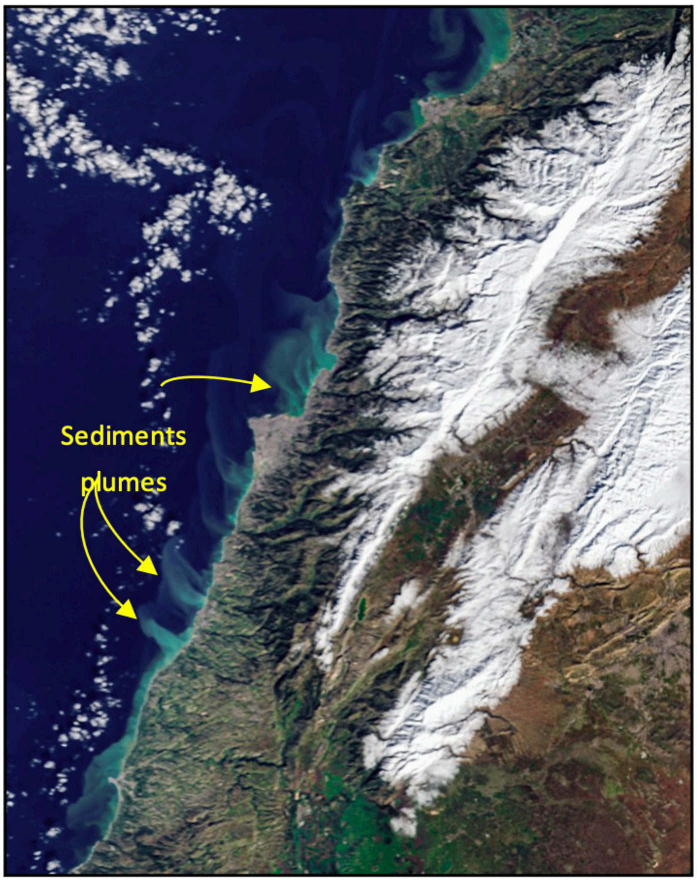

Figure 14. Sediment plumes, resulting from channel processes along streams.

IV.2. Sea level rise

Few studies were carried out on sea level rise in Lebanon; one of them was conducted by Khawlie and Shaban (1998), which used a differential GPS to interrelate between land level and sea geodesy level. However, a recent study has been conducted by El-Hage *et al.* (2011), it modelled the marine components to assess the sea level rise that is affecting Lebanon coastal areas. The study relied on the coastal vulnerability index calculation (CVI), that is based on the following six variables: geomorphology, coastal slope %, relative value of the sea level rise (±mm/year), erosion/advancement of the coastal line between 1962 and 2005 (±m), average height of the tide (m), and average waves' height (m). The model showed that the most vulnerable areas are the North and South (Figure 15). Those with low elevation and sandy beaches are estimated at a length of 18 km (5%). The least vulnerable areas have a length of 125 km (33%), and they are formed and built by artificial coast due to several factors such as resistance, erosion, and high elevation (Table 4).

Table 4. Length of different coastal segments in relation to coastal vulnerability index (CVI)

Length	Vulnerability				
	Very low	Low	Moderate	High	Very High
(Km)	125	67	119	46	18
%	33	18	32	12	5

The impact of sea level rise on the local population was also determined. In fact, the reported current sea level rise is equivalent to 6 mm/year, and it represents the average value that is derived from different IPCC scenarios. If this average is considered low, then the modelling on future risks from different scenarios of sea level rise that is equal to 9 mm (average in mm + Tide coefficient), 5 cm (average + Tide coefficient + wave) and 7.5 cm (as extreme conditions), will result in an increasing number of areas with higher inundation risk according to predictions. The assessment of four pilot zones stretching along the coastal area from North to South revealed that areas 3.7, 5, 43.8 and 73.3 km^2 had submerged under sea water respectively (Figure 16).

According to the above-described four scenarios, the increasing number of local populations is under risk. For instance, while the first scenario with sea level rise of 6 mm/year can cause limited casualties and as well, a quite reduced number of affected people that is equal to 4,700 people. On the contrary, the second scenario, when the higher sea level rises to 9 mm, 5 and 7.5 cm/year can cause damage to the lives of 7,000, 136,000 and 216,600 people respectively. Apart from human lives damage there is also other damage and devastating impact on local infrastructure, agriculture, industrial activities, coastal landscape, and coastal tourism.

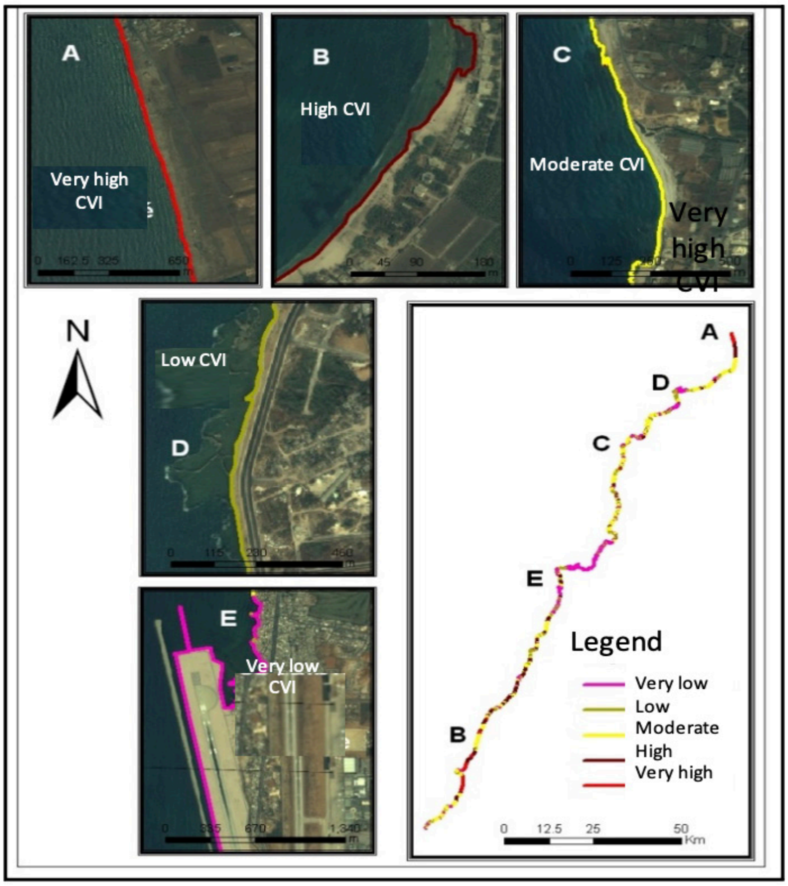

Figure 15. Vulnerability Index of different Lebanese coastal zones

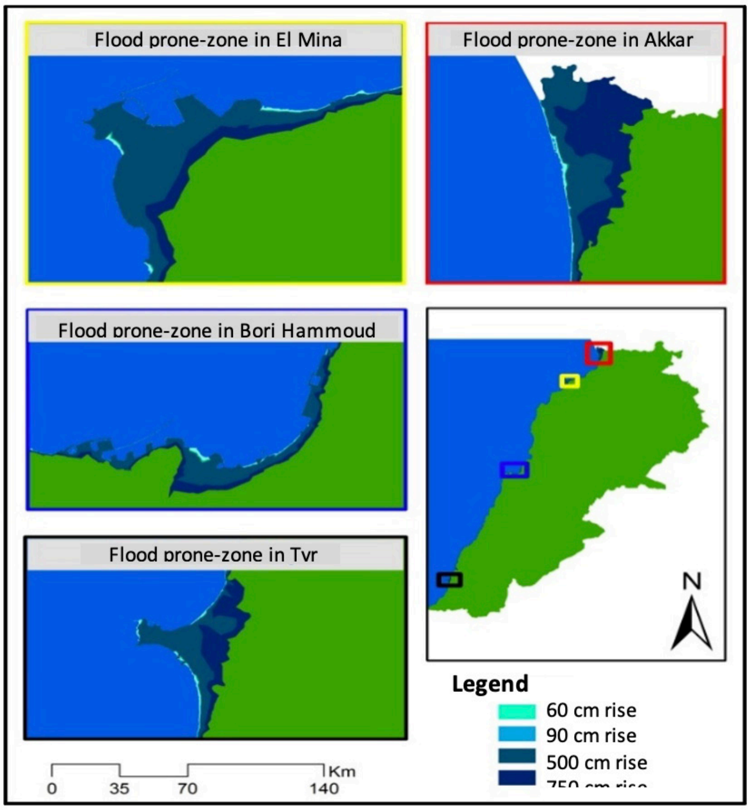

Figure 16. Floodable Lebanese areas in relation to tested scenarios of sea level rise.

IV.3. Marine floods

Marine flood, also described as tidal flood, often occurs when the coast is flooded by seawater caused by the blowing windstorms that push seawater upward. Thereby, creating higher waves. Furthermore, marine floods can also be caused by the flooding of in-land water inputs, such as deltas, estuaries, rainfall, and river discharge. Marine flooding is almost harmful and risky. In fact, it usually results in severe damage, namely in the urban areas located along the coast. Therefore, it destroys the natural landscape, the urban settlements, and the whole infrastructure. It leads as well to coastal erosion, shoreline etching, and many other types of coastal damages.

There is always confusion between marine flooding and sea level rise. Marine flooding is mainly a flash event of natural hazards, while sea level rise is a long-term and gradual event. Moreover, confusion also exists between marine floods and tsunamis. In fact, the former is the outcome of the tides emerging from the nearby coast, while tsunamis are a side-effect of the huge tides resulting from intense submarine tectonic activity within the depth of the sea (*e.g.*, undersea earthquakes, landslides, volcanic eruptions, to cite amongst others).

Along the Lebanese coastal strip, seawater invasion (flooding) into land is a common phenomenon that is usually known in specific areas. Even though marine floods are generated by several marine factors, shoreline characteristics and the adjacent land area, are considered the most influential ones. In addition, windstorms that are the outcome of extreme weather, have also played a crucial part in triggering and causing marine floods which interact respectively with the in-land vulnerability components. The marine factors (*e.g.*, sea currents, wind speed, upwelling, *etc*.) are often considered as a constant acting process, and each of their components has been attributed a degree of impact (*i.e.*, weight of impact). Thus, these factors and their weights can be summarized as follows:

- Low-level shoreline with respect to the sea level (20%)
- Meandered shores and bays (25%)
- Dominance of friable and soft coastal materials (10%)
- Presence of elongated barriers and construction into the sea (10%)
- Absence of engineering controls (35%)

To implement these factors to the Lebanese coastal strip, two main categories can be adopted as follows (Figure 17):

- Highly vulnerable shoreline to marine flooding, which is mainly consistent with coasts dominant with littoral sand and fragmented rocks and debris. This occupies 68 km, which is equivalent to about 30% of the entire coastline (Figure 17).
- Slightly (or moderately) vulnerable to marine flooding, where it occupies a miscellany of coastal strips with low-land and vulnerability to marine flooding, but with the presence of engineering controls. This component occupies about 41.39 km which is equivalent to about 17% of the entire coastline (Figure 17).

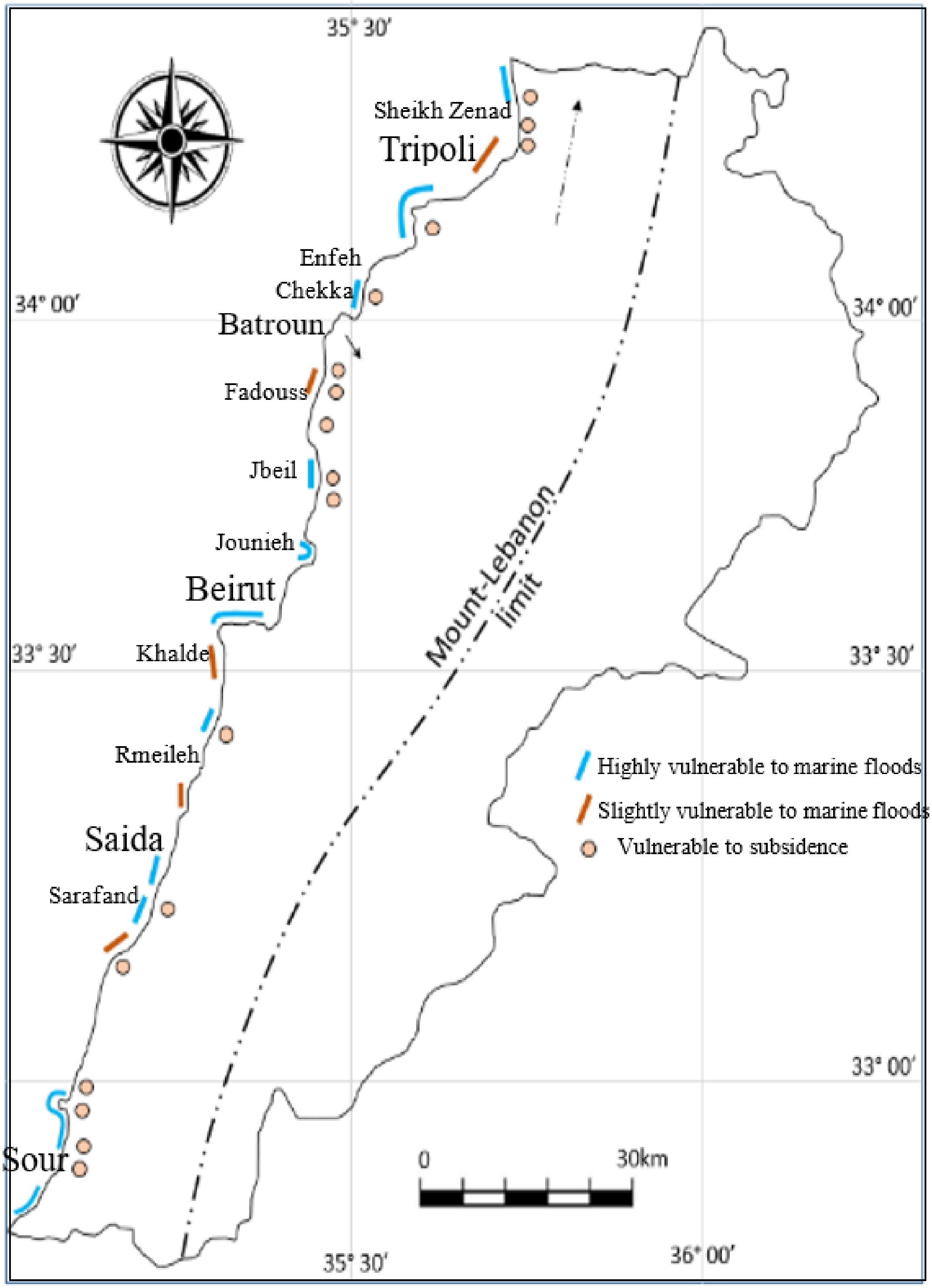

Figure 17. Presumed localities for marine flooding and in-land subsidence along the Lebanese shoreline.

IV.4. Subsidence and Lowlands

Subsidence (or the bending down of terrain surface) is represented by either a sudden sinking or a gradual downward settling of land surface together with negligible lateral horizontal displacement. A subsided ground may be acquired either by natural processes or by human activities. In addition, subsidence encompasses different dimensional rates and aspects, and it is usually harmful and destructive for both constructions and lands, particularly in urban areas including the terrestrial and marine zones.

There are many factors resulting in terrain subsidence, where both natural and man-made factors are almost equal in this regard. Basically, natural factors imply the tectonic activities and the rock deformation development (*e.g.*, fractures, karstification, *etc*.) whereas, human influential factors are mainly the groundwater abstraction, explosions, excavation, tunnelling and many other different interventions.

For the Lebanon shoreline, subsidence has often occurred in many different areas, and it is sometimes reflected on the construction settlement. Hence, the presumed localities for in-land subsidence adjacent to the coastal strip were identified according to a set of different factors which differ greatly in terms of impact, and this can be summarized as follows:

- Surface material types and characteristics (30%)
- Groundwater abstraction, notably in detrital sediments (25%)
- Developed fracture systems (20%)
- Sudden seismic activities (10%)
- Human activities, notably excavation and explosions, contribute with 15% of the factors leading to shoreline subsidence in Lebanon.

Based on the above-mentioned factors, areas that are vulnerable to subsidence along the coastal strip and its surroundings were determined preliminarily (Figure 17). These areas are located mainly in regions with friable, sandy, and clayey materials, as well as in regions where groundwater abstraction from shallow coastal aquifers exists, and they stretch further along 23 km which is roughly equal to 10% of the entire coastline.

V. Conclusions

Both nature and human activities are often influencing each other in space and time. However, there are many physical factors affecting different vital sectors, thereby leading to an impact on human life stability. In this regard, the two natural conditions (*i.e.*, climate and morphology) are the crucial components that govern the touristic sector in Lebanon. This country, which is known for its mild, moderate climate and remarkable landscape, have witnessed severe repercussions on tourism due to the unexpected drastic climate change, especially in the coastal zone where the changes are striking.

This report introduces a typical example of the climatic conditions and trends that can enable us both to analyze and predict their effects on the coastal ecosystems related to tourism. In fact, they represent not only prerequisite natural data but also information from which touristic sustainability assessment could be inspired.

The researched climatic parameters (*e.g.*, precipitation, temperature, aridity, *etc.*) have shown that Lebanon is a country with favorable meteorological conditions, especially for the touristic sector. For instance, the moderate rainfall rate and the snow abundance that is covering the mountains for a couple of months, make it suitable and even attractive for tourism. In addition, the considerable amount of rainfall feeding water resources is considered as one of the most important phenomena of Lebanon ecology which contributes essentially in providing rivers with water, and filling in groundwater grottos (*e.g.*, Jeita Grotto).

Like other regions worldwide, the changing climate is a factual threat that strikes Lebanon and influences many sectors such as water, agriculture, tourism, and the coastal region. The changing climate in Lebanon is known mainly by the increased temperature and the torrential rain which are highlighted in this report.

To sum up, the predicted temperature increase, as well as sea level rise, and floods caused by torrential rains, are all predicted to greatly affect the coastal zone. As a result, these new predicted climatic conditions may make the coastal region less available and less exploitable for tourism for many reasons. First, the loss of certain coastal lands and beaches which may be submerged by sea water, flooding or erosion of certain beaches. Second, several other factors may badly influence touristic coastal zones like the decreasing availability of domestic water at the touristic establishments as well as the subsidence of some coastal areas. Accordingly, this report will be highly useful for decision makers to be able to set and adopt the appropriate strategies and to be able to take the right decisions to conserve both the natural resources and their related sectors such as coastal tourism.

Climate change impact was deeply discussed in the 3rd National Communication Report. Table 5 summarizes the major climate change impacts in Lebanon.

Table 5. Aspects of climate change impact in Lebanon

Major Impact	Description
Less snow	• Less precipitation will fall. Snow that currently falls at 1500 m will be falling at 1700 m by 2050 and at 1900 m by 2090. • Decrease in snow residence time from 110 days to 45 days. • Loss of ski season since a reduction of 40% of Lebanon snow cover will take place together with an increase of 2°C in temperature, reaching a 70% decrease in snow cover with an increase of 4 °C.
Less water availability	• Snow will melt earlier in Spring, thereby affecting the recharge of most springs, reducing the availability of irrigation water supply as well during Summer, and increasing floods in Winter up to 30%. • The decline in precipitation will exacerbate the existing challenges of water resources for agriculture, commercial and residential uses as well. In addition, it may adversely impact both rivers and groundwater recharge.
Increased drought period	• Droughts will last almost from 15 days to 1 month; in fact, drought periods will last 9 days longer by 2040 and 18 days longer by 2090. • Cost loads will be added to irrigation issues since more pumping hours will be required. thereby consuming more energy.
Less agricultural productivity	•Soil moisture will ultimately decline due to higher temperatures, reduced precipitation, and higher evapotranspiration. • Changes in temperature and rainfall will decrease productivity of lands that are currently used to produce most crops and fruits. • Most crops also will face increased infestation of fungi and bacterial diseases.
Higher energy demand	Higher temperatures will increase demand for cooling. Thereby, increasing electricity and energy consumption to 1.8% for a 1°C increase in temperature, and 5.8% for a 3°C increase in temperature.
Sea level rise	• Sea levels will rise to 30-60 cm in 30 years if the recent rate of rise of approximately 20 mm/year keeps on rising steadily. • Higher sea levels will lead ultimately to seawater intrusion into aquifers, thereby increasing the risk of coastal flooding and inundation, the increase of coastal erosion, as well as the increase of cover sand beaches. As a result, all the above factors will contribute to altering the coastal ecosystems in natural reserves and elsewhere.
Forests at risk	Forests will be adversely affected, especially those forests that have already suffered from fragmentation, pest outbreaks, forest fires and human hazardous practices and activities.
Weakened tourism	• Winter outdoor tourism will diminish because of the upcoming warmer temperatures in the future. Besides, the reduced precipitation will ultimately shorten the skiing season. • Other impacts on tourism will occur due to the ecosystem changes, as well as the loss of natural attractions, such as sandy public beaches, and finally it will be devastating to the nation's archaeological heritage.

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