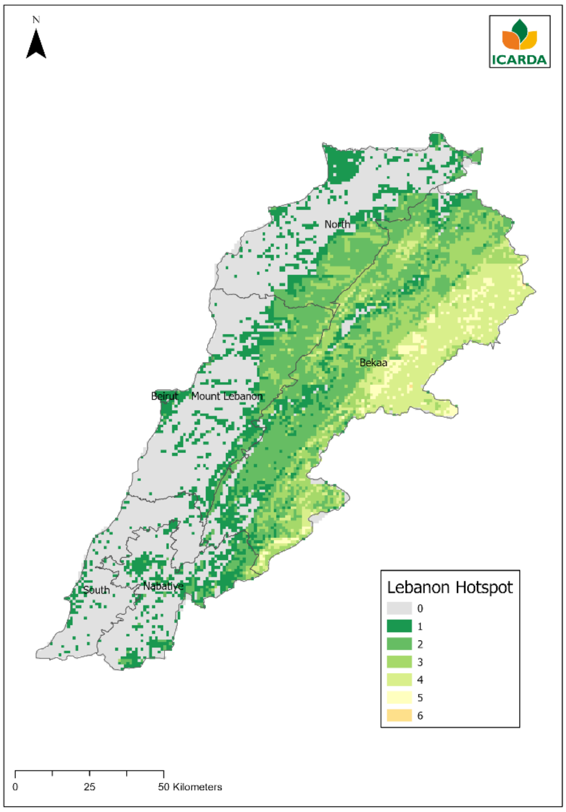
INITIATIVE ON
Fragility to Resilience in
Central and West Asia

Science for resilient livelihoods in dry areas

Report on: Mapping natural resource (soil, weather, agro-biodiversity) to identify hot-spots and suitable areas in Lebanon.



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Summary

This report summarizes the trend in average temperature, precipitation over time and space from different region in Lebanon. Also, it includes identification of hot spots for various climatic and soil parameters such as long-term rainfall patterns, rainfall variability, areas prone to drought, as well as average, maximum, and minimum temperatures essential for wheat cultivation. Furthermore, parameters related to soil fertility, such as texture, soil organic carbon content, slope/elevation, and soil salinity, are considered. Soil-water resources, including groundwater availability, dam locations, and soil displacement by water, are also evaluated. Vegetation indices such as NDVI (Normalized Difference Vegetation Index) and ground cover are mapped for different region in Lebanon.

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Introduction

The Fragility to Resilience (F2R) in Central and West Asia and North Africa (CWANA) (F2R-CWANA) Initiative, part of OneCGIAR, is dedicated to agricultural research and development, especially addressing the unique challenges and opportunities within the region. One of the key activities of the F2R-CWANA initiative involves mapping natural resources, particularly focusing on wheat cultivation in countries across the CWANA region, including Egypt, Uzbekistan, Morocco, Lebanon, and Sudan.

This mapping effort encompasses the identification of hot spots for various climatic and soil parameters essential for wheat cultivation. These parameters include long-term rainfall patterns, rainfall variability, areas prone to drought, as well as average, maximum, and minimum temperatures. Additionally, trends in rainfall and temperature over time and space are analyzed. Furthermore, parameters related to soil fertility, such as texture, soil organic carbon content, slope/elevation, and soil salinity, are considered. Soil-water resources, including groundwater availability, dam locations, and soil displacement by water, are also evaluated. Vegetation indices such as NDVI (Normalized Difference Vegetation Index) and ground cover are mapped as well.

To carry out this comprehensive mapping, remote sensing data from satellites such as Sentinel-2, Landsat-8, and Modis are utilized. Data from reputable sources like the Food and Agriculture Organization (FAO) for soil salinity and soil organic carbon, ISRIC for soil parameters, and ESRI for high-resolution land use and land cover data are integrated into the analysis. Ultimately, by considering thirteen major parameters related to climate, soil, and water, hotspot and suitability mapping tailored to each country in the CWANA region was conducted. This mapping exercise provides valuable insights into the distribution of natural resources and climatic conditions crucial for wheat cultivation, thereby aiding in the development of targeted strategies for enhancing agricultural resilience and sustainability in Lebanon.

Geospatial and temporal mapping of natural resources

1. Climatic parameters

1.1. Long-term rainfall, rainfall variability, and dry/drought-prone areas

Between 2015 and 2021, the amount of rainfall received during the wheat cultivation period (November to April) across different areas in Lebanon showed considerable fluctuations, with measurements varying between 344.3 mm and 1273 mm (see Figure 1). The Mount Lebanon governorate observed the highest rainfall amounts, with figures ranging between about 900 mm and 1273 mm. On the other hand, the Bekaa governorate's northeast area experienced the least rainfall, with amounts close to 340 mm.

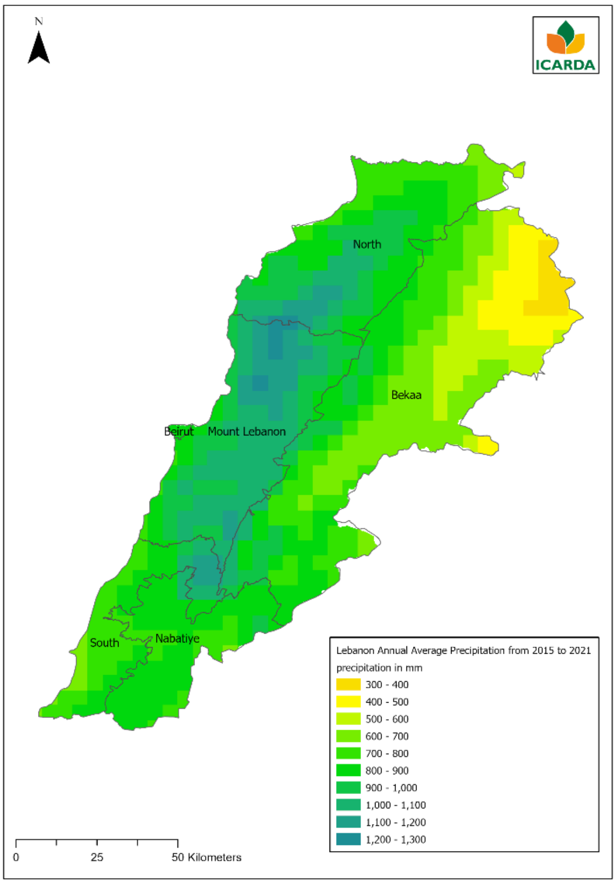

Figure 1. Map of annual average precipitation in Lebanon from 2015 to 2021 (Data source: TerraClimate).

1.2. Temperature

From 2015 to 2021, the analysis of Lebanon's temperature data was conducted using the TerraClimate database through the Google Earth Engine code editor, focusing on temperature datasets with a 250-meter spatial resolution tailored to the nation's borders. During this period, the yearly highest temperatures varied between 10.85°C and 26.23°C (refer to Fig. 2). The warmest areas were identified along the country's coast, stretching from the northern to the southern governorates, where temperatures spanned from 22.5°C to 26.2°C. Conversely, the cooler regions were located in the mountainous zones of the North, Mount Lebanon, and Bekaa governorates, where temperatures ranged from 10.8°C to 12.5°C. The lowest recorded temperatures fluctuated between 2.6°C and 17.9°C (see Fig. 3), with the mountain areas of the North governorate experiencing the chilliest conditions, where temperatures hovered around 2°C to 5°C (as shown in Fig. 3). Over the same period, the average annual temperature varied from a cool 6.7°C in the mountainous regions of the North, Mount Lebanon, and Bekaa governorates to a warmer 21.8°C along the coastal areas, encompassing North Mount Lebanon, Beirut, and the southern governorates (illustrated in Fig. 4).

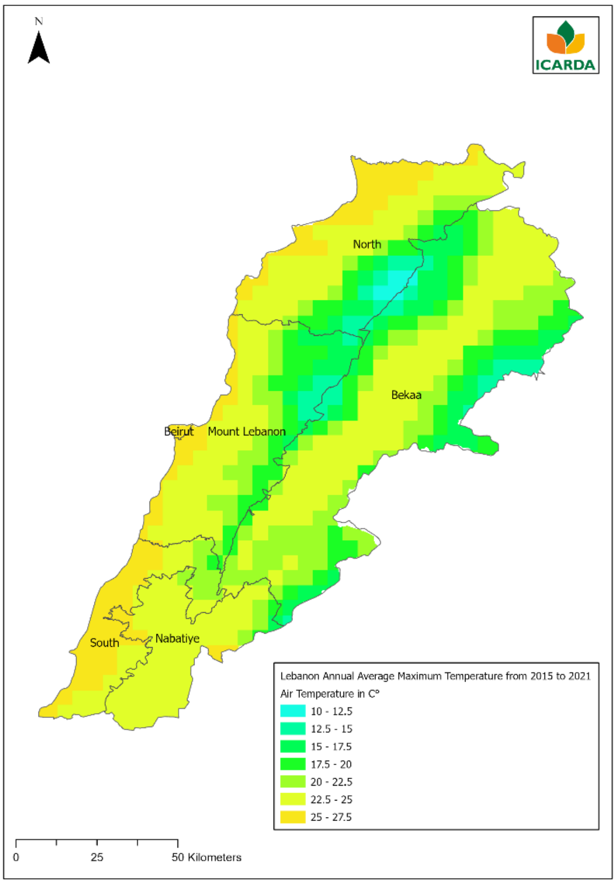

Figure 2. Maximum temperature (°C) from 2015 to 2021 in Lebanon (Data source: TerraClimate).

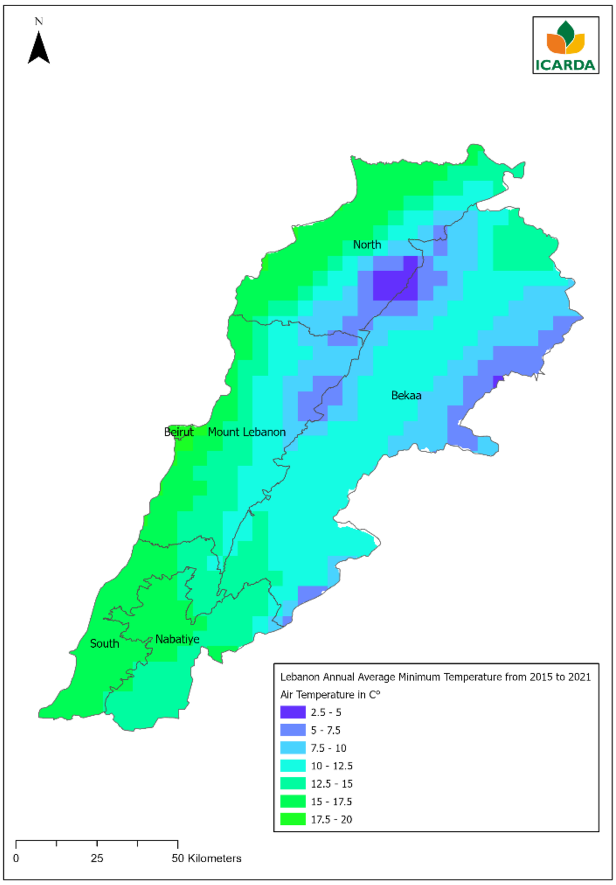

Figure 3. Minimum temperature (°C) from 2015 to 2021 in Lebanon (Data source: TerraClimate).

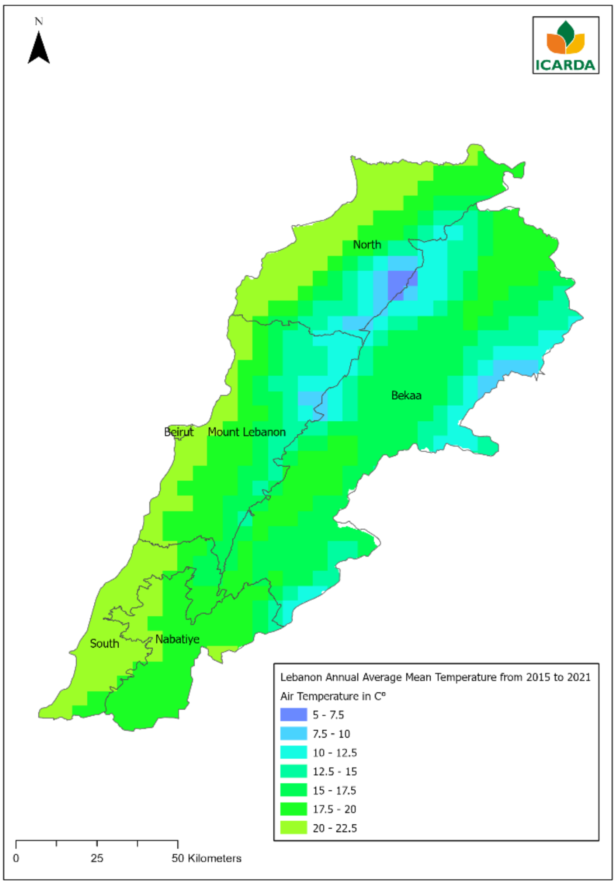

Figure 4. Average annual temperature (°C) from 2015 to 2021 in Lebanon (Data source: TerraClimate)

1.3. Change in climate change parameters.

Climate change indicators, including variations in rainfall, as well as maximum and minimum temperatures, were sourced from the TerraClimate database through the use of the Google Earth Engine's coding interface. The process involved analyzing data spanning from 2000 to 2020 to identify trends in these climatic factors by implementing time series analysis with a linear trend model. The resulting map illustrates the change per pixel over the last two decades for each of the specified climatic elements.

Overall, Lebanon experienced a general decrease in precipitation, with reductions ranging from 10 to 17.2 mm, particularly in the Mount Lebanon governorate, which is marked in dark red and orange. The remainder of the country saw decreases between 2.5 and 10 mm, highlighted in light orange and yellow. The map demonstrates that Lebanon has become drier over the past 20 years, as shown in Figure 5.

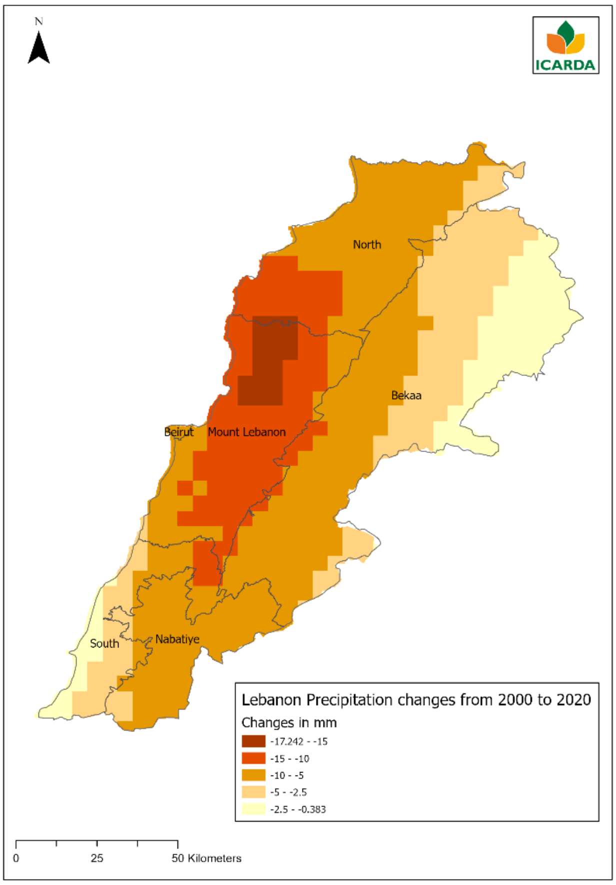

Figure 5. Precipitation changes in Lebanon from 2000 to 2020 (Data source: TerraClimate).

The maximum temperature increased in almost most of Lebanon by about from about 1 to 1.5 C° in the last 20 years (Fig. 6).

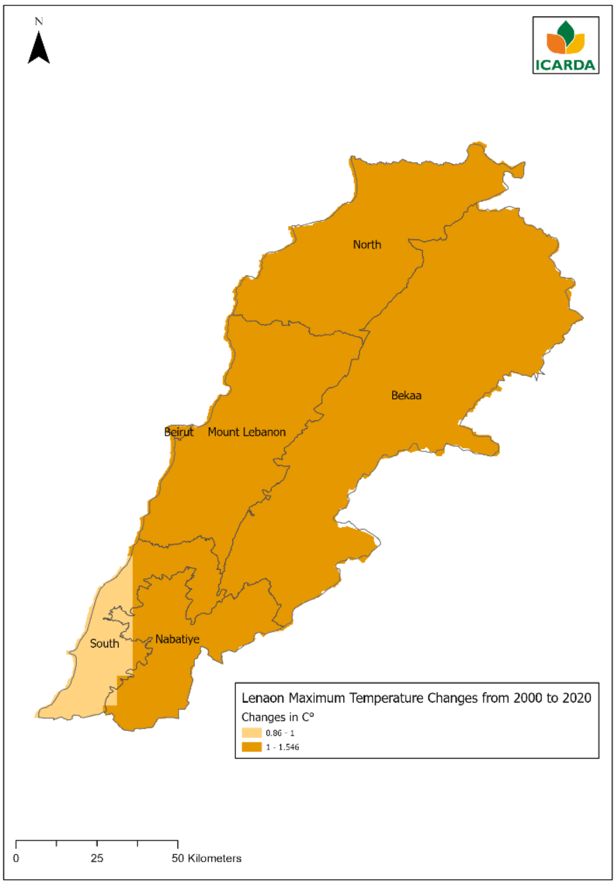

Figure 6. Maximum temperature change in Lebanon from 2000 to 2020 (Data source: TerraClimate).

In nearly all regions of Lebanon, the minimum temperature rose by approximately 1.5°C, indicated by orange shading, especially in the northern parts of the country and, more specifically, in the North of the North and Bekaa areas, where the increase ranged from 1.5

to 1.7°C, shown in dark orange, over the past 20 years, as depicted in Figure 7.

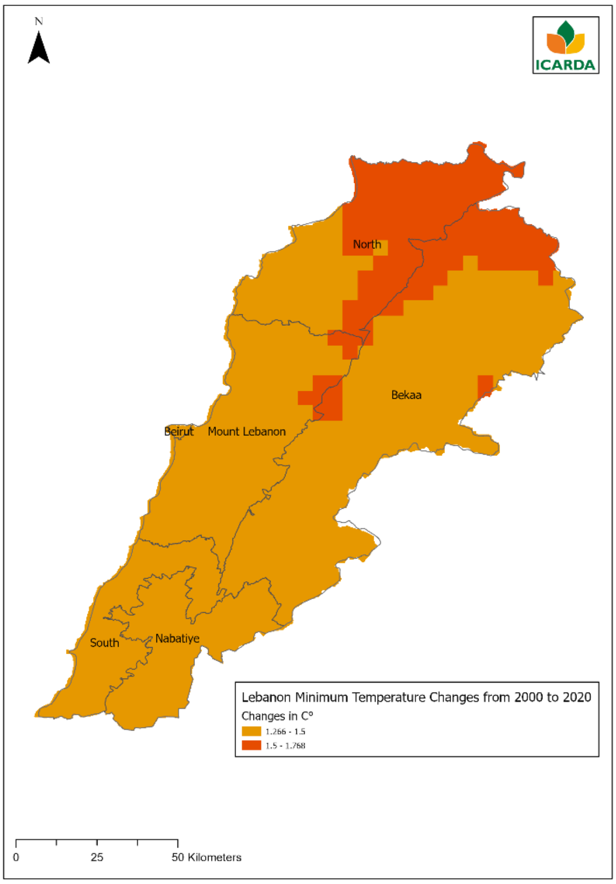

Figure 7.Annual minimum temperature change in Lebanon from 2000 to 2020 (Data source: TerraClimate).

2. Soil type, soil fertility indicators, and other soil constraints

2.1. Soil texture

The soil composition of Lebanon, measured in hectares, was charted utilizing the advanced and comprehensive Harmonized World Soil Database (HWSD) by FAO, adhering to the USDA soil classification standards. The extent of different soil textures across each Lebanese governorate was determined from HWSD's soil texture raster data, employing the zonal statistic tool in ArcGIS Pro.

Lebanon's terrain is predominantly composed of clay loam and loam soils, as illustrated in Figure 8. The Bekaa governorate, in particular, is a prime region for wheat cultivation, reflecting a significant presence of loam soil, covering approximately 363,956.0 hectares, and clay loam soil, spanning about 63,013.2 hectares, as detailed in Table 1.

Table 1. Soil texture area (ha) in different Governorate of Lebanon (Source: FAO HWSD database)

Governorate	Clay	Clay Loma	Silty Clay Loam	Sandy Clay Loam	Loam	Sandy Loam
Beirut	0.0	325.4	0.0	216.9	1235.5	0.0
Bekaa	1037.4	63013.2	0.0	23.6	363956.0	514.0
Mount Lebanon	0.0	80724.6	0.0	47.2	111615.8	9.4
Nabatiye	0.0	87590.3	0.0	0.0	18583.8	0.0
North	0.0	70685.3	0.0	0.0	122937.7	0.0
South	18.9	66365.9	4.7	0.0	21983.6	0.0

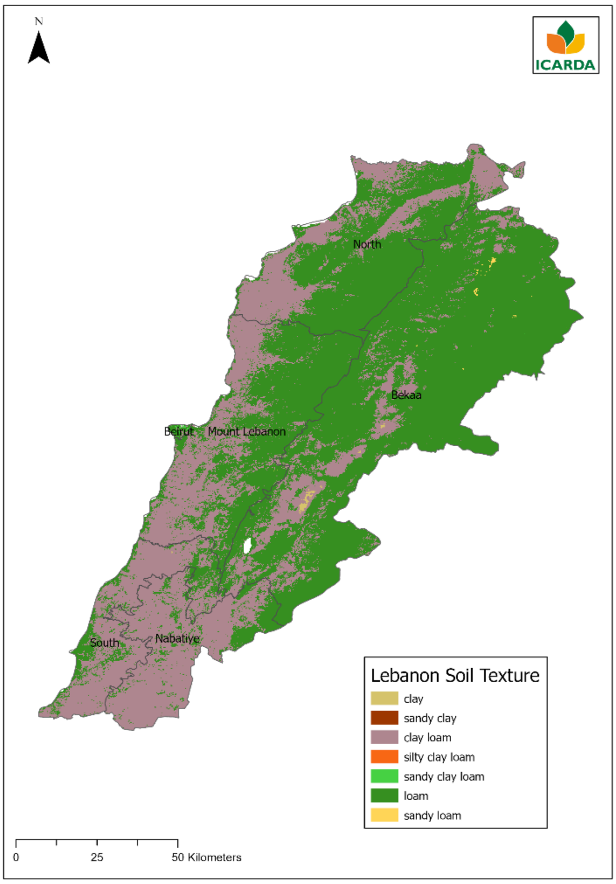

Figure 8. Lebanon soil textural classes (Data source: FAO HWSD).

2.2. Slope/Elevation

The elevation and slope of Lebanon were obtained from the SRTM30 Shuttle Radar Topography Mission data, which offers a resolution of 1 arc-second (about 30 meters) through the ArcGIS Pro platform. The SRTM30 data encompasses all land areas between latitudes 60° N and 56° S, covering approximately 80% of the Earth's land surface. This digital elevation data is the result of an international research collaboration, produced using digital elevation models. Unlike other datasets that may have unfilled gaps or use commercially sourced data for gap-filling, this dataset has been enhanced with void-filling processes utilizing open-source data, including ASTER GDEM2, GMTED2010, and NED.

Lebanon, characteristic of mountainous nations, features a complex physical geography with significant variations in landforms over short distances. Elevations span from sea level along the Mediterranean coastline to 3,088 meters at the peak of Qurnat as Sawda, Lebanon's tallest mountain. Most of the country exhibits slopes exceeding 5%, with the notable exception of the Bekaa Valley. A map detailing these slopes can be found in Figure 9.

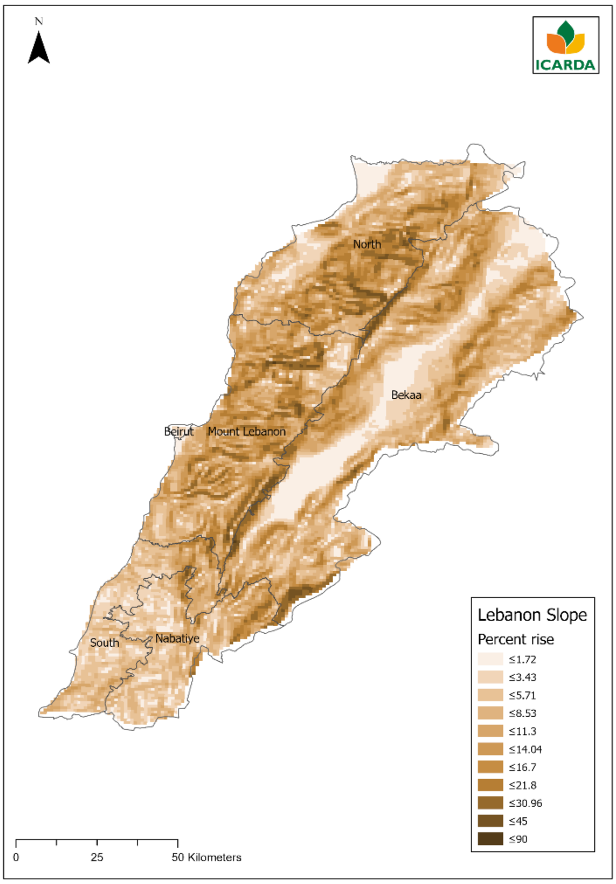

Figure 9. Slope in (%) for different governorates of Lebanon (Data source: derived from SRTM30 Shuttle Radar Topography Mission).

2.3. Soil organic carbon

The soil organic carbon (SOC) content across different soil layers is quantified in grams per kilogram (g/kg). The ISRIC's global soil organic carbon map stands as the inaugural map of its kind, produced through a collaborative and participatory process with input from member countries, marking its novelty and uniqueness. This map was developed under the supervision of the Intergovernmental Technical Panel on Soils and the Global Soil

Partnership Secretariat, with countries reaching a consensus on the methodology for the map's creation and receiving training in contemporary tools and techniques for crafting their national maps. The Global Soil Partnership consolidated these national maps into the final composite, ensuring a comprehensive harmonization process.

In Lebanon, the SOC content displayed on the map varies between 8.03 and 85.7 g/kg. The majority of Lebanese territory exhibits a high SOC concentration, exceeding 30 g/kg in the top 30 cm of soil, whereas areas with SOC levels below 30 g/kg are primarily found in the Bekaa governorate, as indicated in Figure 10.

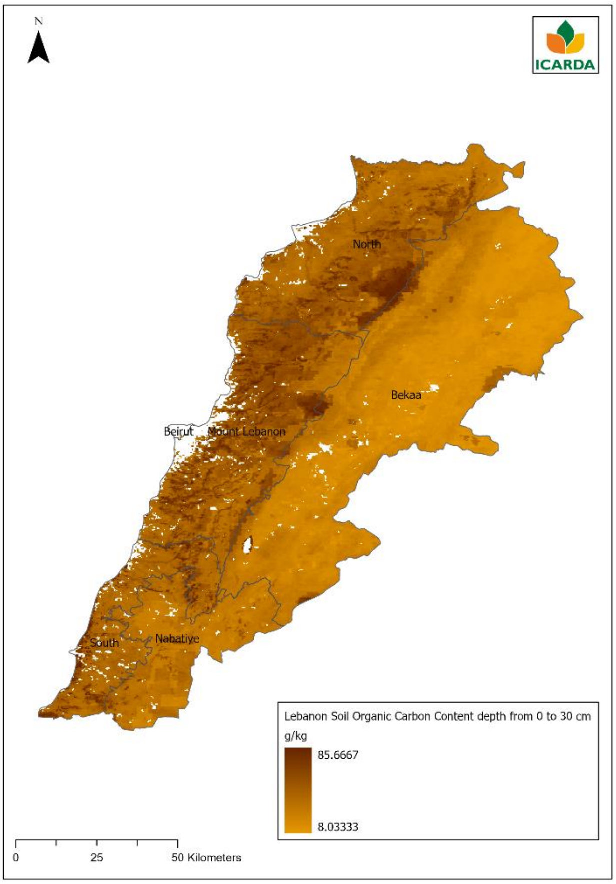

Figure 10. Soil organic carbon (g/kg soil) content at 0-30 cm soil profile in Lebanon (Data source: ISRIC digital soil data).

2.4. Soil salinity

Salinity levels were determined using data from the Harmonized World Soil Database (HWSD), a comprehensive 30-arc-second (about 100 meters) raster database featuring over 15,000 distinct soil mapping units. This dataset integrates a wide array of existing soil information from around the globe, including SOTER, ESD, the Soil Map of China, WISE, etc., at a scale of 1:5,000,000. The HWSD is a product of collaborative efforts among the Food and Agriculture Organization (FAO), the International Institute for Applied Systems Analysis

(IIASA), ISRIC-World Soil Information, the Chinese Academy of Sciences (ISSCAS), and the Joint Research Centre of the European Commission (JRC). The comprehensive raster database it produces contains 21,600 rows and 43,200 columns, each linked to harmonized data on soil properties. By employing the ArcGIS platform, this project linked attribute data to the raster map and extracted information on soil salinity, measured as electrical conductivity (EC) in deciSiemens per meter (dS/m), either from a saturated soil paste or a diluted soil-water suspension. According to agronomically relevant thresholds outlined in the HWSD documentation, soil salinity is categorized into four classes: very low (less than 2 dS/m), low (2 to 4 dS/m), moderate (4 to 8 dS/m), and high (8 to 16 dS/m).

The values of Lebanon soil salinity are 0.1 dS m-1. All the Lebanon country has very low salinity as shown in (Fig. 11).

The soil salinity map was derived from the FAO-UNESCO Soil Map of the World at a scale of 1:5,000,000 (FAO, 1971-1981). Due to gaps in the HWSD raster data for the South governorate of Lebanon, available data suggests that Lebanon predominantly features soil with very low salinity levels. Figure 11 displays the salinity percentage in the soil for each pixel, providing a detailed view of salinity distribution across different regions.

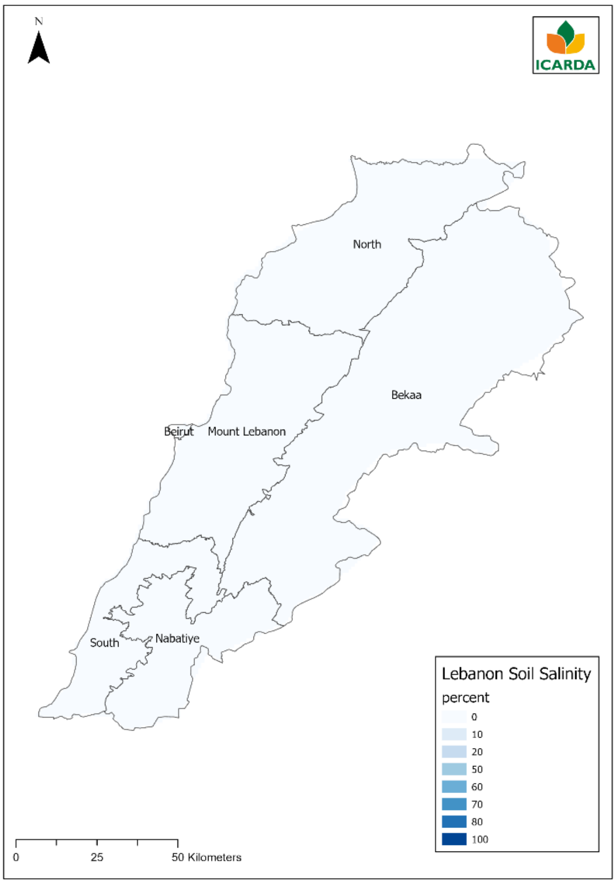

Figure 11. Lebanon soil salinity percentage in each pixel (Data source: FAO Soil Map of the World).

2.5. Soil displacement by water

Soil displacement due to water erosion was sourced from the European Soil Data Centre (ESDAC), utilizing the Global Soil Erosion map with a 25km resolution. This map is derived from Version 1.1 of the JRC/UniBasel "RUSLE-based Global Soil Erosion Modelling platform (GloSEM)" (Borrelli et al. 2013). Figure 12 presents the 2019 soil displacement by water across Lebanon, measured in megagrams per hectare per year (Mg ha−1 yr−1). It indicates that areas with low soil erosion are predominantly found in the Bekaa Valley within the Bekaa governorate and certain regions in the northern part of the North governorate, where the soil erosion rate is less than 1 Mg ha−1 yr−1. Table 2 details the extent in hectares of the various soil erosion categories within each Lebanese governorate. Notably, the Bekaa governorate, which boasts the largest wheat cultivation area, encompasses an area of 82,154.16 hectares experiencing soil erosion rates of less than 1 Mg ha−1 yr−1.

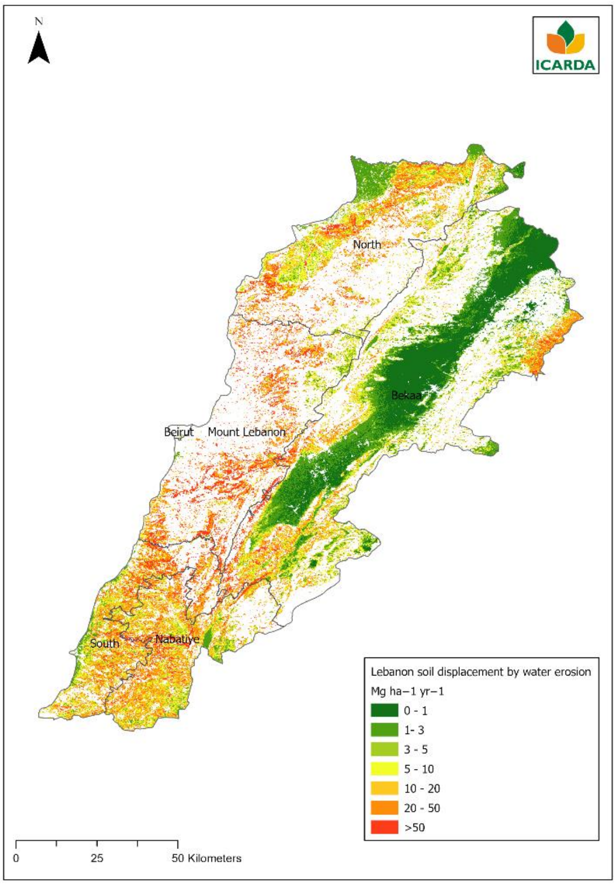

Figure 12. Soil Erosion map of Lebanon (Data source: ESDAC).

Table 2. Shows the area in ha of the different soil erosion classes in (Mg ha−1 yr−1) for each governorate of Lebanon.

Governorate	0-1	**1-3**	**3-5**	**5-10**	**10-20**	**20-50**	**>50**
BEIRUT	0.00	27.80	38.49	11.76	2.14	0.00	0.00
BEKAA	82154.16	61660.26	22801.41	29610.61	24568.94	19225.73	5065.20
MOUNT LEBANON	5.35	1317.36	2133.22	5196.72	7880.62	17965.04	17127.79
NABATIYE	21.39	3452.72	5898.17	13373.54	17726.59	21324.73	6619.94
NORTH	675.79	13181.06	10186.00	18036.68	17541.60	19643.82	7287.17
SOUTH	2.14	3122.31	4500.62	9909.06	12337.40	17992.84	7334.22

3. Soil-water resources

3.1. Groundwater recharge

The groundwater recharge map for Egypt was derived from the Groundwater Resources Map of the Worldwide Hydrogeological Mapping and Assessment Program (WHYMAP), incorporating all relevant published data available to date. This map highlights different groundwater characteristics using a color-coded system:

- Blue signifies extensive and relatively uniform groundwater basins, including aquifers and aquifer systems typically found in large sedimentary basins, which may present favorable conditions for groundwater extraction
- Green indicates areas with complex hydrogeological structures characterized by highly productive aquifers in heterogeneous, folded terrains adjacent to areas lacking significant aquifers
- Brown represents areas with limited groundwater resources, often due to the presence of shallow aquifers.

In Lebanon, a small portion, notably in the Bekaa Valley within the Bekaa governorate, features limited groundwater resources with a very high to high recharge rate exceeding 100 mm per year. To the east of the Bekaa Valley, complex hydrogeological structures prevail, showing a low to very low recharge rate of less than 20 mm per year. The remainder of Lebanon exhibits complex hydrogeological structures with a medium recharge category, ranging from 20 to 100 mm per year. Notably, the coastal area of the North Governorate includes uniform groundwater basins within the medium recharge category of 20 to 100 mm per year. These findings are illustrated in the groundwater recharge map (Fig. 13).

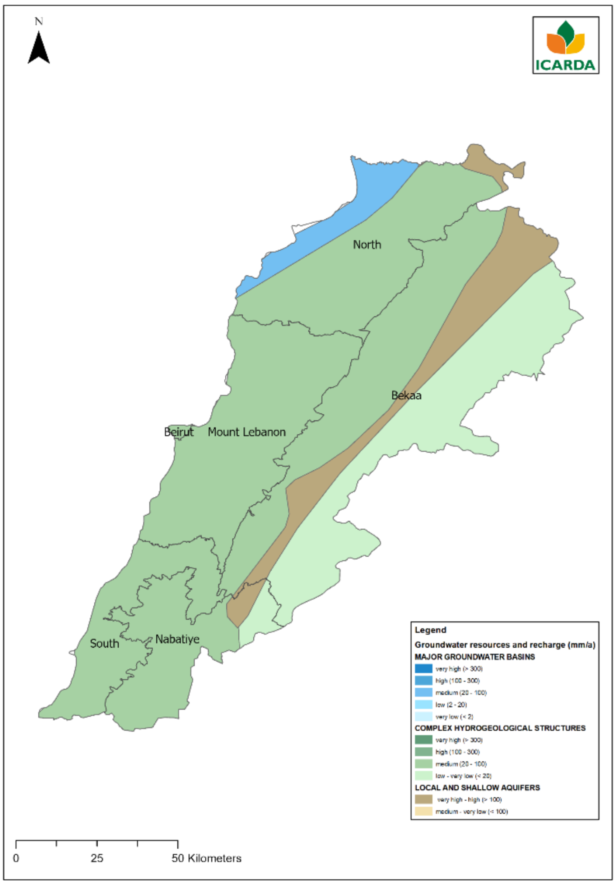

Figure 13. Groundwater recharge in Lebanon (Data source: WHYMAP).

3.2. Dams

The map of the existing dams of Lebanon was obtained from the Global Reservoirs and Dams (GRanD) version 1.01 dataset created by Lehner et al. (2011). The Karaoun dam on the Litani River (which has a capacity of 160 million cubic meters) is the major dam in Lebanon (Fig. 14).

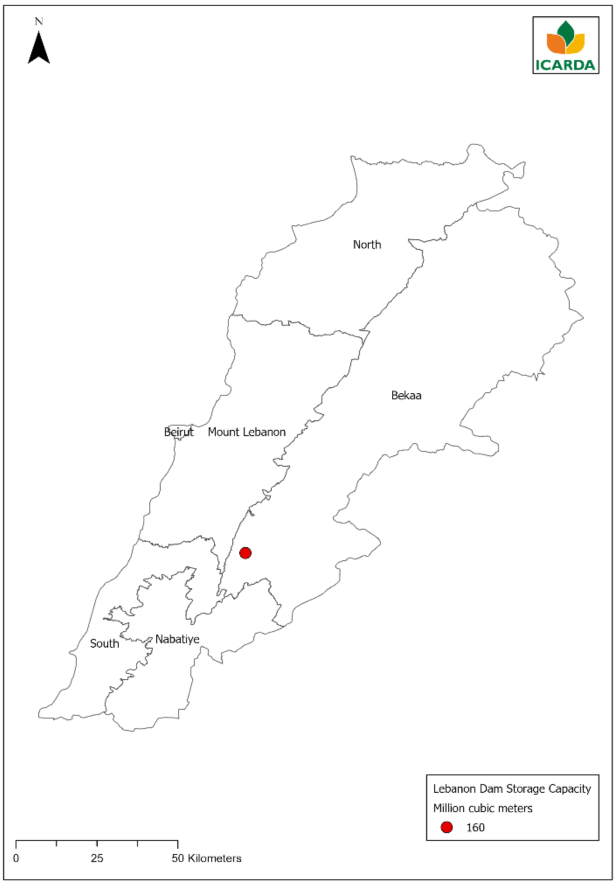

Figure 14. Existing dams in Lebanon (Data source: Lehner et al., 2011, Global Reservoirs and Dams).

4. Land use land cover, hot-spots, and land use

4.1. Normalized difference vegetation index

Winter crops, including wheat, exhibit their peak vegetation from January to March. The average seasonal Normalized Difference Vegetation Index (NDVI) map, shown in Figure 15, was derived from the MODIS NDVI data from the MOD13Q1 V6 product. NDVI values in MODIS are calculated from atmospherically corrected bi-directional surface reflectances, with adjustments to exclude water bodies, clouds, heavy aerosols, and cloud shadows. The seasonal NDVI for Lebanon, processed using the Google Earth Engine platform, varies between 0 and 0.8. Figure 15 illustrates the NDVI values during the peak vegetation period from January to March, showing values between 0.5 and 0.8 in many regions. The North, Mount Lebanon, Nabatiye, and South governorates feature extensive areas within this NDVI range, whereas the Bekaa governorate has a smaller portion of its area, specifically in the southern Bekaa Valley, falling within this range.

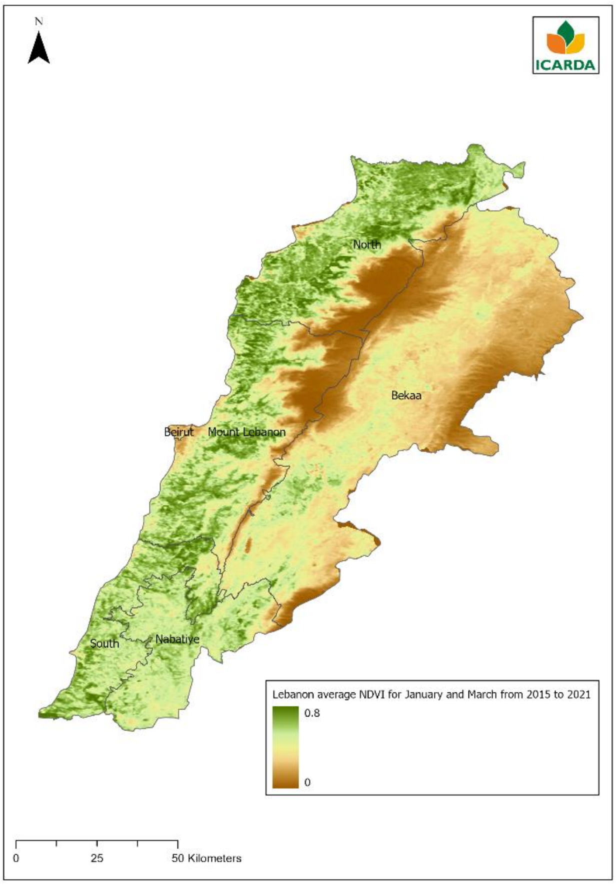

Figure 15. NDVI in Lebanon from November to March from 2015-2021.

4.2. Hotspot and suitability mapping

The threshold values for various biophysical characteristics essential for wheat cultivation in Lebanon were established based on expert knowledge from agronomists. These values were used to identify hot spot constraints for wheat cultivation and to map the suitability for wheat cultivation in Lebanon, as detailed in Table 3 and Table 4, respectively.

Table 3. Threshold values of biophysical parameters for mapping hotspot constraints for wheat cultivation in Lebanon.

SN	Biophysical characteristics	Hotspot
1	Annual average rainfall (mm)	<50
2	Groundwater recharge (mm/ha)	<20
3	Annual minimum temperature change (^{0}C)	>0.5
4	Slope (%)	>20
5	Maximum temperature (^{0}C)	>40
6	Minimum temperature (^{0}C)	<10
7	NDVI January to March	<0.3

8	Annual precipitation changes (mm)	<5
9	Soil displacement by erosion (Mg/ha)	>5
10	Soil organic carbon in 0-30 cm (g/kg)	<20
11	Annual temperature change (^{0}C)	>0.5
12	Soil salinity	>50 (>5 dS/m)

Table 4. Threshold values of biophysical parameters for suitability mapping for wheat in Lebanon.

SN	Biophysical characteristics	Suitability
1	Annual average rainfall (mm)	>200
2	Groundwater recharge (mm/ha)	>100
3	Annual minimum temperature change (^{0}C)	<0.5
4	Slope (%)	<20
5	Maximum temperature (^{0}C)	<40
6	Minimum temperature (^{0}C)	>10
7	NDVI January to March	>0.5
8	Annual precipitation changes (mm)	>5
9	Soil displacement by erosion (Mg/ha)	<5
10	Soil organic carbon in 0-30 cm (g/kg)	>30
11	Annual temperature change (^{0}C)	<0.5
12	Soil salinity	<50 (<5 dS/m)

4.2.1. Suitability Mapping

Twelve raster datasets, representing various biophysical parameters crucial for wheat cultivation, were adapted using details from Table 4 for integration into the suitability modeling tool within the ArcGIS Pro platform. This adaptation was pivotal in generating the suitability map for Lebanon, as shown in Figure 16. The suitability assessment ranged from 1, indicating no or very low suitability, to 10, denoting high suitability. This scale did not employ weighting since all criteria were deemed equally significant.

The adaptation process involved two approaches. For datasets with a range of classes, a transformation table (Table 5) outlined the methodology. This table included columns for class, start, end, and suitability values. The start and end columns specified the numerical range defining each class, while the suitability values column indicated how each range would be adjusted to fit the suitability scale for that particular criterion.

For data pertaining to unique categories, such as groundwater recharge, another transformation table (Table 6) was employed. This table listed Class, Category, and Suitability values. Here, the Category column determined the class to which a suitability value was attributed, and the Suitability values column described the conversion of these categories into the overall suitability scale for the given criterion.

Table 5. The transformation table of the biophysical characteristics for suitability mapping of data that has a range of classes.

Slope			
Class	Start value	End value	Suitability
1	0	20	10
2	20	46.75	1
Soil displacement by erosion			
1	0.1	5	10
2	5	200	3
Soil Organic carbon			
1	1.9	30	5
2	30	85.6	10
Minimum temperature			
1	2.69	10	1
2	10	17.99	10
NDVI			
1	0	0.5	5
2	0.5	0.82	10

Table 6. The transformation table of the biophysical characteristics for suitability mapping of data with unique categories.

GWR Class	category	Suitability
1	11	10
2	22	2
3	23	10
4	34	10

The datasets for annual average rainfall, annual minimum temperature change, maximum temperature, annual precipitation changes, annual temperature changes, and soil salinity fell within the threshold values outlined in Table 4 for assessing wheat cultivation suitability in Lebanon and were thus excluded from the analysis. The completed suitability map, depicted in Figure 16, identifies the Bekaa Valley, south, Nabatiye, and the western regions of the North governorates in Lebanon as the areas with the highest suitability for wheat cultivation.

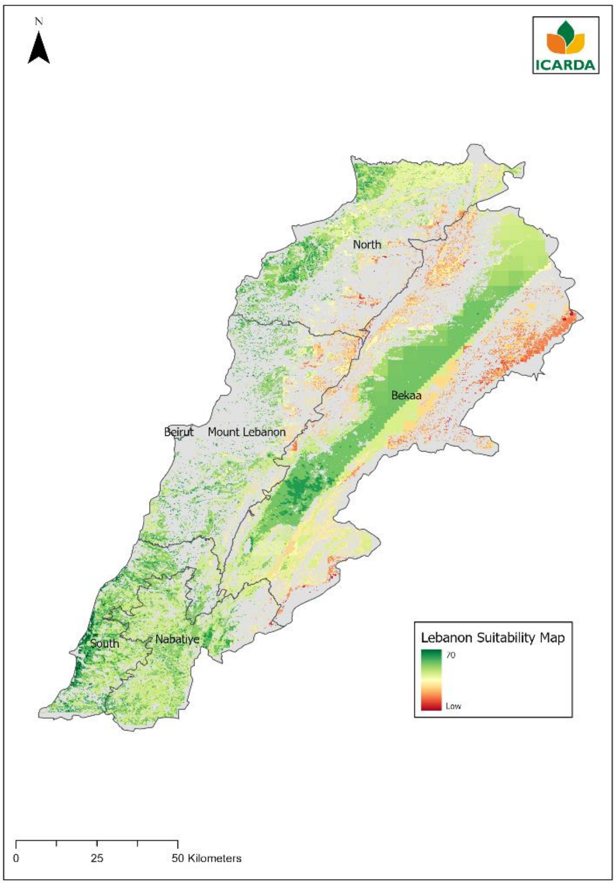

Figure 16. Suitability for wheat cultivation in Lebanon.

4.2.2. Hotspot Mapping

For the purpose of identifying areas with potential constraints for wheat cultivation, biophysical parameters outlined in Table 3 were used. The process involved converting each biophysical raster dataset into two categories based on the specified threshold values. This classification was performed in ArcGIS Pro using the IF condition, where a value of 1 indicates the data falls within the desirable range (true condition), and a value of 0 signifies it falls outside the specified range (false condition). Notably, certain parameters were excluded from the hotspot analysis due to the absence of extreme values in Lebanon: maximum temperatures exceeding 40°C, annual average rainfall below 50mm, changes in annual minimum temperature over 0.5°C, changes in annual precipitation below 5mm, changes in annual temperature over 0.5°C, and soil salinity levels above 5. To compile the hotspot map, the cell statistics tool from ArcGIS Pro's spatial analyst toolkit was employed, aggregating the transformed datasets. The resulting hotspot map, depicted in Figure 17, illustrates areas with minimal restrictions for wheat growth in green, predominantly in the Bekaa, followed by the North and Mount Lebanon governorates. Conversely, areas marked in yellow represent regions with moderate limitations to wheat cultivation.

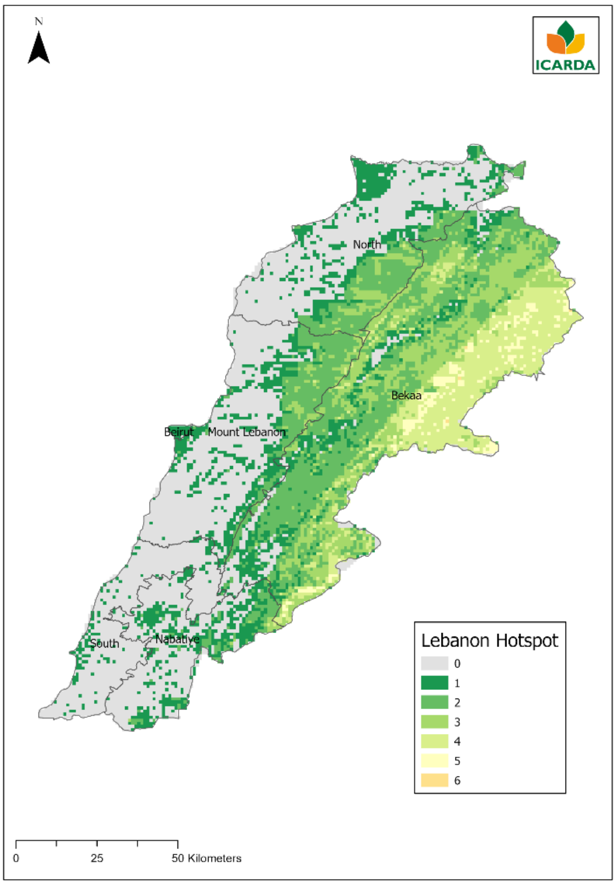

Figure 17. Map of hotspot constraints for wheat cultivation in Lebanon.

Acknowledgments

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