CP 2.1

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2nd Multi-stakeholder Consultation on the WEFE Nexus in Lebanon

Damour Coastal Aquifer Vulnerability and SGDs

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UN environment programme

Mediterranean Action Plan Barcelona Convention

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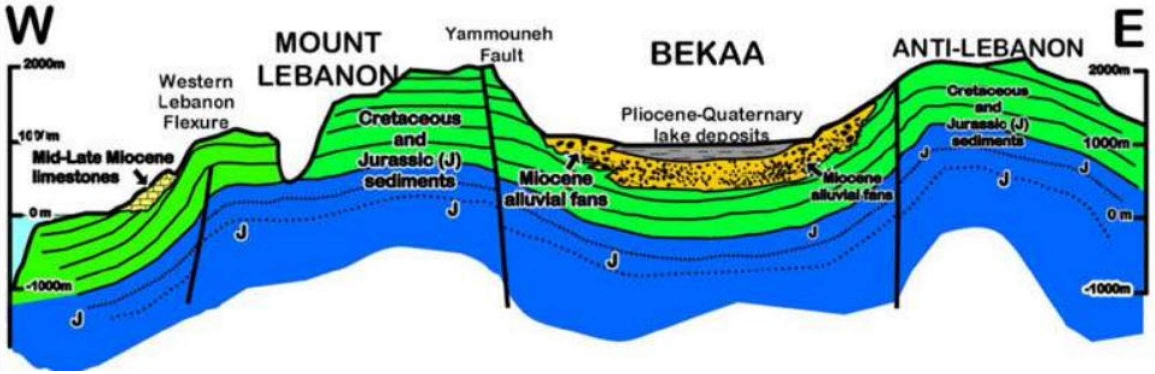
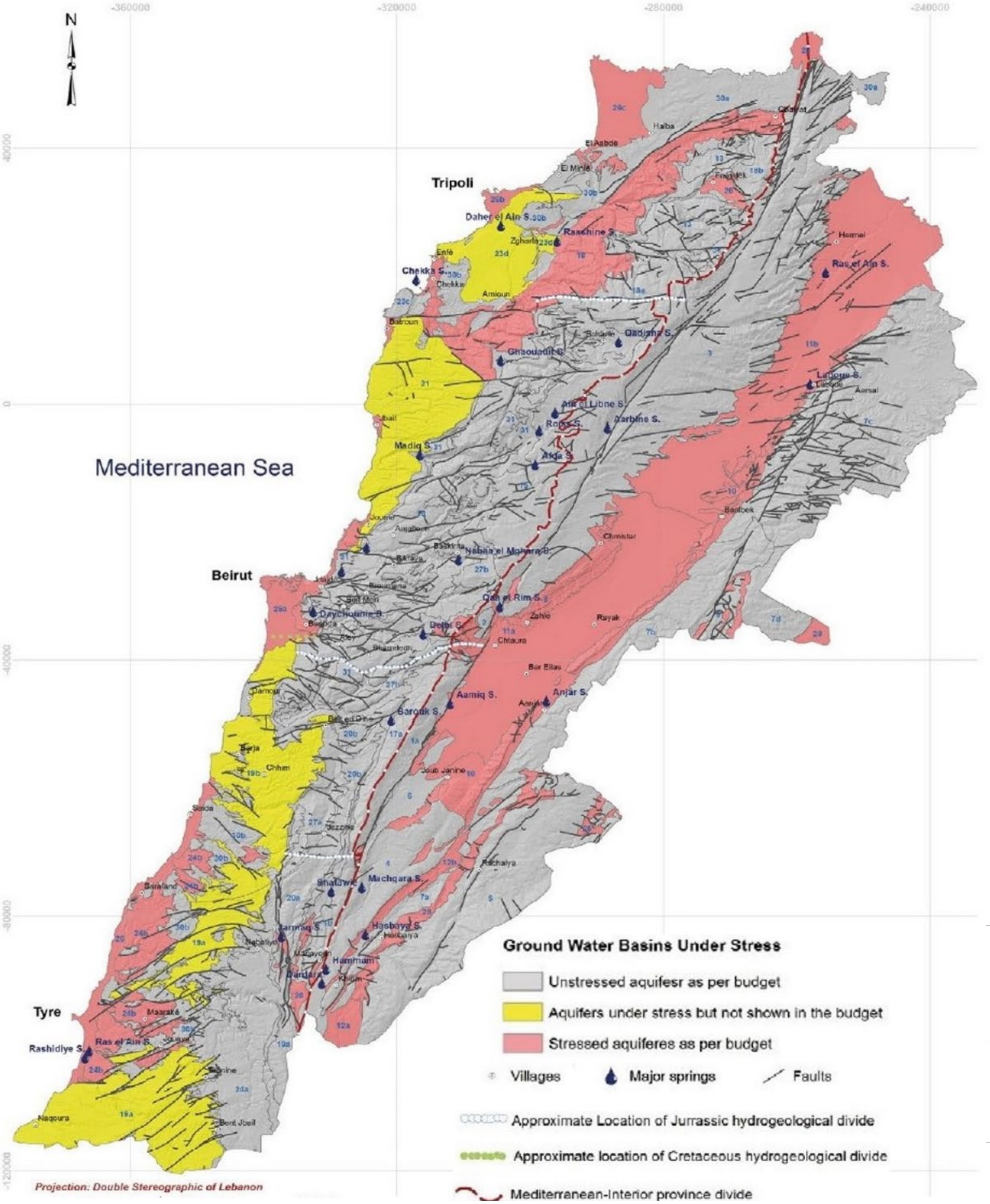
Lebanese Republic Ministry of Energy and Water

COASTAL AQUIFERS IN LEBANON

- The groundwater (GW) divide between the Interior and Mediterranean provinces is marked by the peaks of Mount Lebanon (UNDP, 1970).
- The Mediterranean Province covers the regions located west of the divide, and is subdivided into 3 major units:
  - Jurassic limestone;
  - Cenomanian limestone (gradually lowering towards the sea);
  - Senonian and Eocene chalks (also dipping towards the sea).
- Most of the Lebanese coastal aquifers are stressed (MoEW and UNDP, 2014).
- Usually overexploited (heavily urbanized coast).



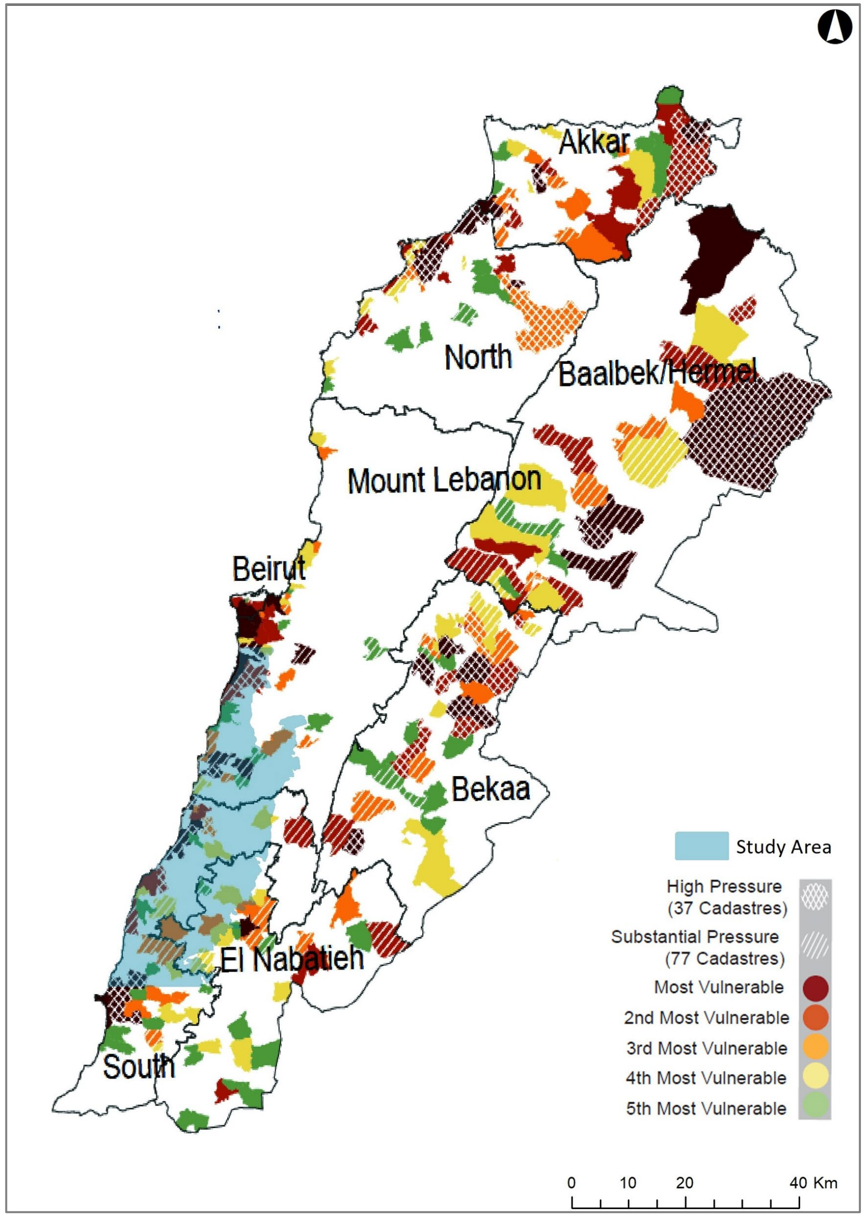
Schematic east-west cross section across North Lebanon (Walley, 1998)



Stressed aquifers of Lebanon (MoEW and UNDP, 2014)

STUDY AREA

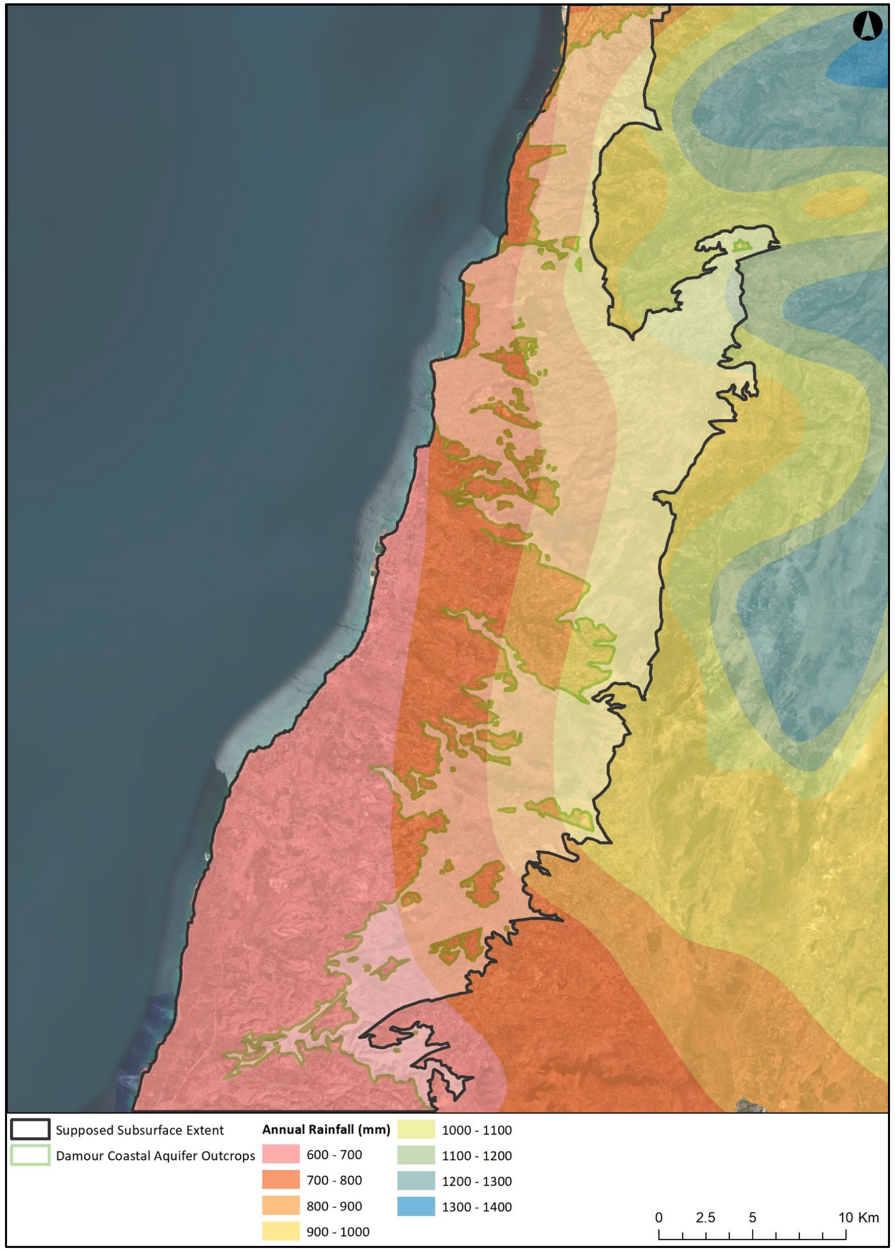
- Located between Beirut and Tyre.
- Approximate surface: 796 km² (7.6% of Lebanon's surface).
- BMLWE and SLWE responsible for the supply of potable water.
- Beirut's aquifer was salinized in the 60s ⇒ Damour coastal aquifer became a main water source for the Greater Beirut (Daher et al., 2011).
- The Environmental Resources Monitoring in Lebanon (ERML) implemented by MoE under the management of UNEP in collaboration with UNDP, identified the Damour river estuary as high priority ecological site (MoE et al., 2013).



Study area's socio-economic vulnerability (modified from GoL and UN, 2018)

CLIMATE CONDITIONS

- Mild moist winters and dry summers.
- Annual rainfall: 600mm (south) and 1100mm (northeast).
- Temperature:
    - Saida, 30m AMSL: 12.5°C (January) to 26°C (August).
    - Jezzine, 950m AMSL: 7.1°C (January) to 21.9°C (August).
- Average actual evapotranspiration (ETA): 260 mm/year (can reach 600 mm/year in the northeast and southwest) (Frem and Saad, 2021).



Rainfall isohyets (digitized from the original map of Plassard (1971))

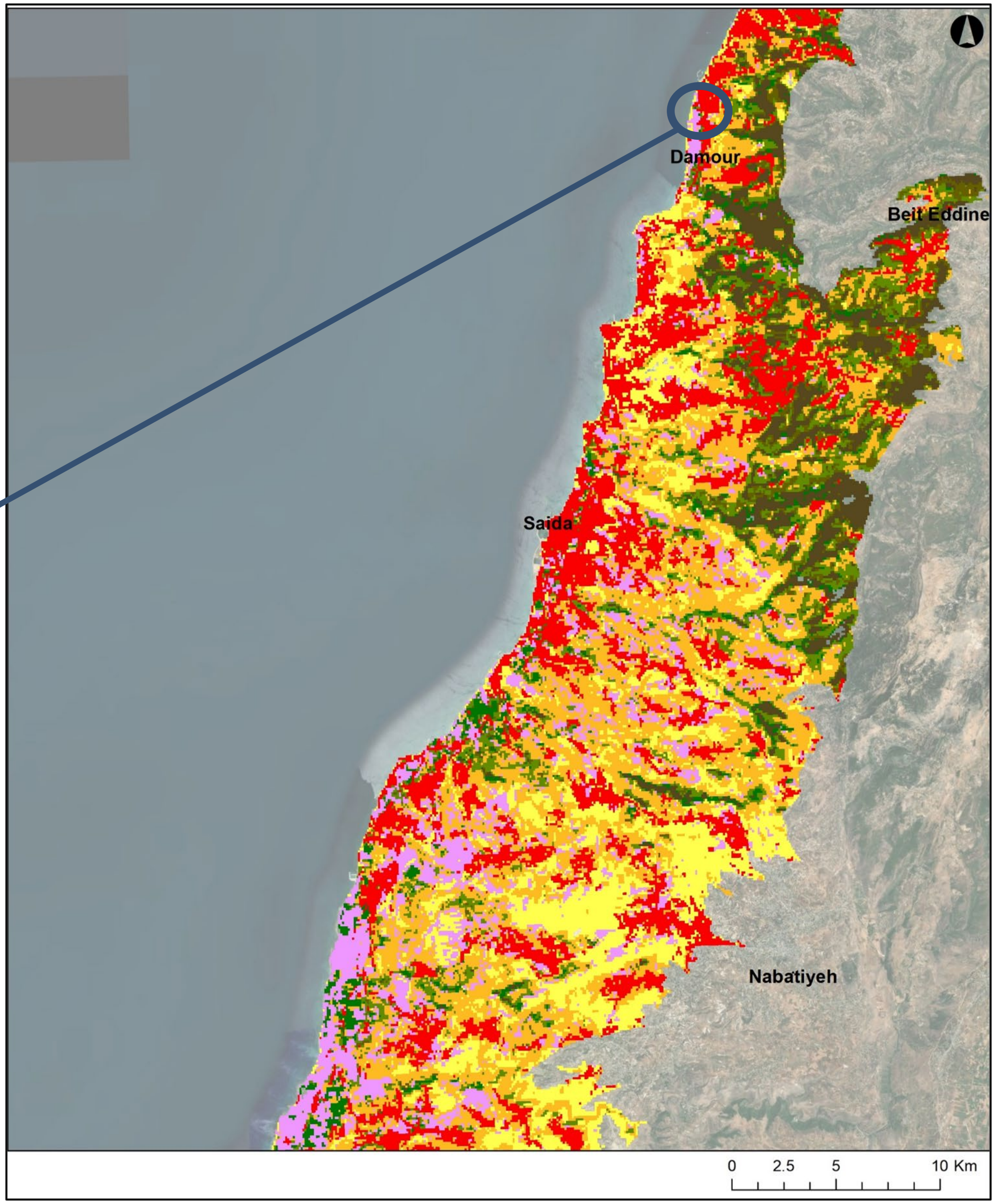
TOPOGRAPHY

- Ground elevations between 0 and 1050m AMSL.
- Slopes between 0° and 109° (flat and very steep slopes).
- The slope raster is useful for the vertical vulnerability mapping.

DEM and slopes (data source: Aster 1 arc-second products)

LAND COVER

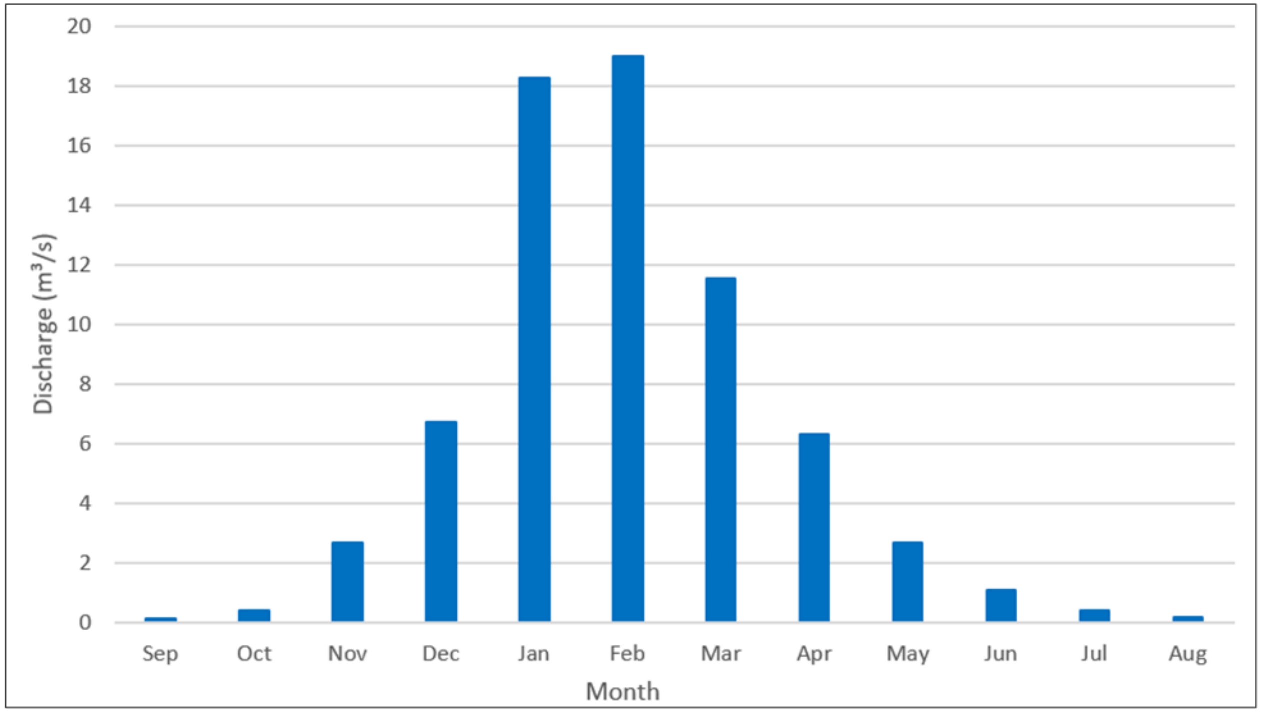
- Copernicus Global Land Service data.
- Ideal for fishing (rock and sand mixture) (UNEP-MAP-PAP, 2004).
- Coast width decreased by 25m (1940 to 1990) (Bakhos, 2003).
- Main natural areas: seascapes and river valleys.
- Coastal agriculture: bananas, mulberries and citrus (along the Damour coast since the 1950s).



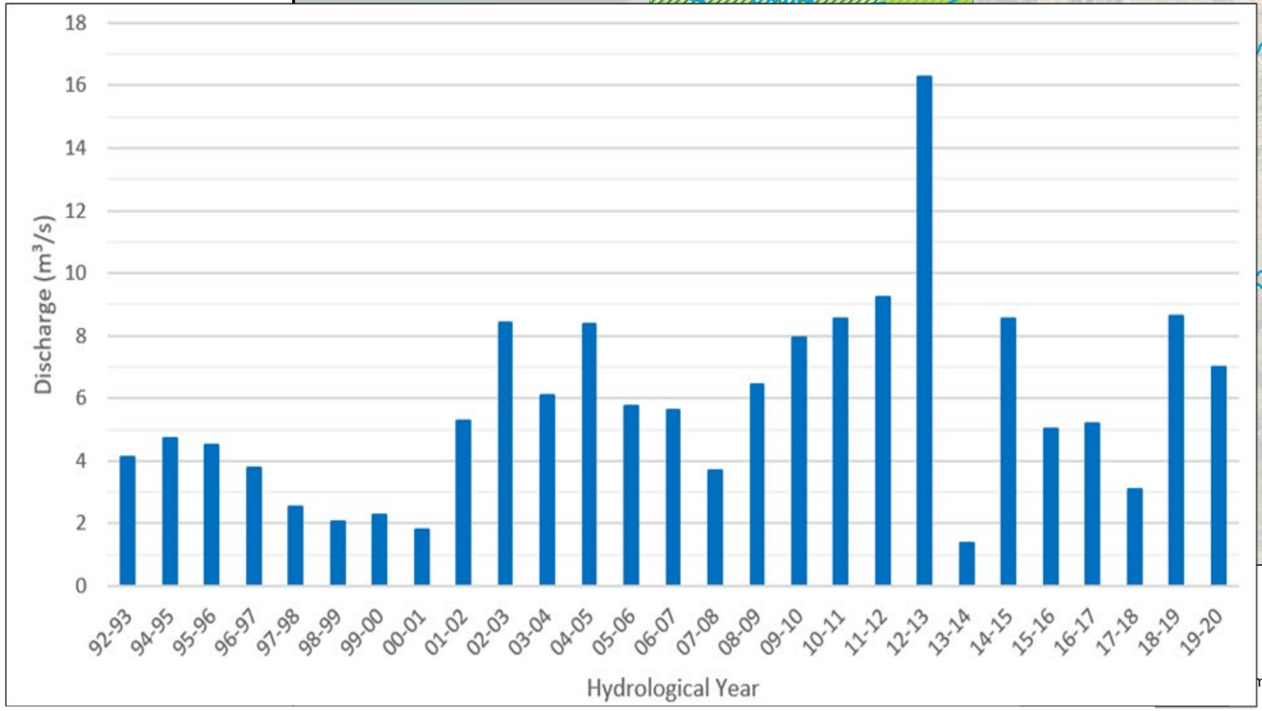
Land cover within the study area (100m resolution)

HYDRO(GEO)LOGY

- Five main rivers: Damour, Awali, Sainiq, Zahrani and the Litani.
- Damour River:
  - Highest discharge between January and February;
  - High interannual discharge variability between 1992 and 2020 (average: 5.8 m^3/s).



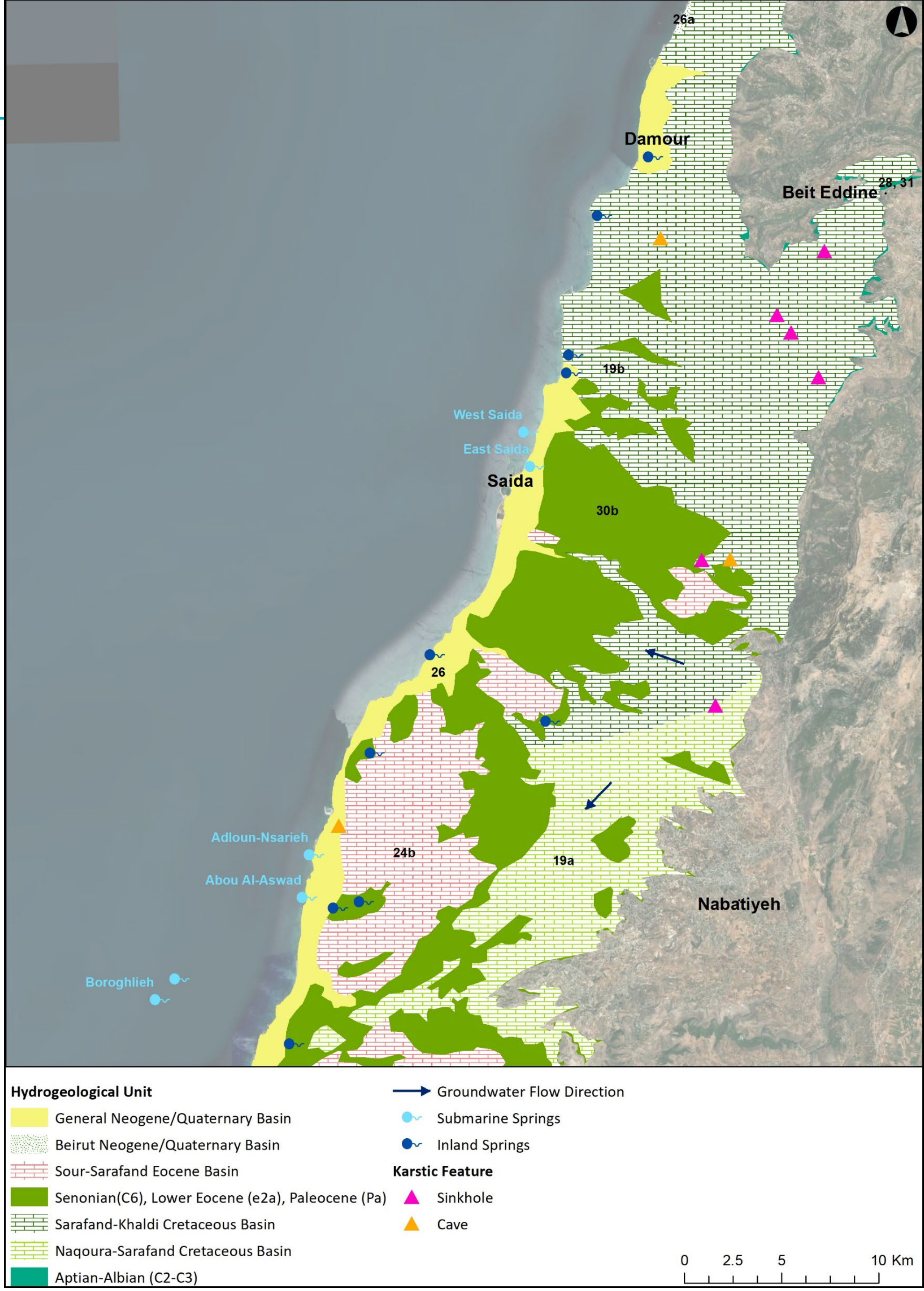
Damour River's average monthly discharge (between 1992 and 2020)



Damour River's average annual discharge (between 1992 and 2020)

HYDRO(GEO)LOGY

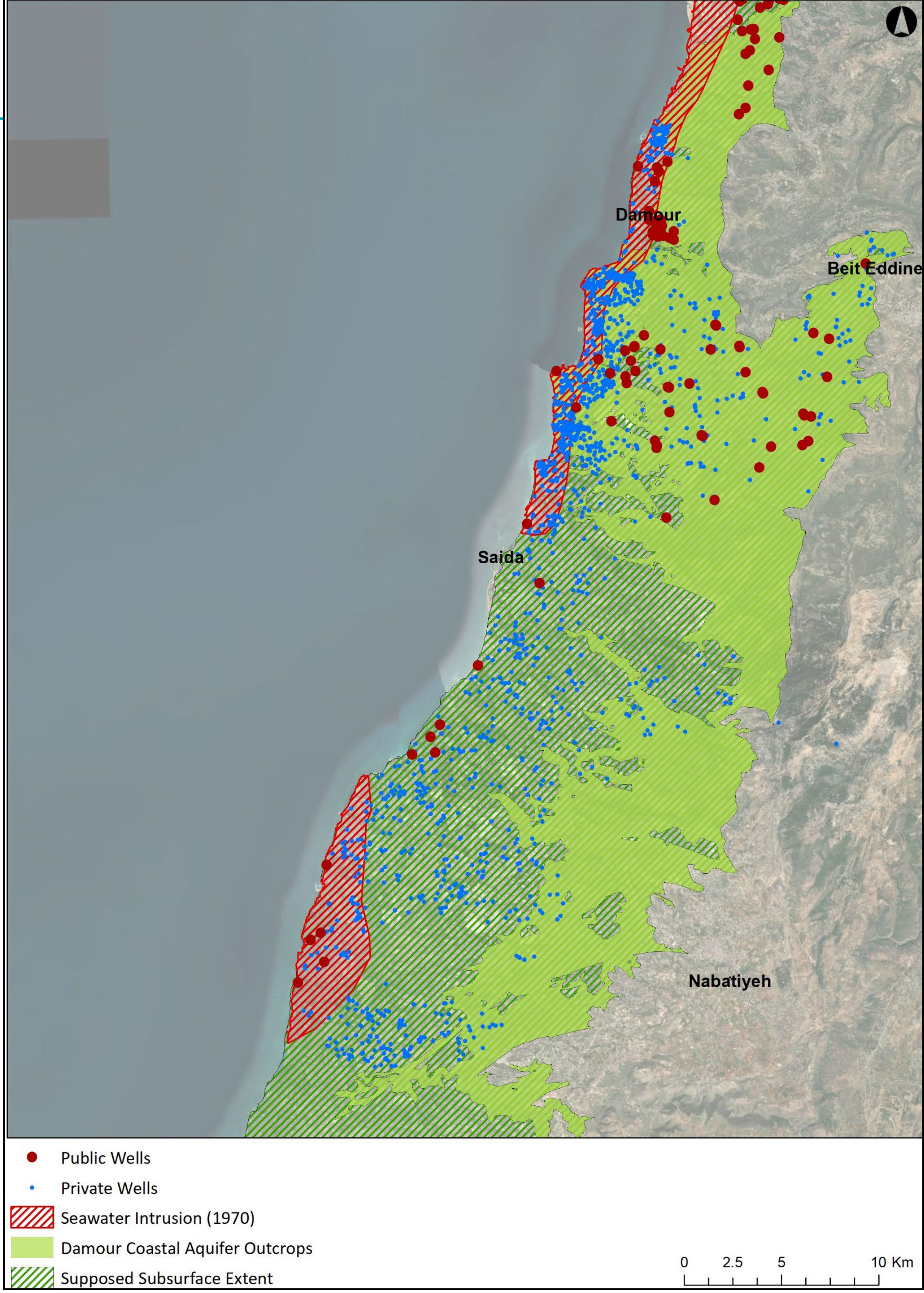
- Hydrogeological units (MoEW and UNDP, 2014):
  - Naqoura-Sarafand Cretaceous (13.8% of the study area);
  - Sarafand-Khaldi Cretaceous (38.8%);
  - Sour-Sarafand Eocene (12.9%);
  - General Neogene/Quaternary (7.3%);
  - Senonian, Paleocene, Lower Eocene (C6-Pa-e2a) (25.7%);
  - Beirut Neogene/Quaternary and Aptian-Albian.
- C4-C5 is a major karstified aquifer (high storage and recharge).
- Khadra (2017): Long response time (rainfall - GWL) ⇒ poor/no conduit flow.
- Recharge (MoEW and UNDP, 2014): 331 MCM (dry year) to 582 MCM (wet year).
- Lack of typical downgradient hydrochemical patterns (Khadra and Stuyfzand, 2014) ⇒ Local GW origin.



Hydrogeological units within the study area

GROUNDWATER SALINITY

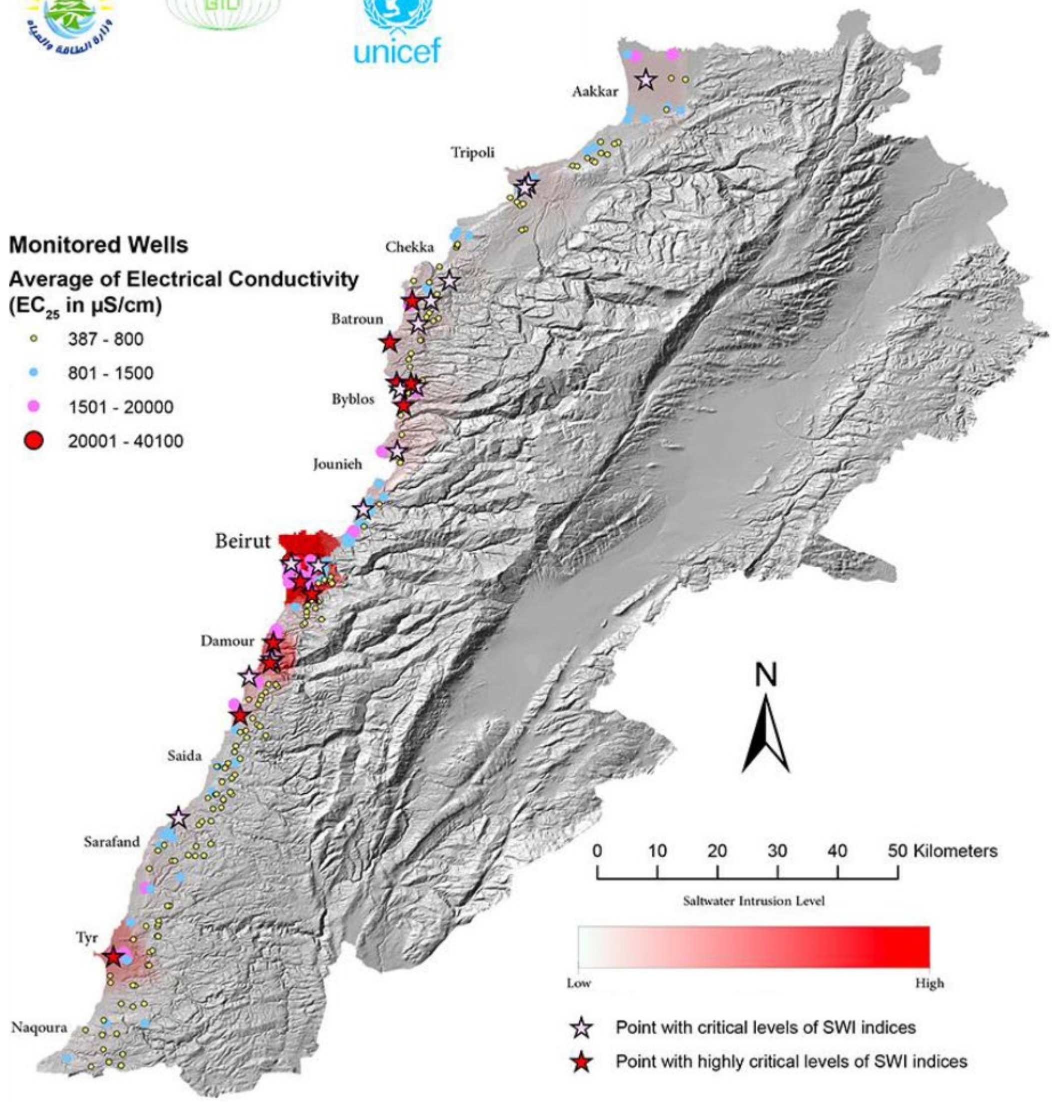
- Northern part of the aquifer: Na-K-Cl-SO_4 facies (mixing with salt water, hence direct contact with the sea and seawater intrusion).
- Southern part of the aquifer: Ca-Mg-HCO_3 facies (karstic aquifers not in contact with the sea).
- 2 zones are distinguished:
  - Between Khalde and Saida: limestones are generally (except Damour) in direct contact with the sea;
  - South of Saida: the Senonian marls constitute a screen which limits the exchanges between freshwater and seawater, and confines the aquifer.
- MoEW and UNDP (2014): freshwater-saltwater interface shifted 500-2400m further inland as compared to the 1970's intrusion line.



1970 Seawater Intrusion Line

GROUNDWATER SALINITY

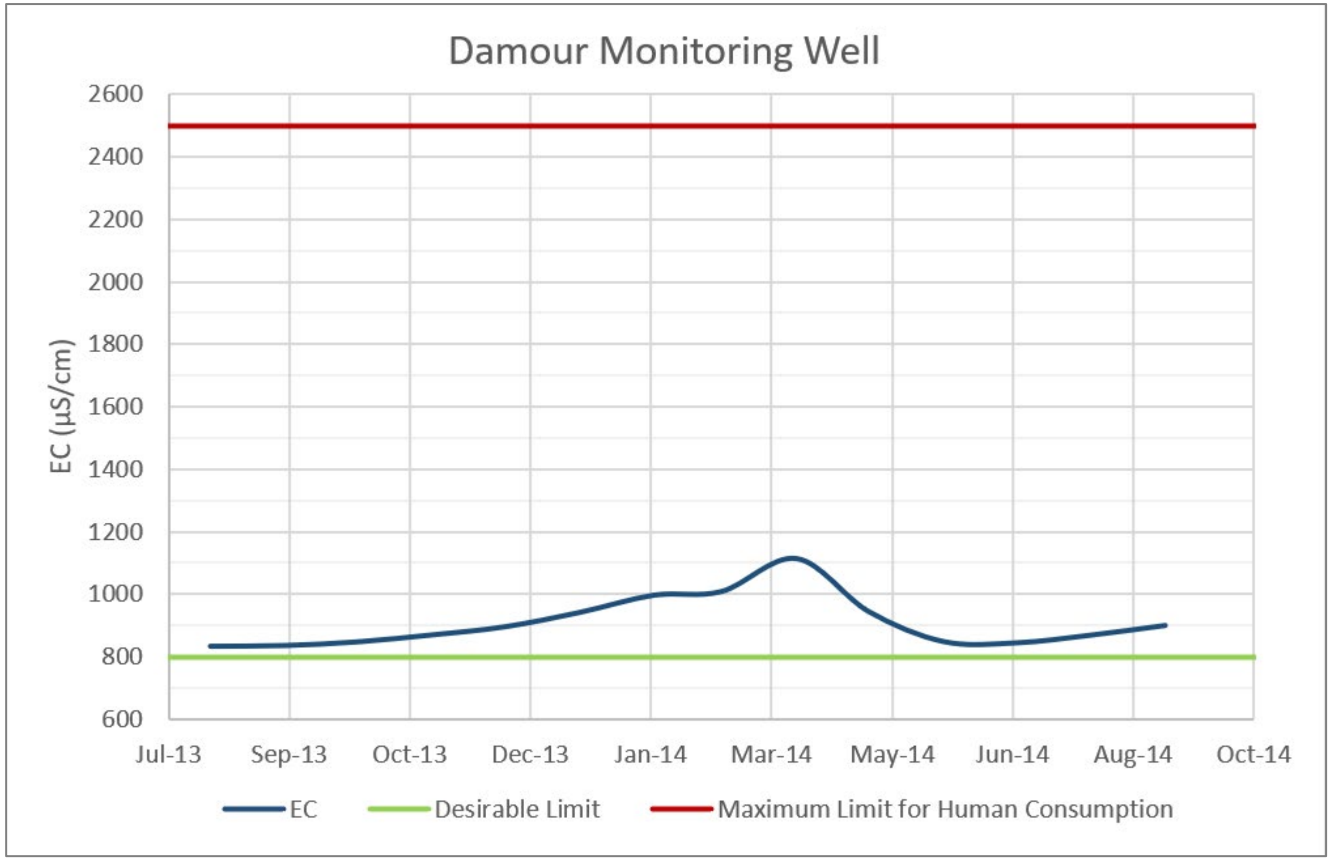
- Field data collected in 2020, including EC levels and concentration of major ions (BTD, 2022).
- EC values measured between 2011 and 2012 (by MoEW and UNDP (2014) during the wet season) are between the minimum and maximum EC values measured between August and December 2020.
- A significant increase in EC was noticed in some areas.
- Damour is one of the areas with the most serious seawater intrusion concerns: average EC measured in 17 wells between 1350 and 4470 µS/cm except Mechref Well Number 6 with EC values between 7800 and 10800 µS/cm.
- Damour: fresh-brackish to brackish-salt groundwater reflected by the CaMix to NaCl chemical water type.



Seawater intrusion map along the Lebanese coast based on indicators surveyed in 2020 (BTD, 2022)

GROUNDWATER SALINITY

- Damour's monitoring well (1400m away from the shoreline): EC < 1100 μS/cm.

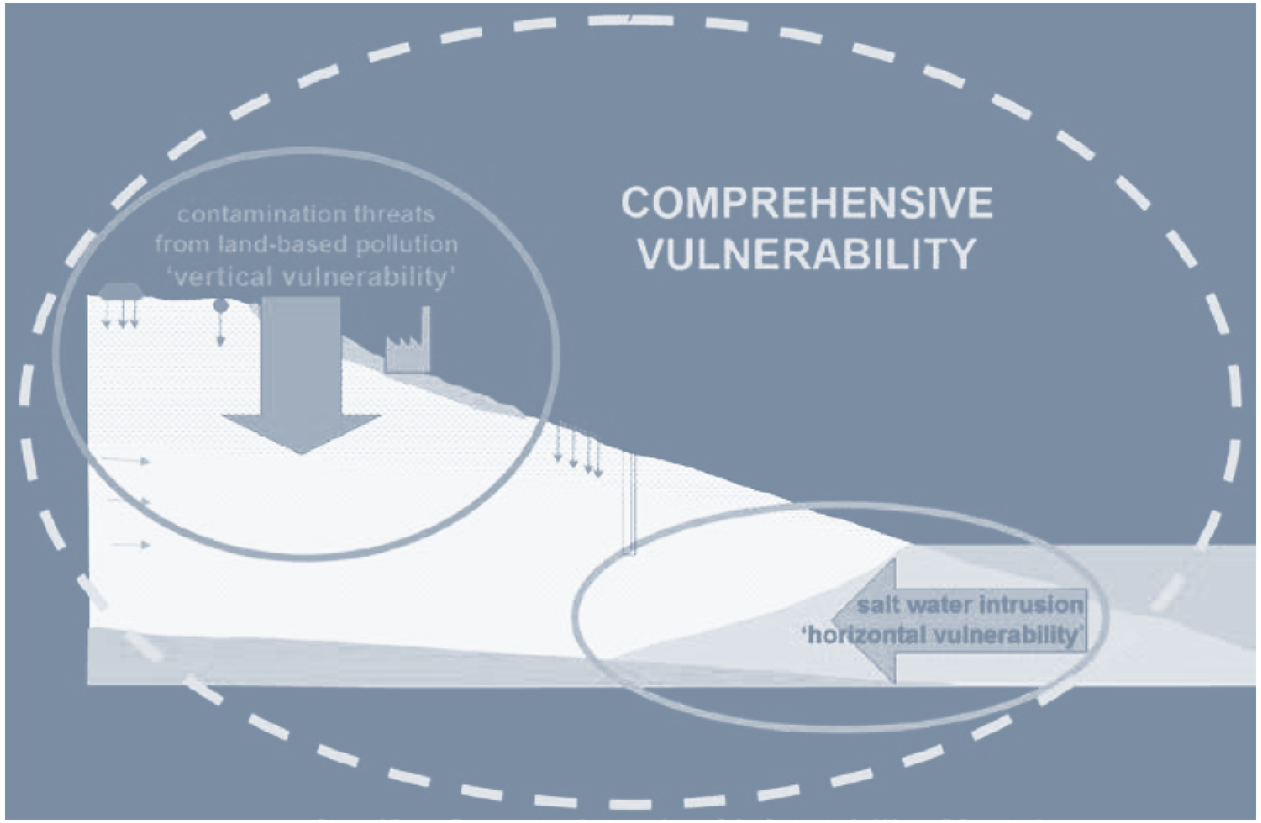


EC at Damour monitoring well between 2013 and 2014; EC limits adopted from Taylor (1996)

Aquifer Vulnerability Assessment

VULNERABILITY MAPPING

- Coastal aquifers can be polluted by surface contaminants and/or by saline water intrusion.
- GW vulnerability mapping should consider 2 components:
  - Vertical vulnerability (accounts for contamination coming from the surface);
  - Horizontal vulnerability (accounts for saline water intrusion) (UNEP-MAP and UNESCO-IHP, 2015).
- Long-term vulnerability also considers the influence of sea level changes.
- The homogeneous zoning approach was adopted.

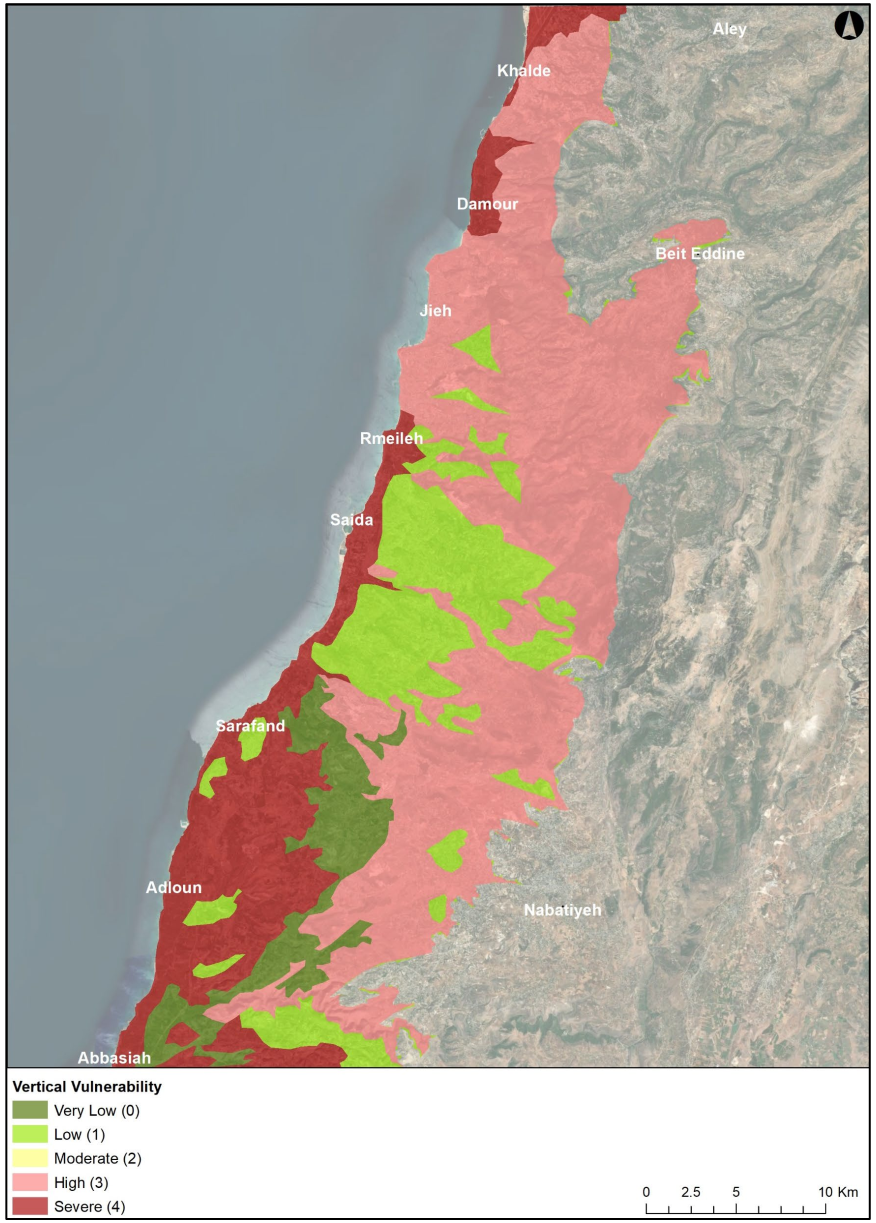


Coastal area vulnerability mapping (ACVM methodology) (UNEP-MAP and UNESCO-IHP, 2015)

VERTICAL VULNERABILITY

- "Severe": aquifers having gentle (< 10%) and moderate (10 to 15%) slopes.
- "High": aquifers with moderately steep slope (15 to 25%).
- "Low" : aquicludes sloping into an aquifer area.
- "Very low": aquicludes not sloping into an aquifer area.

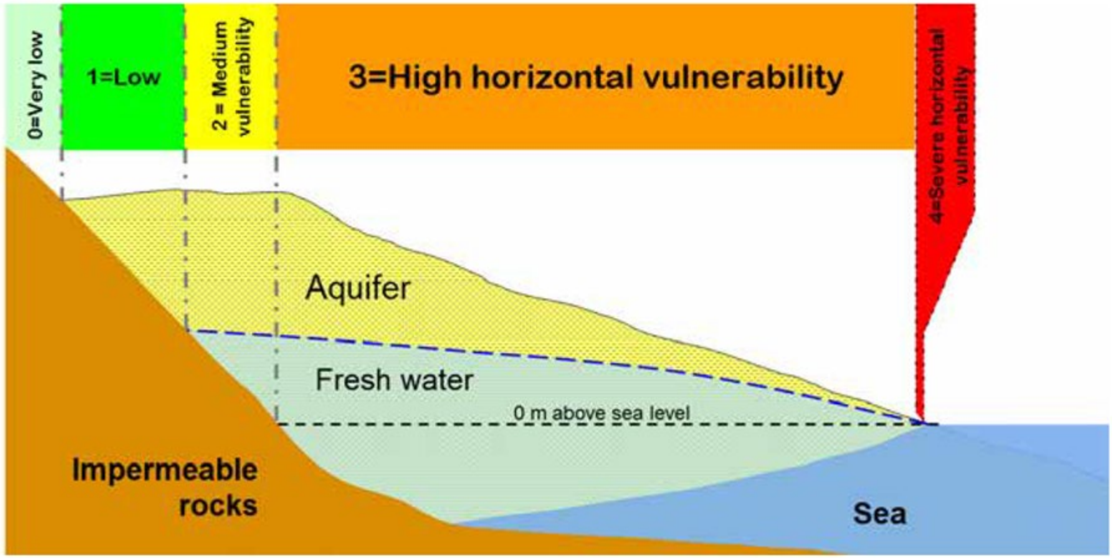
- The spatial distribution of the vertical vulnerability is mostly consistent with the (hydro)geological outcrops.



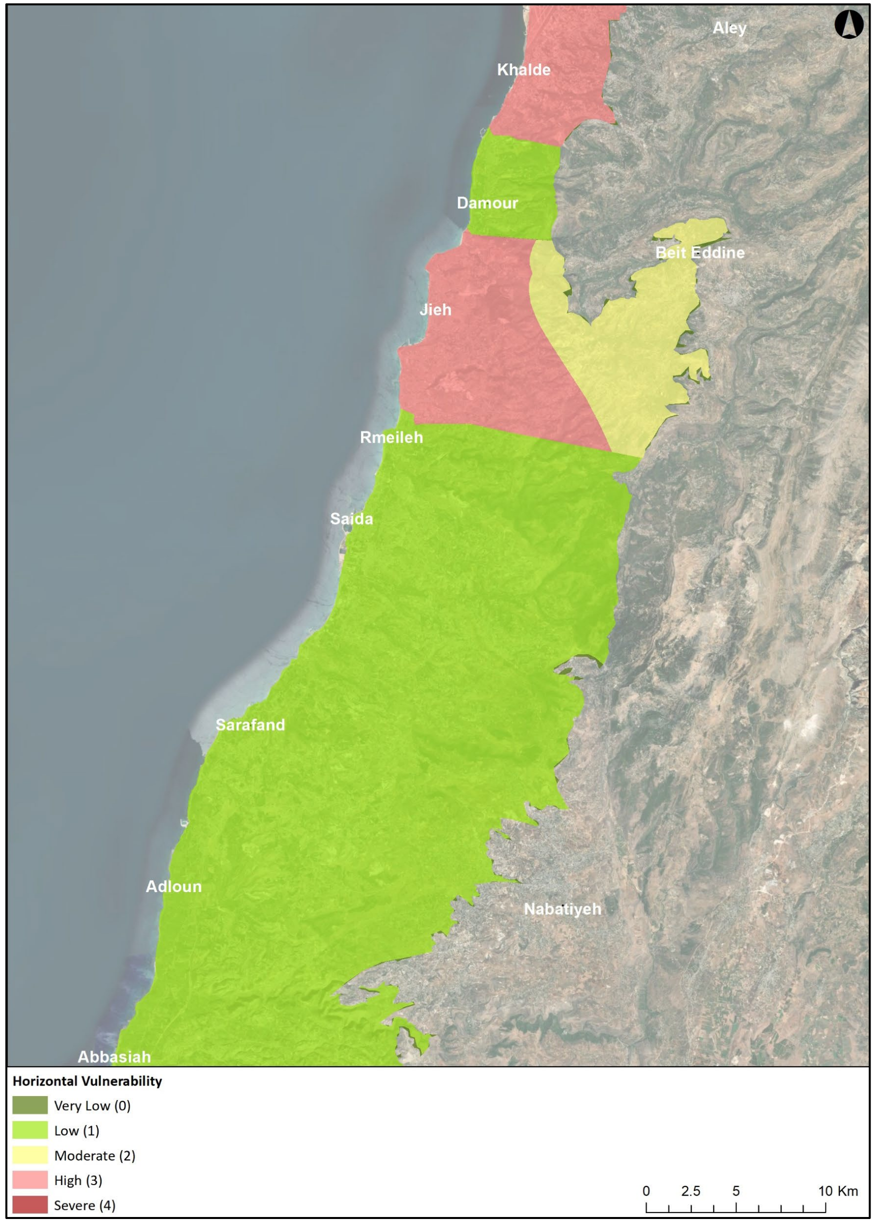
Vertical vulnerability

HORIZONTAL VULNERABILITY

- “Severe”: aquifers where (fresh) GWL ≤ 0m AMSL;
- “High”: aquifers where (fresh) GWL > 0m AMSL
  and aquifer’s bottom level ≤ 0m AMSL;
- “Medium”: where aquifer bottom > 0m AMSL;
- “Low”: where GW is absent **and** natural conditions should not normally lead to communication between freshwater and saline water;
- “Very low”: where aquifers are absent **or** not hydraulically connected to the sea.



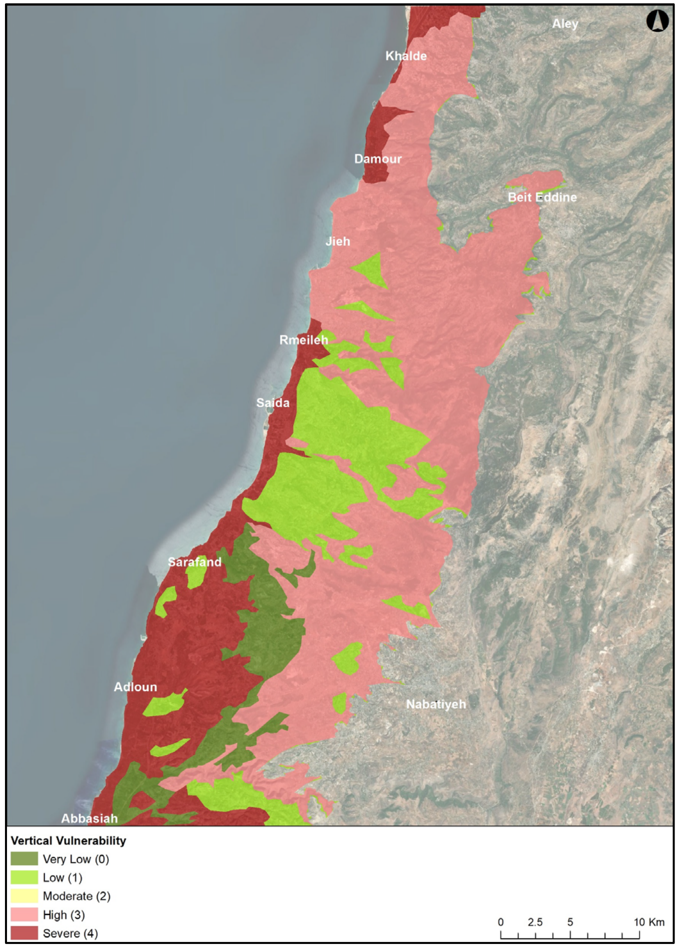
Conceptual representation of the horizontal vulnerability classes (UNEP-MAP and UNESCO-IHP, 2015)



Horizontal vulnerability

COMPREHENSIVE VULNERABILITY

- 73% of the study area's villages have more than one comprehensive vulnerability class each.



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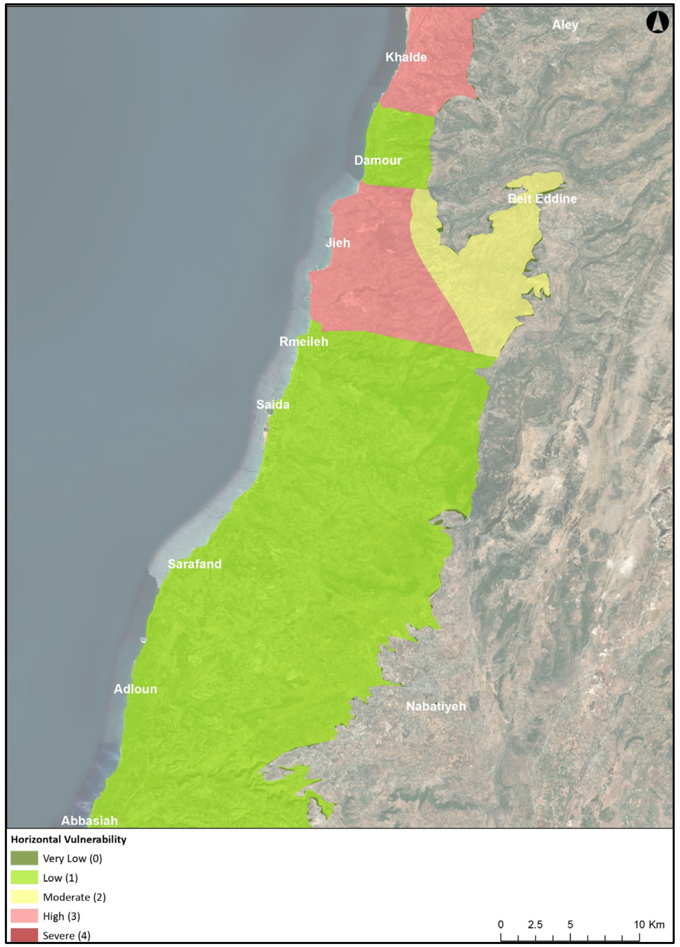

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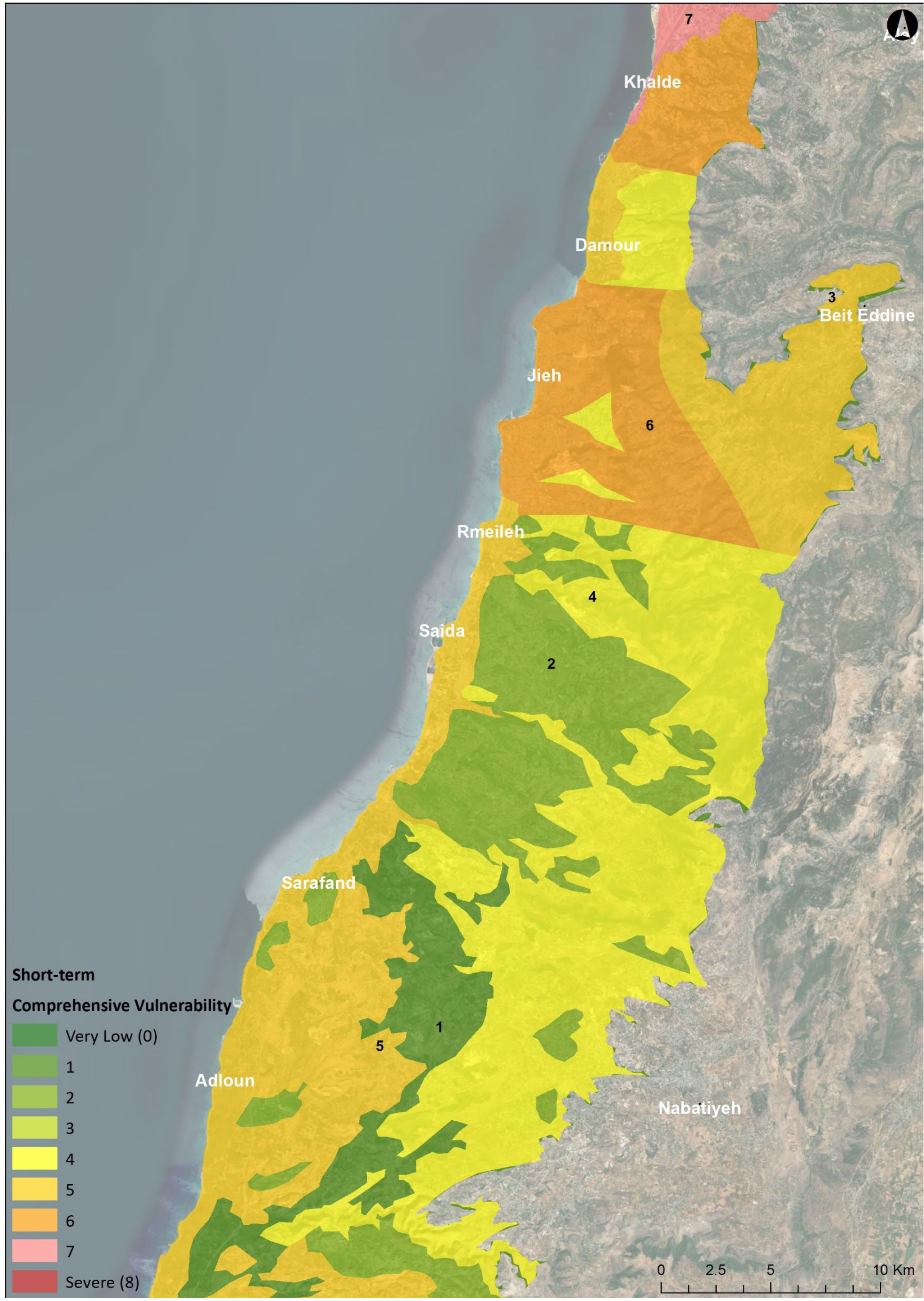
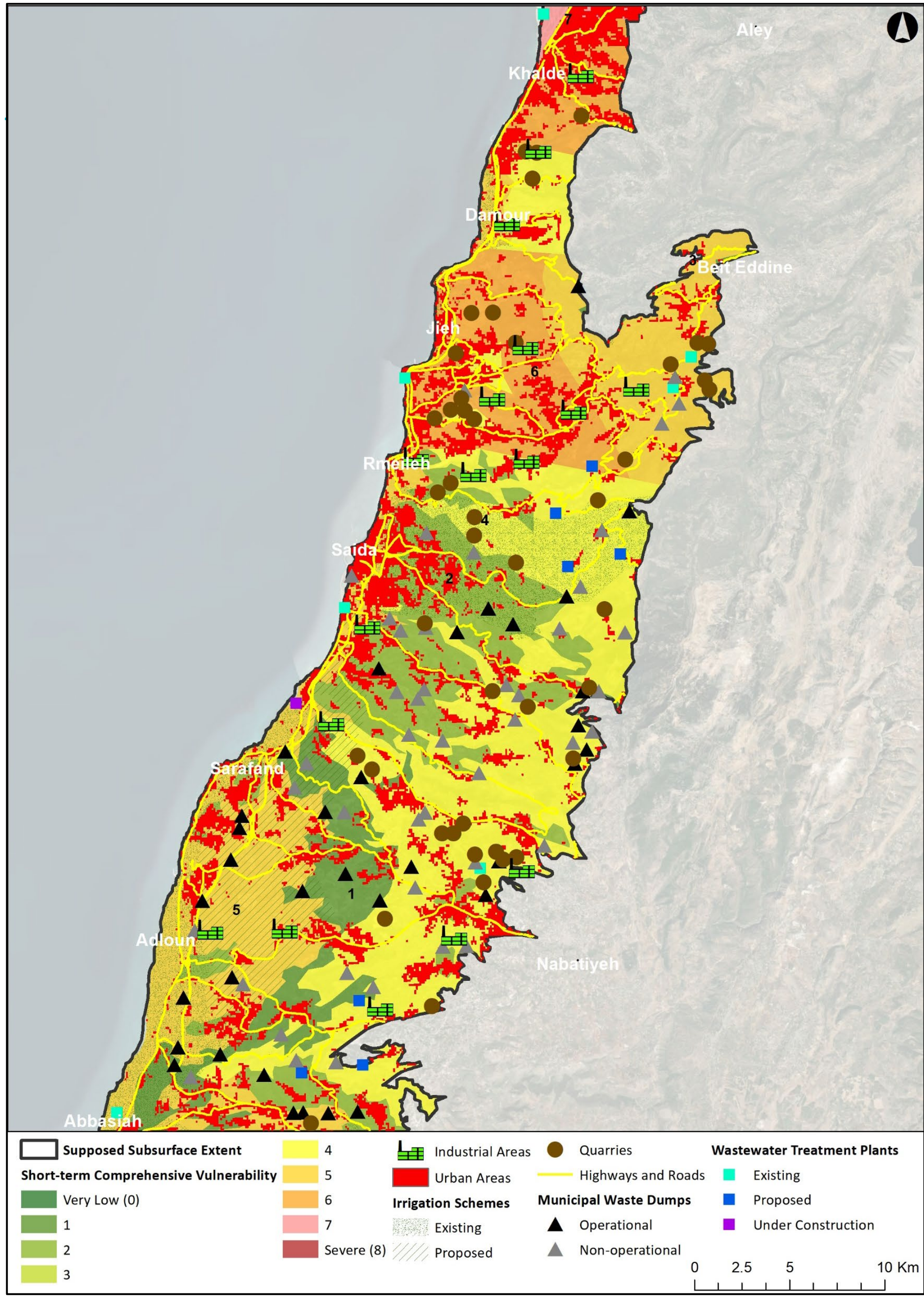


Short-term comprehensive vulnerability

POLLUTION SOURCES

- Anthropogenic sources of pollution:
  - Quarries (excavation machinery's spilled oil or petrol);
  - Urban areas (wastewater leakage, disposal wells, etc.);
  - Waste dumps and wastewater treatment plants;
  - Industrial areas (untreated industrial effluents);
  - Agricultural areas (diffuse pollution, overuse of pesticides and fertilizers);
  - Highways and main roads (dispersion of oil, gasoline and chemicals).
- Displaced people's informal settlements ⇒ additional pressures and serious threats to water security.

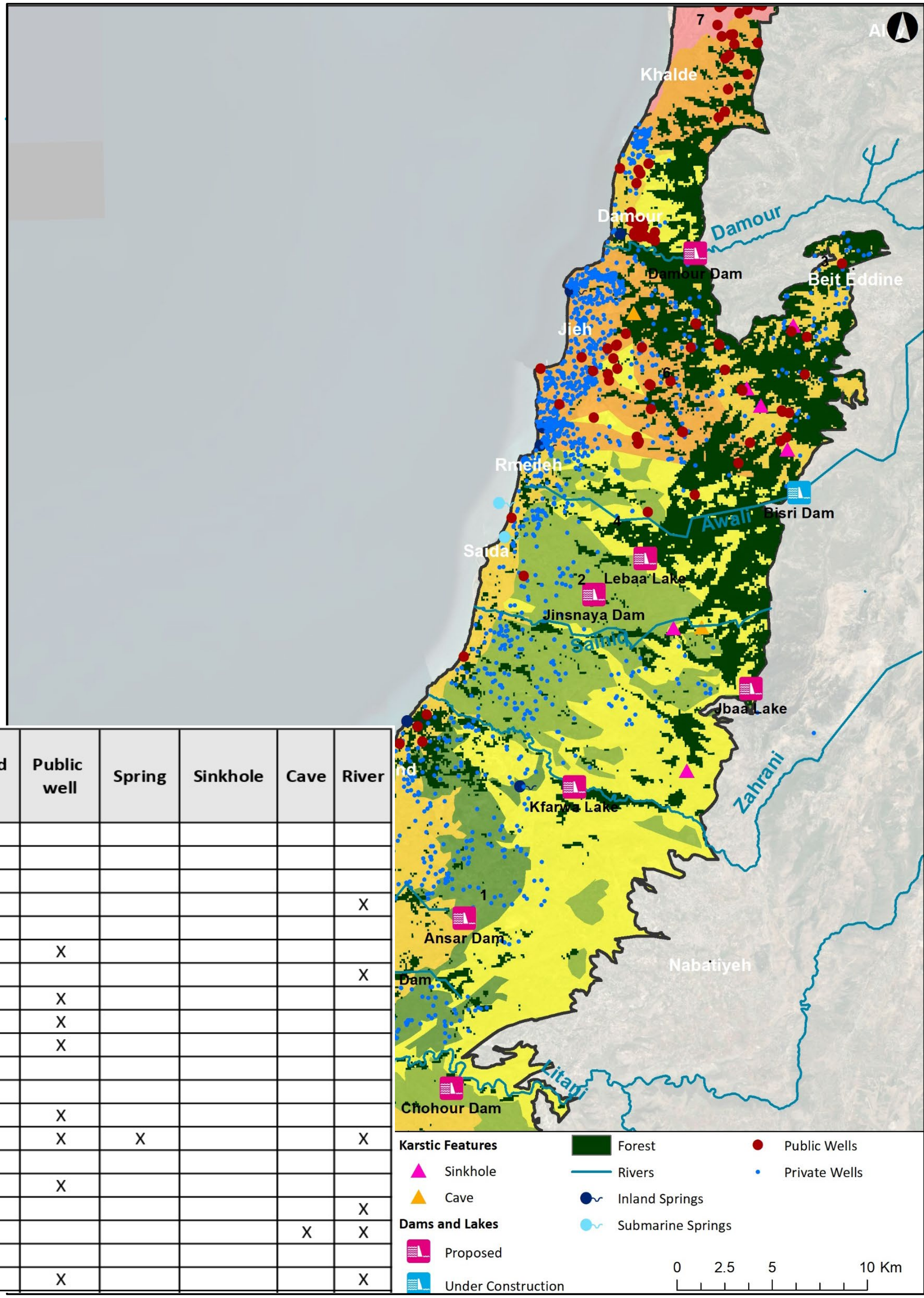


Pollution Sources

POLLUTION TARGETS

- Public and private wells.
- Streams and rivers (especially if they cross pollution source areas).
- Dams and lakes.
- Karstic features (sinkholes and caves).
- Natural lands and forests.

Village	Area of interest (km²)	Comprehensive vulnerability class*	Dense urban areas	Cropland	Forest	Industrial zone	Quarry	Operational waste dump	Existing WWTP	Proposed WWTP	WWTP (under construction)	Proposed dam	Public well	Spring	Sinkhole	Cave	River
Bqosta	5.4	2															
Braikeh	3.6	4				X					X						
Bramiat	0.5	2	X	X													
Bsaba	2.6	5															X
Chawalik	0.9	2															
Chehime	8.6	6	X		X	X							X				
Chehour	6.5	3	X					X				X					X
Chouaifat Amroussyat	2.2	6	X										X				
Chouaifat Oumara	4.0	7	X						X				X				
Chouaifat Qobbat (Khalde)	8.5	6	X										X				
Dahr El Mghara	2.2	6					X										
Dakkoun	0.6	4			X												
Dalhoune	3.0	6			X								X				
Damour	9.7	5	X	X		X						X	X	X			X
Daoudiye	2.3	5		X				X									
Daraya	4.7	5			X								X				
Darbessim	3.2	4	X														X
Debbiyeh	16.6	6	X		X		X									X	X
Debbiyeh (Ain el Haour)	1.4	5															
Deir El Moukhalles Chouf	4.3	4			X						X		X				X



Pollution Targets

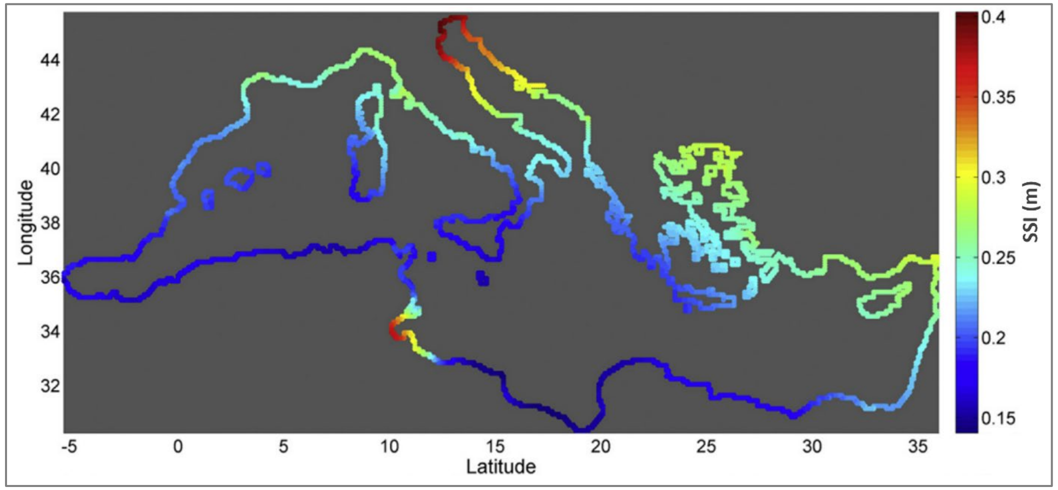
GROUNDWATER-DEPENDENT ECOSYSTEMS

- Law 708 dated 5/11/1998: Establishment of the Tyre Coast Nature Reserve (including a wetland).
- Wetland area: ~3.8 km² (UNEP-MAP and UNESCO-IHP, 2015).
- "Wetland of international importance": Ramsar Convention on Wetlands, and "Specially Protected Area of Mediterranean Importance (SPAMI).
- Many plants species and marsh birds.
- Resting site for migratory birds.
- Water source: shallow groundwater and fluvial inundation
- Wetland genesis: combination of tectonic processes and coastal sedimentation (UNEP-MAP and UNESCO-IHP, 2015).

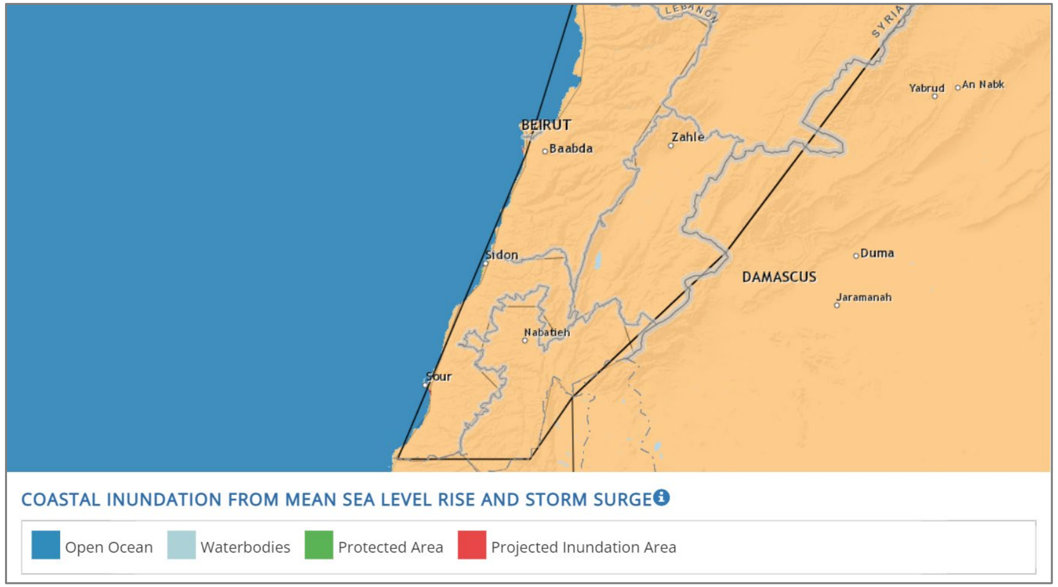
Tyre Coastal Wetlands and Ras Al-Ain springs (map created by the author, photo credits: almayadeen.net)

COASTAL INUNDATION

- Disregarding storm surge:
  - No inundation under scenarios SSP1-1.9 and SSP2-4.5 (for projections up to 2150).
  - No inundation under scenario SSP5-8.5 (for projections up to 2100).
- The Storm Surge Index along the Lebanese coastline as derived from the future 100-year Mediterranean Climate Surge Model (MeCSM) is <0.25m.
- If a storm surge of 0.5m is considered along with a projected SLR for 2150 under SSP5-8.5, coastal inundation may only occur over a limited area in Tyre.



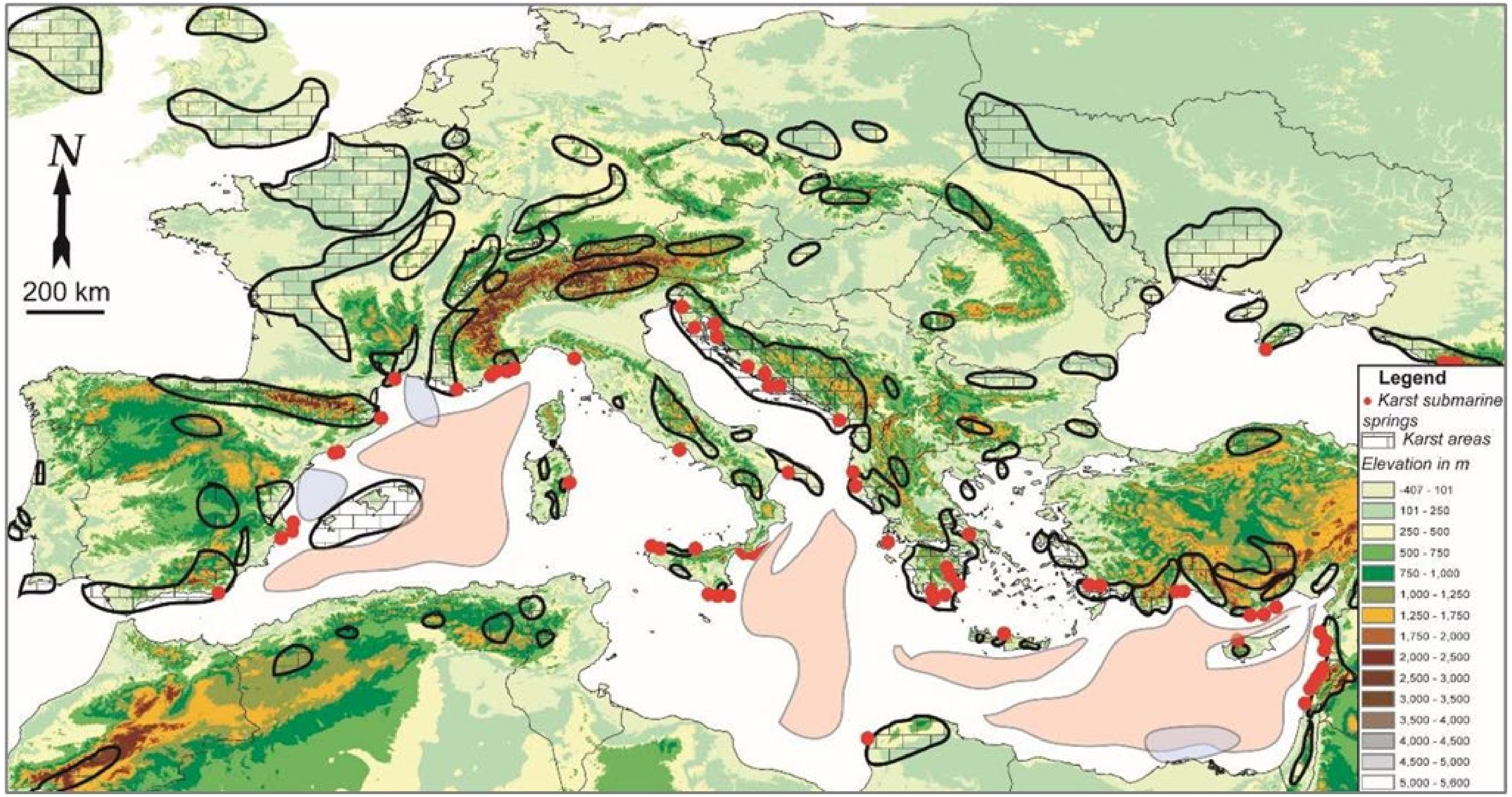
Storm Surge Index along the Mediterranean coastline as derived from the 100-year MeCSM simulation (Androulidakis et al., 2015)



Coastal inundation from projected SLR (for 2150 under SSP5-8.5) and 0.5m Storm Surge (World Bank's Climate Change Knowledge Portal)

Submarine Groundwater Discharges in Lebanon

SGDs in the Mediterranean and in Lebanon

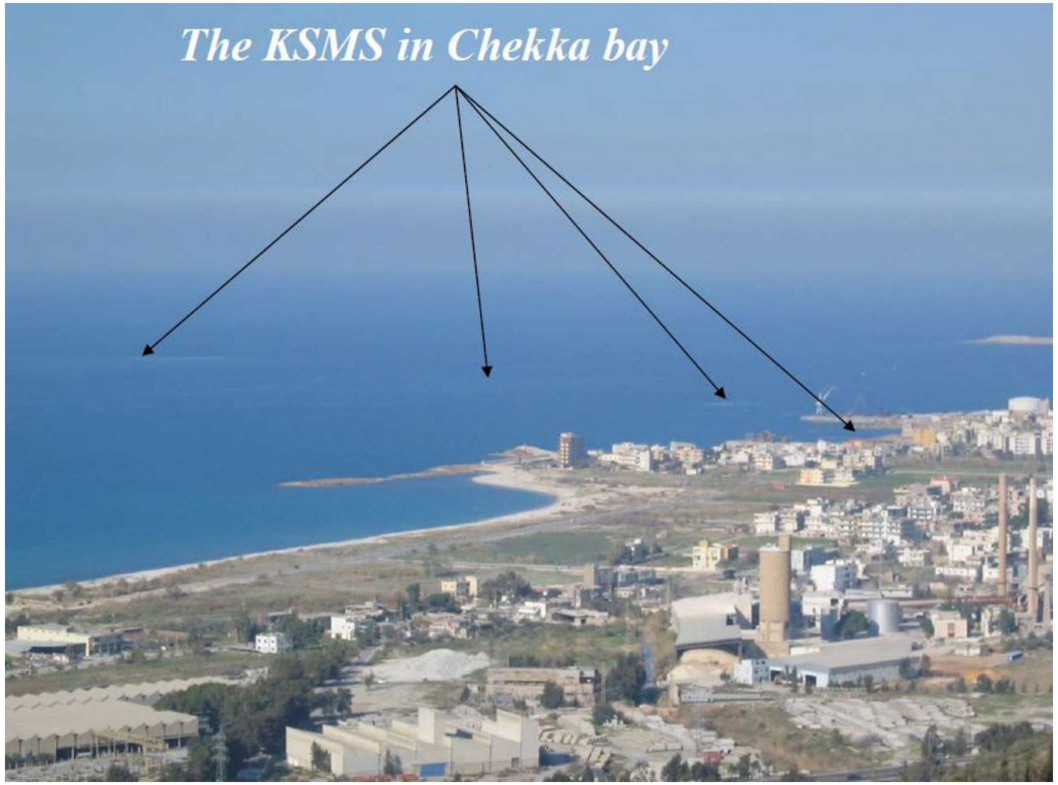


Red dots representing the major Mediterranean karst submarine springs (Fleury, 2005)

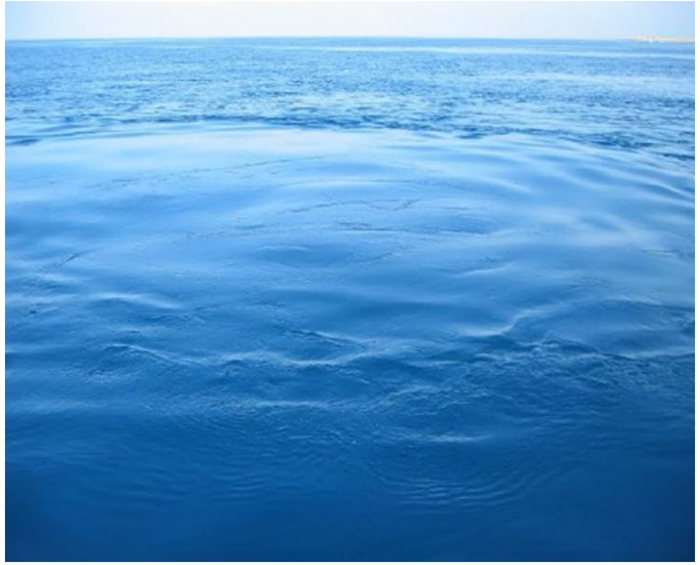
Location of SGDs in Lebanon (Shaban, 1999)

Chekka Submarine Springs

- The most important submarine spring in Lebanon.
- Multiple studies on Chekka: Kareh (1967), Saad et al. (2005), Ayoub et al. (2001), El Hajj (2008).



Chekka submarine springs' aerial view (photo credits: HydroSciences, CNRS and CREEN-ESIB)


Chekka submarine springs' water plume as seen on the surface (El Hajj, 2008)

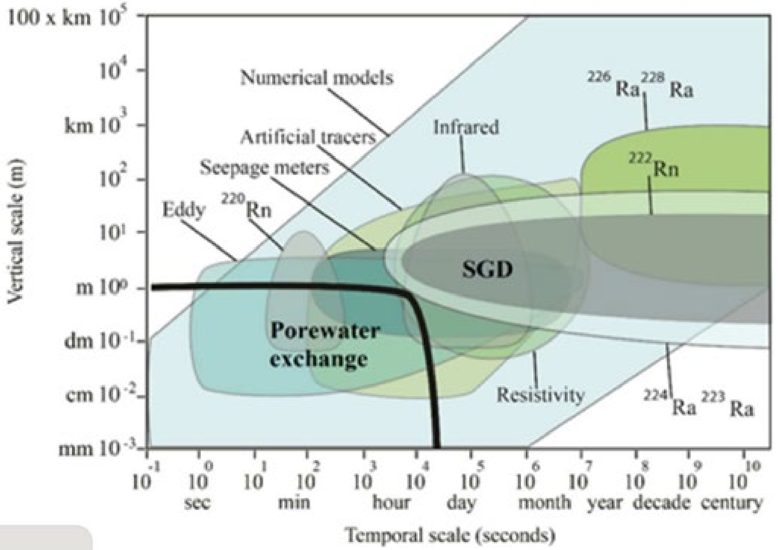
Boroghlieh Submarine Springs

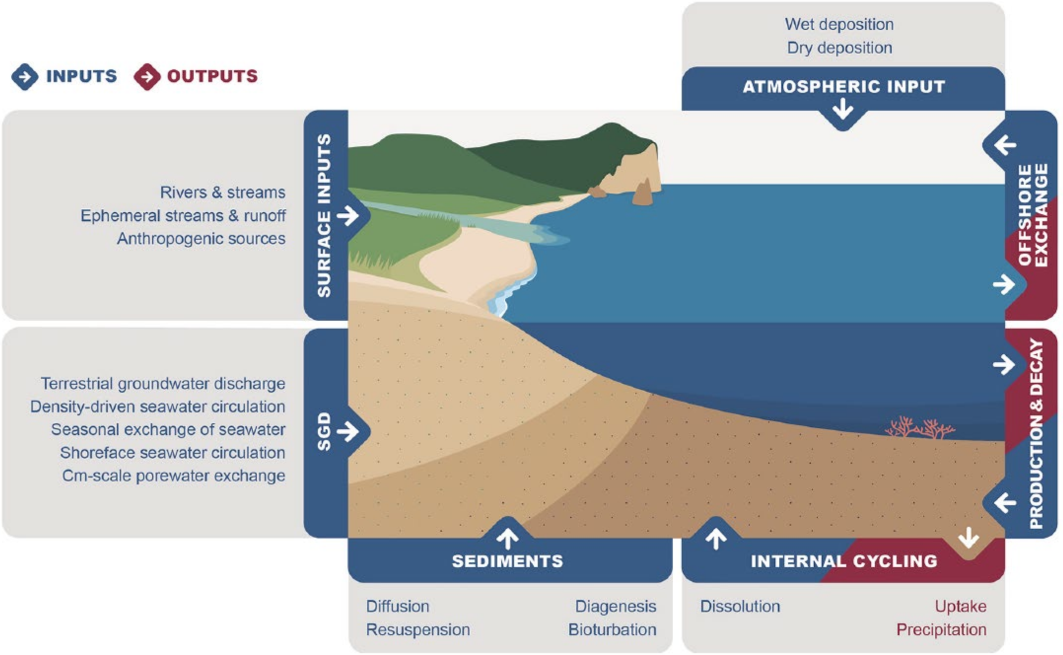
- According to Saad et al. (2005), Boroghlieh submarine springs are characterized by:
  - Estimated yield: 0.2 to 2 m^3/s.
  - EC: 18300 to 19100 µS/cm (brackish water).
  - Artesian flow.
- Professional Divers' Syndicate in Lebanon:
  - Al Kassi, Al Abbas and Al Mayadeen SGDs, 5 to 6km away from the northern coast of Tyre;
  - Al Abbas spring (the most important) has a diameter of 3-5m, at 40-50m below Sea Level.

Exploration of Al Abbas and Mayadeen springs in 2016 (photo credits: Syndicate of Professional Divers in Lebanon)

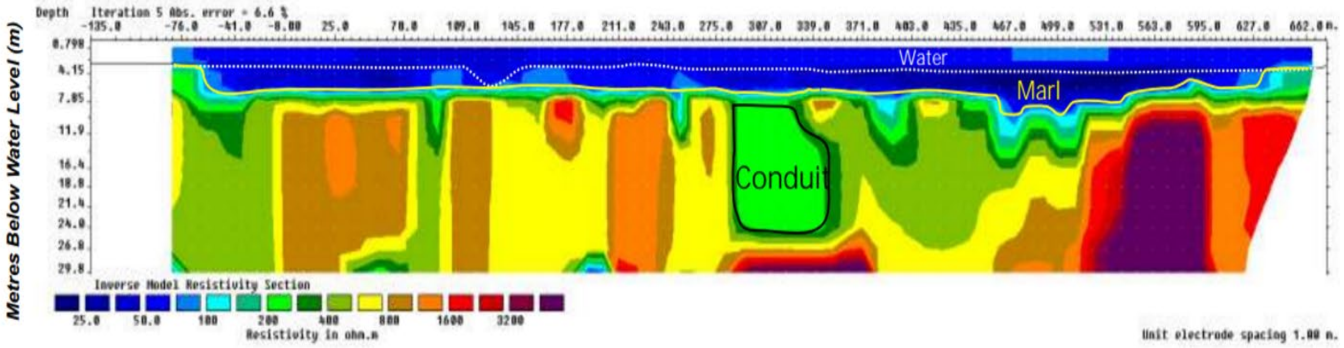
Proposed Methodology for SGD Assessment

SGD quantification approaches (Taniguchi et al., 2019)





Conceptual model showing sources and sinks of Ra isotopes in coastal and marine areas (Garcia-Orellana et al., 2021)



Surface-towed marine ERT Profile (modified from O'Connell et al. (2012))

Summary and Recommendations

SUMMARY

- The main source of drinking water in the study area and its vicinity is groundwater.
- It is crucial to consider the effect of saltwater intrusion.
- The groundwater vulnerability mapping showed a higher vulnerability in the northern part of the study area.
- 66 out of the 204 existing villages within the study area have a relatively low comprehensive aquifer vulnerability (class 1 to 3) and include less than a total of two types of pollution targets and sources.
- 33 villages are characterized by a relatively high comprehensive aquifer vulnerability (class 5 to 8) and include more than a total of two types of pollution targets and sources.
- 10 villages with an area >10 km^2: El Zrariye, Debbiyeh, Ansar, Babliye, Baakline, Joune, Deir El Zehrani, El Merwaniye, Abbassya, Aramoun. Those big villages showed a low to moderate aquifer vulnerability except Aramoun and Debbiyeh having a high aquifer vulnerability.
- The villages of Chouaifat Oumara and Kfarchima have an estimated comprehensive vulnerability class of 7 (the highest value). Those two villages are also highly urbanized and include public wells. In addition, Al Ghadir WWTP is located in Chouaifat Oumara.
- Adloun, Damour and Saida show a slightly high comprehensive aquifer vulnerability; those cities have relatively dense urbanization and agricultural areas, while Damour hosts an industrial zone. Those cities also have a number of pollution targets such as public wells (in Damour and Saida) and rivers, noting that a dam is proposed on the Damour River.

MANAGEMENT RECOMMENDATIONS

- Lack of sustainable legal and institutional frameworks for coastal groundwater resources management.
- The management of coastal aquifers requires a multi-disciplinary approach.
- Evidence-based decision making → appropriate solutions, successful implementation and operation.
- Current abstraction levels are most likely exceeding the aquifer's safe yield → diversify the sources of water supply, control losses and demand management.
- The construction of surface water storage infrastructure is planned by MoEW (Damour and Bisri dams).
- Urban planning strategies should consider groundwater vulnerability and pollution target emplacements while selecting the location of potential pollution sources (urban areas, industrial zones and irrigation schemes).
- Applying the Solid Waste Management (SWM) Strategy to limit the random siting of waste dumps; measures should be taken to control and treat leachates from dumpsites.
- Supporting the implementation of efficient irrigation techniques, and controlling the application of fertilizers and pesticides.
- Assess the sustainable yield which takes into account the needs of the groundwater-dependent ecosystems.

NEXT PHASE…

- Groundwater flow and quality modelling for the Damour coastal aquifer with the support of Deltares.
- Targeted field data collection to support the conceptual understanding of the groundwater system and to feed into the aforementioned numerical groundwater model.
- For the Boroghlieh SGD: geophysical surveying (ideally onshore and offshore), as well as tracer (mainly Ra) and hydrochemical analyses with the support of the Technical University of Cartagena and/or Universitat Autònoma de Barcelona (Spain).
- The estimation of the SGD flows can be also made using flowmeters (which will allow a comparison with the flow estimation based on the Ra mass balance).
- Analyzing some isotopes may be locally possible with the support of the Lebanese Atomic Energy Commission (LAEC).
- Offshore missions can be logistically supported by the Syndicate of Professional Divers in Lebanon.

Deltares

Universidad Politécnica de Cartagena

ebml
مؤسسة مياه بيروت وجبل لبنان

نقابة الغوّاصين المحترفين في لبنان
The Lebanese Union of Professional Divers

LAEC CNRS

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Universitat Autònoma de Barcelona

مؤسّسة مياه لبنان الجنوبي
SOUTH LEBANON WATER ESTABLISHMENT
SLWE

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