Food and Agriculture Organization
of the United Nations

Improved Water Resources Monitoring System/ Integrated Water Resources Management at regional level in Lebanon

WATER ACCOUNTING TOOL

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The project

In many areas of the world, including the Near East and North Africa (NENA) region and Lebanon, sustainable and reliable delivery of water for irrigation and municipal use has become increasingly complex. This issue also extends to affect the protection of the ecosystems from water pollution. Particularly, if the overall demand is outstripping supply, the delivery of water is often less about engineering, although it is still required. The issue is more often related to the governance of the resources to manage and protect them from pollution and over-abstraction, resolve conflicts over water, and ensure rights to water are respected. It is also about understanding water flow pathways in complex river basin systems. This is where water monitoring and accounting can play a crucial role to help water management institutions in managing complexity in light of the challenges facing the water sector.

In this context, the Food and Agriculture Organization of the United Nations, in collaboration with the North Lebanon Water Establishment (NLWE), which represents the Ministry of Water and Energy, is implementing the GCP/LEB/029/SWI project **'Improved Water Resources Monitoring System/Integrated Water Resources Management at regional level in Lebanon'**, funded by the Swiss Government. The main objective of the project is to strengthen Lebanon's water institutions improving their performance at regional level, thereby helping them to address the sector challenges for sustainable use of water resources.

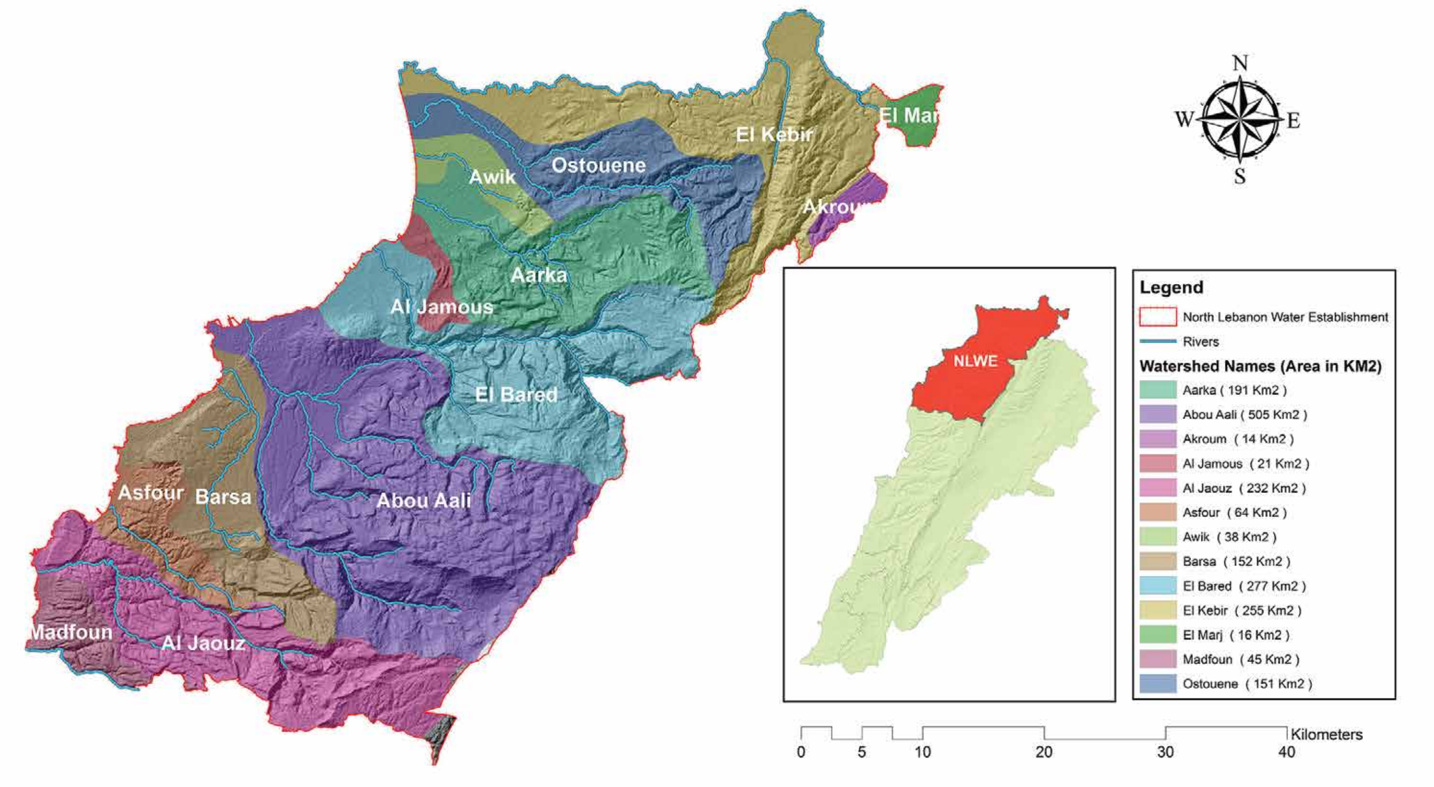
In particular, **Output (4)** of the project '**Water accounting tool**', aims at supporting more effective decision-making at regional level by generating information regarding the vegetation state, leaf area index, biomass production, evapotranspiration (ET) mapping, through remote sensing:

- update, create and monitor the land-cover/land-use of the targeted area through remote sensing;
- generate information regarding vegetation state (e.g. normalized difference vegetation index, leaf area index, etc.), land surface temperature, primary biomass production, and the ET mapping from space;
- combine indicators to generate water accounting information in terms of water productivity (WP) rates to support decision-making reconciled at NLWE; and
- provide the NLWE with monitoring tool and train its professional staff on this tool and its scope to support a range of water management decisions including planning, regulating, allocating and undertaking feasibility studies.

The command area

The project follows a pilot approach, whereby the regional water establishment has been selected through a rapid assessment driving to the greatest possible impact. Based on well-defined selection criteria, including water availability, level of irrigation development, water quality status, scope for institutional capacity building and scalability, the North Lebanon Water Establishment (NLWE) was chosen. The authority of the establishment extends to the complex hydrological systems and diverse topography of North-Lebanon. Amongst the involved watersheds, El-Bared is the second largest with its 277 km2 catchment area.

Figure 1. Watersheds in North-Lebanon



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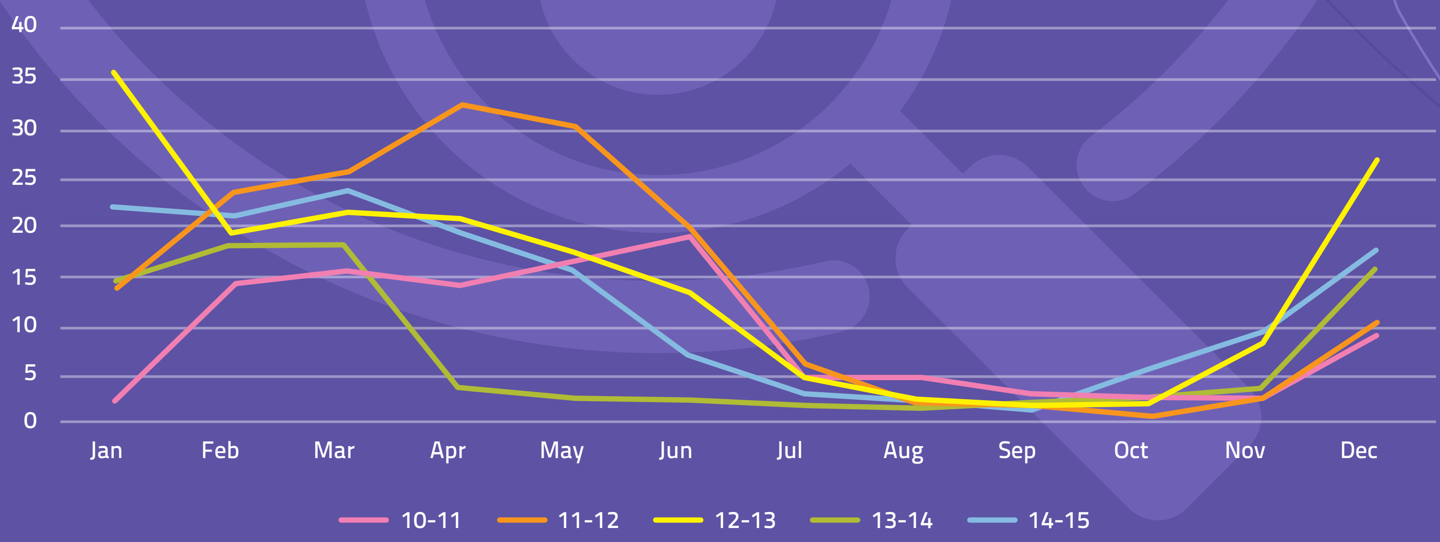
Along its 24 km length, the El-Bared River is characterized by a great intra-annual variation of volume, peaking from April to June. The measured monthly flow volumes between 2010 and 2015 show large disparity amongst years, from 1 037 000 m3 in October 2011 to 35 million m3 in January 2012. Corresponding to the drop of annual rainfall, the lowest annual volume was measured in 2013 and 2014. This indicates large variation in water volume, thus requiring accurate and permanent monitoring of both water availability and water use.

Figure 2: Water volume of El-Bared River



Gradually confining the geographical scope, a set of water accounting methodologies is introduced to provide an assessment tool for decision-makers. Starting with an overall analysis of El-Bared watershed, further specific functions of the tool are developed at pilot area level, covering two adjacent irrigation systems in Akkar and El Minieh.

The approach

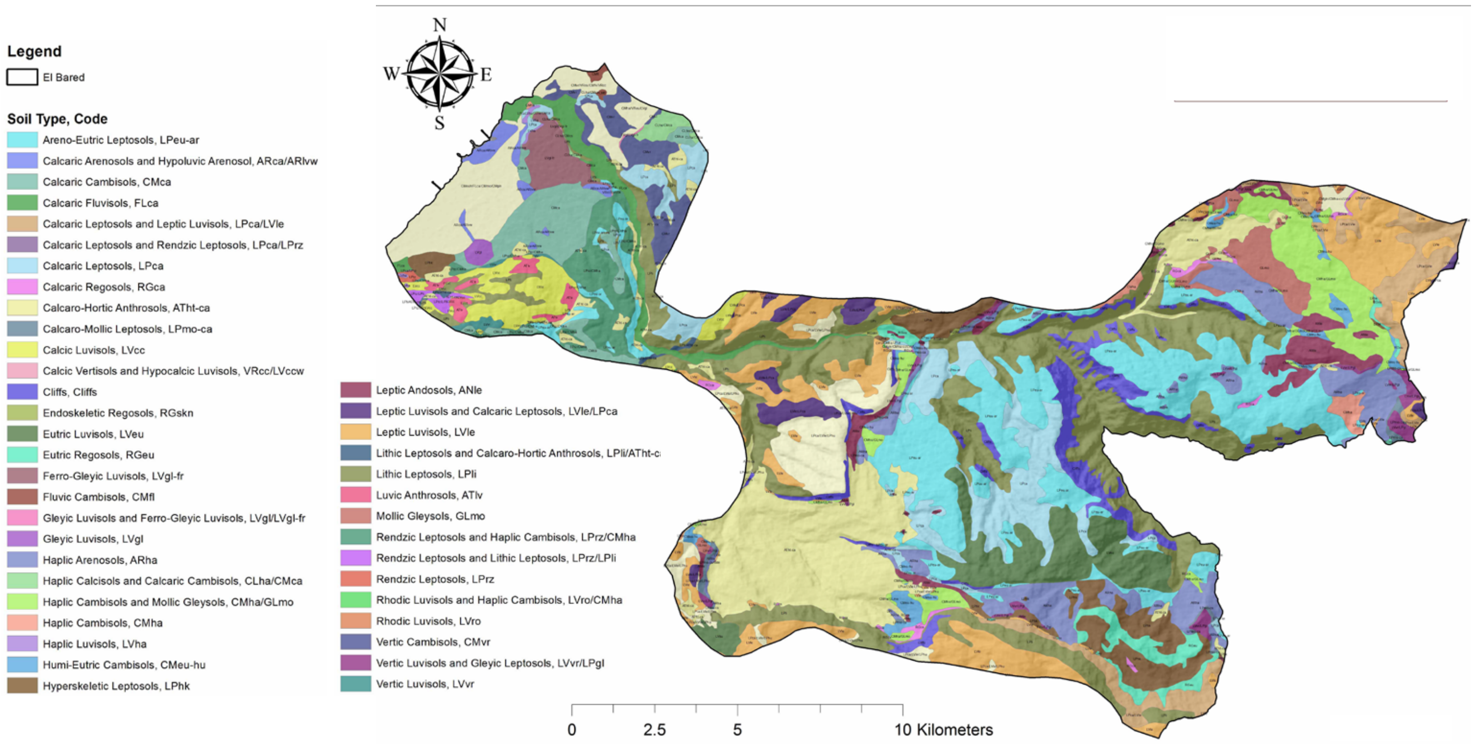
Information generated by remote sensing and geographic information system (GIS) techniques can be of great support for planning and management of natural resources. The process of information generation is built on consecutive steps:

- land cover/Land use maps are produced to build highly accurate and updated land cover database;
- based on real-time climatic datasets coupled with an automated ET retrieval system hosted within the Google Earth Engine, maps of actual evapotranspiration of cropped areas are obtained to calculate crop water consumption;
- map of biomass production is produced to display the dry matter of living biomass, including vegetative and reproductive parts; and
- from the ratio of biomass production and actual evapotranspiration, seasonal and annual water productivity mapping is enabled.

This is followed by the establishment of the water productivity score system (WPS), tailored to the command area. The water productivity scoring system is developed to enhance the applicability of the tool and provide readily available analysis for decision-makers.

The methodology applies the latest iteration of the Surface Energy Balance Algorithm for Land (SEBAL) model, i.e. the Improved Surface Energy Balance Algorithm for Land (SEBALI) model, significantly improved from the previous surface energy balance models. The basic concept of the energy balance model is grounded in the measurement of energy used throughout the hydrological cycle, by deducting the energy going into the soil and air heating, and the energy reflected back to the space from the incoming energy. Using satellite data, the energy balance can be quantified at different scales, depending on the available spatial resolution. The greatest advantage of SEBALI as compared to other available approaches, is the reduced number of factors required for implementation, which were previously constraining or uncertain input requirements. Such eliminated factors are the instantaneous relative humidity, saturated soil moisture content, saturated soil moisture content in the subsoil, residual soil moisture content, field capacity, wilting point. This information, mostly related to soil analysis, is replaced by the water stress approach. The employment of SEBALI is, hence, greatly advisable in the diverse environment of El-Bared watershed, characterized by 42 soil types. In addition, the other main improvement introduced by the project is the production of datasets at 10-m spatial resolution using the recent Sentinel-2 satellite images. This enhancement is particularly significant in small and heterogeneous crop parcels such as those that characterize the command area.

Figure 3: Soil classification in El-Bared watershed



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Further advances include the ability of random shape selection, automatic selection of hot/cold pixels over agricultural lands, water-based internal calibration and corrected atmospheric images.

The simplified flowchart of the calculation mechanism (overleaf) displays the required parameters and processes of obtaining high-accuracy results. The three distinguished groups of input data are climatic database, soil database and satellite imageries. It is important to note that the soil datasets are automatically produced within the system, whereas the satellite images are automatically selected when users input the required date. Thus, merely inserting monthly climatic datasets by users is sufficient to obtain results.

Using acctual ET as energy, the biochemical process is calculated as the residual in the energy balance, more specifically as the partition between the sensible heat flux and the energy required from the plant to evaporate a unit of water (i.e. latent heat of vaporization). In order to scale the methodology at a large area size while considering the diverse landscape, the evapotraspiration fraction (ET fraction) is derived from satellite data. However, this process requires several surface characteristics, such as normalized difference vegetation index (NDVI), leaf area index (LAI), light use efficiency (LUE), fraction of photosynthetically active radiation (FPAR), absorbed photosynthetically active radiation (APAR) and albedo. This information can be retrieved from the satellite images which usually require further processing related to cloud removal and gap filling.

Figure 4: Cloud removal process

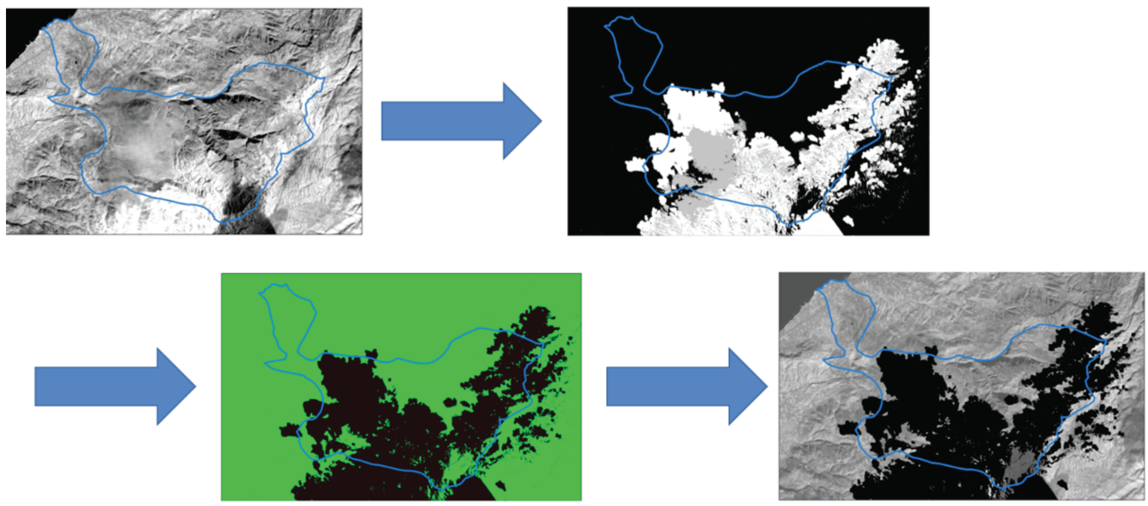
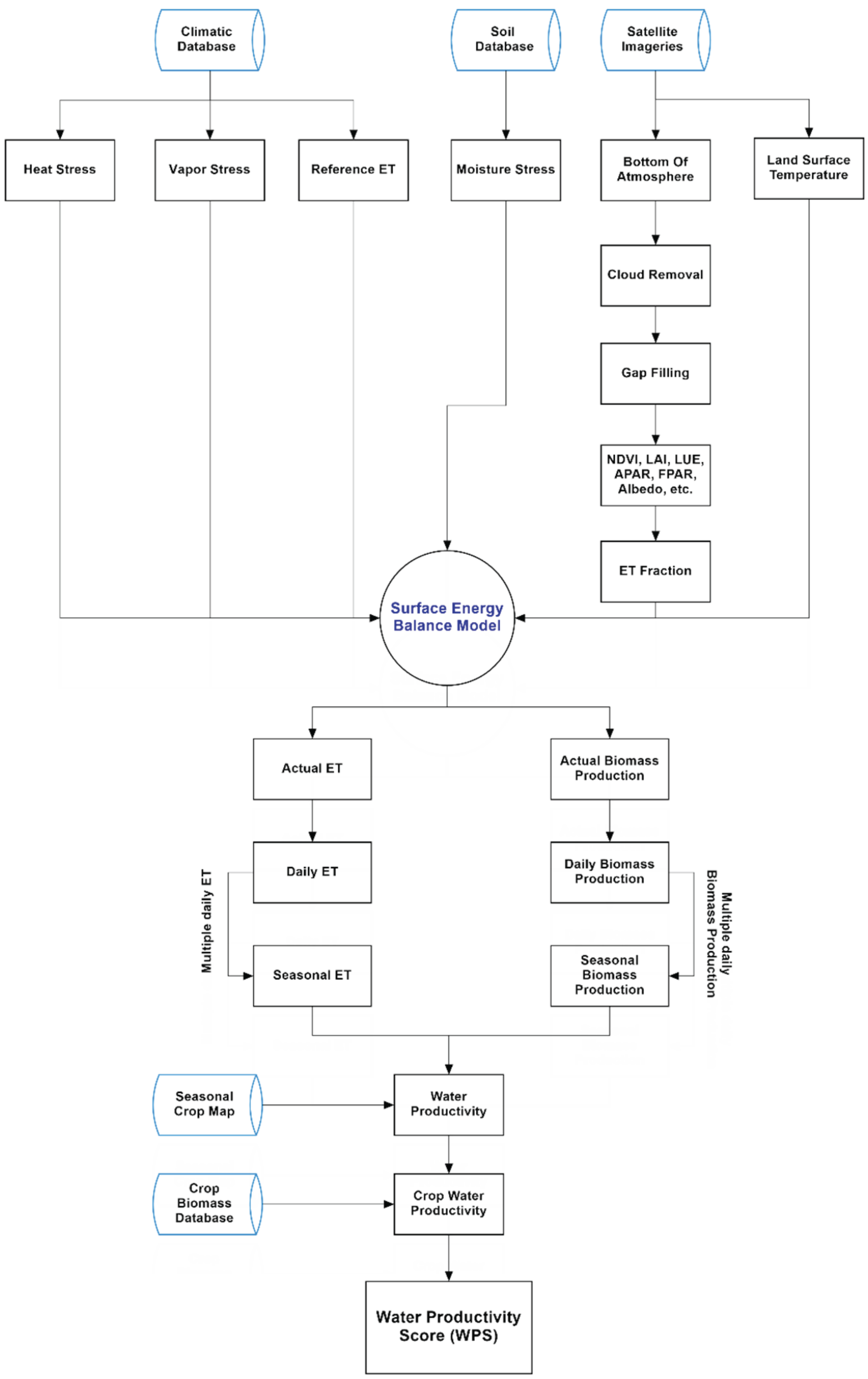


Figure 5: Simplified flowchart of SEBALI modelling



The model proposes a two-step calibration method based on existent local or regional water bodies. Water bodies are treated as cold pixels, where the sensible heat is minimum, transpiration is null and the ET is maximum. Thus, the sensible heat flux over water bodies is calculated and then compared to the generated mean heat flux values over the whole region, from which the highest value is selected. The second step of the calibration concerns the comparison between the latent heat flux of water and then compared to the generated mean ET values. The final ET values are then adjusted accordingly. Furthermore, the calibration value has been automated as well through the validation by the FAO Irrigation and Drainage Paper No. 24 pan coefficient value. It is important to note that these improvements are processed in an automated manner, saving on time and resources.

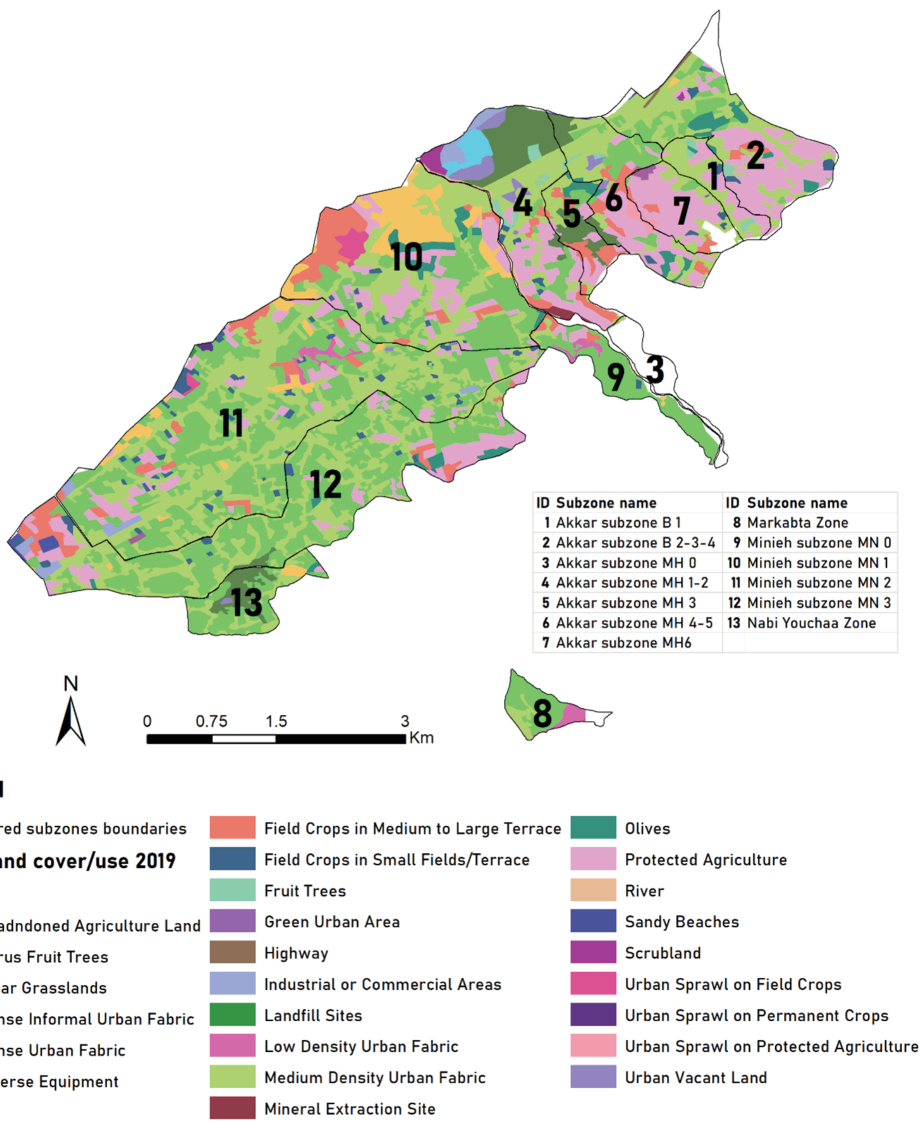
The outcome

The comprehensive approach is implemented and directed towards user-friendly application to reach the ultimate goal of supporting NLWE in accurate and timely decision-making. The developed tool has five interdependent outputs that are systematically built on each other to provide remote-based information about land and water resources use in the command area.

1. Land cover/land use maps (LCLU) are based on crop classification. Long-term land use change at regional level is a critical information for decision-makers to understand the challenges in water management. The pixel-based method to obtain LCLU applies random forest classifier. The object based image algorithm (OBIA) would not be adequate for the considered regions as it is highly diversified and heterogeneous. Although using spectral information is highly accurate, it requires high-resolution imageries that can not be applied in areas such as El-Bared consisting of small-scale and fragmented farming.

LCLU maps provide a large amount of information about the dynamic landscape of the command area. Changing cropping pattern, for instance, can refer to systematic changes in food markets. Or, shrinking agricultural lands might be the indicator of farmers exiting the sector. Highly accurate and updated LCLU is produced to generate information at farm level with a spatial resolution as high as 1 m with a map scale of 1/5000. However, such accuracy requires high-resolution satellite data that is often difficult to obtain. Therefore, an automated crop mapping system is established as a complementary method to identify the main crop types in the region at annual basis. The two methods together allow for monitoring of both long-term and short-term dynamics in the region.

Figure 6.Land Cover Land Use map of the command area



ID	Subzone name	ID	Subzone name
1	Akkar subzone B 1	8	Markabta Zone
2	Akkar subzone B 2-3-4	9	Minieh subzone MN 0
3	Akkar subzone MH 0	10	Minieh subzone MN 1
4	Akkar subzone MH 1-2	11	Minieh subzone MN 2
5	Akkar subzone MH 3	12	Minieh subzone MN 3
6	Akkar subzone MH 4-5	13	Nabi Youchaa Zone
7	Akkar subzone MH6		

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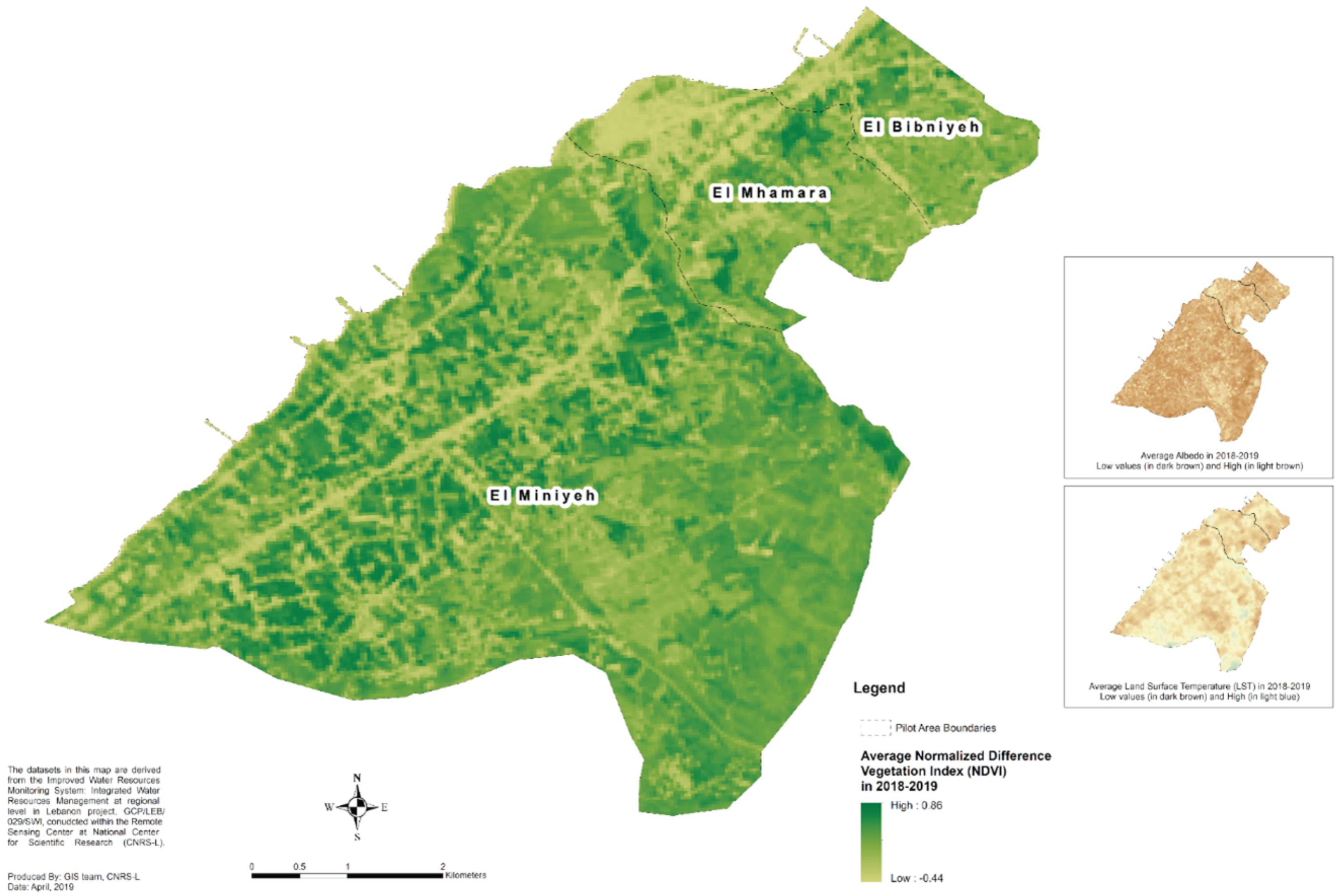
2. Normalized Difference Vegetation Index (NDVI) is the ratio between near-infrared and red light. The indicator is based on the concept that healthy vegetation reflects more near-infrared light and absorbs more red and blue light. Satellite sensors such as the applied Sentinel-2 employs the right bands to recognize the near-infrared and red lights. NDVI is one of the most widely used vegetation indexes, with variations between 1 and –1. A greater value of NDVI reflects a denser and/or greener vegetation.

The regular NDVI monitoring enables the early indication of any deviation from the agricultural trends, such as long-term effect of urbanization, fluctuating rate of fallow lands, or rapid outbreak of pests. One of the particular merits of NDVI monitoring is the ability to forecast and assess the effect of droughts. When crops are water stressed, the density of vegetation is relatively lower, thus alerting decision-makers to rapidly put in place coping strategies.

Figure 7: Normalized Difference Vegetation Index in the command area



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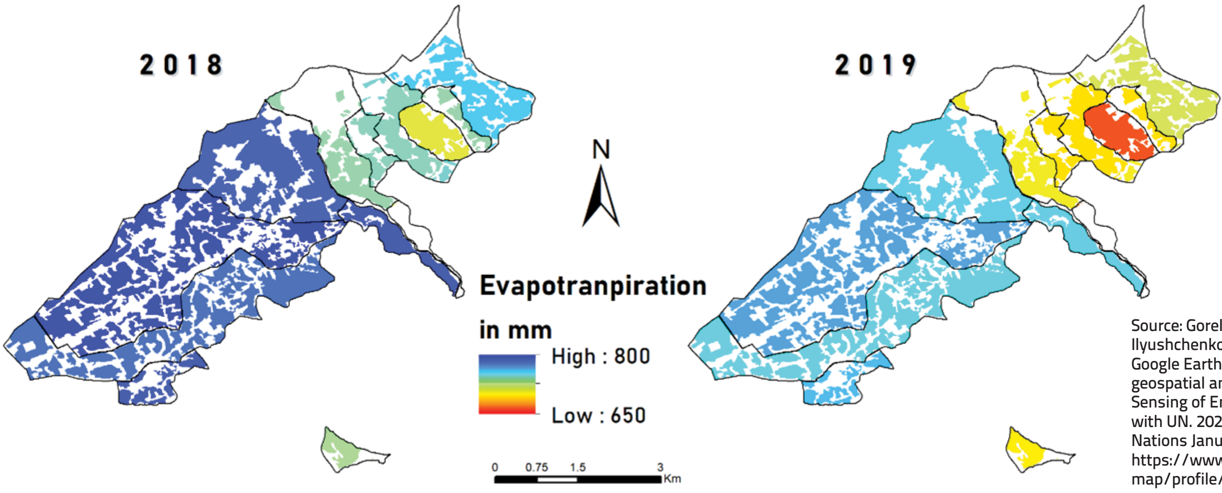
3. ET map provide information about the crop water use for biomass production. Regional-scale ET depends on numerous factors including climatic variables, cropping pattern, farming practices etc. Monitoring the ET at large-scale is particularly difficult when the agricultural area is characterized by temporally and spatially 'patchy' cropping pattern, and the average farm size does not reach one hectare.

Given that ET is not only the indication of the crop production but of changing climatic factors surrounding the environment, the produced ET map in the command area, can be considered a breakthrough in monitoring agricultural water use. As cropping pattern change is often a slow process, any sharp departure from the average can be attributed to hectic weather, and eventually to the long-term impact of climate change.

Figure 8: Evapotranspiration map in the command area



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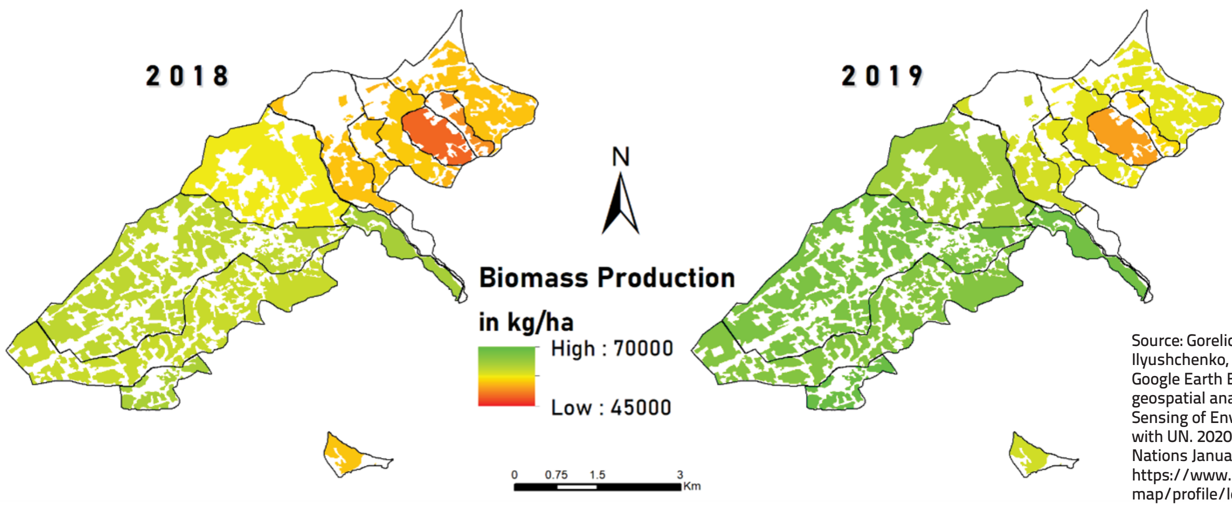
4. Biomass map indicates the temporal and spatial changes in above-ground biomass in the command area. Estimating biomass is a complex procedure that requires a specific regression equation with the specific plants. Hence, measuring biomass production based on the LCLU maps requires the critical step of field validation to reach accurate estimates. Above-ground biomass is sampled per crop type and dried to obtain estimates of the canopy water content, while leaf area index (LAI) is obtained by measuring the surface of leaves in different periods of growth cycle. Satellite data, then, is converted into biomass density by using the established regression equation.

Biomass mapping enables the monitoring of crop production during the growing cycle and measuring interannual variability. Eventually, biomass production provides crucial information about actual crop yield. Actual yield, however, depends on many exogenous (weather, soil, etc.) and endogenous factors (production practice, irrigation practice, input quality, etc.), and any deviation from the potential yield, requires on-ground investigation. Understanding the biomass trends is of paramount importance for decision-makers, as it is considered one of the most powerful indicators of natural resource use efficiency.

Figure 9: Biomass production in the command area



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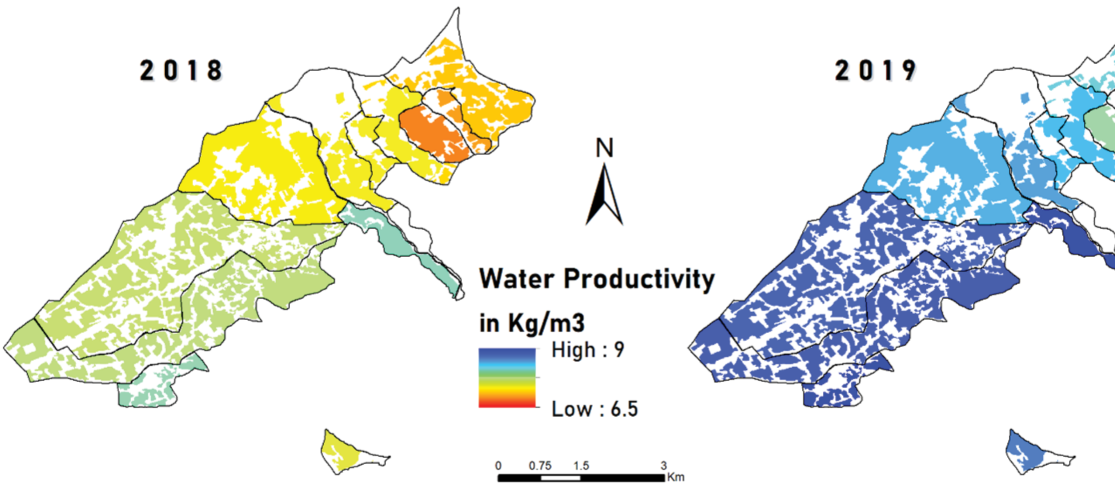
5. Water productivity is the ratio between biomass production and evapotranspiration. The current definition refers to the evapotranspiration-based water productivity and it is calculated from the ratio of biomass production per evapotranspiration. Ultimately, the water productivity value expresses the obtained yield per unit of consumed water. The higher the biomass production, the higher the water productivity. Since water productivity requires the measurement of total harvested yield, the indicator can be obtained at seasonal or annual step.

Figure 10: Water productivity in the command area



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Based on the above-mentioned outputs, the final classification of water productivity is turned into automated, computer-based tool. The classification supports decision-makers in understanding the obtained water productivity values, according to the potential strategies for improvement measures. Applying a 5-point Likert scale, each crop type can be scored and evaluated.

Since each crop has different standard water productivity value, thresholds of scoring ranges are set by crop, while comparing to global reference values.

Table 1: Water productivity scoring thresholds in El-Bared watershed

Crop Type	WPS				
	1	2	3	4	5
Citrus	< 0.92	0.92 - 0.95	0.96 - 0.98	0.99 - 1	> 1
Olives	< 0.84	0.84 - 0.86	0.87 - 0.89	0.9 - 0.92	> 0.92
Potatoes	< 0.77	0.77 - 0.8	0.81 - 0.84	0.85 - 0.88	> 0.88
Vine	< 0.82	0.82 - 0.85	0.86 - 0.89	0.9 - 0.93	> 0.93
Cereals	< 0.83	0.83 - 0.85	0.86 - 0.88	0.89 - 0.92	> 0.92
Temporary crops	< 0.81	0.81 - 0.85	0.86 - 0.89	0.9 - 0.95	> 0.95
Fruit trees	< 0.87	0.87 - 0.91	0.92 - 0.94	0.95 - 0.97	> 0.97

The automated water productivity scoring system guides the users through four steps to obtain analysis at selected time-horizon and geographical scale:

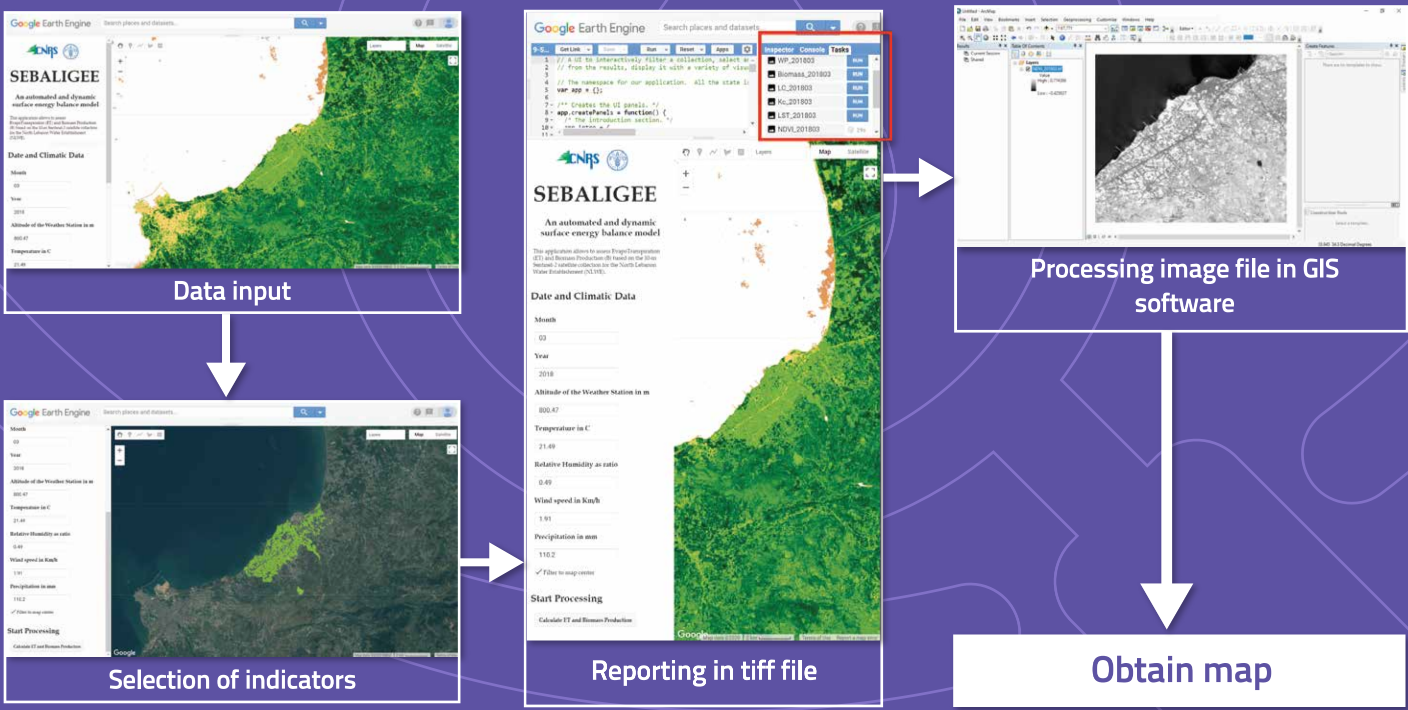
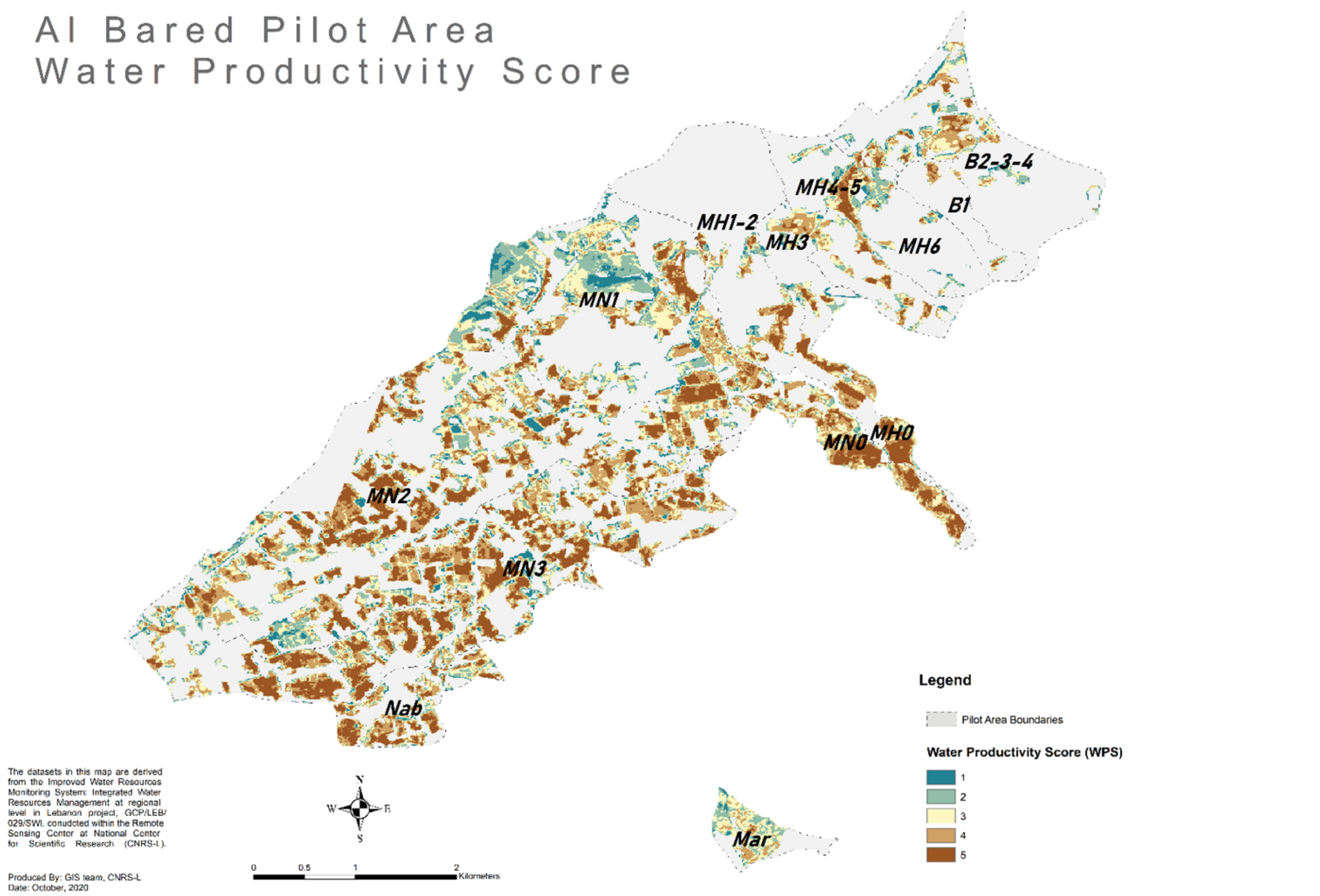


Figure 11: Water productivity score in the command area



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The lessons learned - best practices

The first phase of the project drew lessons from the development of the novel and highly scalable methodology of water productivity scoring through remote sensing. Such lessons can be categorized under three dimensions: land use, water use and planning of water resource development.

Land use	Water use	Planning of water resource development
Land use in the region is undergoing radical changes due to the rapid urbanization rate. LCLU mapping is a powerful tool to investigate the underlying mechanisms in land use change and support the planning of land management **Greenhouses production has an increasingly growing role in the area, thus posing challenges to remote sensing technologies. Combined approach with on-field methods can help filling the gap and establish a robust methodology for land use monitoring** **Any changes in land use of one sector entails changes in land availability for other sectors. Expanding industrial areas, for instance, might affect the natural vegetation and disturb the biodiversity. It is, then, considered more effective to monitor the changes over time to detect harmful trends.**	Climate change puts a spotlight on efficient water allocation to avoid harmful trade-off amongst users. The ability to modify operational rules and water allocation mechanism greatly depends on robust methodologies The variation of crop water use in terms of time and location represent a challenge for modelling tools. Remote-based tools help overcoming these challenges by providing spatio-temporal snapshots from the perspectives of well-defined indicators	Updated and improved methodologies such as the introduced SEBALI modelling helps overcoming the challenges of general data paucity. As the model requires a smaller number of input factors, SEBALI is an optimal methodology to conduct regular monitoring while reducing the pressure on institutional resources. Remote-based tools enhance the recently-introduced mechanisms of resource use planning that are often constrained to on-ground experiments. Beyond planning, these tools are vital to the management and governance of natural resources at basin scale Automated system provides user-friendly application for decision-makers to access information instantly and carry-out meaningful analysis Instead of considering them only rearview mirrors, regular monitoring of indicators enables the measurement of long-term impacts of climatic extremes. The relatively slow onset of drought enables indicators such as biomass production and NDVI to act as powerful forecasting tools.

Figure 12: Stakeholder meeting in the site

Lessons-learnt related to land use, water use and planning of water resource management are critical to maintain the achieved results. Training of professionals is key to reach long-term sustainability of established remote-based system and maintain its gains.

The long-term vision of the project anticipates the scaling-up of implemented and demonstrated practices both within the boundaries of the NLWE, and beyond, extending to other establishments. Dissemination is a built-on complex strategy with multiple publication outlets to reach wide audiences. The scaling-up is phased into three successive steps:

Piloting	▪ **Select pilot sites based on multiple-criteria** ▪ **Design and implement novel approaches** ▪ **Draw lessons from implementation**
Learning	▪ **Train professional staff on traditional and non-traditional methods** ▪ **Extend the training to potential stakeholders at national level**
Scaling-up	▪ **Demonstrate results and assess replicability** ▪ **Implement the developed approach**

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