Baseline Report on the assessment of the current water resources on the Nahr Al Ostuan Basin

Consultancy to Facilitate Integrated Water Resource Management (IWRM) in the Al Ostuan Basin

Ref:
PC/11DBH/90D/DTC/B
RT/23-05-2019/001

Date: March 2020

This page is intentionally left blank

Consultancy to Facilitate Integrated Water Resource Management (IWRM) in the Al Ostuan Basin

Task 1 and 2: Development of a semi-distributed (node-based) water resources management WEAP model for the Nahr Al Ostuan River Basin, and relevant Baseline Report on the assessment of the current water resources in the Nahr Al Ostuan Basin (based of the outputs of the WEAP model)

LDK for Management Consulting LLC LDK Consultants Engineers and Planners SA	University of Balamand

With funding from:	Co-Funded by the European Union بتمويل مشترك من الاتحاد الأوروبي RÉGION SUD PROVENCE ALPES CÔTE D'AZUR
Date:	30 / 03 / 2021
Version:	05
Description:	Baseline Report on the assessment of the current water resources on the Nahr Al Ostuan Basin, based on the outputs of the WEAP model developed for the Al Ostuan RB, including water availability, demand and unmet demand (per sector), and highly-level water quality assessment (on the basis of field survey and sampling)
Status:	Final submittal

	Name, Company	Position	Date
Prepared by:	Dr. Maggie Kossida	Senior Consultant, Water Resources Engineer, Technical Project Manager	05/01/2020 (v3)
	Dr. Ioannis Tsoukalas	Senior Consultant, Water Resources Engineer	
	Dr Najib Gerges	Professor, University of Balamand	
	Dr Marianne Saba	Researcher, University of Balamand	
	Dr Yasmine Jabaly	Researcher, University of Balamand	
	Dr Amal Iaaly	Researcher, University of Balamand	
Checked by:	Mr. Costis Nikolopoulos	Head of LDK Group Environment & Water Division General Manager LDK Middle East Region	06/01/2020 (v3)

Updated	Dr. Maggie Kossida	Senior Consultant, Water Resources Engineer, Technical Project Manager	30/03/2021 (v5)
	Dr Najib Gerges	Professor, University of Balamand	
Approved by:	Mrs. Ciara Noone	Project Manager, ACTED	31/03/2021

How to Reference this publication:

Kossida, M., Tsoukalas, I., Gerges, N., Saba, M., Jabaly, J., Iaaly, A. 2021. Baseline Report on the assessment of the current water resources on the Nahr Al Ostuan Basin. Project Deliverable No. 2, Consultancy to Facilitate Integrated Water Resource Management (IWRM) in the Al Ostuan Basin, ACTED, Lebanon.

Acknowledgements:

The authors would like to thank the Lebanese Ministry of Energy and Water (MoEW) for providing valuable information, and in particular Dr. Fadi Georges Comair, Director General of Hydraulic and Electric Resources, MoEW, and Mrs. Mona Fakih, Director of Water, MoEW, SWIM Focal Point (monafakih@hotmail.com) for her important contribution and excellent collaboration.

Additionally, the authors would like to thank Mr. Gaby Nasr, Director of Exploitation, NLWE, Mr. Georges Moussa, NLWE – Qoubayat Branch, and Mr. Youssef Karam, Head of Water, Wastewater and Infrastructure Department CDR for providing information and valuable expert knowledge.

This page is intentionally left blank

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

GW	Groundwater
hh	Household
IWRM	Integrated Water Resources Management
km^2	Square kilometer
m^3	cubic meter
Mm^3	Million cubic meters
mio	Million
MEW	Ministry of Energy and Water
NLWE	North Lebanon Water Establishment
ORB	Al Ostuan River Basin
RB	River Basin
SW	Surface Water
WRMM	Water Resources Management Model
WWT	Wastewater Treatment
WWTP	Wastewater Treatment Plant

This page is intentionally left blank

1 NON-TECHNICAL SUMMARY

The Al Ostuan River Basin is located in the Akkar casa in Northern Lebanon and flows from the east (its headwaters originate in Akkar Al Atika and Qoubayat) to the Mediterranean Sea in the Sahel area, with a length of 44 km (the main river). The river's average flow (based on records from 2002-2012) at Embouchure station (close to river's outlet) is about 2.3 m^3/sec. The Al Ostuan River and its 8 sub-catchments drain in total about 145 km^2, with an annual runoff volume of 47 million m^3. A total of 51 villages are located (as a whole or part of) within the Al Ostuan River Basin (ORB) boundaries, with a corresponding population of 105,000 people who rely in the Al Ostuan River Basin water resources . Agriculture is an important activity in the area. The main cultivated crops are field crops in terraces (vegetables, legumes), fruit trees, and olives. The areas under irrigation schemes (~ 30% of the total agricultural area in the basin) are extended in the western and northeastern parts of the basin.

Currently the river suffers from many issues due to its mismanagement. Public water supply is provided by the North Lebanon Water Establishment (NLWE) Qoubayat and Halba Branches, yet it is not covering all the villages in the Al Ostuan River Basin. As a result, a high number of private wells are used in the basin, with no public control over the abstracted volumes, which has led to environmental impacts, such as the degradation of the groundwater resources and declining groundwater levels (SISSAF, 2017). The lack of Wastewater Treatment Plants (WWTP) and the direct discharge of urban wastewater into the river also led to high pollution levels in the river and caused severe environmental damage. Integrated water resources management plans or other policy instruments are lacking, and management is not based on pro-active and preparedness approaches.

The state of the water resources in the Al Ostuan River Basin (ORB) has been assessed for the baseline period 2003-2018, based on the outputs of a detailed Water Resources Management Model (WRMM) developed in WEAP21 software for the Al Ostuan River Bain. This baseline assessment investigated the water availability, water demand, water supply required, and unmet demand (per sector) in the basin during the last 16 years, as well as the current state of surface water pollution based on a recently conducted field survey and sampling.

- **Water availability and water supply:**

The primary water demands in the Al Ostuan basin are for urban and irrigation purposes, accounting for ~35% and ~62% respectively. The urban water demand sums up to ~7 million m^3/year (or 183 lt/cap/day) of which 6.2 million m^3/year are for domestic purposes and 0.8 for industrial purposes, while the irrigation water demand is 11 million m^3/year (average of the 2003-2018 period). The irrigation demand is highly dependent on the precipitation and thus varies across the years from 8 to 13 million m^3/year: during the wet years a larger part of the irrigation needs are covered by precipitation (rainfed) and thus the irrigation demand is lower, as opposed to the drier years where the irrigation water demand is higher. The urban demand is mainly for domestic purposes (90%) and also includes a small share (~10%) for industrial purposes. The water supply requirements are in fact higher than the actual water demand due to network losses and irrigation practices' efficiency (Comair, 2007; NWSS 2020). The losses in the urban water supply network are 30% (SISSAF, 2017; communication with NLWE; NWSS 2020), while the overall combined irrigation efficiency has been estimated at 60% since most irrigation networks are local and individual (according to multiple sources). The efficiency of the collective networks is very low, around 45%, since these are dominantly open channels, while furrow (surface) irrigation is extensively used.

Based on the model results, the balance between demand and availability is negative, resulting in unmet demand in all the 8 sub-catchments of the Al Ostuan River Basin every year. The total annual unmet demand in the Al Ostuan River Basin is, on average, 17 million m^3/year over the 16-year period 2003-2018, and has reached up to 22 million m^3 (in 2010). This basically means that, on average, only about 38% of the water needs are covered by the water availability and supply in Al Ostuan. This unmet demand is mainly attributed to the irrigation: ~13.8 million m^3/year on average, with maximum 16-17.5 million m^3 observed in 2010, 2016 and 2017. Nevertheless, the domestic/ urban sector is also highly affected: the average urban unmet demand is ~3.5 million m^3/year (or 9,620 m3/day, or 92 lt/cap/day), with maximum ~5 million m^3 observed in 2016, 2010, 2017 and 2008.

The villages with the higher urban unmet demand are El-Kouachra, Daouce et Baghdadi, Denke et El-Amriyeh, El-Bire, Charbila, Ain El-Zeit, El-Daghle, Kherbet Daoud, El-Msalle, Kefr El-Ftouh (Figure 1-1). All these villages are supplied by the NLWE Qoubayat Branch (system of Qoubayat wells 1/3, 2/3, 3/3) Daouce and Charbila lines. It is concluded that the urban water supply provided by the Qoubayat wells cannot meet all the current needs of these villages. The above findings are aligned with the 2020 NWSS Update (NWSS 2020, Volume IV, Appendix IV C5 – Water Balances, pages IV C127 – IV C 148). The calculated balances in the NWSS 2020 have been found negative within the Qobayate distribution systems No. 22 (Charbila, Ain El-Zeit, El-Msalle, Kefr El-Ftouh), No. 23-24-12 (El-Daghle, Kherbet Daoud, El-Bire), No. 17 (El-Kouachra) and No. 13 (Daouce et Baghdadi, Denke et El-Amriyeh).

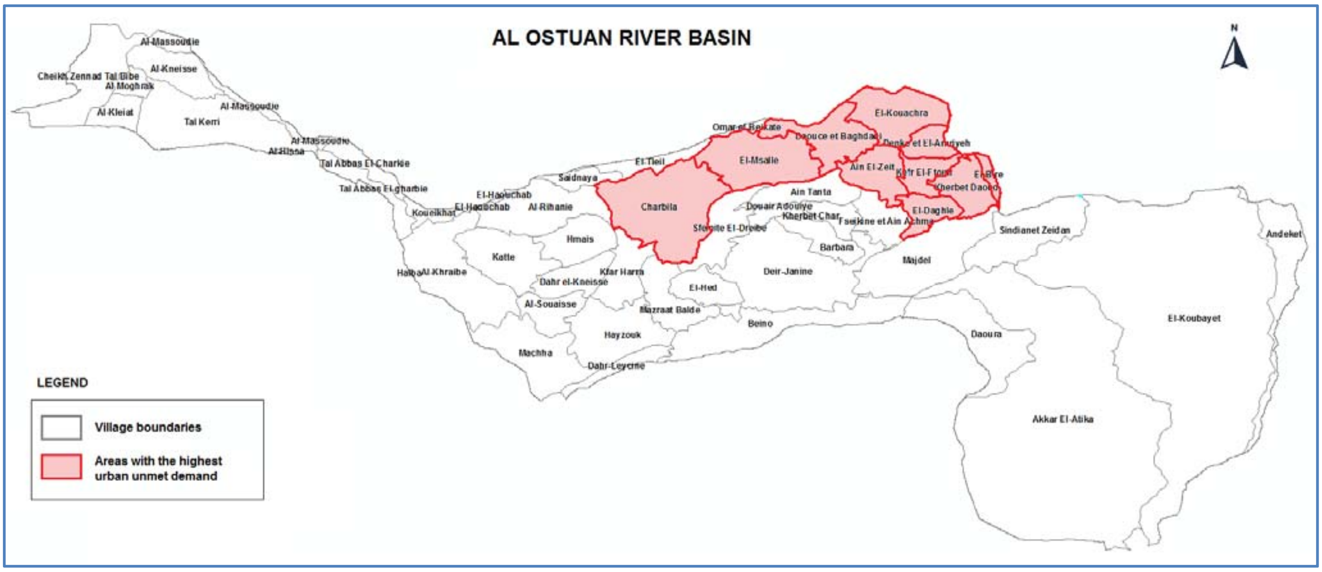


Figure 1-1: Villages with the highest Urban unmet demand (mio m3) per year (from 2003-2018) the Al Ostuan River Basin

The agricultural areas with the highest unmet demand are located in the northern part of the Al Ostuan basin, where extensive irrigation areas of field crops, citrus fruit trees, and olives cover approximately 21 km^2. The available water cannot cover all these irrigation needs. The farms affected are within the villages of Al-Khraibe, Koueikhat, Tal Abbas El-Charkie, Tal Abbas El-Gharbie, Al-Massoudie, Charbila, Ain El-Zeit, El-Daghle, Kherbet Daoud, El-Msalle, Kefr El-Ftouh, El-Kouachra, Daouce et Baghdadi, Denke et El-Amriyeh, El-Bire, Katte, Al-Rihanie, El-Tleil, Omar el-Beikate, El-Haouchab, Hmais, Saidnaya, Al-Khraibe (Figure 1-2).

Figure 1-2: Villages with the highest Agricultural unmet demand (mio m3) per year (from 2003-2018) the Al Ostuan River Basin

The Reliability of the system in supplying the requested demand ranges among the uses. Reliability is defined as the percent of the timesteps in which a demand site's demand was fully satisfied. For example, if a demand site has unmet demands in 6 months out of a 10 years, the reliability would be (10 * 12 - 6) / (10 * 12) = 95%. As domestic use is priority 1, the water allocation to this use has an overall higher reliability (60% on average across all the urban demand sites) comparing to the reliability of the irrigation (58% on average across all the agricultural demand sites).

The percent of the time that the urban water demands are fully satisfied (i.e. the so called “water supply reliability”) ranges from as low as ~29% in some sites (mainly in the west and southwest areas: Dahr-Leycine, Machha, Hayzouk, Al-Souaisse, Dahr el-Kneisse, Al-Khraibe, Koueikhat, Tal Abbas El-Charkie, Tal Abbas El-Gharbie, Al-Massoudie), to 100% in others (mainly in the east and central areas: Akkar El-Atika, El-Koubayet, Majdel, Ain Tanta). Overall, within the urban sector, 62% of the users have very low reliability (i.e. <40% reliability) of water supply, while only 38% have very high (i.e. >95% reliability) as summarized in Table 1 below.

The reliability in the irrigation water supply ranges from as low as ~22% in some sites (Al-Khraibe, Koueikhat, Tal Abbas El-Charkie, Tal Abbas El-Gharbie, Al-Massoudie, Al-Kleiat, Cheikh Zennad Tal Bibe, Al-Kneisse, Al Moghrak, Tal Kerri, Al-Hissa, Al-Massoudie), to 100% in others (Ain Tanta, Douair Adouiye, El-Hed, Deir-Janine, Sfeinite El-Dreibe, Kherbet Char, Fseikine et Ain Achma, Barbara, Mazraat Balbe, Beino, Majdel, Andeket, Akkar El-Atika, El-Koubayet). Overall, within the agricultural sector, 50% of the users have very low reliability of water supply (i.e. <40% reliability), 12.5% have low (i.e. 40-60% reliability), while only 37.5% have very high (i.e. >95% reliability) as summarized in Table 1 below.

Table 1-1: Percent (%) of user for each use category (domestic, irrigation) that fall under the 5reliability classes (very low, low, medium, high, very high) for the 16-year period 2003-2018

Reliability = Likelihood that demand is met	Urban users	Irrigation users
Very High (>95%)	38%	37.50%
High (80-95%)	0%	0%
Medium (60-80%)	0%	0%
Low (40-60%)	0%	12.5%
Very Low (<40%)	62%	50.00%

Concluding the baseline assessment of water resources' availability in the Al Ostuan River Basin for the period 2003-2018, it is observed that the current water supply cannot meet the water demand in the Al Ostuan River Basin, resulting in unmet demands in both the urban and agricultural sector every year. The "exploitable" precipitation in the basin (i.e. total precipitation minus evapotranspiration) is on an annual average basis about 61 mio m^3, of which ~62 mio m^3 becomes surface runoff and the remaining 9 mio m^3 infiltrate to the groundwater. The supply required (including the 30% losses in the urban supply network and 40% in irrigation) on the other hand is ~28 mio m^3 on an annual average basis. This means that the "exploitable" precipitation could in fact cover all demands if adequately captured and exploited, and still leave an adequate volume for the environmental water requirements. Yet, the current supply delivered is only ~10.6 mio m^3 (and fails to cover all demands) simply because only the groundwater is exploited in the basin. The surface water of the river is too polluted to be exploited, especially for drinking purposes. It becomes thus clear, that the water pollution of the river, highly attributed to the direct disposal of sewage waste in the river, impedes the exploitation of the surface water.

The current conditions will be exacerbated in the future, as population growth projection and climate variability will increase the current water demands. It is thus important that demand management is promoted and practiced at the basin, i.e. the adoption of various interventions and measures (technological, legislative, regulatory, financial, etc.) to achieve efficient water use by all sectors of the community (urban/ domestic, agricultural, industrial, etc.). These measures should target to reduce demand and/or introduce water conservation (for example: reduce leakage, install water saving fixtures, increase irrigation conveyance and field application efficiency, create incentives, water tariffs, water markets, taxes, etc.), while in parallel can target to increase water supply and the water available for use (for example: greywater and wastewater reuse, water recycling, desalination, rainwater and stormwater harvesting, natural water retention measures). Caution to potential adverse environmental impacts is important in any case.

- **Water pollution:**

There are multiple sources for the water contamination in the Al Ostuan River Basin, which has been identified as one of the polluted rivers in Akkar region in Northern Lebanon. The direct discharge of untreated wastewater from municipal areas and households has been identified as one of the major causes of environmental pollution. Moreover, outflows from the agricultural and farmlands to the Ostuan River or its tributaries can also be observed and are correlated particularly to the contamination of the water with heavy metals. The lack of correct public networks and waste water treatment plants increase the rate of pollution and contamination in the Al Ostuan River Basin since the untreated waste water is directly released to the river. Thus, the communities living in the Ostuan River basin consider improving the health of the river in parallel to addressing water scarcity as a priority since it directly impacts the health and wellbeing of the communities, the local agriculture, and the tourism sector.

To assess the water quality of the river, two water quality sampling campaign has been conducted in October 2019 (dry season) and February 2021 (wet season), where samples from 17 sites were collected and analyzed in the laboratory of the University of Balamand. These sites were selected to cover the upper area of the river (headwaters), the middle of the river where it is mostly populated (more condensed sampling), as well as the downstream area, near the outflow, where uncontrolled untreated wastewater accumulates. It has been observed that the physical parameters (temperature, pH, electrical conductivity) were at acceptable levels (lower than the values in the referred standards: Libnor Water Standards). As for the chemical parameters, values related to the basic water quality, such as the anions and cations, were all seen to be below the water norms, with the exception of Nitrate and Nitrite (which had high values). The high values of these Nitrate and Nitrite are due to the agricultural activities and the uncontrolled use of fertilizers that is related to the crops abundance. Another major factor that influences the high amounts of Nitrate and Nitrite is the lack of wastewater treatment plants that increases their content in surface waters. Regarding the presence of heavy metals, all of the obtained results showed exceedance of the accepted standards in all 17 sampling sites. This is directly related to the fertilizers and industrial effluents that expel heavy metals directly into the ecosystem. Finally, the microbiological parameters (fecal coliforms and E.coli) were all found to be above the acceptable limits, since wastewater effluents are discharged in the river, as well as uncontrolled agricultural runoff. Table 1-2 summarizes the water quality testing findings and the possible sources of pollution, while Table 1-3 provides an overview of the water pollution (as assessed by the water quality sampling and analysis).

Table 1-2: Possible sources of pollution for the sampled locations

Sampling Sites	Parameters above the Maximum Contaminant Level (MCL)	Possible Source of Pollution
S14,S16, S17	BOD5, High Ecoli, Temperature	Untreated municipal and domestic waste Open dumping
S15	Ecoli, Temperature	
S10	BOD5	
S13	TDS	Leaching of soil Agricultural and urban runoff Discharge of untreated sewage
S1 to S17	DO, Nitrite, Hg, Pb	Discharge of untreated wastewater Open dumping Animal waste Use of fertilizers and chemicals

Table 1-3: Al Ostuan River Basin Water Pollution Overview

Sampling Site	Village (CAD_Name)	Nearby landmark	*Temperature*	*Conductivity*	*Salinity*	*TDS*	*Fluoride*	*Chloride*	*Sulfate*	*Nitrate*	*Nitrite*	*Sodium*	*Potassium*	*Magnesium*	*Calcium*	*pH*	*DO*	*Heavy Metals (Al, Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd)*	*Heavy Metals (Hg, Pb)*	*E coli*	*Fecal*	*BOD*
S1	Akkar El-Aatiqa	Crops or animals all around the area																				
S2	Nabaa El Chouh El Ali	Green Area																				
S3	Nabaa El Chouh El Wati	Canal																				
S4	Nabaa El Jaouz	Chicken breading all around																				
S5	Nabaa El Cheikh Jneid																					
S6	Nabaa Omar Kaylo	Tap/ Origin Ain Tayea																				
S7	Ain I Watyeh	Karst																				
S8	Ain I homsiyeh																					
S9	Ain El Abiad																					
S1 0	Nabaa Hmadeh																					

Sampling Site	Village (CAD_Name)	Nearby landmark	Temperature	Conductivity	Salinity	TDS	Fluoride	Chloride	Sulfate	Nitrate	Nitrite	Sodium	Potassium	Magnesium	Calcium	pH	DO	Heavy Metals (Al, Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd)	Heavy Metals (Hg, Pb)	E.coli	Fecal	BOD
S1 1	Ain I Fouar																					
S1 2	Nabaa El Qolqas																					
S1 3	Nabaa El Tine																					
S1 4	Ain Taqiyeh	Mazeret El Baldeh/ In the middle of the river																				
S1 5	Nabaa Abou Chawkat																					
S1 6	Ain El Hajal																					
S1 7	Ain Taba																					

*<u>Note</u>: *Results based on field sampling and analysis conducted on October 3rd, 2019*
***Red** cells show concentration **above** the limits; **Green** cells show a concentration **below** the limits*

The major sources of water pollution in the Ostuan river basin can be described as follows:

- The lack of urban development planning that increases flash flooding and water
- The lack of Wastewater Treatment Plants (WWTPs)
- The direct disposal of domestic sewage into the river without any treatment from municipal councils & villages located near the river
- The uncontrolled solid waste dumping in the river which increases especially microbiological contamination as well as heavy metals
- The re-surfacing of previously deposited pollutants
- The uncontrolled human activities such as large agricultural activities,local farming, livestock breeding, vehicle washing

In order to have a full assessment of the water quality in the Akkar governorate, a broader surface water quality study of the Ostuan river, with major analysis of fertilizers and pesticides availability in the water, should be performed in the near future. The short terms mitigation measures for the Ostuan river basin are listed below:

- Treatment facilities should be adopted at the source as the first step for decentralised and small cluster services

- Effective implementation, operation and maintenance of waste water treatment plants
- Control over solid waste dumping
- Effective collection and transfer mechanism for sewage from septic tanks; to proposed treatment facilities via sewer lines

2 STUDY BACKGROUND

The current report provided a baseline assessment of the water resources in the Al Ostuan River Basin (ORB) in northern Lebanon, based on the outputs of a detailed Water Resources Management Model (WRMM) developed in WEAP21 software for the Al Ostuan RB. This baseline assessment presents the state of the water availability, water demand, water supply required, and unmet demand (per sector) in the basin during the last 16 years (i.e. from 2003-2018), as well as the current state of surface water pollution based on a recently conducted field survey and sampling.

The work has been conducted in the framework of the project "Consultancy to Facilitate Integrated Water Resource Management (IWRM) in the Al Ostuan Basin", funded by ACTED Lebanon. The overall scope of this consultancy project is to improve water management in the Al Ostuan River Basin by implementing a bundle of demand management measures which can alleviate the prevailing water stress. In parallel to these water quantity issues, the work also focuses on assessing the current pollution levels in the surface waters, in order to mobilize the local community and stakeholders to take action to reduce pollution loads in the basin, and to mitigate the current problem. The project pursues and promotes an inclusive participatory approach, not only by disseminating the results and outputs to the various target groups, but by also involving them in a consultation process: Policy relevant targets for water conservation, water reuse, etc. will be developed together with the stakeholders using this baseline report as a starting point in the analysis and quantification of the imbalance between sectoral water demands and available supply sources and prevailing trends.

The following activities have been concluded so far:

- Mobilization of local and national stakeholders (Municipalities, North Lebanon Water Establishment - NLWE, Ministry of Energy and Water – MEW, etc.)
- Data collection and analysis of hydrometeorological data, geological and land use data, information on the water supply systems, GIS cartographic data, etc.
- Development of a semi distributed (node-based) Water Resources Management Model for the Al Ostuan River Basin in WEAP21 software, at monthly timestep and for the period 2003-2018.
- Field investigation (conducted in October 2019) to select sampling points in terms of their representativeness to the major pollution sources
- Collection and laboratory analysis of water samples from 17 sampling sites in the Al Ostuan River Basin for the dry season (31 water quality parameters have beenanalyzed: pH, water temperature, electric conductivity (EC), salinity, total dissolved solids (TDS), turbidity, and dissolved oxygen (DO), chloride (Cl^{-}), sulphate ($SO4^{2-}$), fluoride (F^{-}), nitrate ($NO^{-\,3}$), calcium (Ca^{2+}), phosphate (PO_4^{2-}), magnesium (Mg^{2+}), potassium (K^{+}), sodium (Na^{+}), ammonium (NH^{4+}), heavy metals, microbiological parameters BOD_5, total coliforms, *E.Coli*.
- Development of a GIS database for the Al Ostuan River Basin

- Implementation of 2 workshops with the stakeholders (in the MEW July 2019, and in Balamand University October 2019)
- Drafting of the Baseline Report on the assessment of the water resources in the Al Ostuan River Basin, based on the outputs of the WEAP model, including a water quality assessment based on the outputs of the field survey and sampling campaign.

To conclude the work, the following activities will be realized in the coming months:

- Collection and laboratory analysis of water samples from 17 sampling sites in the Al Ostuan River Basin for the wet season
- Mapping of the critical water pollution sites based on the level of contamination
- Cost-effectiveness analysis of different demand management measures in the Al Ostuan RB for the urban and agricultural sectors, and simulation of their performance in the WEAP WRMM under the baseline and future scenarios of water availability and demand.
- Development of a Decision Support Platform in WEAP for the identification of the optimal mix of measures (using optimization processes)
- Consultation workshop with the stakeholders to discuss on the feasibility of the selected measures (applicability, implementability aspects, barriers and constraints, enabling factors, etc.)
- Definition of indicative policy-relevant targets and Programme of Measures (PoM) in the Al Ostuan RB together with the stakeholders

Similar work has been also recently conducted in the Nahr El-Kelb River Basin in Lebanon in the framework of the EU funded project SWIM-H2020 SM (2016-2019), where policy targets have been defined together with stakeholders following the same process.

This bottom-up approach, implemented here in Al Ostuan, for designing and implementing Programmes of Measures (PoMs) at the River Basin scale is of paramount importance as it shifts the paradigm from centralised to participatory decentralised water management, while the prescribed targets and measures result from a policy-to-science interfacing process (i.e. rather than been designed solely based on scientific evidence neglecting the local context, or vice-versa solely on local norms neglecting scientific evidence and best practices). These “stakeholders’-proofed” policy targets can be then communicated upstream to the central decision-making level (i.e. the Ministry) with the purpose of being integrated into development frameworks and action plans related to the Water Law (and other sectors). This bottom-up process implemented in Al Ostuan can further act as a pilot application, to be replicated in other River Basins in Lebanon, so that systematic information on needs and remedies is communicated from the local level to the central level, and this information can be adopted and updated in view of future changing conditions (socio-economic, climatic, etc.) to better inform the national water policy.

3 DESCRIPTION OF THE STUDY AREA: AL OSTUAN RIVER BASIN

3.1 PHYSICAL AND ECONOMIC CHARACTERIZATION

The Al Ostuan River (Figure 3-1) is located in the Akkar casa in Northern Lebanon and flows from the east (its headwaters originate in Akkar Al Atika and Qoubayat) to the Mediterranean Sea in the Sahel area, with a length of 44 km (the main river). The river's average flow (based on a record spanning from 2002-2012) at Embouchure station (close to river's estuary) is about 2.28 m3/sec (~5.90 Mm3 per month), with a standard deviation of 3.34 m3/sec and a skewness coefficient of 3.34. Figure 3-2 depicts the observed streamflow at three locations (Embouchure, Beit El Hajj and Pont Halba) of Al Ostuan river, while Figure 3-3 demonstrates the characteristics of the hydrograph at Embouchure station.

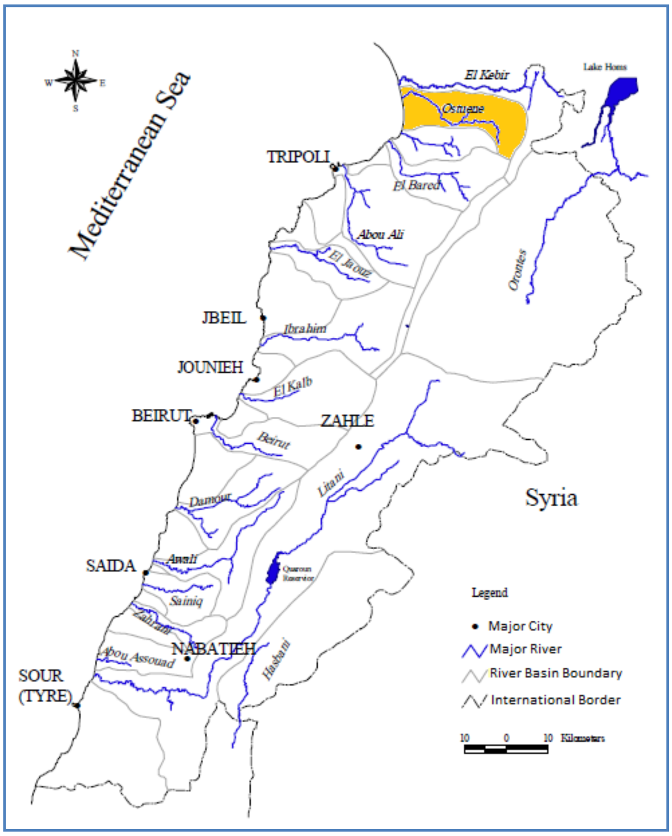


Figure 3-1: Major River Basins in Lebanon. Source: El-Fadel et al., 2000a, In: MOE, LEDO, 2001. State of the Environment report in Lebanon, Chapter 8.

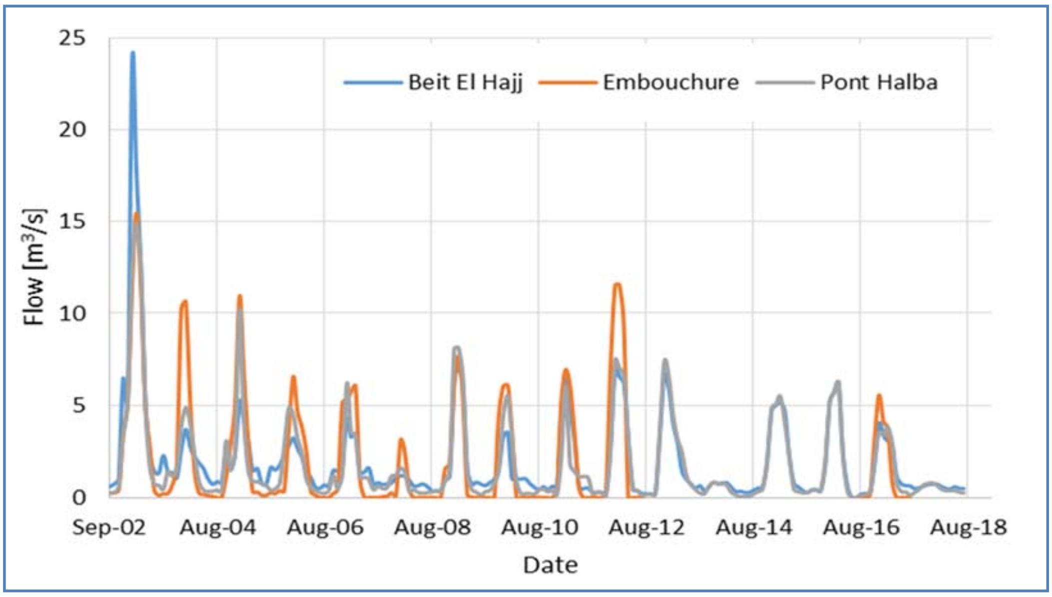


Figure 3-2: Observed streamflow at three gauging stations along the Al Ostuan river.

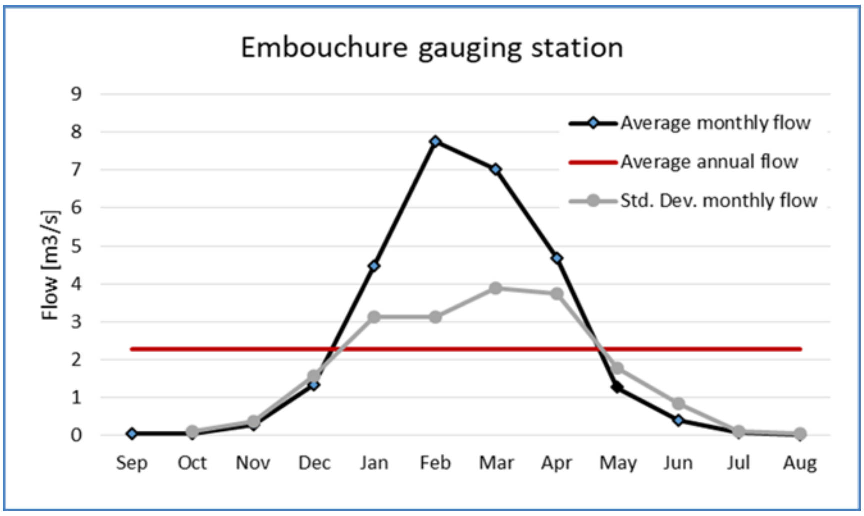


Figure 3-3: Hydrograph of Al Ostuan River at Embouchure gauging station and basic statistics.

The Al Ostuan River and its tributaries drain in total about 145 km^2 with an annual volume of 47 Mm^3. The River Basin comprises of 8 sub-catchments as demonstrated in Figure 3-4. Their main characteristics are presented below.

Table 3-1: Main characteristics of the Al Ostuan sub-catchments

Sub-catchment ID	Area (km^2)	Slope	Mean Elevation (m)
22	11.06	0.01	69.43
15	4.19	0.11	107.92
16	28.55	0.55	357.31
17	12.11	0.50	327.91
18	24.68	0.77	429.37
19	30.01	1.21	662.57
20	15.63	2.06	1,121.71
21	18.44	2.02	1,008.15
8 sub-catchments	146.67		510.55

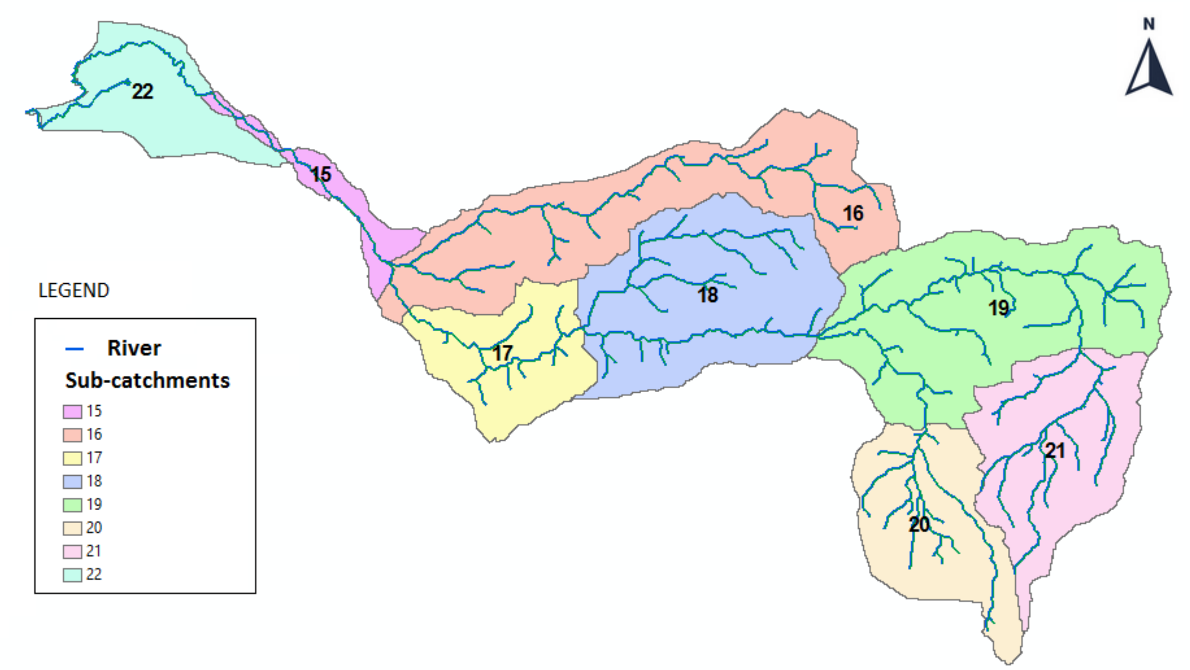


Figure 3-4: The sub-catchments of the Al Ostuan River Basin

The main cultivated crops are field crops in terraces (vegetables, legumes), fruit trees, and olives (refer to Table 3-3, according to Corine Land Cover 2017 (CLC2017)). The areas under irrigation schemes (currently about 27% of the total agricultural areas) are extended in the western and northeastern parts of the basin, currently managed by the NLWE. The imbalance between demand and supply (water stress) is widespread, and the unmet demand is most pronounced during the summer period (SISSAF, 2017Mouchref, 2008). As a result a high number of private wells are used in the basin (SISSAF, 2017; MEW Database), with no public control over the abstracted volumes, which can lead to environmental impacts, such as the degradation of the groundwater resources and declining groundwater levels (Mouchref, 2008).

Water pollution is also a major threat to freshwater biodiversity in the region and in the Mediterranean Sea. The main sources of pollution are from urban sewage and wastewater (untreated), as well as from agricultural runoff (pesticides and nutrients) (Bouaoun and Nabbout, 2016). The Al Ostuan River is contaminated by waste water. Direct discharges of sewage waters are sighted along the river which contributes to alter the quality of the freshwater and its organic content.

The communities living in the Al Ostuan River basin consider improving the health of the river and addressing water scarcity as a priority for their communities since it directly impacts the health and wellbeing of their communities, local agriculture and the tourism sector. Currently the river suffers from many issues due to its mismanagement

Main Issues:

- Public water supply is not covering all the villages in the Al Ostuan River Basin
- The intense exploitation of groundwater is leading to the deterioration of the already disturbed water balance and the degradation of water resources.
- The lack of Wastewater Treatment Plants (WWTP) and the direct discharge of urban wastewater into the river led to high pollution levels in the river and has caused severe environmental damage
- Integrated water resources management plans or other policy instruments are lacking, and management is currently based on “crisis management” rather than on a pro-active and preparedness approach.

A total of 51 villages are located (as a whole or part of) within the Al Ostuan River Basin (ORB) boundaries (Figure 3-5). Three main urban centers, El-Koubayet, Akkar El-Atika and Daouce et Baghdadi are within the basin, while numerous significant peri-urban settlements are also present (e.g. Tal Kerri, Machha, Kefr El-Ftouh, Al-Souaisse, Majdel, etc.). The total population of the area is 104,538 inhabitants, while the population of each village and the respective population equivalent within the boundaries of the ORB are presented in Table 3-2 below. The largest villages in terms of population (number of inhabitants) are Akkar El-Atika, El-Koubayet, Daouce et Baghdadi, Machha, Tal Kerri, Kefr El-Ftouh, and Al-Souaisse. The average population density is about 1,079 inhabitants per km^2, with maxima of 6,339 inhabitants/km^2 observed in Daouce et Baghdadi and 5,418 inhabitants/km^2 in Kefr El-Ftouh, while the minimum population densities are observed in El-Hed (8 inhabitants/km^2) and Chabrila (77 inhabitants/km^2).

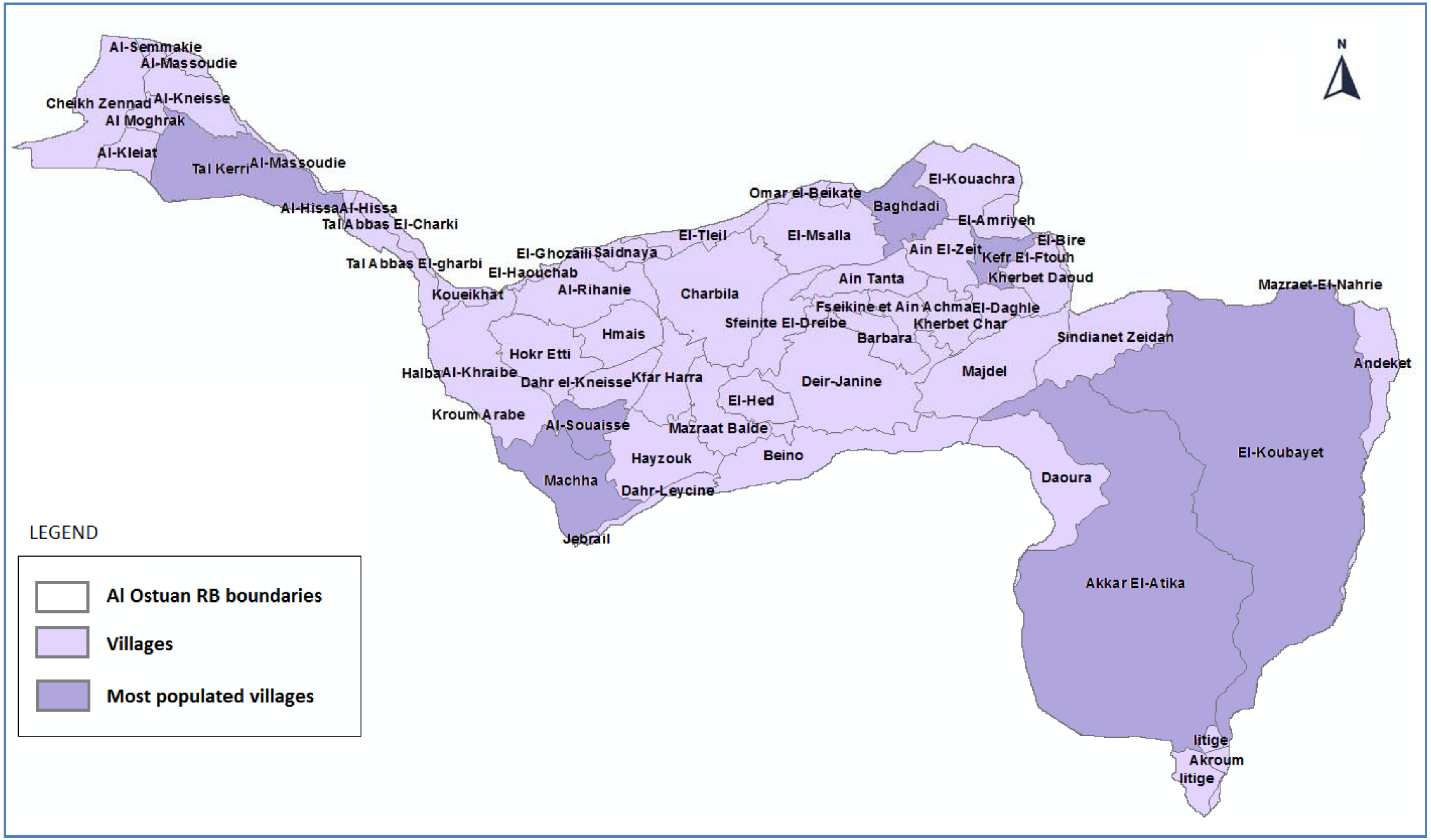


Figure 3-5: The villages within the Al Ostuan River Basin boundaries

Table 3-2: Villages within the Al Ostuan River Basin (ORB) and their respective area and population

Village Code (CAD_CODE)	Village Name (CAD_NAME)	Village area within the Al Ostuan RB (km^2)	% of the village area that falls within ORB	Total Population of the village (inhabitants)	Village Population equivalent within the ORB (inhabitants)
35078	El-Koubayet	27.39	89%	13,000	11,524
35085	Akkar El-Atika	24.99	89%	17,000	15,097
35099	Deir-Janine	5.84	100%	1,400	1,401
35095	Charbila	5.18	100%	400	400
35017	Tal Kerri	4.54	63%	7,000	4,384
35033	Al-Khraibe	4.25	88%	1,018	895
35137ND	Majdel	4.02	100%	3,200	3,202
35075	Beino	3.94	41%	5,000	2,052
35200ND	Daoura	3.29	47%	3,500	1,645
35120	El-Msalle	3.28	100%	1,600	1,601
35012	Cheikh Zennad Tal Bibe	3.15	35%	2,544	901
35082	Machha	3.14	55%	10,000	5,490
35113	Sindianet Zeidan	3.08	96%	776	744
35083	Hayzouk	3.00	100%	2,000	2,002
35101	Al-Rihanie	2.94	99%	1,800	1,785
35098	Katte	2.53	100%	1,050	1,051
35166ND	Andeket	2.53	9%	6,000	559
35111	El-Kouachra	2.45	44%	2,500	1,101
35117	Daouce et Baghdadi	2.20	55%	25,448	13,959
35201ND	Mazraat Balde	1.81	100%	2,800	2,802
35102	Sfeinite El-Dreibe	1.81	100%	670	671
35015	Al-Kneisse	1.74	100%	205	205
35157ND	Hmais	1.71	100%	1,200	1,201
35094	Kfar Harra	1.65	100%	270	270
35112	Ain El-Zeit	1.61	100%	3,000	3,002
35116	Ain Tanta	1.52	100%	2,000	2,002
35118	Kherbet Daoud	1.42	100%	2,500	2,502
35105	Dahr el-Kneisse	1.36	100%	602	602
35122	Fseikine et Ain Achma	1.31	100%	1,303	1,304
35090	El-Hed	1.23	100%	10	10

Village Code (CAD_CODE)	Village Name (CAD_NAME)	Village area within the Al Ostuan RB (km^2)	% of the village area that falls within ORB	Total Population of the village (inhabitants)	Village Population equivalent within the ORB (inhabitants)
35096	Al-Souaisse	1.22	100%	3,500	3,503
35127	Barbara	1.15	100%	550	550
35034	Tal Abbas El-gharbie	1.06	21%	3,594	750
35114	El-Daghle	1.01	100%	700	701
35131	Kefr El-Ftouh	0.97	100%	5,276	5,262
35045	Al-Massoudie	0.91	18%	6,000	1,074
35011	Al-Kleiat	0.89	14%	6,000	818
35108	El-Tleil	0.83	27%	1,800	489
35036	Tal Abbas El-Charkie	0.82	22%	650	142
35124	Denke et El-Amriyeh	0.80	25%	1,600	407
35119	Kherbet Char	0.74	100%	1,500	1,501
35067	Dahr-Leycine	0.73	24%	509	123
35093	Saidnaya	0.66	79%	2,150	1,708
35121	Douair Adouiye	0.60	100%	1,200	1,201
35016	Al Moghrak	0.52	100%	150	150
35035	Koueikhat	0.50	43%	3,000	1,278
35135ND	El-Bire	0.28	8%	2,500	192
35109	Omar el-Beikate	0.19	5%	2,000	99
35115	El-Haouchab	0.09	6%	400	24
35018	Al-Hissa	0.07	3%	6,000	195
35030	Halba	0.00	0.06%	12,000	7
			Sum	**180,875**	**104,538**

Source: data collected by ACTED from Governor's Office. Missing values have been supplemented by the population data provided in the study "Water Supply Master Plan for North Lebanon, Chapter 10 Akkar Water Master Plan, SISSAF, 2017".

In terms of land use, the area is dominated by agriculture (~37% of the basin area). The land use types are presented in Figure 3-6, while their respective coverage (in km2 and as % of total area) is presented in Table 3-3. The area is dominated by agricultural land (~ 37%) and forests (~ 25%), followed by grasslands and scrublands (~ 16%) and urban areas (~ 12%), while abandoned agriculture land also accounts for another 8%. Wetlands and water bodies only account for 0.7% of the total area. With regard to other land use types, few industrial and/or commercial facilities are located in the river basin (~ 0.14% of the area), few poultry breeding units (~ 0.02% of the area), and few mineral extraction sites (~ 0.06% of the area). Finally, burnt wooded lands and rocky outcrops cover 0.07% and 1.43% respectively.

Table 3-3: Land Use types within the Al Ostuan River Basin (ORB) according to Corine Land Cover 2017 (CLC2017)

Land Use Type	CLC2017 codes included	Area (km^2)	% coverage of the total basin area
Urban areas	1111, 1112, 1121, 1123, 1124, 1230, 1340, 1410, 2100, 2200, 3100, 3200, 3300	17.20	11.90%
Industrial or Commercial areas	1210	0.20	0.14%
Mineral Extraction Site	1310	0.09	0.06%
Poultry Breeding	2421	0.03	0.02%
Field crops	2110, 2120	22.70	15.70%
Fruit Trees & Citrus Fruit Trees	2230, 2240	9.46	6.54%
Olives	2210	20.83	14.41%
Vineyards	2220	0.025	0.02%
Protected Agriculture, Greenhouses	2310	0.96	0.66%
Abandoned Agriculture Land	2130	11.73	8.11%
Forests	3111, 3113, 3121, 3122, 3130, 3211, 3213, 3221, 3222, 3230	35.60	24.63%
Grasslands, Scrublands	3310, 3320, 4100	22.52	15.58%
Burnt Wooded Lands	3400	0.10	0.07%
Rocky Outcrops	6100, 6310, 6500	2.06	1.43%
River, Lake, Wetland	5200, 7110, 8000	1.04	0.72%
TOTAL		**144.55**	**100%**

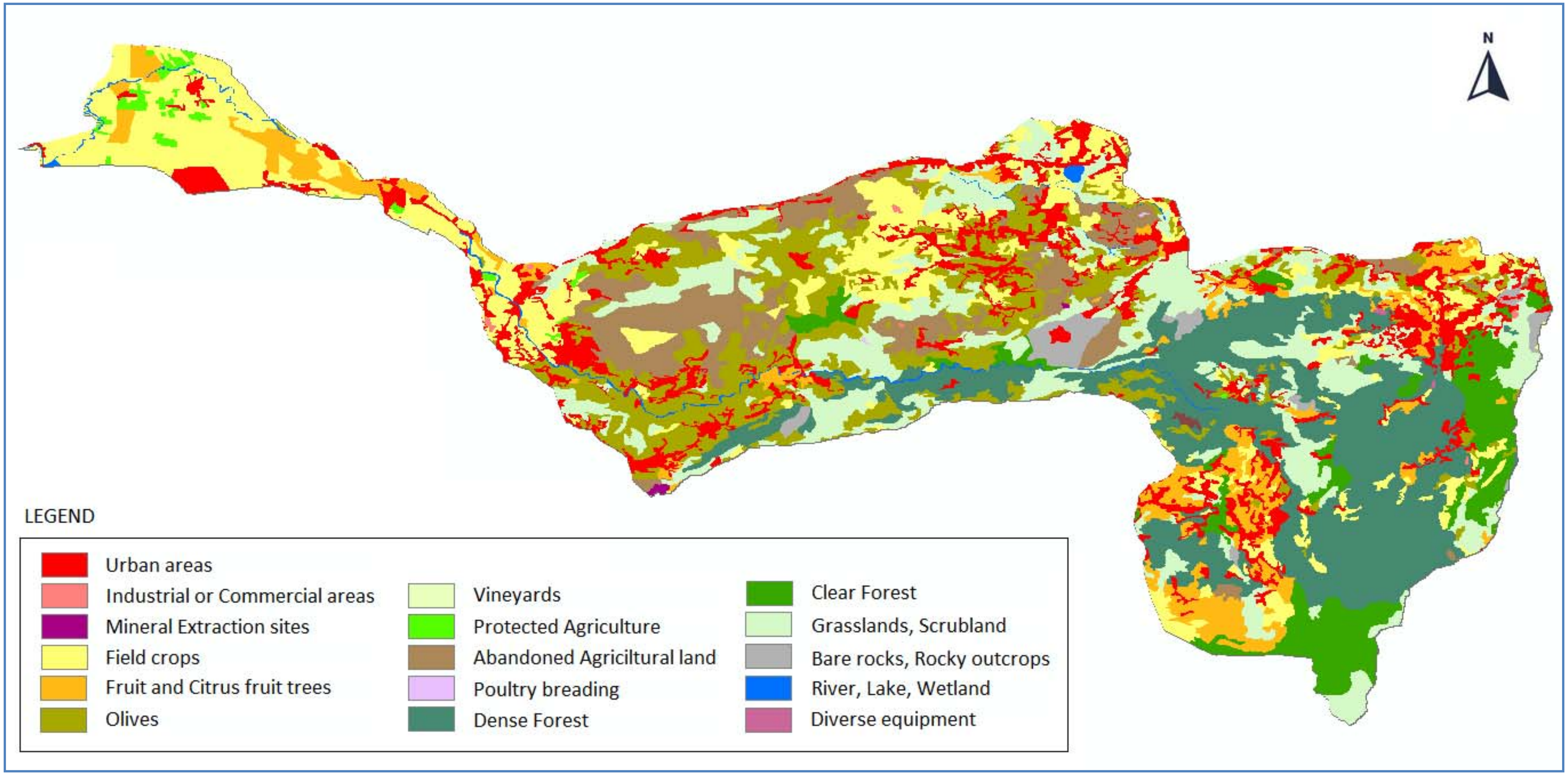


Figure 3-6: Land use in the Al Ostuan River Basin

The share of cultivated crops (within the agricultural land use) which are covered by irrigation schemes is about 30% (Table 3-4). The irrigation schemes and the areas they cover are presented in Figure 3-7.

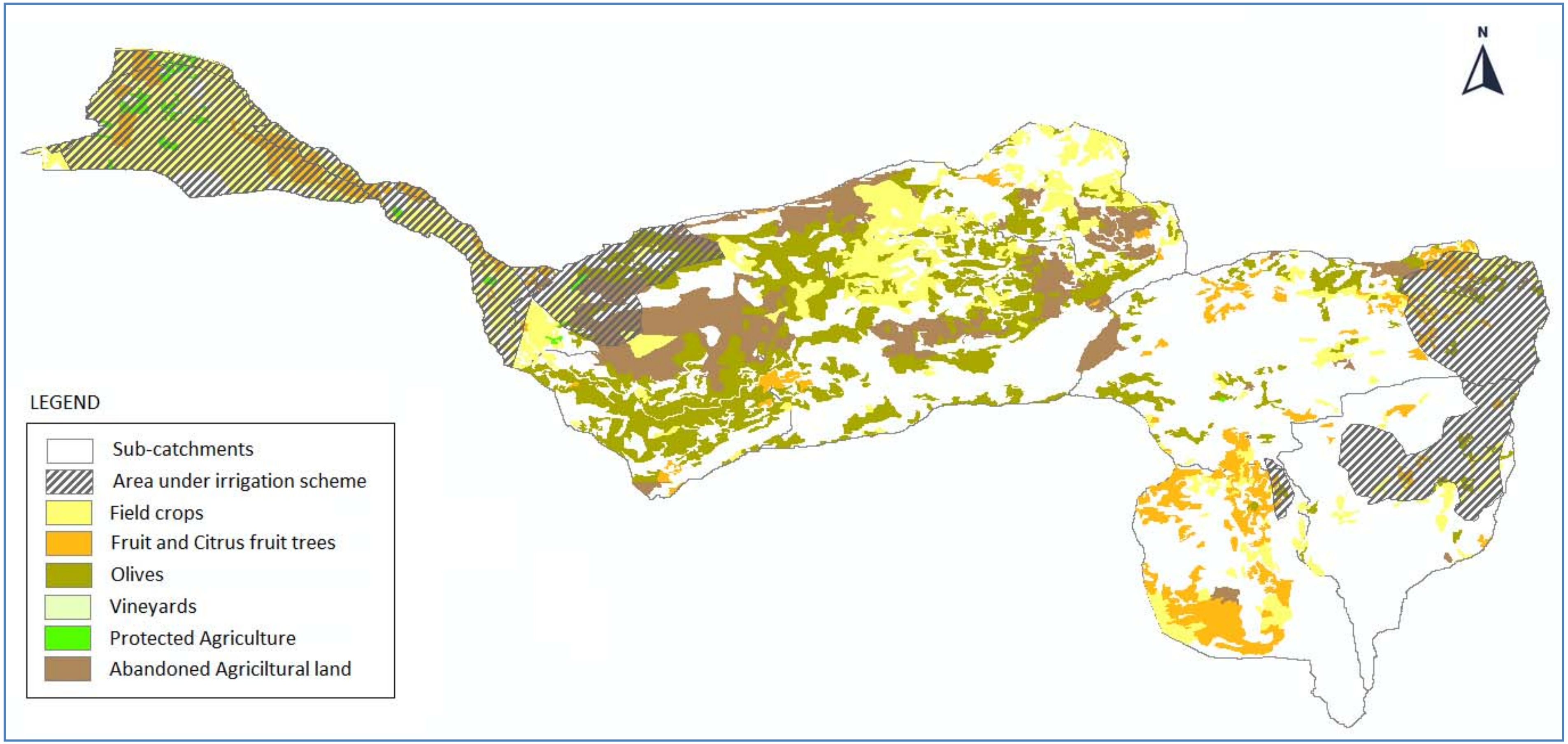


Figure 3-7: Irrigation schemes and agricultural land use in the Al Ostuan River Basin

Table 3-4: Irrigation schemes in the Al Ostuan River Basin

Irrigation scheme	Areal extent of the scheme (km²)	Status	Agricultural area covered by the scheme (km²)	% coverage of the total agricultural area*
Akkar El Attiqa	0.41	Existing	0.12	0.22%
Mashta Hassan - Mashta Hammoud - Qoubaiyat	12.24	Existing	2.71	5.03%
Akkar plain	15.21	Existing	13.17	24.40%
Noura Et Tahta	*6.33*	*Proposed*		
TOTAL	**27.85 (existing)** ***34.18 (incl. proposed)***		**16.00**	**29.65%**

* The total agricultural area (field crops, fruit trees, citrus fruit trees, olives, protected agriculture/greenhouses) is approximate 53.97 km^2 (excluding the abandoned agricultural lands) (Source: CLC 2017)

The areal precipitation in the Al Ostuan River Basin has been calculated based on data from three nearby meterorological stations, namely the Klaiaat and Qoubayat stations of Civil Aviation, and the Fnaidek station of LARI, using the Thiessen polygons method as illustrated in Figure 3-8. The statistics of each station are summarised in Table 3-5. The long-term annual average (LTAA) precipitation of the entire Al Ostuan River Basin for the 16-year period 2003-2018 is 121 Mm^3, with a standard deviation of 42 Mm^3. The maximum observed annual precipitation was 254 Mm^3 in 2003, while the minimum observed was 78 Mm^3 in 2010. The annual precipitation shows a declining trend in the period 2003-2018 (Figure 3-9). Most of the precipitation is observed duting the months of January, February and March, while the months with the lowest precipitation are July, August, and September (Figure 3-10). On an annual basis, an average of 57% of the precipitation is lost to evapotraspiration, which varies across the months. Lower evapotranspiration rates of 35-45% are observed during the winter months, and higher rates of 75-80% are observed during the summer months.

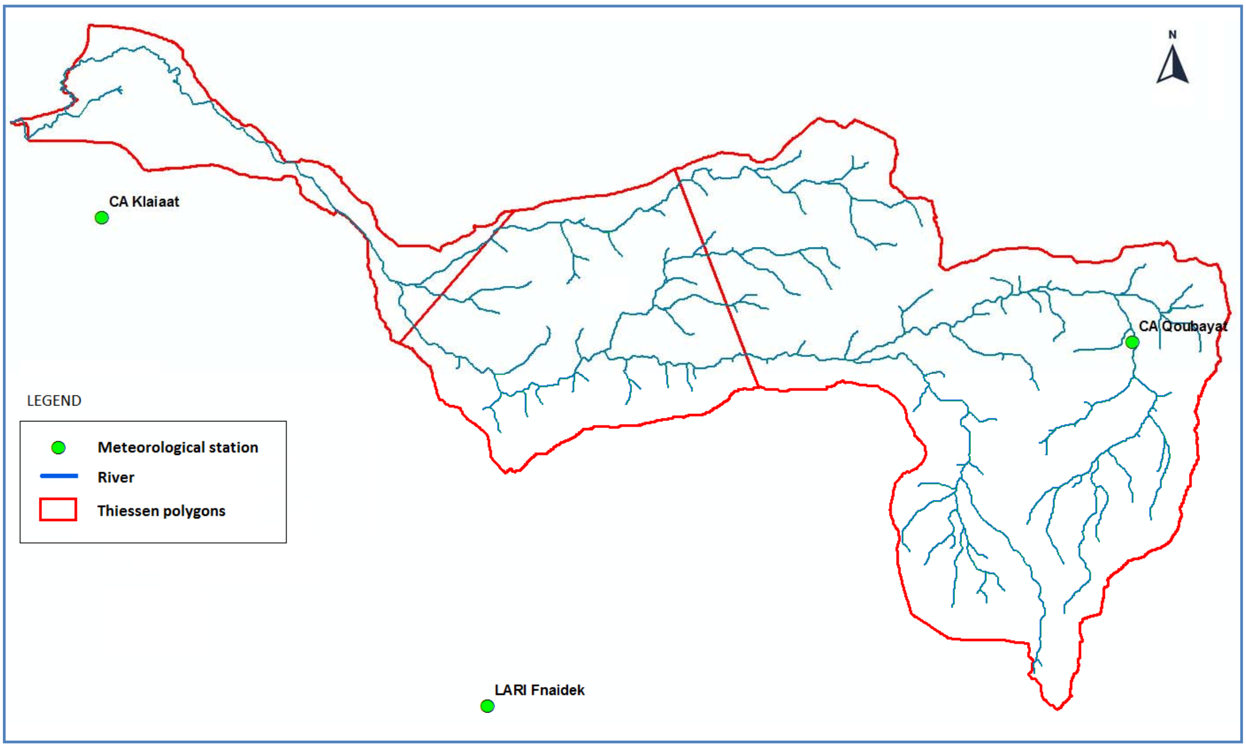


Figure 3-8: Location of meteorological stations in the vicinity of the Al Ostuan River Basin.

Table 3-5: Meteorological stations' statistics

Meteorological Station	Operator	Period of record	Long-term Annual Average (LTAA) Precipitation (mm)	Standard Deviation (mm)	Max Annual Precipitation of the period	Min Annual Precipitation of the period
Qoubayat	Civil Aviation	2001-2011	956	343	1,686 (in 2003)	490 (in 2008)
Klaiat	Civil Aviation	2003-2011	738	360	1,541 (in 2003)	430 (in 2011)
Fnaidek	LARI	2009-2018	849	213	1,143 (in 2018)	550 (in 2017)

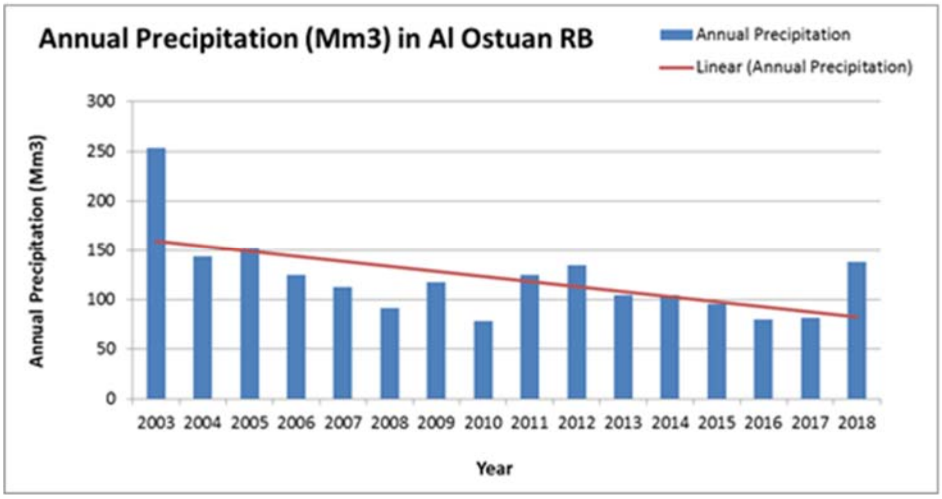


Figure 3-9: Annual precipitation in the Al Ostuan River Basin for the period 2003-2018.

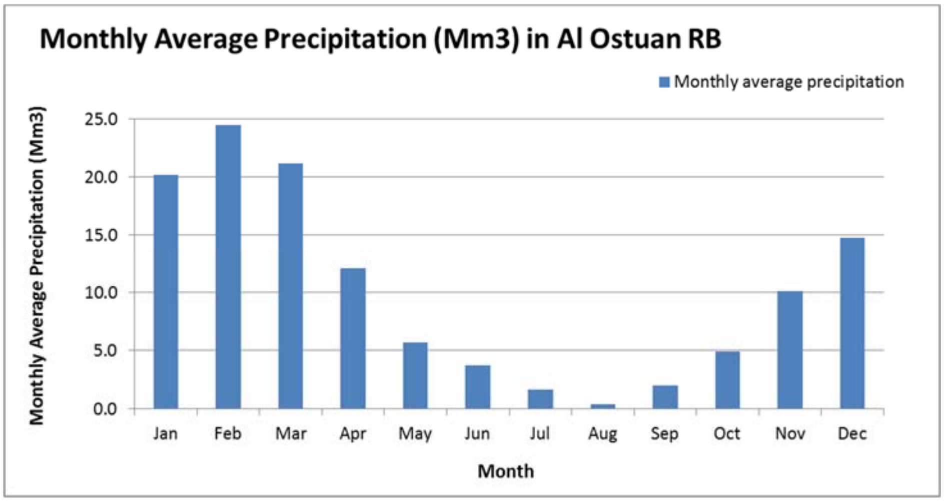


Figure 3-10: Monthly average precipitation in the Al Ostuan River Basin for the period 2003-2018.

The Al Ostuan River basin expands over six groundwater basins, five of which belong to the so-called Mediterranean hydrogeological province (GWB 26c, 18, 18b, 13, 31, 30a) and one to the Interior Mediterranean province (GWB 3). Five of them are productive aquifers, and two are unproductive aquicludes as summarized in Table 3-6 below. The area covered by each groundwater basin is illustrated in Table 3-6.

Table 3-6: Groundwater Basins (GWB) in the Al Ostuan River Basin

GWB	GW Basin Name	Hydrogeolo-gical Province	Aquifer	Aquifer Type	Aquifer Characteri-stic	Area (km2)	% RB covered
26c	Akkar Quaternary Basin	Mediterranean	ncg-Qcg	Aquifer	Neogene/ Quaternary	12.92	8.9%
3	Mount Lebanon-Bekaa Cretaceous Basin	Interior	C4-C5	Aquifer	Cretaceous	5.59	3.9%
18	North Lebanon Cretaceous Basin	Mediterranean	C4-C5	Aquifer	Cretaceous	35.83	24.8%
18b	Qammoua Cretaceous Basin	Mediterranean	C4-C5	Aquifer	Cretaceous	17.92	12.4%
13	Sir Ed Danieh-Ain Yacoub Jurassic Basin	Mediterranean	J4	Aquifer	Jurassic	4.54	3.1%
31	Unproductive	Mediterranean	C2-C3	Aquiclude	Cretaceous	6.12	4.2%
30a	Unproductive	Mediterranean	Aquiclude	Aquiclude	Basalt	61.74	42.7%

Box 3.1: Aquifers' characteristics (Source: UNDP, 2014)

Characteristics of the Aquifers in the study area

Source: UNDP, 2014. Nationwide Assessment of Groundwater Resources Across Lebanon, Data Synthesis & Basin Water Resources Characterization Report, II. Groundwater Basins-Boundaries and Geology , Part of Deliverable No.9, Prepared by ELARD in association with BURGEAP-IGIP-RIBEKA.

Akkar Neogene-Quaternary Basin (Basin 26c): The Akkar Neogene-Quaternary Basin (Basin 26c) occupies the coastal area of Akkar. Structurally the basin is part of the Akkar platform. Its thickness ranges between few meters in the peripheries to more than 100m in the central part of the basin. The Quaternary deposits of the basin are overlying C6-Pa-e2a and Pliocene basalt aquicludes. The boundaries of this basin are actually limited to the outcrops of the aquifer. However, the deposits extend beyond the coast line in the western side; thus favoring the hydraulic connection with the sea. Outlets of this basin are most likely in the form of diffused flow along the coast and beyond.

Mount Lebanon-Bekaa Cretaceous Basin (Basin 3): The Mount Lebanon-Bekaa Cretaceous Basin (Basin) of the interior hydrogeological province is located partly in the Bekaa plain and partly in the high elevation areas of Mount Lebanon. Structurally the basin has an elongated shape, with two (2) main zones. It forms a rectangular zone of 4 to 7km wide, centered on the Yammouneh Fault system. It includes closed depressions / pull apart basins. Beds in this zone are mainly dipping towards the Yammouneh Fault (YF). The second zone, has a rectangular shape that stretches east of the Yammouneh basin, with a width ranging between 5 and 10km. It is a plateau like feature plunging in a NE direction underneath the Quaternary deposits of the Bekaa plain. Beds in this zone dip in a NE direction. The basin is desiccated by ENE-WSW trending faults creating preferential pathways for groundwater to flow from the recharge areas of the aquifer in the high elevation areas to the lower parts of the aquifer at lower elevations. The C4-C5 aquifer of this basin plunges underneath the Homs basalts in the north and underneath the ncg-Qcg aquifer and C6-P-e2a aquiclude of the Bekaa plain in the east. The western boundary of Basin 3 is mainly the boundary between the two hydrogeological provinces. The maximum thickness of this aquifer is defined at approximately 900m. Natural outlets in this basin are in the form of springs in the pull apart basins created along the Yammouneh fault (YF) and at the outcrop peripheries, such as the Aarbine, Orghoch, and Jaouz Springs. The groundwater flow direction is between NE and SE, from the high land areas mainly towards the springs. The groundwater also seeps through the sinking streams present in the pull apart basins into the deeper parts of the aquifer and follows a deeper passage. The general direction of the deep groundwater flow is also trending between NE and SE direction. The groundwater flowing in an easterly direction travels long distances, sometimes in the C4-C5 aquifer of Basin 3 underneath younger Neogene-Quaternary beds of the Bekaa Plain, to resurface in springs such as Zarqa spring.

North Lebanon Cretaceous Basin (Basin 18): The North Lebanon Cretaceous Basin (Basin 18) is located in the northern coastal areas of the Mediterranean hydrogeological province. The basin has an elongated shape that stretches parallel to the coast. Structurally the basin is mainly formed of gently dipping beds that grade into deformed and steeply dipping beds close to the coastal flexure and Akkar fault to become gentle again after the flexure and to extend underneath the younger beds all the way towards the Mediterranean Sea. The maximum thickness of this aquifer is defined at approximately 900m. The lower boundary of this aquifer is not exposed in this basin however; it extends to great depths possibly to the marl and volcanic rocks of C2-C3 aquiclude.The groundwater flows in a direction ranging between SW and NW. Natural outlets of this basin are in the form of overflow springs along the Akkar fault system, such as Rachaaine and Kadi spinrgs and further west in the form of submarine springs like the Chekka submarine springs.

Qammoua Cretaceous Basin (Basin 18b): The Qammoua Cretaceous Basin (Basin 18b) is located in the high latitude areas of the Mediterranean hydrogeological province in the northern part of Mount Lebanon. The Qammoua Cretaceous Basin is similar in hydrogeological conditions to the Bcharre-Dannieh Cretaceous Basin (parallelogram shaped basin, mainly formed of a broad high elevation platform of gently dipping beds., and a groundwater flow direction ranging between the SW and NW) but it is separated by the Jurassic outcrops of the Sir el Dannieh - Ain Yacoub Jurassic Basin.

Sir Ed Danieh-Ain Yacoub Jurassic Basin (Basin 13): The Sir Ed Danieh – Ain Yacoub Jurassic Basin (Basin 13) is located in the Mediterranean hydrogeological province. The outcropping beds of the Jurassic rocks of this basin are gently dipping towards the west. They plunge underneath the younger Cretaceous units in the northern and western sides. The limit of the boundary that was first suggested by the UNDP (1970) as the limit of the outcrops is now shifted further northwards and westwards to reach the Akkar fault system. It is not clear if the boundary can be extended beyond that fault. Form the east the gentle beds are dipping slightly towards the east and extend all the way to the Yammouneh Fault (YF). The eastern limit of the boundary is not very well defined. The Yammouneh Fault system was considered to be the eastern limit of this basin. The major E-W and NNE-SSE trending secondary faults, such as the Danieh fault (DnF) act as groundwater preferential pathways.

The general direction of the groundwater flow in Basin 13 ranges between SW and NW. Major natural groundwater outlets in this basin are in the form of springs outcropping in valleys close to the western limits of the J4 aquifer outcrops, such as the Zahlan Spring. There is also a deep groundwater flow component. A portion of the groundwater seeps into the deeper parts of the basin, where it flows following a trend that ranges between SW and NW.

Aquicludes (31, 30a): The aquicludes are hydrostratigraphic units of low permeability that might sometimes contain permeable horizons of limited extent and of very low water yield capacity. These aquicludes act as confining units located between two more permeable formations (aquifer or semi-aquifer). The formations that are classified as aquicludes are: Bhannes - J5 aquiclude, Hammana - C3 aquiclude, Chekka - Paleocene-Lower Eocene marls - C6-Pa-e2a aquiclude, Pliocene Basalts - BP aquiclude, and Quaternary Basalts - BQ aquiclude.

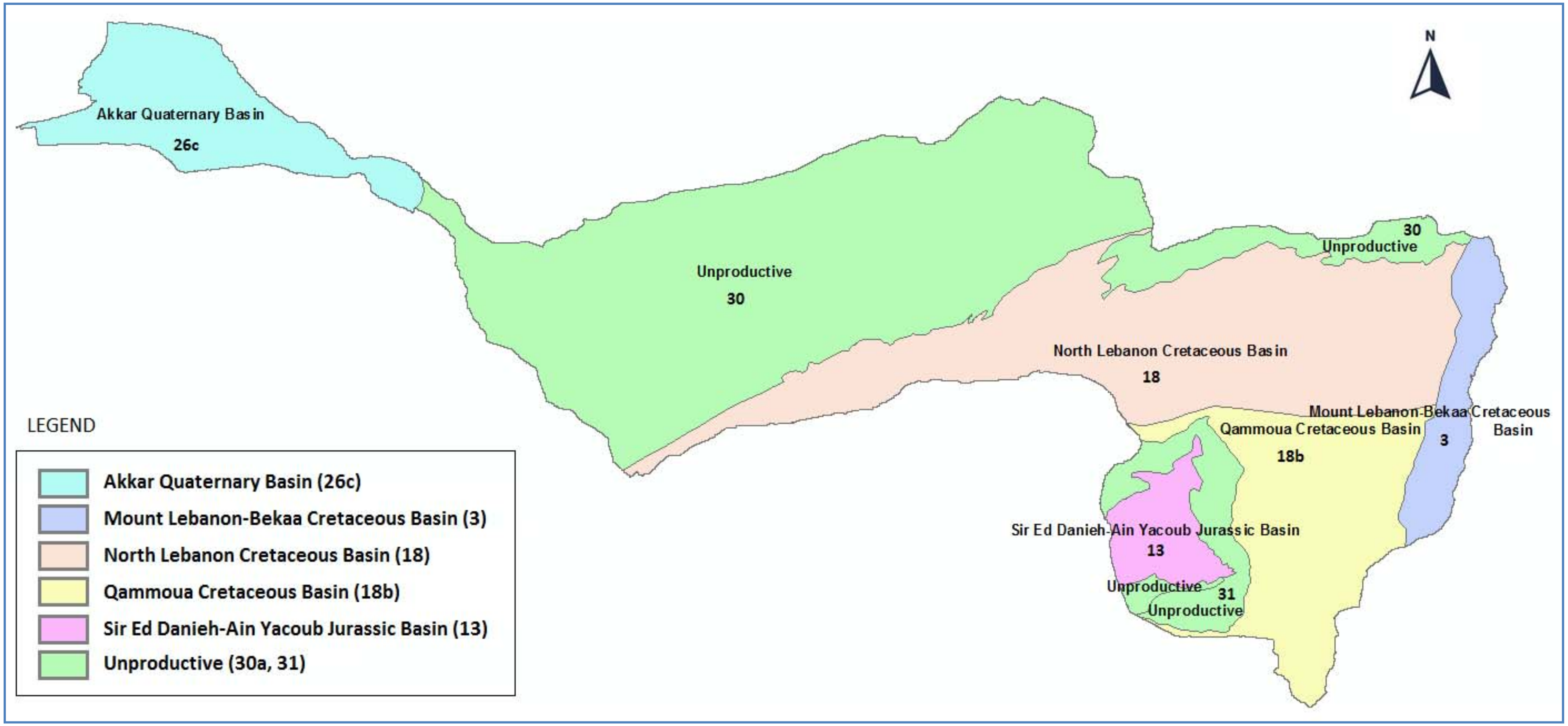


Figure 3-11: Hydrogeological map of the Al Ostuan river basin (six Groundwater basins).

3.2 INSTITUTIONAL AND POLICY SETTING

Lebanon is committed to the Paris Pact on water and adaptation, and currently implementing the new Water Code 77 (Code de l' Eau, 2005), which targets rational water use and increase of water efficiency across the economic sectors, and promotes decentralized/ regional water management at the river basin scale. Implementation challenges still prevail when it comes to developing, internalizing and implementing specific measures which target to minimize water losses, manage demand and introduce savings at the decentralized basin level, alongside with the management of wastewater. All these aspects are still weak and implementation is challenged by the lack of tools and capacities.

The water management in the Al Ostuan River Basin has not been sustainable so far and an integrated water resources management approach has not yet been implemented. The North Lebanon Water Establishment (NLWE) is the public entity responsible for the water supply in the Al Ostuan area. NLWE is a public entity that was founded in 2000 under the oversight of the Ministry of Energy and Water (MEW) in compliance with the Decree 221. It provides water to Tripoli and the entire Northern Governorate. It is sub-divided into 9 branches (Qoubayat, Koura, Minieh, Tripoli, Halba, Dinnieh, Batroun, Zgharta and Bcharreh). The Qoubayat and Halba branches are concerned with the water supply of the villages located within the Al Ostuan River Basin. Currently, the operation of the water supply and sanitation and the wastewater collection and treatment systems in the Al Ostuan area are sub-optimal. The challenges faced include:

- poor service quality, in particular intermittent water supply and absence of wastewater treatment plants;
- slow implementation of the water reform including the non-efficient share of responsibilities between various entities such as the Council for Development and Reconstruction (CDR) which is in charge of investment, and the North Lebanon Water Establishment (NLWE), which is in charge of operation and maintenance;
- limited institutional and staff capacity in the NLWE
- poor monitoring, weak enforcement and control leading to uncontrolled illegal groundwater abstractions
- poor information about water resources, sector performance and assets
- lack of public understanding of the environmental concerns and cause-effect relationships
- lack of incentives to comply with legislation
- very low percentage of installed water meters and absence of volumetric water tariffs high level losses in the water distribution network
- limited number of subscribers, limited cost recovery for water supply services and no cost recovery for sewerage and wastewater treatment

The loose institutional setting and the weak cooperation among the responsible authorities has contributed to the inability of enforcement and control, subsequently leading to the realization of numerous illegal groundwater abstractions and wastewater outlets into the river, and the building-up of water conflicts among the users (SISSAF, 2017). All the above-mentioned challenges persist when it comes to managing the Al Ostuan water resources, and lead to unsustainable management in terms of uncontrolled groundwater exploitation and uncontrolled surface water pollution.

3.3 WATER SUPPLY

The North Lebanon Water Establishment (NLWE) is the public entity responsible for the water supply in the Al Ostuan area. Alongside with the NLWE, some municipalities have their own water supply system, e.g. the Qoubayat village water supply is under the control of a private committee (QWC). Two regional branches, the Qoubayat and the Halba branches, provide water to the villages located within the Al Ostuan River Basin (NWSS, 2020, Volume IV). Few villages are also covered by the Sahel Akkar region distribution systems. The water source is groundwater from wells and springs. Figure 3-12 shows the location of the main public wells of both Qoubayat and the Halba branches, while Figure 3-13 shows the location of the main sprigs. There are also numerous private wells used for domestic and/or irrigation purposes (i.e. 245 wells registered in the database UNDP, 2014 based on the MEW database, with and without exploitation permits) as presented in Figure 3-14. This number, included in the aforementioned databases, is indicative of the extent of the number of private wells, yet there might be much more which cannot be verified by this study.

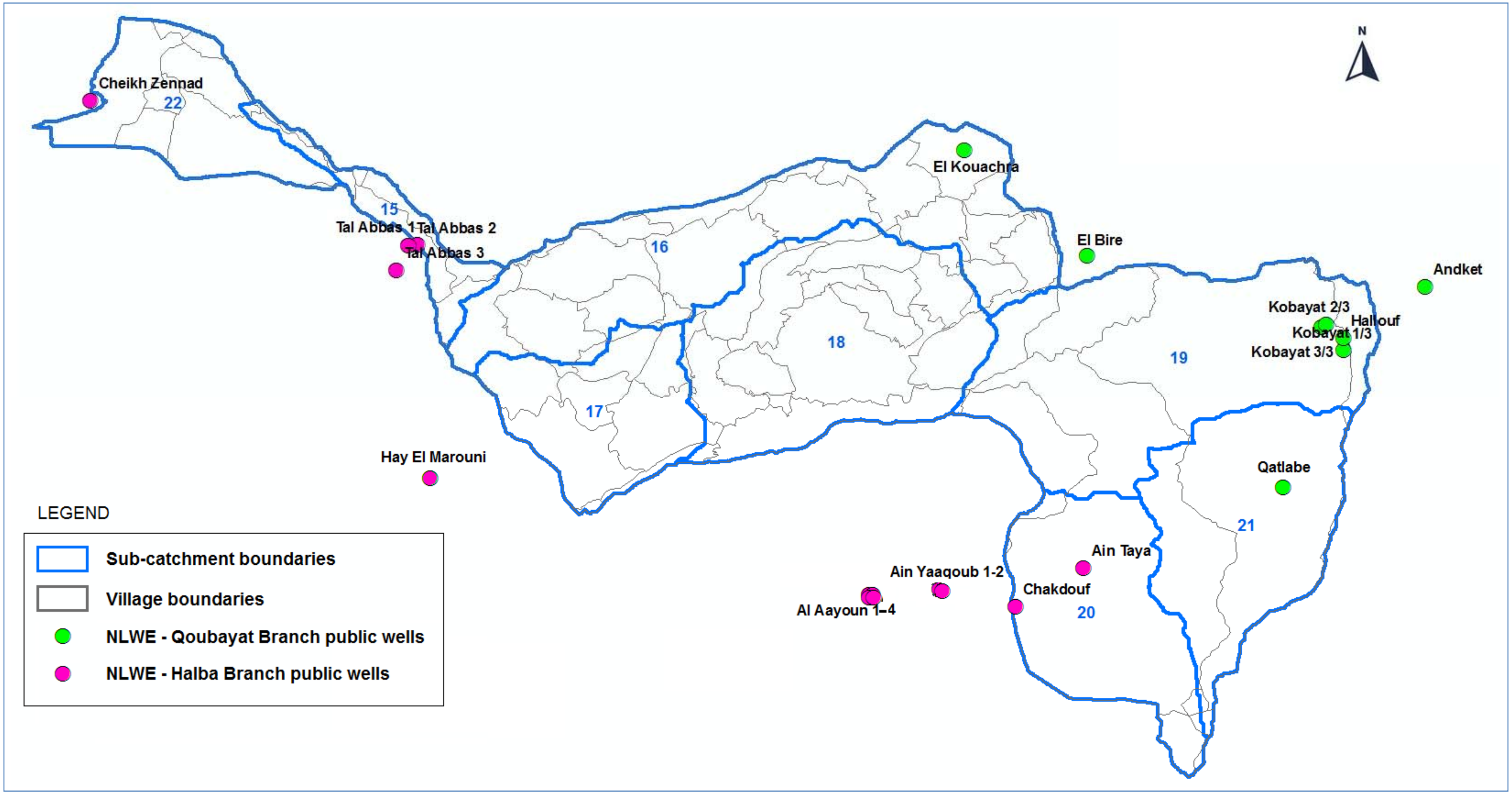


Figure 3-12: Public water supply wells of the NLWE Qoubayat and the Halba branches within and around the Al Ostuan River Basin.

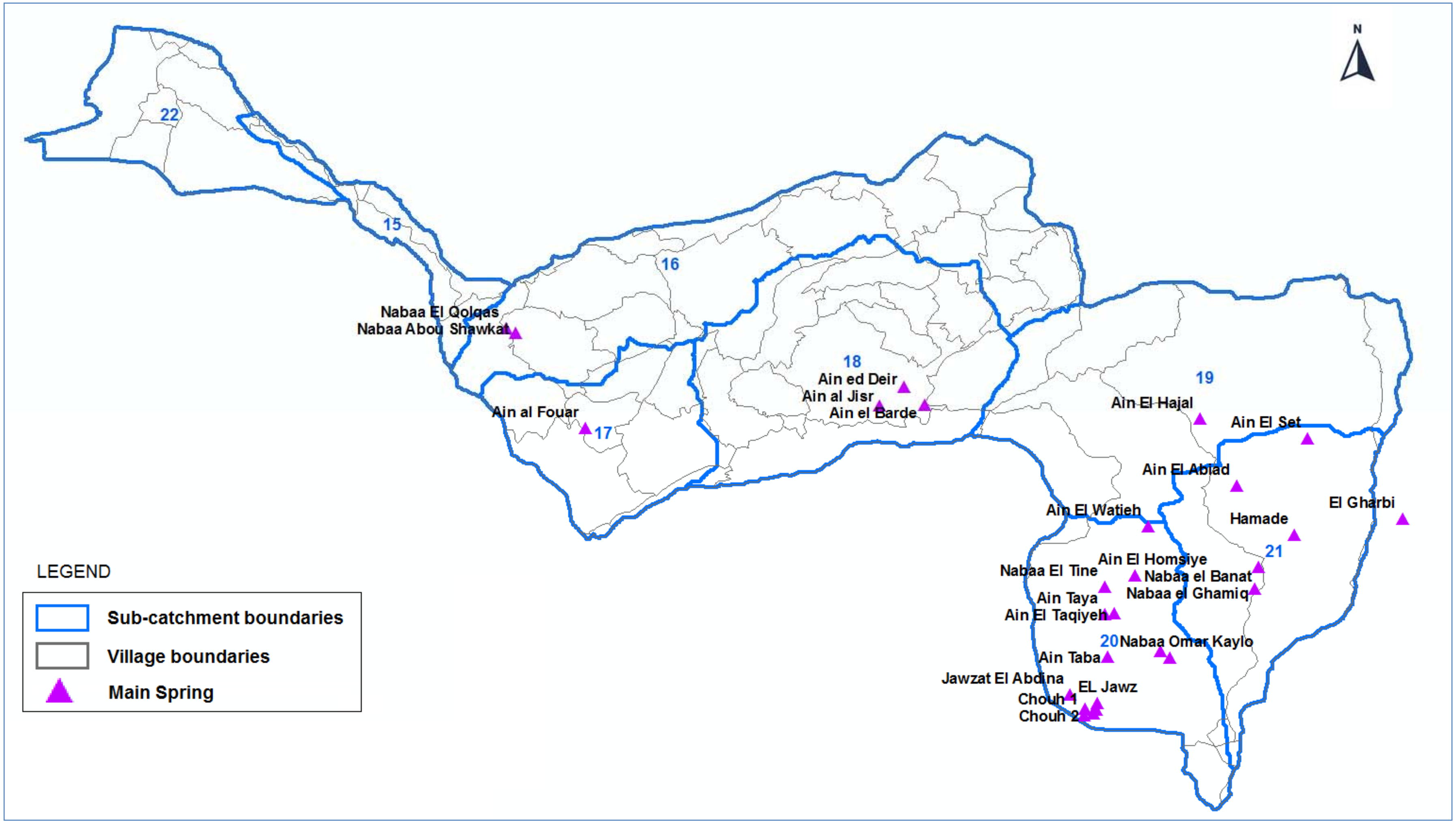


Figure 3-13: Springs within and around the Al Ostuan River Basin.

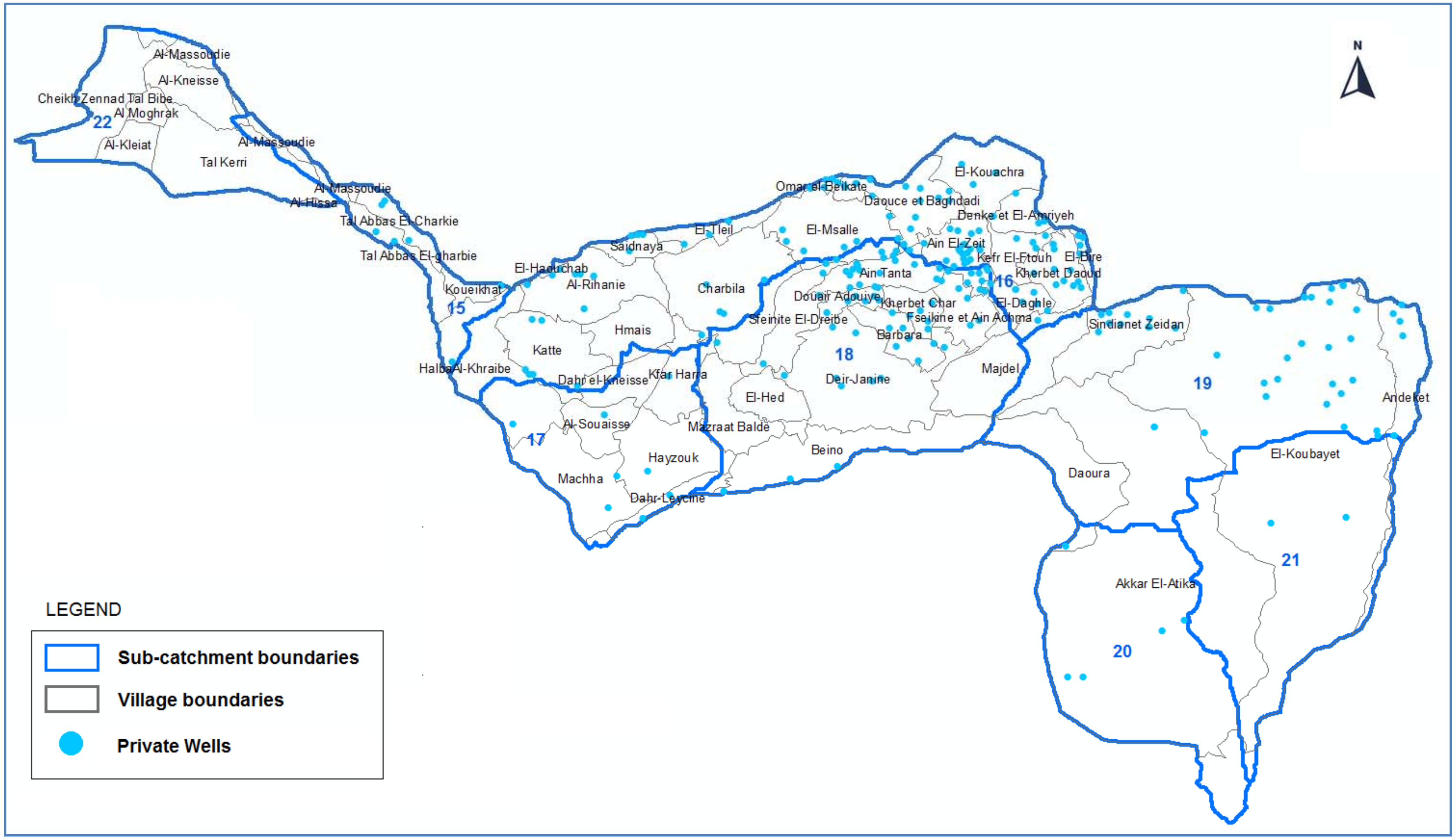


Figure 3-14: Private water supply wells within the Al Ostuan River Basin. (Note: The data are extracted from the database UNDP, 2014 based on the MEW database, and may not reflect the total number and location of all currently existing private wells in the area due to lack of most recent updating)

- Qoubayat Branch:

There are three wells in Qoubayat (Qoubayat 1/3, 2/3, 3/3) which constitute the main public water supply source for the northeastern and central villages of the Al Ostuan River Basin. The Hallouf well is not working any more (the well is currently dry). Two of the wells pump 36 m^3/hr and work for 14hrs per day, and the third well pumps 45 m^3/hr and works 18 hrs per day. The water pumped from these 3 wells goes to the principal Reservoir in Qoubayat (1,000 m^3 storage capacity) and then to the Biret Reservoir (500 m^3 storage capacity) in El Bire. The Biret well is inactive (dry). The line that leaves Qoubayat wells and goes northeast to Chadra is not operated currently (Chadra is supplied by their own 3 wells in Chadra).

From El Bire there are three lines going to:

i) Danke-Qsair (north, outside the Al Ostuan boundaries). Water there is not supplied every day, it depends on the availability, it is not the first priority of the system

ii) El Dawsen. The supply stops at Daouce et Baghdadi; the villages further out (e.g. El Tleil, Saidnaya) are not supplied

iii) Khirbet Daoud. Two lines start from Khirbet Daoud, one going all the way to Charbila, and one going to Kfar Harra.

The villages along all these public supply lines also have private wells that they use in parallel to the public water supply system.

The Qoubayat village gets water from Al Jawz spring, controlled by a private committee (Qoubayat Water Committee, QWC) and is not under the NLWE control. The Al Jawz spring discharges about 1,200 m^3/day. The Qatlabah village is supplied from the Hamade spring (discharge about 450 m^3/day). The Andeket village is supplied from the Al Gharbi and Al Qabou springs and a well. Private wells also exist in Qoubayat and Andeket.

The schematic of the public water supply system of the NLWE Qoubayat Branch is illustrated in **Figure 3-15**, while data on the productivity of the public wells and main springs is presented in **Table 3-7**.

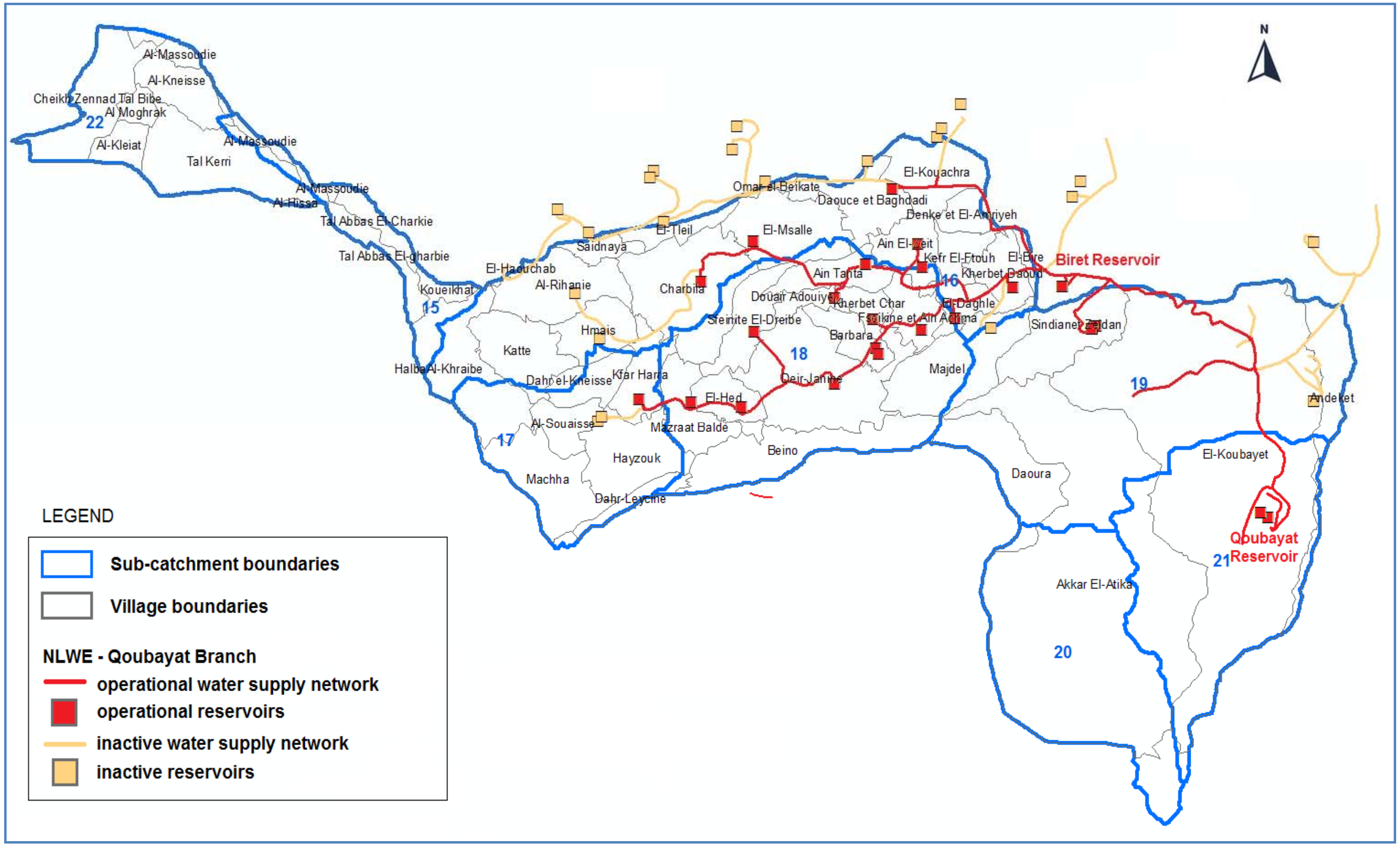


Figure 3-15: Overview of the public water supply system of the NLWE Qoubayat Branch

Table 3-7: Productivity (m^3/day) of the main public supply wells and springs under the operation of the NLWE Qoubayat Branch

Well Name	Current Production (according to communication with the NLWE-Qoubayat Branch) (m^3/day)	Production in 2017 (according to the Masterplan – SISSAF, 2017) (m^3/day)	Villages supplied (within the ORB)
Qoubayat 1/3	810	860	Sindianet Zeidane, El-Bire, Denke et El-Amriyeh, El-Kouachra, Daouce et Badhdadi Kherbet Daoud, El-Daghle, Kefr El-Ftouh, Ain El-Zeit, Ain Tanta, Douair Adouiye, El-Msalle, Charbila Fseikine et Ain Achma, Kherbet Char, Barbara, Deir-Janine, Sfeinite El-Dreibe, El-Hed, Mazraat Balde, Kfar Harra
Qoubayat 2/3	504	648	
Qoubayat 3/3	504	259	
Hallouf	Non-operational	259	-
Bire	Non-operational (dry)	144	-
El Kouchra	Non-operational	179	-
Spring Name	**Current Production (according to communication with the NLWE-Qoubayat Branch) (m^3/day)**	**Production in 2017 (according to the Masterplan – SISSAF, 2017) (m^3/day)**	**Villages supplied (within the ORB)**
Al Jawz	1,200	1,728	Qoubayat village
Hamade	450	458	Qatlabah
Al Gharbi		35	Andeket
Al Qabou			Andeket

- Halba Branch:

The Halba Branch public water supply system is divided into 5 separate systems (Beit Mellat, Ain Yaaqoub, Akkar El Atiqa, Barghash, Sahl Akkar) and the individual municipalities' water supply systems. Within the Al Ostuan River Basin, 4 of those systems are relevant.

The villages of Dahr Leycine, Machha and Hayzouk (in the south-central area of the ORB) are supplied by the Beit Mellat system which gets water from the four Al Aayoun public wells (Al Aayoun 1, 2, 3, 4). The Beino village is connected to the Ain Yaaqoub system which gets water from the two Ain Yaaqoub public wells (Ain Yaaqoub 1, 2). These groundwater sources are located outside the boundaries of the Al-Ostuan catchment.

The Akkar El-Atika is connected to the Akkar El-Atika system, which in turn gets water from two sub-systems: (i) the El-Jawz sub-system (El Jawz spring and Ain Taya well), (ii) the Chouh sub-system (Chouh 1 spring, Chouh 2 spring, and Chakdouf). The later (Chouh sub-system) also provides water to Daoura village. Private wells also exist in Akkar El-Atika both for drinking water and irrigation purposes.

The villages in the western part of the Al Ostuan River Basin (Sahl Akkar system), i.e. Al-Kleiat, Al-Kneisse, Al Moghrak, Tal Kerri, Al-Hissa, Al-Massoudie, Tal Abbas El-Charkie, Koueikhat, Al-Massoudie, depend on the private wells or water tankers for their water supply. Cheikh Zennad and Tal Abbas El-Gharbie are the only villages with local (municipality) water systems (1 well in Cheikh Zennad and 3 wells in Tal Abbas El-Gharbie). These wells are barely located on the boundaries of the Al Ostuan River Basin.

The schematic of the public water supply system of the NLWE Halba Branch is illustrated in Figure 3-16, while data on the productivity of the public wells and main springs is presented in Table 3-8.

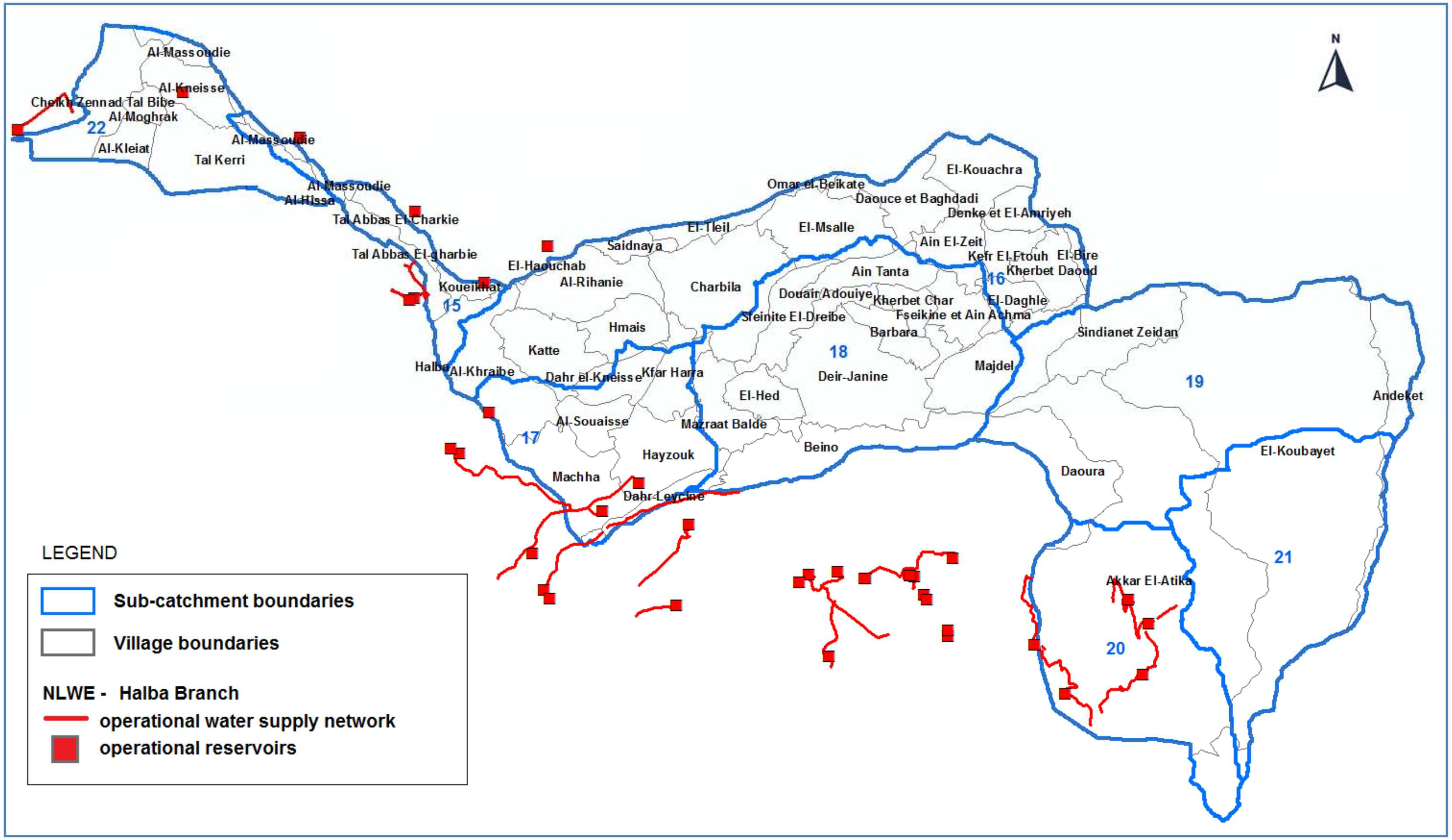


Figure 3-16: Overview of the public water supply system of the NLWE Halba Branch

Table 3-8: Productivity (m3/day) of the main public supply wells and springs under the operation of the NLWE Halba Branch

Well Name	Current Production (according to the database of the NLWE) (m^3/day)	Production in 2017 (according to the Masterplan – SISSAF, 2017) (m^3/day)	Villages supplied (within the ORB)
Al Aayoun 1	4,957	4,957	Dahr Leycine, Machha, Hayzouk
Al Aayoun 2	4,964	4,964	
Al Aayoun 3	6,034	6,034	
Al Aayoun 4	6,034	6,034	
Ain Yaaqoub 1	1,980	1,980	Beino
Ain Yaaqoub 2	2,800	2,800	
Chakdouf	432 winter / 2,592 summer	1,836	Akkar El-Atika, Daoura
Ain Taya	540 winter/ 2,484 summer	2,326	Akkar El-Atika
Cheikh Zennad	2,160	2,160	Cheikh Zennad
Tal Abbas 1	288	288	Tal Abbas El-Gharbie
Tal Abbas 2	288	288	
Tal Abbas 3	576	576	
Spring Name	**Current Production (according to the database of the NLWE) (m^3/day)**	**Production in 2017 (according to the Masterplan – SISSAF, 2017) (m^3/day)**	**Villages supplied (within the ORB)**
Al Jawz	1,200	1,728	Akkar El-Atika, Qoubayat village
Chouh 1	384	384	Akkar El-Atika, Daoura
Chouh 2	1,000	1,000	Akkar El-Atika, Daoura

- Subscribers and Water Pricing:

The total number of subscribers of the Qoubayat branch is 4,206 (data provide by the NLWE – Qoubayat Branch in January 2020, Table 3-9) and of Halba is 10,090 (data from the SISSAF, 2017).

The annual water tariff for a subscriber is broken down as follows (SISSAF, 2017, and confirmed via communication with the NLWE):

Basic amount: 228,000 L.L. (~151 USD)

Maintenance fees: 24,000 L.L. (~16 USD)

Wastewater fees: 20,000 L.L. (~ 13 USD) [10,000 L.L. if connected to the system]

Taxes: 10% VAT

Table 3-9: Number of subscribers in the NLWE Qoubayat Branch (Source: data provide by the NLWE – Qoubayat Branch (in January 2020)

Village	Village Population equivalent within the ORB (inhabitants)	No. of Subscribers	Total No. of Subscribers (including some pending)	Total Subscribers as % of the Population
Villages located within the Al Ostuan RB and supplied by the NLWE				
Ain El-Zeit	3,002	46	48	1.60%
Ain Tanta	2,002	13	13	0.65%
Barbara	550	3	3	0.55%
Charbila	400	13	13	3.25%
Daouce et Baghdadi	13,959	60	60	0.43%
Deir-Janine	1,401	23	23	1.64%
Denke et El-Amriyeh	407	28	28	6.88%
Douair Adouiye	1,201	3	3	0.25%
El-Bire	192	333	335	174.48%
El-Daghle	701	7	7	1.00%
El-Hed	10	10	10	100.00%
El-Kouachra	1,101	271	273	24.80%
Kefr El-Ftouh	5,262	360	383	7.28%
Kfar Harra	270	21	21	7.78%
Kherbet Char	1,501	10	10	0.67%
Kherbet Daoud	2,502	37	37	1.48%
Majdel	3,202	67	67	2.09%
Mazraat Balde	2,802	18	20	0.71%
Omar el-Beikate	99	150	151	152.53%
Qatlabe	1533	185	185	12.07%
Sfeinite El-Dreibe	671	8	8	1.19%

Sindianet Zeidan	744	153	157	21.10%
TOTAL	**43,512**	**1,819**	**1,855**	**4.26%**

Additional villages supplied by the NLWE, located outside the Al Ostuan RB				
Village	**Village Population* (inhabitants)**	**No. of Subscribers**	**Total No. of Subscribers (including some pending)**	**Total Subscribers as % of the Population**
Al Dbabeye	745	9	11	1.48%
Al Mounse	1,862	84	84	4.51%
Al Nahreye	621	21	21	3.38%
Al Sahle	2,483	2	2	0.08%
Aydamoun	4,345	180	184	5.94%
Jadaydeh Aydamoun		62	62	
Chekhlar		3	3	
Meghraka		9	9	
Chadra	3,228	404	412	12.76%
Fraydis	366	33	33	9.02%
Hlwas		5	5	
Jawset		1	1	
Kfarnoun	2,781	37	41	1.47%
Kobor Al Beed		16	16	
Kosayr		19	19	
Kounieh		172	177	
Machta Hamoud	5,586	223	228	8.20%
Machta Hassan	2,793	236	244	4.40%
Mazareaa Jabal Akroum		254	259	
Monjez		196	196	
Mrah Al Kokh		47	47	
Nosoub		7	7	
Ouwanynat		85	85	
Qeshleq	410	60	61	
Rmah	807	56	57	7.06%
Wady Al Hawr	422	48	50	
Wate Sehle		36	37	
TOTAL	**26,449**	**2,305**	**2,351**	

*Note: Some of the villages covered by the NLWE Qoubayat Branch are not located within the Al Ostuan RB (in red cells), so equivalent population data are not relevant, they actually refer to the total population of the village

4 METHODOLOGICAL APPROACH

4.1 DATA COLLECTION AND ANALYSIS

Different types of data was requested and collected from different authorities and data providers. A quality assurance was performed to detect possible erroneous values. The data was processed and analyzed to achieve the required level of temporal and spatial disaggregation, while gap filling with proxies was performed in case of missing data. The data collected and used is presented in the following Table 4-1.

Table 4-1: Data collected and used in the development of the Al Ostuan water resources management model

Data Type	Data Specifications	Data Provider
A. HYDROMETEOROLOGICAL TIMESERIES DATA		
Precipitation from meteorological stations (monthly timeseries)	Qoubayat station (06/2000 - 12/2011) Klaiat station (03/2003 - 12/2011) Fnaidek station (01/2009 - 08/2019)	Civil Aviation Civil Aviation LARI
Temperature from meteorological stations (monthly timeseries)	Qoubayat station (06/2000 - 12/2011) Klaiat station (03/2003 - 12/2011) Fnaidek station (01/2009 - 08/2018)	Civil Aviation Civil Aviation LARI
Streamflow from hydrometric stations (monthly timeseries)	Embouchure station (09/2002 - 08/2018) Beit el Hajj station (09/2002 - 08/2018) Pond Halba station (09/1999 - 08/2018)	LITANI LITANI LITANI
Spring discharge (mean daily discharge)	Main springs in Qoubayat and Halba Branches	NLWE SISSAF, 2017
B. WATER USE & WATER SUPPLY DATA		
Population per village	Population (No. of inhabitants) in each village	NLWE SISSAF, 2017 ACTED (Governor's office)
Subscribers per village in the NLWE-Qoubayat Branch	No. of subscribers in each village under the system of NLWE-Qoubayat Branch	NLWE-Qoubayat Branch
Subscribers in the NLWE-Halba Brach	Total No. of subscribers in the NLWE-Halba Branch	SISSAF, 2017
Annual water tariffs for the subscribers of the NLWE		SISSAF, 2017 NLWE

Data Type	Data Specifications	Data Provider
Productivity (Abstraction rates) of Groundwater wells (hourly pumping rates, hrs of operation per day, daily pimping rates)	Main public supply wells in Qoubayat and Halba Branches, under the NLWE authority	NLWE NLWE-Qoubayat Branch SISSAF, 2017
Water supply network of NLWE-Qoubayat Branch	Transmission lines, Villages supplied by each line, Reservoirs, Pump stations	NLWE-Qoubayat Branch SISSAF, 2017 NLWE GIS Database
Water supply network of NLWE-Halba Branch	Transmission lines, Villages supplied by each line, Reservoirs, Pump stations	SISSAF, 2017 NLWE GIS Database
Private Wells	Private wells with or without exploitation permits from the MEW Database	MEW
Households water supply sources	Information on drinking water sources, drinking water associated costs, willingness to subscribe to NLWE and pay fees, etc. from 333 households in 9 Municipalities	ACTED Survey 2016
B. CARTOGRAPHIC GIS DATA		
DEM	Digital Elevation Map, contourlines	Univ. Balamand ACTED
Hydrographic network (rivers, lakes, catchments)	Al Ostuan River Basin boundaries, river network, hydrological sub-catchments' boundries	Univ. Balamand ACTED
Village polygons	Shapefiles (polygons) of the village and area	Univ. Balamand ACTED
Hydrogeology	Hydrogeological map of the area, with the different aquifers and Groundwater Basins	Univ. Balamand ACTED
Geology	Geological map of the area, with the different formations	Univ. Balamand
Soil	Geological map of the area, with the different soil types	Univ. Balamand
Land Use/ Land Cover (LULC)	Corine LULC 2017, Corine LULC1998	Univ. Balamand
Irrigation Schemes	Area under irrigation schemes, name of schemes, areas covered	Univ. Balamand NWSS 2020
C. POLLUTION DATA AND PRESSURES		
Outfalls	Location of wastewater discharge outfalls (29 points)	ACTED
Water Test Results	Water test results for E.coli and Nitrates at specific locations in the river (116 points in Kfar Harra, El Hedd, Deir Jannine, Fsayqin, Mazraet Baldem, Barbara, Daghle, Kherbet Shar, Kherbet Daoud)	ACTED
Quarries	Location (GIS) and current operational status	Univ. Balamand
Wastewater Treatment Plants	Location (GIS), level of treatments, current status	Univ. Balamand

Data Type	Data Specifications	Data Provider
Dumps	Location (GIS) and area	Univ. Balamand
UOB Sampling_Physical	Water test at 17 specific locations in the river for physical parameters (Temperature, Conductivity, Salinity, TDS)	Univ. Balamand
UOB Sampling_Bacteria	Water test at 17 specific locations in the river for E.coli, Fecal, BOD	Univ. Balamand
UOB Sampling_Carbonates	Water test at 17 specific locations in the river for Carbonates	Univ. Balamand
UOB Sampling_Chemical	Water test at 17 specific locations in the river for chemical compounds (Flu, Cl, SO4, NO3, NO2, Na, K, Mg, Cal)	Univ. Balamand
UOB Sampling_Heavy Metals	Water test at 17 specific locations in the river for heavy metals (Al, Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd, Hg, Pb)	Univ. Balamand
D. ADDITIONAL INFORMATION		
Information on groundwater recharge rates and conductivity		UNDP, 2014. Groundwater Modeling within The Akkar Basin, Deliverable No. 14
Information on irrigation methods and networks		17 Municipalities within the Al-Ostuan boundaries, local farmers, agronomists, NLWE

The following issues have been identified during the data collection and analysis process:

- Data collection has been a very slow process, while the response time of some authorities to the data requests was too long.
- Exchanges with the consultants involved in the updating of the New Water Strategy have not been fruitful. Although the current study reached out to them, and through the MEW, the specific data requests to achieve harmonization in the work undertaken were never fulfilled.
- Data inconsistencies have been observed in the population of the villages among the different data sources (SISSAF 2017 vs. ACTED collected data though the Governor’s Office).
- Water use data have not been available. This, proxies based on activity levels have been used to calculate urban, industrial and agricultural water uses.
- Water abstraction data is not complete. A complete record of the monthly abstractions per source (well or spring) is not available. Some abstraction data from the main public wells and springs have been available, while for some others the monthly abstraction rates are

calculated on the basis of approximate hours of operation per day. No records of the private wells monthly abstractions are available.

- Some water imports and exports are effective in the River Basin: the Qoubayat Branch which draw water from the 3 Qoubayat wells (located within the Al Ostuan boundaries) also supplies water to Danke-Qsair, located in the north, outside the Al Ostuan boundaries. Water there is not supplied every day, it depends on the availability, it is not the first priority of the system, yet there is no information on the exact volume of water supplies, which consists an "Export" of the Al Ostuan basin. The villages of Dahr Leycine, Machha and Hayzouk (in the south-central area of the ORB) are supplied by the Beit Mellat system which gets water from the four Al Aayoun public wells (Al Aayoun 1, 2, 3, 4). The Beino village is connected to the Ain Yaaqoub system which gets water from the two Ain Yaaqoub public wells (Ain Yaaqoub 1, 2). These groundwater sources are located outside the boundaries of the Al-Ostuan catchment, thus these volumes are considered and "Import" to the Al Ostuan Basin. Information on the specific volume of these imports has not been available.
- Exact estimation of network efficiency and losses (conveyance losses in the urban and irrigation networks, field application efficiency and practices in irrigated areas) are not available. Proxy calculations have been used. The lack of data of the network efficiency can lead to over-estimation or under-estimation of the water supply required, since this is strongly linked to the prevailing losses
- Detailed information on the number of hectares per irrigated crops, and the specific types of crop, is not available. The analysis has been based on the Corine Land Use / Land Cove (LULC) 2017.
- Information on livestock and animal breeding in the area is not available. The livestock water use has been considered negligible in this study since minor comparing to the irrigation and urban water uses.
- Information on groundwater safe yield is not available. There is information on the safe yield of each Groundwater Basin in the UNDP 2014 Study, which has been taken into account, which concerns though the entire groundwater basin (as opposed to the area falling within the Al Ostuan). Relevant proxies have thus been used for extrapolation, also considering the Deliverable No. 14 (Groundwater Modeling within The Akkar Basin) of this UNDP Study.

Table 4-2: Summary of data gaps, resulting risks and actions needed

Data Gaps	Resulting Risks related to the current study	Resulting Risks related to the water management in the Al Ostuan RB	Actions needed
Inconsistencies have been observed in the population of the	The domestic water demand has been based on proxies using population data, and may has thus	The drinking water supply needs cannot be properly evaluated by the NLWE if the	Consolidation of population data, and consistency checks between the different

villages among the different data sources	been over or under-estimated if these population data are not accurate	population data are not accurate	data sets used by the Municipalities, the NLWE, and the Governor's office
Water use data are not available	The proxies (based on activity levels) that have been used to calculate urban, industrial and agricultural water uses may over or under-estimate the real situation	The water supply needs cannot be properly evaluated by the NLWE if no monitoring of the water use is performed	Install (at least is a pilot area) water meters and monitor water use in the different sectors
Water abstraction data is not complete. A complete record of the monthly abstractions per source (well or spring) is not available. No records of abstractions from private wells' are available	The abstractions from groundwater may be under-estimated in the model	The knowledge and monitoring of the exact volumes of water abstracted from the groundwater bodies in a fundamental requirements for sound water management. The lack of groundwater abstraction monitoring and control (from public and private wells) will lead to groundwater overexploitation and unsustainable conditions in the basin	Monitoring of monthly abstractions per source (well or spring) for public wells based on actual measurements (as opposed to calculations) Recording of all private wells and monitoring of the abstractions from all private wells at monthly (ideally) or seasonal (every 3 months) scale
The volumes of water exported from the basin (i.e. to supply Danke-Qsair) and imported to the basin (i.e. to supply Dahr Leycine, Machha, Hayzouk, Beino) are not recorded at monthly scale	These volumes may have been over under-estimated in the model	The knowledge of the exact volumes of exports and imports is essential in water supply management. These demands need to be accounted for when planning the water supply schemes, in order to be properly considered as external sinks or gains to the system. Otherwise, the risk of failure of the system is increasing	Monitoring of monthly volumes of water exports and imports
Lack of systematic information on the number of hectares per irrigated crops, and the specific types of crop	Since the analysis of the crop mix and crop coverage has been based on the CLC2017, the actual irrigation water demand may have been over or under-estimated if the current crop mix is different	The irrigation water supply needs cannot be properly evaluated by the NLWE if the crop mix and coverage is not updated	Farm surveys needs to be performed periodically (i.e. once a year) to record and monitor the current crop mix and coverage (number of hectares per crop)

Exact estimation of network efficiency and losses (conveyance losses in the urban and irrigation networks, field application efficiency and practices in irrigated areas) are not available.	Proxy calculations have been used. The lack of data of the network efficiency can lead to over-estimation or under-estimation of the water supply required in the model, since this is strongly linked to the prevailing losses.	The water supply needs cannot be properly evaluated by the NLWE if the efficiency of the water supply networks (both domestic and irrigation networks) is unknown. Network losses contribute to large amounts of non-revenue water, and thus need to be properly evaluated. Open channels used for irrigation have great losses, especially if not properly maintained and rehabilitated. The lack of knowledge on the irrigation methods applied (% drip, sprinklers, surface) impedes the drafting of a concrete plan to improve irrigation efficiency.	Inspection and evaluation of the state of the drinking water supply network. Inspection and evaluation of the state of the irrigation water supply network and the irrigation practices. Rehabilitation of all networks where needed. Conversion to closed pipes (as opposed to open channels) for irrigation, expansion of the collective irrigation schemes, conversion to drip irrigation.
Information on livestock and animal breeding, as well as on industrial water demand in the area is not available.	The livestock water use has been considered negligible in this study since minor comparing to the irrigation and urban water uses. Industrial water use, together with the business/ commercial have been estimated as 10% of the domestic in the model, and may have been under-estimated	Livestock and industry may not be important sectors in the basin in terms of water demand (as compared to the domestic and agricultural). Yet, they generate pollution loads, which are usually proportional to their activity levels. Thus, information on the number, types and annual yields of these sectors are impartant.	Create and inventory of both livestock/ animal breeding facilities and industries in the basin, including their locations, number of animals or production yield (for industries), annual activity levels, volume of water needed, and volume of waste and wastewater generated.
Information on groundwater safe yield is not available.	Relevant proxies have thus been used for extrapolation, considering the UNDP 2014 Study “Groundwater Modeling within The Akkar Basin”. The safe yield may have been over or under-estimated	Water supply in the Al Ostuan RB is based on groundwater. Extensive abstractions are effectuated through public and private wells. The knowledge of the safe yields of the aquifers in the basin is paramount for	Implement a specific study (and tests) to evaluate the groundwater safe yield in the Al Ostuan basin

		assessing the level of sustainable abstraction	

4.2 THE WATER RESOURCES MANAGEMENT MODEL (WRMM) OF AL OSTUAN BASIN

4.2.1 THE AL OSTUAN WEAP MODEL SETUP

A detailed water balance model has been set up for the Al Ostuan River Basin in Akkar Governorate in northern Lebanon, using the WEAP21 software at monthly timestep for the period 2003-2018 in order to assess the state of water resources. This baseline assessment investigated the water availability, water demand, water supply required, and unmet demand (per sector) in the basin during the last 16 years. The 2003-2011 period has been used for model calibration, while the years 2016-2017 have been used for the validation of the model. The entire 2003-2018 period represents the baseline scenario (business as usual, BaU).

Box 4.1: WEAP21 software functionalities

WEP21 software features and functionalities

The WEAP21 (Water Evaluation and Planning System), developed by the SEI Stockholm Environment Institute's US Center (www.sei-international.org), is a Decision Support Platform that incorporates the principles and philosophy of integrated water management resources. It provides the ability to model both the physical and socio-economic system at a highly disaggregated level (if desired), and assists the user in visualizing (through an interactive and user-friendly Graphical User Interface) the system interactions and cause-effect relations, supporting thus the decision making process.

The design of WEAP is guided by a number of methodological considerations: an integrated and comprehensive planning framework; Use of scenario analyses in understanding the effects of different development choices; Demand-management capability; Environmental assessment capability; and Ease-of-use (SEI, 2015). As such, the WEAP system supports the spatial and temporal definition of the problem, the schematization and modeling of the study area for determining the initial conditions (Current Accounts), the creation and organization of databases, the processing of the raw data, the presentation of the processed information in an understandable and supervisory way, the creation of future scenarios of hydrological change and socio-economic development or management options, and the simulation of these scenarios to assess the impact of each scenario/option on the hydrological, environmental or socio-economic state. Therefore, based on the above, WEAP21 provides to the user the ability to obtain a comprehensive and in-depth perspective on impacts which will result from each decision. The user and decision maker assess these effects and ultimately selects the decision considered closer to their goals. These software capacities are summarized below:

- Water balance database: WEAP provides a system for maintaining water demand and supply information.
- Scenario generation tool: WEAP simulates water demand, supply, runoff, streamflow, storage, pollution generation, treatment and discharge and instream water quality.
- Policy analysis tool: WEAP evaluates a full range of water development and management options, taking into account the various competing uses that participate in a complex water system.

WEAP operates on the basic principle of a water balance and can be applied to urban and agricultural systems, a single watershed or complex transboundary river basin systems. Moreover, it can simulate a broad range of natural and engineered components of these systems, such as: rainfall-runoff, baseflow and groundwater recharge from precipitation, sectoral demand analyses, reservoir operations, hydropower generation, pollution tracking and water quality, water conservation, water rights and allocation priorities, vulnerability assessments, and ecosystem requirements. A financial analysis module also allows the user to investigate cost-benefit comparisons for projects. The analyst represents the system in terms of its various supply sources (e.g. rivers, creeks, groundwater, reservoirs, and desalination plants), withdrawals, transmission and wastewater treatment facilities, water demands, pollution generation, and ecosystem requirements. The data structure and level of detail can be easily customized to meet the requirements and data availability for a particular system and analysis. The main highlights of the WEAP21 software are presented below (SEI, 2015).

- Integrated water resources planning system
- Built-in models for: rainfall-runoff, infiltration, evapotranspiration, crop requirements and yields, surface water/groundwater interaction, in-stream water quality
- GIS-based, graphical "drag and drop" interface
- Model-building capability with a number of built-in functions
- User-defined variables and equations
- Dynamic links to spreadsheets and other models
- Embedded linear program solves allocation equations
- Flexible and expandable data structures

- Powerful reporting system including graphs, tables and maps
- Ability to establish dynamic interaction with other models and software such QUAL2K, MODFLOW, MODPATH, PEST, Excel and MATLAB

In order to set up the node-based disaggregated WEAP model, a detailed analysis of the study areas has been implemented to post-process all the data collected and create the necessary input data for the model. A scheme of the model, with all the nodes and their interconnection links is depicted in Figure 4-1. The model comprises of 8 sub-catchments, 8 groundwater bodies, 16 runoff/infiltration links (carrying runoff and infiltration from catchments to rivers and groundwater bodies), 29 demand sites (21 for domestic and 8 for irrigation water users), 35 transmission links (transmitting water from a surface or groundwater withdrawal node to a user), 29 return flow links (directing the water that is not consumed in a demand side to a surface or groundwater body). The above elements are illustrated in Figure 4-1 below.

Box 4.2: Definitions (terminology) of the WEAP scheme elements (Source: SEI, 2015)

Definitions (terminology) of the WEAP scheme elements (Source: SEI, 2015)

Node: a node represents a physical component such as a demand site, wastewater treatment plant, groundwater aquifer, reservoir or special location along a river. Nodes are linked by lines that represent the natural or man-made water conduits such as river channels, canals and pipelines. These lines include rivers, diversions, transmission links and return flow links.

Catchment: a user-defined area within the schematic with specified processes such as precipitation, evapotranspiration, snow and ice accumulation and melt, runoff, irrigation and yields on agricultural and non-agricultural land.

Groundwater: Groundwater bodies can have natural inflow, infiltration from Catchments, returns from demand site and wastewater treatment plants, inflows from transmission and return flow link leakage, river interactions and storage capability between months. A groundwater supply node can be linked to any number of demand sites.

Infiltration/ Runoff link: carries runoff and infiltration from catchments to rivers, reservoirs, and groundwater nodes. Catchment runoff and infiltration is water from precipitation, snow and ice melt, irrigation and soil moisture storage that is not consumed by evapotranspiration or losses to increased soil moisture. Runoff/infiltration links can also link one groundwater node to another, in order to model subsurface flow from one to the other.

Demand site: a set of water users that share a physical distribution system, that are all within a defined region, or that share an important withdrawal supply point. Examples of demand sites: major cities or counties, individual user which manages a surface or groundwater withdrawal point (such as an industrial facility), irrigation districts, demands which return to a unique wastewater treatment plant, water utilities, etc. Each demand site needs a transmission link from its source, and where applicable, a return link either directly to a river, wastewater treatment plant or other location. The user-defined priority system determines the order of allocations to demand sites.

Transmission link: delivers water from surface water (reservoir nodes, and withdrawal nodes), groundwater and other supplies to satisfy final demand at demand sites. In addition, transmission links can deliver wastewater outflows from demand sites and wastewater treatment plants to other demand sites for reuse.

Return flow link: water that is not consumed at a demand site can be directed to one or more demand sites, wastewater treatment plants, surface or groundwater nodes. Return flows are specified as a percentage of outflow.Wastewater treatment plant return flow can be directed to one or more demand sites, river nodes or local supply sources. Like demand site return flows, they are specified as a percentage of outflow.

Streamflow gauges: they are placed on river reaches and represent points where actual streamflow measurements have been acquired and can be used as points of comparison to simulated flows in the river.

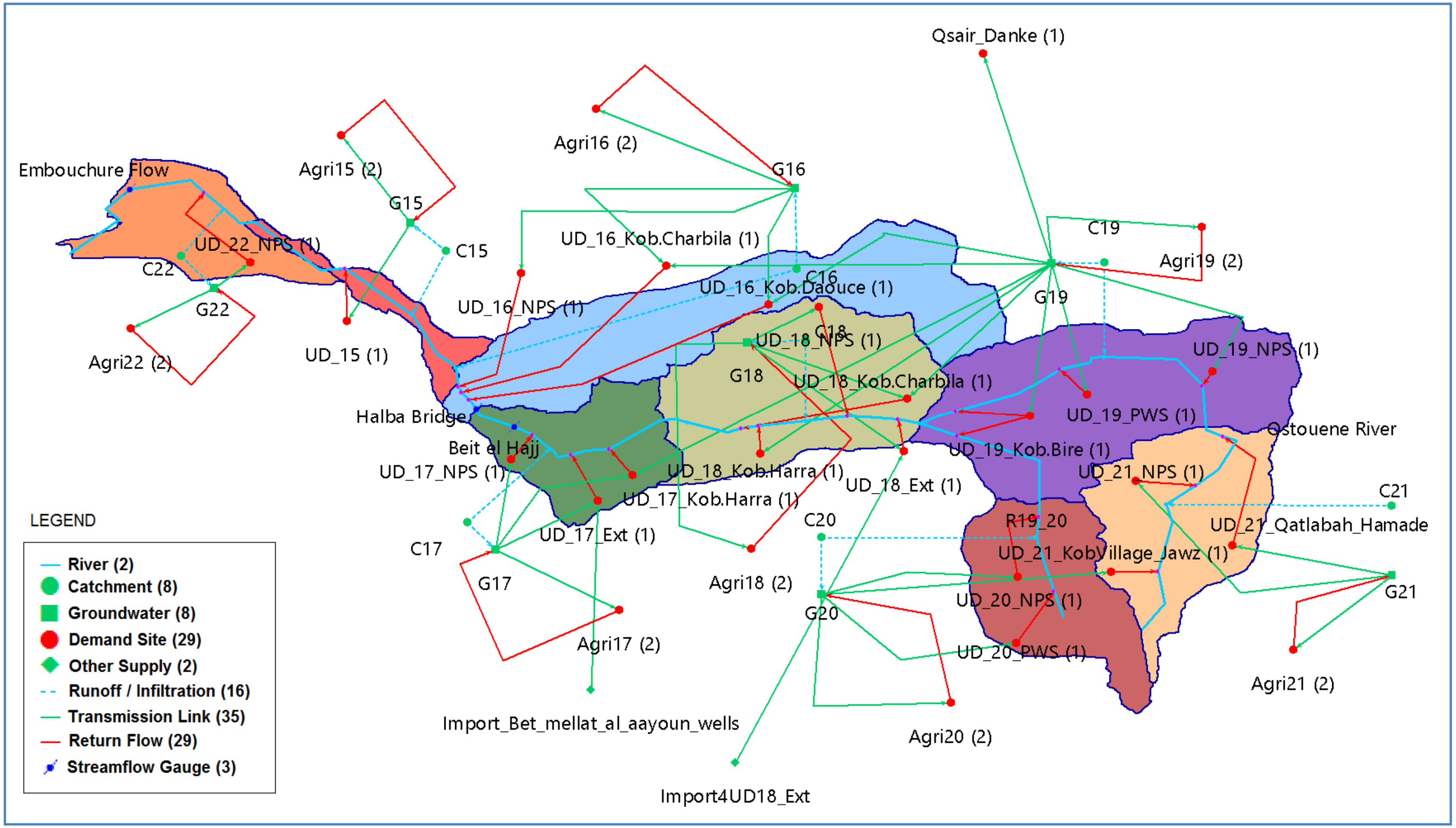


Figure 4-1: Schematic representation of the WEAP model for the Al Ostuan River Basin

- **Demand sites and catchments**

The model is set-up around 8 sub-catchments. The water demands sites in the study area are represented in WEAP by 21 domestic/urban demand nodes and 8 irrigation demand nodes, implemented within the sub-catchments, all simulated as "demand sites". One of the domestic/urban nodes represents water export to an upstream basin, for the supply of the Danke and Qsair villages/ reservoirs. In terms of water allocation priorities, meeting domestic water demand has been assigned as a priority 1, while irrigation have been assigned as a priority 2.

To model the **domestic/urban water demand** the "Specify yearly demand and monthly variation" method of WEAP has been chosen, and the demand per node (site) has been inserted as a function of the following parameters:

*Monthly Domestic Demand (m3) = Population[cap]*Population change*Daily Water Use per capita[m^3]*Losses Correction Factor*Month Duration[day]*

Monthly Domestic Consumption = 20% of Monthly Domestic Demand [it represents the % inflow consumed, lost from the system]

Return flow = Inflow(1-consumption)*

It has to be noticed that the domestic/urban demand aggregates both the household water demands as well as the urban commercial (i.e. business, restaurants, etc.) and public (i.e. schools, public buildings, etc.) water demand.

Table 4-3: Key assumptions (user-defined variables) used in the domestic water demand calculations for the baseline 2003-2018 scenario.

Key Assumption	Value
Daily water use rate	0.16 m3/cap/day (or 160 lt/cap/day)
Losses correction factor	1/0.7 = 1.429 (30% losses are considered)
Urban water consumption	20%
Population change (scenarios)	x % (1 in the baseline)

As previously mentioned, a total of 51 villages are located (as a whole or part of) within the Al Ostuan River Basin (ORB) boundaries (Figure 3-5). These villages are spread across the 8 sub-catchments. Their water supply comes from different systems as presented in Section 3.3. In order to model the domestic/ urban water demand nodes in WEAP, the villages have been clustered into groups according to their water supply source and the public water supply system (PWSS) branch they are connected to. The provision of groundwater (GW) from private wells for domestic purposes (as a primary source in villages not connected any PWSS, and as a secondary/ supplementary source to villages connected to a PWSS) has been set as default for all villages. The villages clustered under each urban demand node are presented in Table 4-4.

Table 4-4: Clustering of the villages into the WEAP urban demand nodes

No	Urban Demand Node	Village CAD_CODE	Village CAD_NAME	Total Node Population in WEAP, ORB	Water supply source_1	Water supply source_2
1	UD_22_NPS	35011	Al-Kleiat	7,190	GW_22	
		35012	Cheikh Zennad Tal Bibe			
		35015	Al-Kneisse			
		35016	Al Moghrak			
		35017	Tal Kerri			
		35018	Al-Hissa			
		35045	Al-Massoudie			
2	UD_15	35030	Halba	3,009	GW_15	
		35034	Tal Abbas El-Gharbie			
		35035	Koueikhat			
		35036	Tal Abbas El-Charkie			
		35045	Al-Massoudie			
		35033	Al-Khraibe			
3	UD_16_Kob.Charbila	35095	Charbila	13,468	GW_19	GW_16
		35112	Ain El-Zeit			
		35114	El-Daghle			
		35118	Kherbet Daoud			
		35120	El-Msalle			
		35131	Kefr El-Ftouh			
4	UD_16_Kob.Daouce	35111	El-Kouachra	15,658	GW_19	GW_16
		35117	Daouce et Baghdadi			
		35124	Denke et El-Amriyeh			
		35135ND	El-Bire			
5	UD_16_NPS	35098	Katte	6,652	GW_16	

No	Urban Demand Node	Village CAD_CODE	Village CAD_NAME	Total Node Population in WEAP, ORB	Water supply source_1	Water supply source_2
		35101	Al-Rihanie			
		35108	El-Tleil			
		35109	Omar el-Beikate			
		35115	El-Haouchab			
		35157ND	Hmais			
		35093	Saidnaya			
		35033	Al-Khraibe			
6	UD_17_Ext	35067	Dahr-Leycine	7,614	External source from South	GW_17
		35082	Machha			
		35083	Hayzouk			
7	UD_17_Kob.Harra	35094	Kfar Harra	270	GW_19	GW_17
8	UD_17_NPS	35096	Al-Souaisse	4,409	GW_17	
		35105	Dahr el-Kneisse			
		35033	Al-Khraibe			
9	UD_18_Kob.Charbila	35116	Ain Tanta	3,202	GW_19	GW_18
		35121	Douair Adouiye			
10	UD_18_Kob.Harra	35090	El-Hed	8,239	GW_19	GW_18
		35099	Deir-Janine			
		35102	Sfeinite El-Dreibe			
		35119	Kherbet Char			
		35122	Fseikine et Ain Achma			
		35127	Barbara			
		35201ND	Mazraat Balde			
11	UD_18_Ext	35075	Beino	2,052	External source from South	GW_18
12	UD_18_NPS	35137ND	Majdel	1,601	GW_18	
13	UD_19_Kob.Bire	35113	Sindianet Zeidan	744	GW_19	
14	UD_19_PWS	35078	El-Koubayet	4,876	GW_19	
15	UD_19_NPS	35137ND	Majdel	7,412	GW_19	

No	Urban Demand Node	Village CAD_CODE	Village CAD_NAME	Total Node Population in WEAP, ORB	Water supply source_1	Water supply source_2
		35200ND	Daoura			
		35166ND	Andeket			
		35085	Akkar El-Atika			
16	UD_20_NPS	35166ND	Andeket	168	GW_20	
17	UD_20_PWS	35085	Akkar El-Atika	8,304	GW_20	
18	UD_21_KobVillage_Jawz	35078	El-Koubayet	5,319	GW_20	
19	UD_21_Qatlabah_Hamade	35078	El-Koubayet	1,330	GW_21	
20	UD_21_NPS	35085	Akkar El-Atika	3,019	GW_21	

To model the **industrial water demand** per node (site) the daily domestic water use rate of 160 lt/cap/day has been technically inflated by 10% (given the limited presence of industries in the Al Ostuan area[1]) resulting thus in an industrial equivalent demand on 16 lt/cap/day (or 5.84 m^3/cap/year). A scenario with an industrial demand equal to the 30% of the domestic water demand has also been created.

To model the **irrigation water demand** per node (site) the irrigation areas (km^2) have been incorporated in the catchment according to crop types (calculation of the areas occupied by each type of crop). The crops included field crops in medium to large terraces (legumes, vegetables), olives, vineyards, fruit trees, citrus fruit trees and protected agriculture (green houses). Based on the Reference Evapotranspiration (ETref) and the crop coefficient Kc, the potential evapotranspiration PETcrop has been calculated for each crop type. Then, the irrigation need for each crop area has been identified based on the difference between the available precipitation and the PETcrop, and the required supply per crop and area has been determined. Since during the conveyance and application of irrigation on the fields losses do exist, the irrigation supply required is divided by a coefficient (the “irrigation efficiency

[1] According to data provided by the Ministry of Industry, the following 3 industries are located within the Al Ostuan River Basin:
BIOCLEAN, located in Akkar El-Atika, producing fertilizers
AHMAD Katib , located in Akkar El-Atika, producing dairy products
OSMAN Kilani, located in Al-Khraibe, producing nails and screws

coefficient") to obtain the final irrigation needs of the crops. The irrigation efficiency coefficient takes into account the conveyance method (closed pressurized pipe or open channel), and the method of irrigation (drip irrigation, furrow or sprinklers). Here we assumed 60% irrigation efficiency as presented in Table 4-5 below.

Table 4-5: Irrigation efficiency assumptions in the Al Ostuan river basin for the Baseline

Conveyance networks and irrigation methods	% coverage of the irrigated area	% losses	% conveyence efficiency
Collective Networks - Closed Pipes	1%	10%	90%
Collective Networks - Open Channels	37%	55%	45%
Small individual networks - Groundwater wells	62%	35%	65%
Aggregated network conveyance efficiency	(1% x 0.9) + (37% x 0.45) + (62% x 0.65) = **57.85% or 42.15% losses**		
Drip irrigation	7%	20%	80%
Sprinklers' irrigation	15%	30%	70%
Furrow irrigation	78%	40%	60%
Aggregated field application efficiency	(7% x 0.8) + (15% x 0.7) + (78% x 0.6) = **62.90% or 37.10% losses**		
Overall combined irrigation efficiency = 60.38%, i.e. 60%			

To calculate the total supply required in the catchment, all the individual requirements of the crops have been added up.

Irrigation Need_crop = Max(0;(PETcrop[mm]-Available Precipitation[mm]))

Supply Required_crop (m^3) *= Area*[m^2]**Irrigation Need_crop[mm]/(1000*Irrigation Efficiency Coefficient*

Supply Required_catchment (m^3) *= ΣSupply Required_crop* (m^3)

Box 4.3: Investigation of the irrigation efficiency in the Al-Ostuan basin

Investigation of the irrigation efficiency in the Al-Ostuan basin

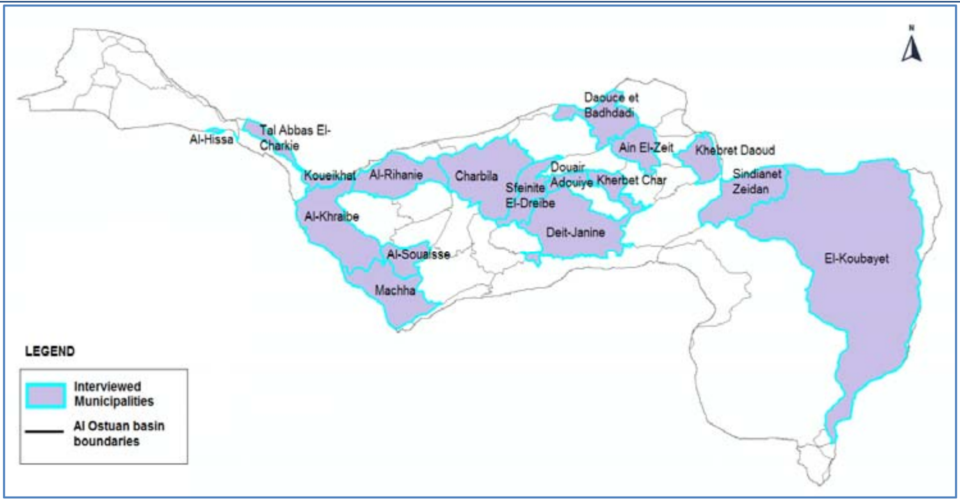
In an effort to assess the irrigation efficiency in the Al-Ostuan River Basin a copiousness of sources have been examines, including the NWSS 2012 and 2020 update, interviews with the NLWE, MEW, MoA, Municipalities, local farmers, agronomists.

Source 1:

Representatives from 17 Municipalities have been interviewed within the AO boundaries. Most of them are in the center (*see Map A below*), and thus not covered by irrigation schemes according to the NWSS GIS (Figure 3-7). Six of the 17 interviewed municipalities are covered by the GIS irrigation schemes, namely: Tal Abbas El-Charkie, Koueikhat, Al-Rihanie, Al-Hissa (barely within AO), Al-Khraibe (very small part covered by the scheme), Koubayet. Yet, people from the other 11 also municipalities that they have public water supply for irrigation (e.g. Deir-Janine, Charbila) which questions the accuracy of the NWSS GIS on the collective irrigation scheme.

- The agricultural areas (km^2) reported by the 17 Municipalities do not match the Corine LULC in GIS (Figure 3-6, Table 3-3), with the exception of maybe 1-2 which are close enough. This is an issue that needs to be investigated with field surveys (i.e. the actual area of irrigated crops).
- About 55% of the interview Municipalities reported that they have open channels and 45% closed pipes. Among the 6 Municipalities that are under public irrigation schemes in the NWSS GIS, Al-Rihanie and Al-Khraibe reported they have closed pipes, while the other 4 reported they have open canals (so about 30%-70%, but if we look at this ratio in terms of areas covered by each of these municipalities the ratio becomes 20% closed pipes – 80% open channels). For the remaining 11 Municipalities, that we assume they have small individual networks, the ratio is 60% closed pipes – 40% open channels, but if we look at this ratio in terms of areas covered by each of these municipalities the ratio then becomes 80% closed pipes – 20% open channels
- Looking at the irrigation methods, 7 Municipalities reported surface only, 1 drip only, 2 sprinkler only. 5 Municipalities reported a mix of surface + drip. So, applying some sensible splitting, the overall percentages come up to: 63% surface, 15% sprinklers, 22% drip

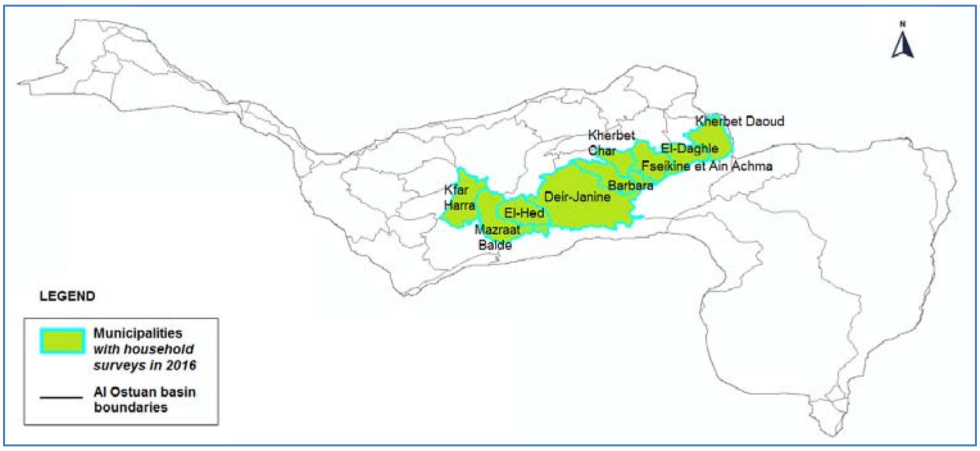
Map A: Location of the Municipalities interviewed during the study



<u>Source 2</u>:

Based on a **Household Survey carried out by ACTED in 2016, a total of 181 households declared they have a farm** (from nine Municipalities: Barbara (10 households hh), Daghle (9 hh), Deir Jenin (13), Fsaiqin (4 hh), El Hedd (6 hh), Kherbet Char (53 hh), Kherbet Daoud (48 hh), Kfar Harra (9 hh), Mazrat Balde (31 hh). Most of them are in the center (*see Map B below*), and none is covered by irrigation schemes according to the NWSS GIS (Figure 3-7). Three Municipalities are common with the ones interviewed by this study as previously presented under Source 1 (Deir Jenin, Kherbet Char, Kherbet Daoud). Based on the analysis, only 7% of the households/farmers reported they get their irrigation water from the NLWE, and all the others said they have private boreholes. 89% reported they apply surface irrigation and 9% drip. But if we look at these percentages at the Municipality level, 17% of the households in the Kherbet Char use drip irrigation and 20% in Barbara. Note that the representatives of the Kherbet Char Municipality declared that they only use sprinklers during the interview conducted in this study (Source 1 mentioned above).

Map B: Location of the Municipalities surveyed by ACTED in 2016



Source 3:

In the **NWSS 2012** the following percentages are overall reported for Lebanon irrigation methods and efficiencies:

Irrigation method	% Coverage	% Efficiency
Surface (furrow)	70.4%	60%
Sprinklers	23.4%	70%
Drip	6.2%	80%

In the **NWSS 2020 update**, there is not breakdown presented, only a genral mention that “under the presently prevailing irrigation conditions, considering network losses and the irrigation practices, the irrigation efficiency is around 50 to 60%” (NWSS 2020, Volume IV, page IV B 4). With regards to the conveyance efficiencies, in the NWSS 2012 it is mentioned that irrigation is the largest water consumer with low efficiencies, as open channels still constitute the majority of the networks. In Karaa et al. (2009), it is mentioned that the actual efficiency of the traditional gravity systems in Lebanon is 45%

Source 3:

An **interview with expert agronomist Ms. Rebecca El Khoury and Ms. Nour Katerji**, regarding the Akkar plain irrigation, the following points were highlighted:

We can divide Akkar plain to 4 type of irrigation system:

1. Green houses: We have a good number of green houses in Akkar that use the drip irrigation from their private water well or from the collective channel
2. Farmers that produces potato and onion:

- Potato: the season starts from mid-December and ends in May (they use sprinkler system according to water demand because is the winter period) and the water used comes from a private water well or from the collective canal (use of tractor for pumping)
- Onion: the season starts from mid-September till June, they use a sprinkler system (especially if they plant at mid-September, they need to irrigate around 4 time or more depend on precipitation). The water used comes from a private water well or from a collective channel (use of tractor for pumping)
- After the potatoes, they cultivate forage corn or sweet corn, and they use sprinklers for the first two months and furrow for the end of season

3. Other farmers:

- Produce crucifera crop: from September to March, they use furrow system and some small number use drip irrigation (winter period)

- From March to September: they produce different crops and use furrow system and drip system maybe (summer period), the water comes from private water wells or collective channels.

4. Fruit trees:

- Citrus: the major citrus orchards are old and the space between the tree is large so it's very costly to be irrigated from a water wall or through drip irrigation, Therefore, they use furrow system and source water from the collective channel (there are of course some exceptions)
- Lately we start replacing our citrus orchards by Avocado tree. The water supply system is the same, but we have a good number of drip systems used for Avocado orchard
- Olive tree: Rain-fed

For the village with an altitude around 800 and more:

1. Fruit tree: mainly furrow irrigation and some use drip irrigation systems
2. Vegetables: mainly drip irrigation systems and some use furrow

The resulting total annual water demand (the actual demand, excluding any network losses) of the all the above users, which was applied to the WEAP model, is summarized in Table 4-6 below. The share (as percentage of the total demand) per sector is illustrated in Figure 4-2. The largest percentage is the demand irrigation purposes (61.66%), followed by the domestic water demand (34.86%), while industry accounts only for 3.49%.

Table 4-6: Total annual water demand (actual, excluding losses) per user category in the Al Ostuan River Basin

Year	Demand for Irrigation (mio m^3)	Demand for Domestic use (mio m^3)	Demand for Industry (mio m^3)	Total Demand (mio m^3)
2003	9.65	6.18	0.62	16.45
2004	12.31	6.18	0.62	19.11
2005	10.27	6.18	0.62	17.07
2006	11.35	6.18	0.62	18.15
2007	11.38	6.18	0.62	18.18
2008	10.95	6.18	0.62	17.75
2009	10.48	6.18	0.62	17.28
2010	13.12	6.18	0.62	19.92

Year	Demand for Irrigation (mio m^3)	Demand for Domestic use (mio m^3)	Demand for Industry (mio m^3)	Total Demand (mio m^3)
2011	10.44	6.18	0.62	17.24
2012	10.48	6.18	0.62	17.28
2013	11.85	6.18	0.62	18.65
2014	10.21	6.18	0.62	17.01
2015	10.10	6.18	0.62	16.90
2016	12.00	6.18	0.62	18.80
2017	12.00	6.18	0.62	18.80
2018	8.39	6.18	0.62	15.19
TOTAL	**175.00**	**98.93**	**9.89**	**283.82**
Average	**10.94**	**6.18**	**0.62**	**17.74**

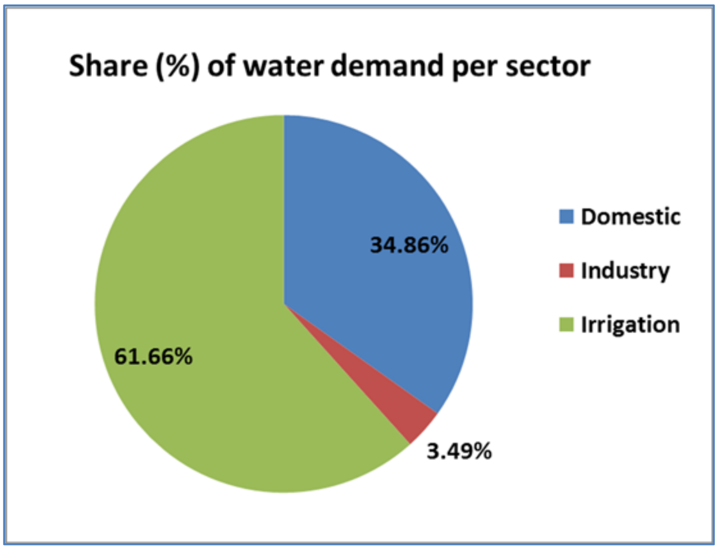


Figure 4-2: Share of water demand per sector

- **Hydrological modeling,**

The catchment processes in the model, such as evapotranspiration, runoff, infiltration, etc., have been simulated using the FAO Rainfall-Runoff (RR) method which requires the land use and climate of the catchment site. Land use consists of three parameters: area, crop coefficient (as discussed in FAO Irrigation and Drainage Paper N°56, Allen et al., 1998) and effective precipitation, while climate is defined by the precipitation and the reference evapotranspiration (Penman-Monteith equation). The RR method determines evapotranspiration for irrigated and rainfed crops using crop coefficients. Irrigation demand that may be required to fulfill that portion of the evapotranspiration requirement that rainfall cannot meet is then determined (as described previously). The remainder of rainfall not consumed by ET is simulated as runoff to the river, or proportioned among runoff to the river and flow to groundwater via catchment links. The detailed calculation algorithms of the RR method are presented in Box 4.3.

Box 4.4: Calculation Algorithms used in the Rainfall-Runoff (RR) method

Calculation Algorithms used in the Rainfall-Runoff (RR) method

Crop requirements are calculated assuming a demand site with simplified hydrological and agro-hydrological processes such as precipitation, evapotranspiration, and crop growth emphasizing irrigated and rainfall agriculture. Non-agricultural land classes can be included as well. The following equations were used to implement this approach where subscripts LC is land cover, HU is hydro-unit, TS is timestep (e.g., month), I is irrigated, and NI is non-irrigated:

- $PrecipAvailableForET_{LC} = Precip_{HU} * Area_{LC} * 10^{-5} * PrecipEffective_{LC}$
- $ETpotential_{LC} = ETreference_{HU} * Kc_{LC} * Area_{LC} * 10^{-5}$
- $PrecipShortfall_{LC,I} = Max (0, ETpotential_{LC,I} - PrecipAvailableForET_{LC,I})$
- $SupplyRequirement_{LC,I} = (1 / IrrFrac_{LC,I}) * PrecipShortfall_{LC,I}$
- $SupplyRequirement_{HU} = \Sigma_{LC,I}\ SupplyRequirement_{LC,I}$

The above four equations are used to determine the additional amount of water (above the available precipitation) needed to supply the evapotranspiration demand of the land cover (and total hydro unit) while taking into account irrigation efficiencies.

Based on the system of priorities, the following quantities can be calculated:

- $Supply_{HU}$ = Calculated by WEAP allocation algorithm
- $Supply_{LC,I} = Supply_{HU} * (SupplyRequirement_{LC,I} / SupplyRequirement_{HU})$
- $ETActual_{LC,NI} = Min (ETpotential_{LC,NI} , PrecipAvailableForET_{LC,NI})$
- $ETActual_{LC,I} = Min (ETpotential_{LC,I} , PrecipAvailableForET_{LC,I}) + IrrFrac_{LC,I} * Supply_{LC,I}$
- $EF_{LC} = \Sigma_{TS} ETActual_{LC} / \Sigma_{TS} ETpotential_{LC}$

As a result, the actual yield can be calculated with the following equation:

- *ActualYield*LC = *PotentialYield*LC * Max (0, (1 - *YieldResponseFactor*LC * (1 - *EF*LC)))
- *Yield*LC = *ActualYield*LC * AreaLC
- *MarketValue*LC = *Yield*LC * MarketPriceLC

In the Rainfall Runoff method, runoff to both groundwater and surface water can be calculated with the following equations:

- *Runoff*LC = Max (0, *PrecipAvailableForET*LC - *ETpotential*LC) + (*Precip*LC * (1 - *PrecipEffective*LC)) + (1 - *IrrFrac*LC,I) * *Supply*LC,I
- *RunoffToGW*HU = ΣLC (*Runoff*LC * *RunoffToGWFraction*LC)
- *RunoffToSurfaceWater*HU = ΣLC (*Runoff*LC * (1 - *RunoffToGWFraction*LC))

Units and definitions for all variables above are:

Area [HA] - Area of land cover

Precip [MM] - Precipitation

PrecipEffective [%] - Percentage of precipitation that can be used for evapotranspiration
PrecipAvailableForET [MCM] - Precipitation available for evapotranspiration

Kc [-] - crop coefficient

ETreference [MM] - Reference crop evapotranspiration

ETpotential [MCM] - Potential crop evapotranspiration

PrecipShortfall [MCM] - Evapotranspiration deficit if only precipitation is considered

IrrFrac [%] - Percentage of supplied water available for ET (i.e. irrigation efficiency)

SupplyRequirement [MCM] - Crop irrigation requirement

Supply [MCM] - Amount supplied to irrigation (calculated by WEAP allocation)

EF [-] - Fraction of potential evapotranspiration satisfied, averaged over the season (Planting Date to Harvest Date)

YieldResponseFactor [-] - Seasonal factor that defines how the yield changes when ETActual is less than ETPotential (water stress)

PotentialYield [KG/HA] - The maximum potential yield given optimal supplies of water

ActualYield [KG/HA] - The actual yield given the available evapotranspiration

Yield [KG] - Actual yield for the land class

MarketPrice [$/kg] - Unit value of the crop

MarketValue [$] - Total value of the crop for the land class

RunoffToGWFraction [-] - Fraction of runoff that goes to groundwater

RunoffToGW [MCM] - Runoff to groundwater supplies

RunoffToSurfaceWater [MCM] - Runoff to surface water supplies

Source: Stockholm Environment Institute (SEI), 2015. WEAP Water Evaluation And Planning System. User Guide for WEAP 2015, August 2015.

Regarding precipitation data, in this study we employed historical monthly data from three gauging stations (Fnaidek, Klaiaat and Qoubayat), and then estimated the catchment precipitation through spatial integration using the Thiessen using the Thiessen polygons method as previously illustrated in Figure 3-8 (in Chapter 3.1). However, before this, and due to non-overlapping periods of the available records (e.g., the data Fnaidek span from 2009 to 2018, while those of Klaiaat span from 2002 to 2011), as well as due to missing values, a method to complete the time series and fill the missing values/ data gaps was first employed. Particularly, we employed a novel stochastic extrapolation method that relies on the notion of copulas. The method is related with a recently introduced stochastic simulation method (Tsoukalas et al., 2018, 2019) that is based on the notion of Nataf's joint distribution model. This model is capable of simulating stationary processes (univariate or multivariate) with any marginal distribution and correlation structure, while the missing values has been imputed using the Naraf-based conditional distribution model described in Tsoukalas (2019), which also allows the description of conditional distributions with any marginal distribution and correlation. Eventually, the time series have been completed, while being conditioned on the historical flow series of available records in the region, maintaining their cross-correlation as well as their distribution. Figure 4-3 and Figure 4-4 depict the annual and monthly precipitation at the 8 sub-catchements of Al Ostuan basin for the period 2003-2018.

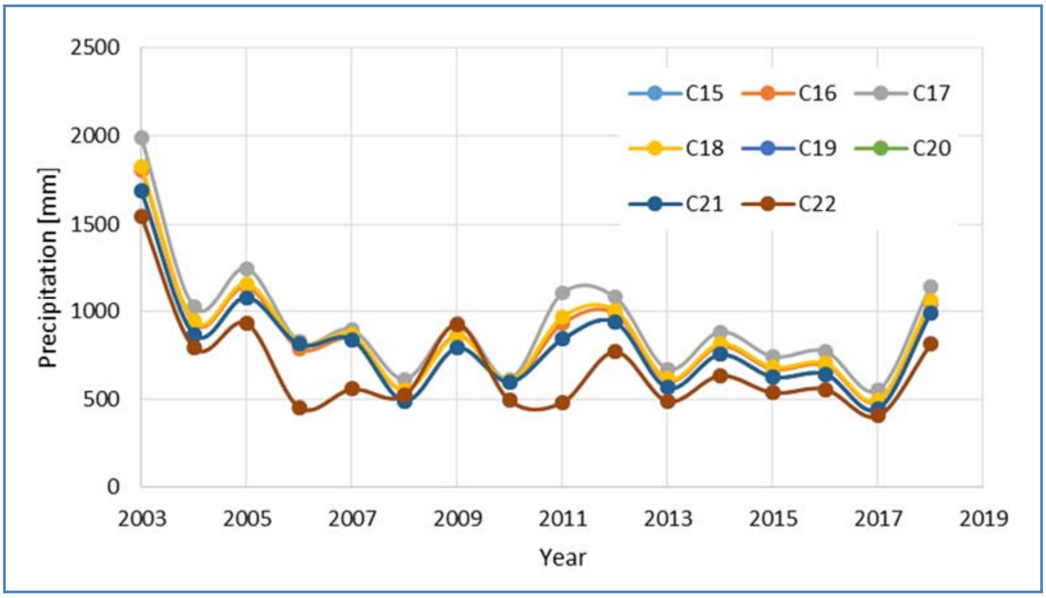


Figure 4-3: Total annual precipitation at the 8 sub-catchments of Al Ostuan River Basin

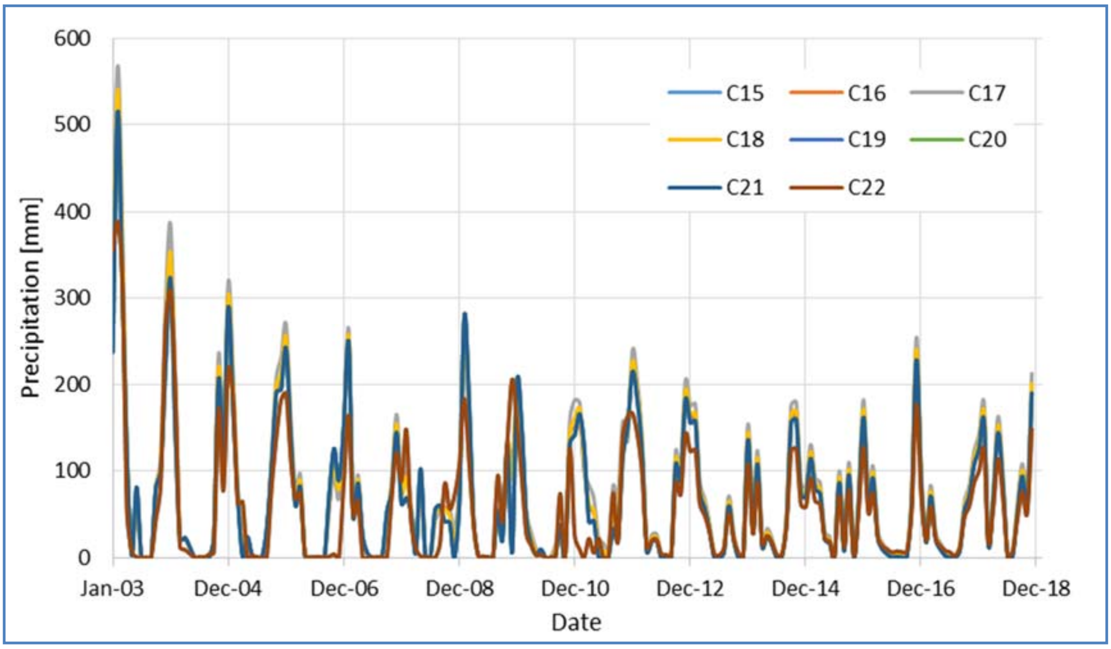


Figure 4-4: Monthly precipitation at the 8 sub-catchments of Al Ostuan River Basin

Regarding the estimation of the reference evapotranspiration (ET_O), we employed temperature data from the same stations as above (i.e., Fnaidek, Klaiaat and Qoubayat), while in this case the missing values have been computed on the basis of seasonal averages (since average monthly temperature, and hence evapotranspiration, exhibit strong seasonality, and small variation from year-to-year). To estimate the reference evapotranspiration (ET_O), aiming to ensure robust and unbiased estimation, in this study we employed the ensemble of two methods, that is the well-known temperature-based method of Blaney–Criddle, and the parametric model of Tegos et al. (2017) – hereafter denoted parametric ET_O model. The Blaney–Criddle reads as follows:

$$ET_0 = p(0.457\,\bar{T} + 8.128) \quad (1)$$

where, ET_O is the reference evapotranspiration [mm/day]], $\bar{T}$ is the mean daily temperature [^{0}C] estimated as $\bar{T} = (T_{max} - T_{min})/2$, and p mean daily percentage of annual daytime hours (that can be obtained by the station's latitude).

On the other hand, the parametric ET_O model is given by,

$$ET_0 = \frac{aR_a + b}{1 - c\bar{T}} \quad (2)$$

where, R_A is the extraterrestrial radiation [kJ/m^2], and α [kg/k], b [kg/m^2], and c [$^0C^{-1}$] are model parameters, obtained by calibration. In more detail, $R_α$ is given by,

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(d)\sin(\omega_s)] \quad (3)$$

where, G_{sc} is the solar constant, with typical value 82 kJ m^{-2} min^{-1}, d_r is the inverse relative distance of the Earth from the Sun, ω_s [rad] is the sunset hour angle, φ is the latitude [rad] and δ is the solar declination [rad]. Variables d_r and δ are periodic functions of time, while ω_s is function of latitude and time. For details on computing astronomic variables, the reader may refer to the literature (e.g. Allen et al., 1998).

Further to this, in the later work, based on 4300 stations across the world, the authors performed a global-wise calibration of the model (using as reference the well-known Penman-Monteith equation), which highlighted its high accuracy and the robustness of its parameters. Further to this, they provided a dense database that can be used for parameter inference across ungauged locations, thus estimation of ET_O (requiring only temperature data). In this work, the parameters of the model have been obtained from the aforementioned database. The reference evapotranspiration of the catchments has been estimated using the well-known Thiessen polygons for both methods, and next the final values of ET_O a simple ensemble of the methods has been obtained, i.e. the average of the two outputs. Figure 4-5 depicts the estimated reference evapotranspiration (ET_O) of all catchments for the period 2003-2018.

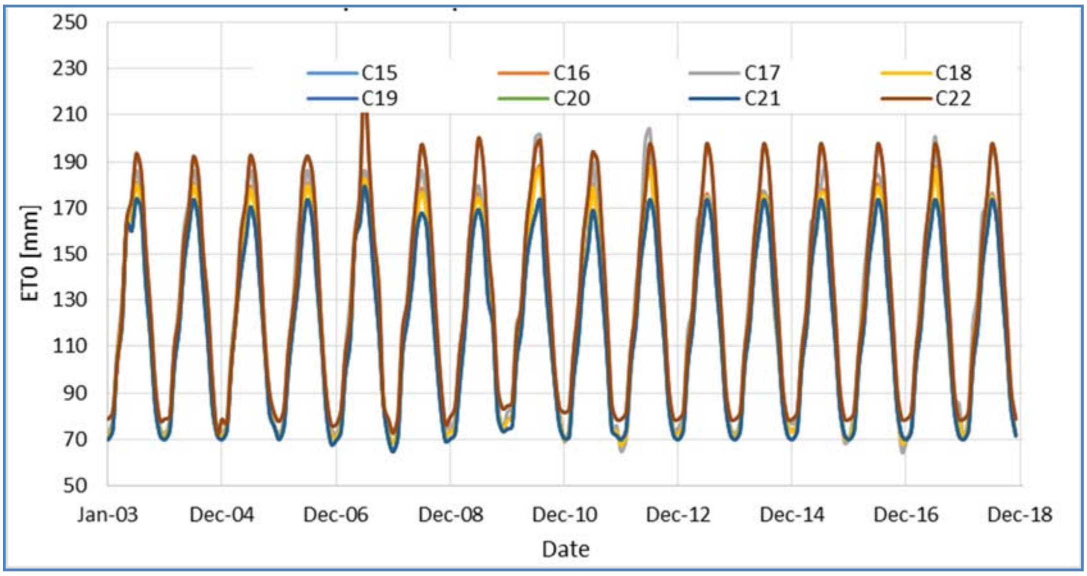


Figure 4-5: Monthly Evapontranspiration at the 8 sub-catchments of Al Ostuan River Basin

4.2.2 CALIBRATION AND VALIDATION PROCEDURE

The purpose of the calibration was to achieve a better representation of the catchment physical processes. The selected parameters to be calibrated are the "% of effective precipitation", the "infiltration fraction" per catchment, and the "groundwater outflow" from the river bed to the groundwater. The exact values of these parameters present some uncertainty in the model due to the simplified RR model used within the WEAP which lacks snow accumulation and snowmelt routines, and the presence of karstic aquifers in the basin and associated lag-time in their discharge through the springs. The model has been overall calibrated for the period 2003-2011, using observed streamflow data at "Embouchure" gauging station (where the available record was complete) (Figure 4-6), while the XA Solver (built-in in WEAP) has been used. The objective function to maximize was selected to include three goodness-of-fit metrics, namely: the efficiency E (Nash-Sutcliffe), the correlation factor r, and the BIAS, defined as follows:

$$r = \frac{\sum (Q_{obs} - \overline{Q}_{obs}) \cdot (Q_{sim} - \overline{Q}_{sim})}{\sqrt{\sum (Q_{obs} - \overline{Q}_{obs})^2 \cdot \sum (Q_{sim} - \overline{Q}_{sim})^2}} \quad (1)$$

$$E = 1 - \frac{\sum (Q_{obs} - Q_{sim})^2}{\sum (Q_{obs} - \overline{Q}_{obs})^2} \quad (2)$$

$$BIAS = \frac{\overline{Q}_{sim} - \overline{Q}_{obs}}{\overline{Q}_{obs}} \quad (3)$$

Where, Qobs and Qsim are the observed and simulated values respectively.

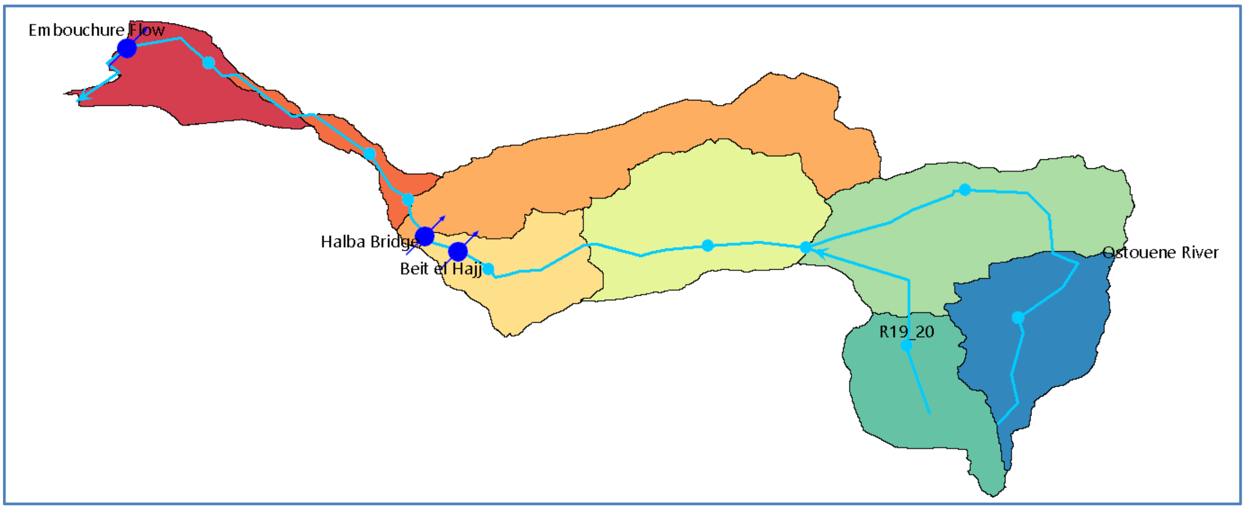


Figure 4-6: The streamflow stations used in the model calibration

The results of the calibration are presented in Table 4-7 and Figure 4-7. It is concluded that the model performs well, exhibiting high efficiency (~0.68), low bias (0.008), and high correlation (0.839), while it can be said that it underestimates winter streamflow and slightly increases the baseflow of the river, thus not accurately capturing the role of the snow accumulation/snowmelt in the basin and the associated runoff lag time. Based on the new calibrated parameters the model was accordingly tuned and adopted to better represent the physical process. The performance of the calibrated model at the outlet is visually depicted in Figure 4-7 where we compare the observed versus simulated streamflows at the “Embouchure” gauging station near the river outlet. Note that the aforementioned plot extends beyond the calibration period (2003-2011), depicting also the period 2011-2018, which contains the validation period (Sep 2016 – Aug 2017).

Table 4-7: Goodness-of-fit parameters from the calibration process comparing streamflow at the Embouchure gauging station.

Gauge Station	Calibration period	E	r	bias
Embouchure	1/2003 - 12/2011	0.680	0.839	0.008

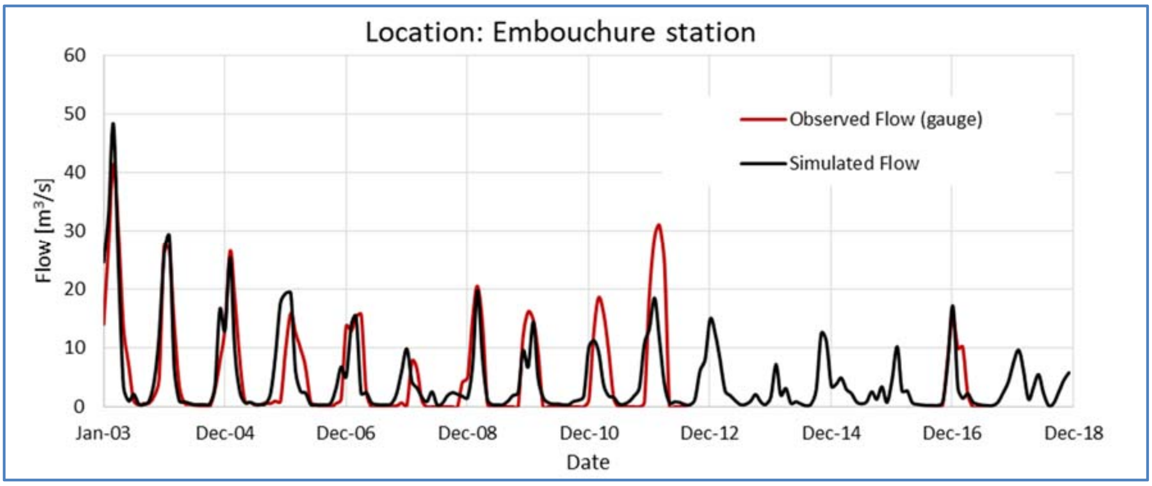


Figure 4-7: Comparison of observed versus simulated streamflows at the Embouchure gauging station. Note: the plot extends beyond the calibration period (2003-2011) into the 2011-2018, which contains also the validation period (Sep 2016 – Aug 2017).

To further assess the robustness of the model, it has been validated for the period 2003-2011 in the two upstream stations of Beit El Hajj and Pont Halba, and for the period 2016-2017 in the Embouchure station at the outlet, using observed streamflow data from these gauging stations (the period of verification varies among the stations). The same three goodness-of-fit metrics, with the ones used during the calibration process, have been evaluated. The results, presented in Table 4-8, show a good modeling performance (in terms of goodness-of-fit between the observed and the simulated streamflows) in all three stations, while this can be visually confirmed in Figure 4-8, Figure 4-9 and Figure 4-10 which depict the comparison between the modeled and observed streamflows.

Table 4-8: Goodness-of-fit parameters from the validation process comparing streamflow at the 3 gauging station.

Gauge Station	Validation period	E	r	bias
Embouchure	09/2016 – 08/2017	0.641	0.803	- 0.247
Pont Halba	1/2003 - 12/2011	0.456	0.829	0.355
Beit El Hajj	1/2003 - 12/2011	0.425	0.739	-0.440

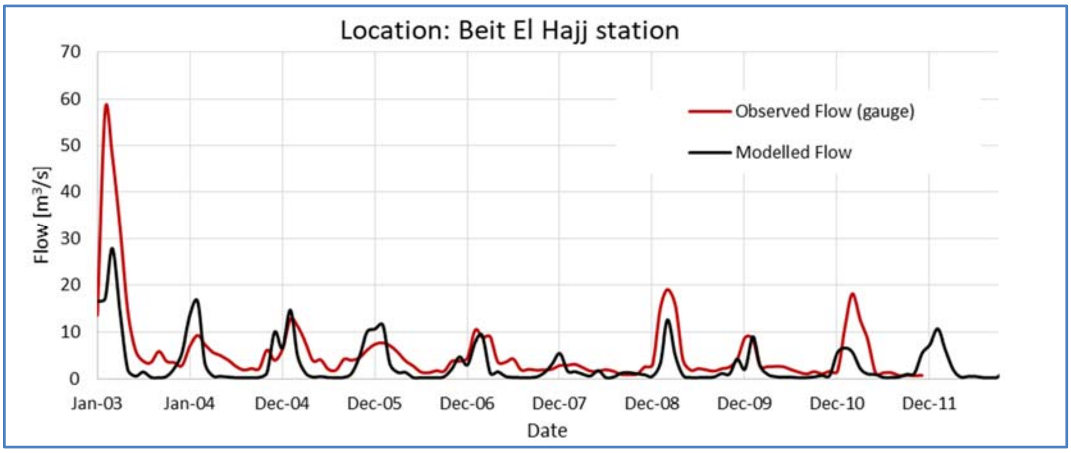


Figure 4-8: Comparison of observed versus simulated streamflows at the Beit El Hajj gauging station for the validation period 2003-2011.

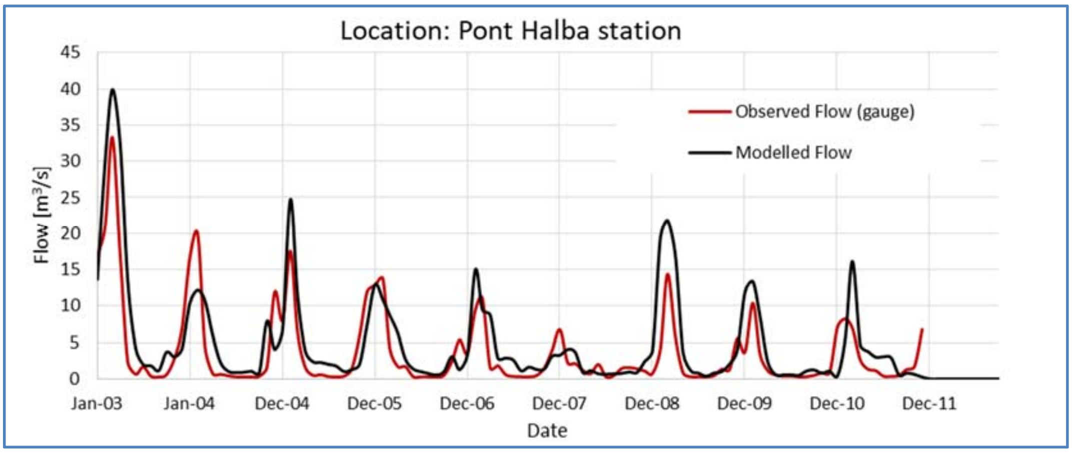


Figure 4-9: Comparison of observed versus simulated streamflows at the Pont Halba gauging station for the validation period 2003-2011.

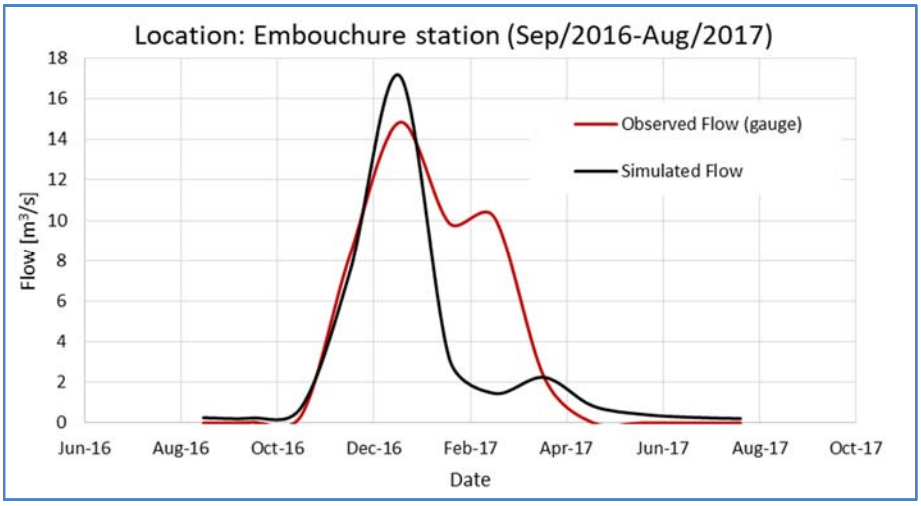


Figure 4-10: Comparison of observed versus simulated streamflows at the Embouchure gauging station for the validation period 2016-2017.

5 RESULTS AND OUTPUTS OF THE WEAP MODEL

The inflows and outflows for the entire basin per year are illustrated in Table 5-2, while Figure 5-1 and Figure 5-2 present the inflows and outflows per year for the entire river basin, and the annual average (of the period 2003-2018). Furthermore, Figure 5-3, Figure 5-4, Figure 5-5 present the annual inflows and outflows per sub-catchment for the dry year 2010, the normal year 2011 and the wet year 2003 respectively.

It can be observed that the years 2010, 2016, 2017 and 2008 have been dry, while 2003, 2004, 2005, and 2018 have been wet. The long-term annual average precipitation is in the basin is about 121 Mm^3, of which 50% is lost due to evapotranspiration, about 42% is turned into surface runoff and about 8% infiltrates in the groundwater. This indicates that most of the water available for potential exploitation ends up in the river.

With regards to the sub-catchments, most precipitation is observe in sub-catchments C19 (~ 25 Mm^3/year on average), C16 (~ 24 Mm^3/year on average) and C18 (~ 22 Mm^3/year on average), which are the largest sub-catchments, while the sub-catchments with the lower precipitation are C15 (~ 3 Mm^3/year on average) and C22 (~ 8 Mm^3/year on average). This comparison is made in terms of total volume of precipitation received over the entire sub-catchment (which is influenced by the sub-catchment area), and not it terms of unit precipitation received (i.e. precipitation per m^2) which reflects the intensity. In terms of intensity, the highest precipitation rate is observed in C17 (928 mm), C18 (872.5 mm) and C16 (857 mm), while the lowest in C22 (679 mm) and C15 (680 mm) (refer to Table 5-1).

The higher volume of infiltration to the groundwater is observed in sub-catchment C19 (~ 3 Mm^3/year on average, representing 11.5% of its precipitation), and sub-catchment C18 (~ 2 Mm^3/year on average, representing 8.5% of its precipitation). The lower infiltration volumes are observed in C15 (~ 0.2 Mm^3/year on average, representing 7% of its precipitation), C17 (~ 0.3 Mm^3/year on average, representing 3% of its precipitation) and C22 (~ 0.4 Mm^3/year on average, representing 6% of its precipitation). Given the fact that the later sub-catchments (C15, C17, C22) have extensive irrigation areas, and water is pumped from the groundwater to cover irrigation needs, the combination of low infiltration volumes and excusive abstraction for irrigation can cause significant groundwater level deterioration and lead to unsustainable conditions.

The higher volume of surface runoff is observed in sub-catchment C16 (~ 33 Mm^3/year on average, representing 53% of its precipitation), and sub-catchment C18 (~ 10 Mm^3/year on average, representing 48% of its precipitation). The lower surface runoff volumes are observed in C15 (~ 1.2 Mm^3/year on average, representing 42.5% of the precipitation) and C22 (~ 2.7 Mm^3/year on average, representing 35% of the precipitation).

Table 5-1: Comparison of precipitation, groundwater infiltration rates and surface runoff rates among the 8 sub-catchments of the Al-Ostuan RB

Sub-catchments *(from West to East)*	Villages within the sub-catchment boundaries (CAD_NAME)	Unit Precipitation (mm)	Groundwater Infiltration rate vs. Surface Runoff rate (as % of the Precipitation)
22	Al-Kleiat, Cheikh Zennad Tal Bibe, Al-Kneisse, Al Moghrak, Tal Kerri, Al-Hissa, Al-Massoudie	679 mm	6% vs. 35%
15	Halba, Tal Abbas El-Gharbie, Koueikhat, Tal Abbas El-Charkie, Al-Massoudie, Al-Khraibe	680 mm	7% vs. 43%
16	Charbila, Ain El-Zeit, El-Daghle, Kherbet Daoud, El-Msalle, Kefr El-Ftouh, El-Kouachra, Daouce et Baghdadi, Denke et El-Amriyeh, El-Bire, Katte, Al-Rihanie, El-Tleil, Omar el-Beikate, El-Haouchab, Hmais, Saidnaya, Al-Khraibe	857 mm	3% vs. 53%
17	Dahr-Leycine, Machha, Hayzouk, Kfar Harra, Al-Souaisse, Dahr el-Kneisse, Al-Khraibe	928 mm	3% vs. 56%
18	Ain Tanta, Douair Adouiye, El-Hed, Deir-Janine, Sfeinite El-Dreibe, Kherbet Char, Fseikine et Ain Achma, Barbara, Mazraat Balde, Beino, Majdel	873 mm	9% vs. 48%
19	Sindianet Zeidan, El-Koubayet, Majdel, Daoura, Andeket, Akkar El-Atika	837 mm	12% vs. 34%
20	Andeket, Akkar El-Atika	837 mm	11% vs. 34%
21	El-Koubayet, Akkar El-Atika	837 mm	11% vs. 33%

Table 5-2: Inflows and Outflows (mio m^3) per year for the Al Ostuan River Basins

Year	Precipitation	Evapotranspiration	Surface Runoff	Flow to Groundwater
2003	254.14	-77.18	-148.11	-28.84
2004	143.98	-49.12	-80.20	-14.66
2005	151.90	-62.04	-75.79	-14.07
2006	125.33	-57.89	-56.77	-10.66
2007	112.55	-59.15	-44.97	-8.43
2008	91.46	-59.84	-26.87	-4.75
2009	117.75	-59.96	-48.65	-9.14
2010	78.13	-43.82	-29.21	-5.10
2011	125.41	-66.42	-50.10	-8.89
2012	134.93	-63.78	-60.14	-11.02
2013	104.67	-56.26	-40.98	-7.43
2014	104.78	-58.46	-39.10	-7.22
2015	95.54	-67.42	-24.06	-4.06
2016	79.66	-47.74	-27.20	-4.72
2017	81.33	-46.19	-29.75	-5.39
2018	137.95	-84.76	-45.21	-7.97
LTAA	**121.22**	**-60.00**	**-51.69**	**-9.52**
%	**100%**	**-49.50%**	**-42.65%**	**-7.85%**

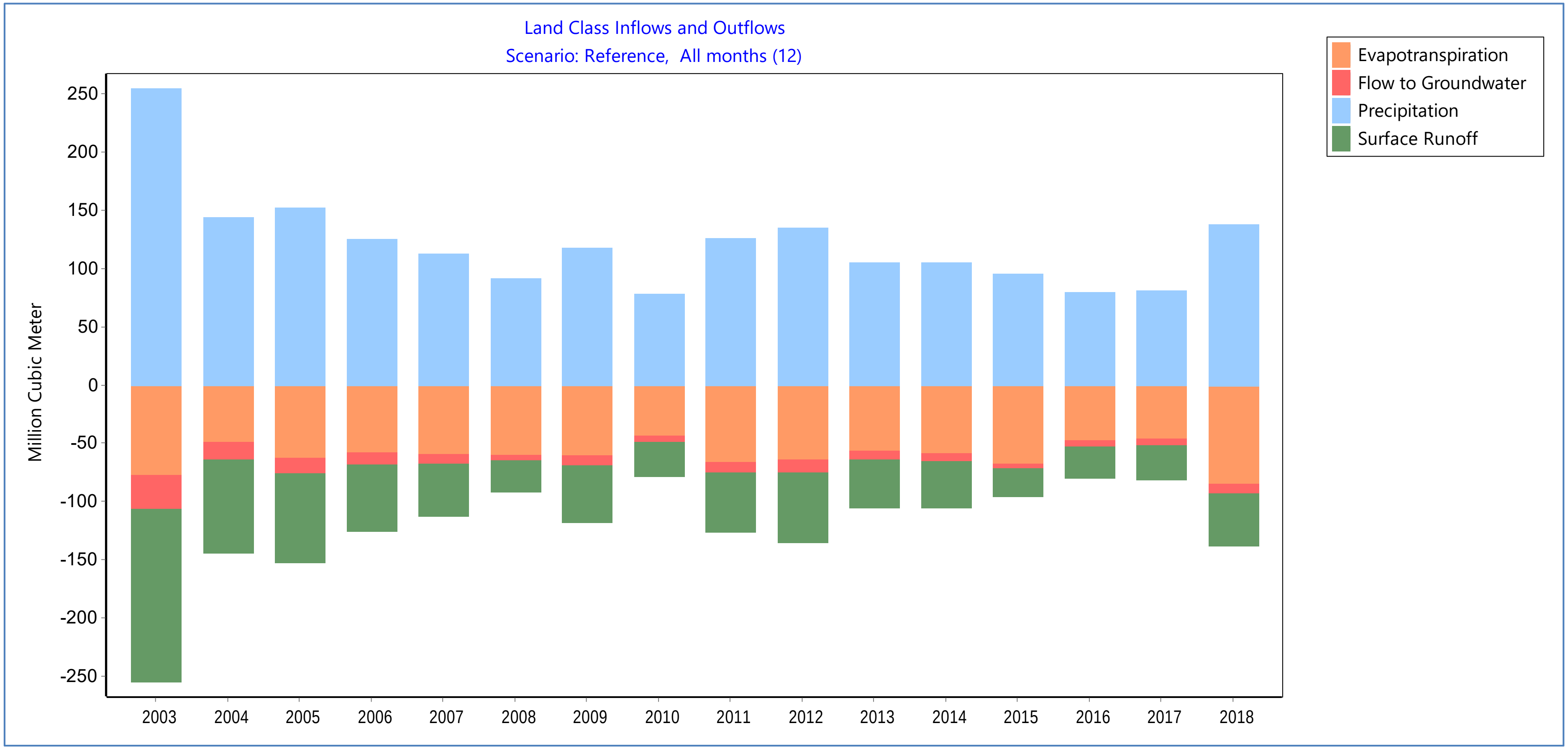


Figure 5-1: Inflows and Outflows (mio m3) per year in the Al Ostuan River Basin for the period 2003-2018

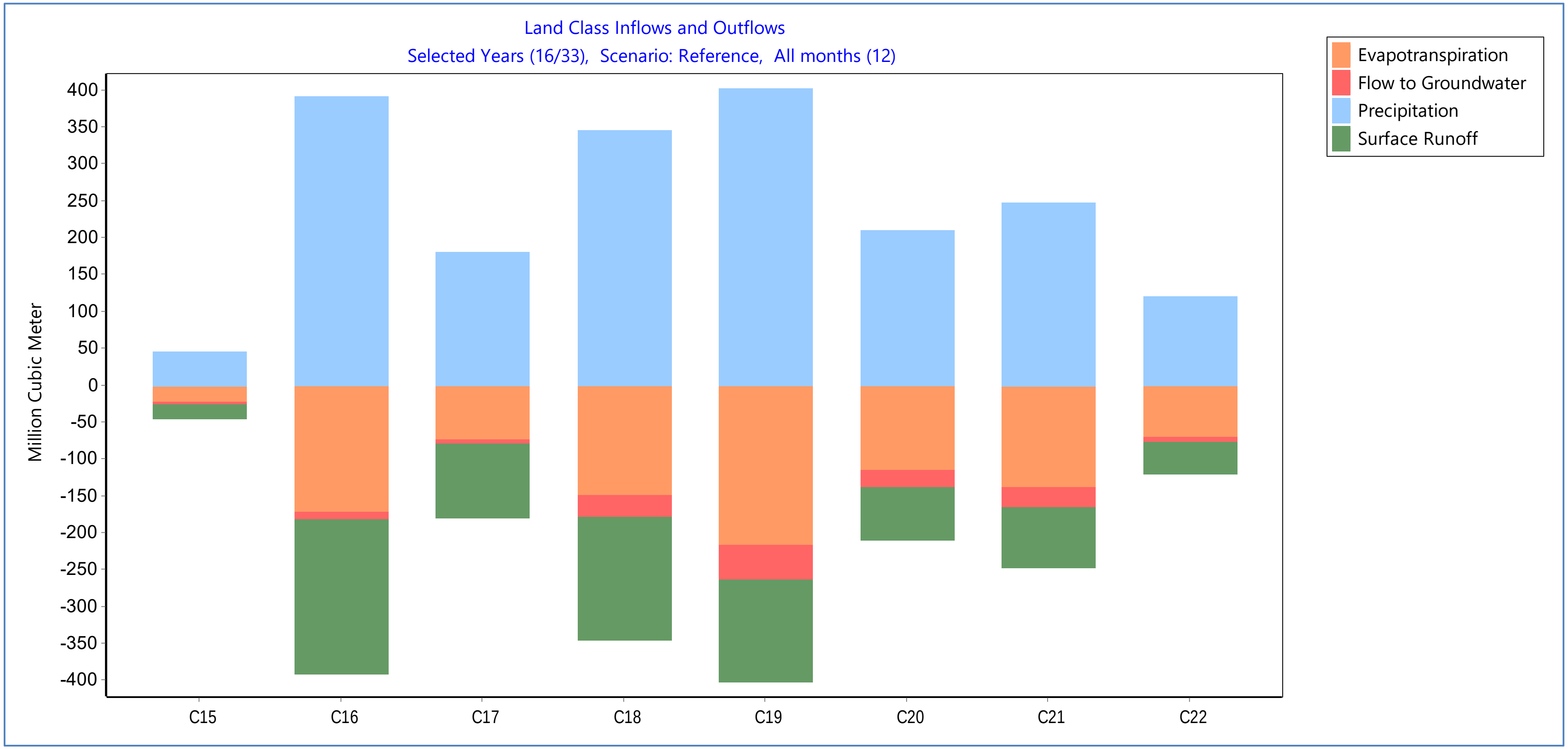


Figure 5-2: Average Annual Inflows and Outflows (mio m3) per sub-catchment in the Al Ostuan River Basin, for the period 2003-2018

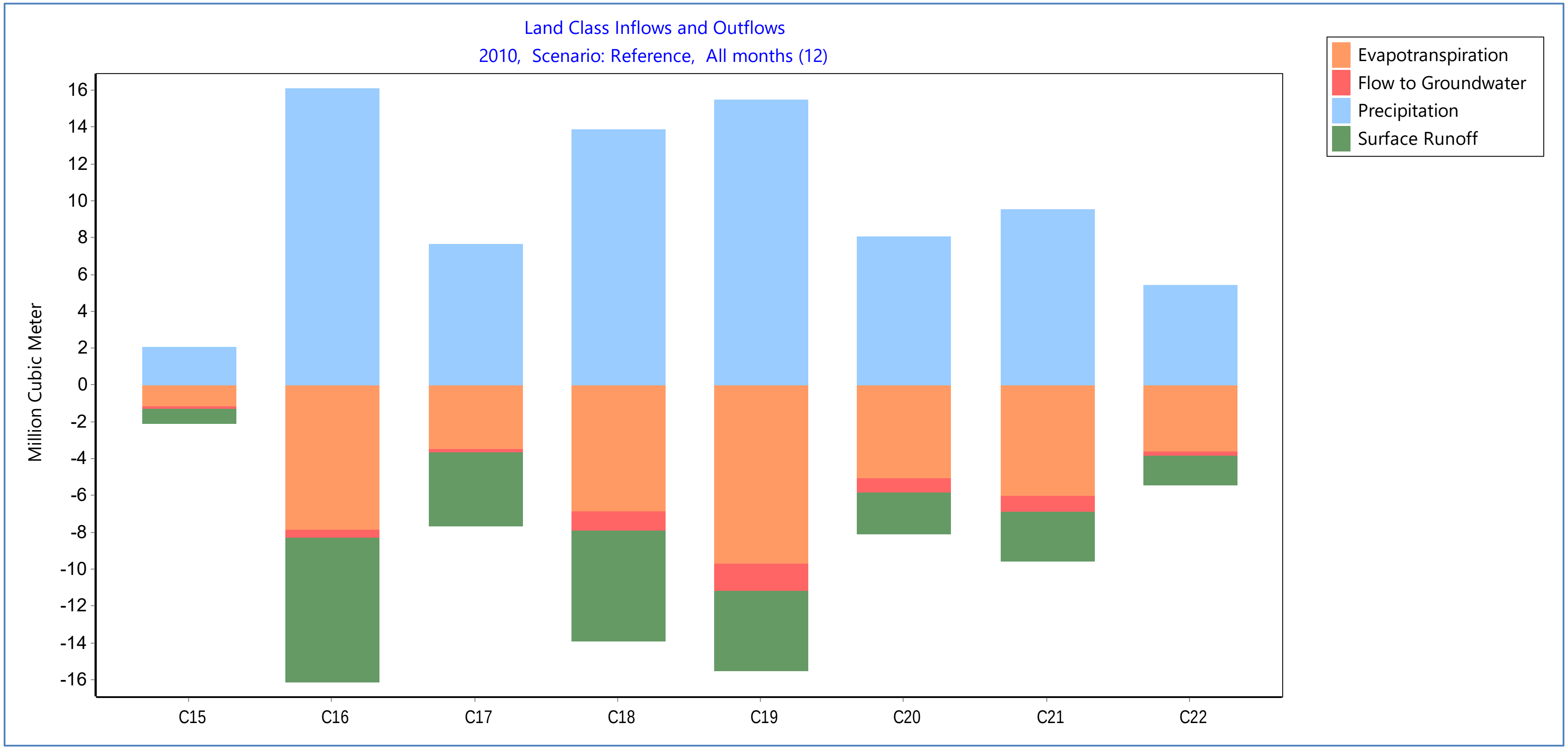


Figure 5-3: Inflows and Outflows (mio m3) per sub-catchment in the Al Ostuan River Basin, for the dry year 2010

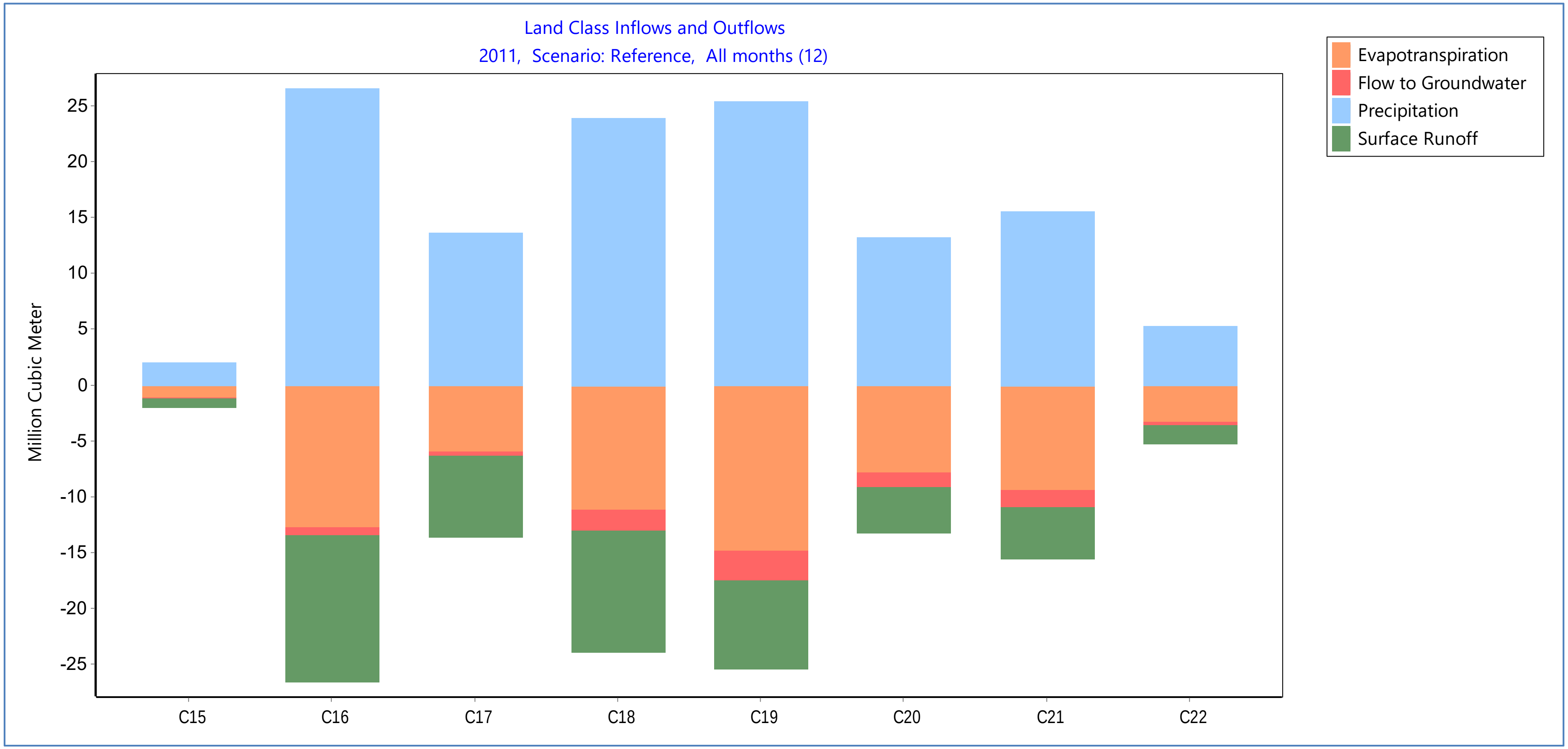


Figure 5-4: Inflows and Outflows (mio m3) per sub-catchment in the Al Ostuan River Basin, for the normal year 2011

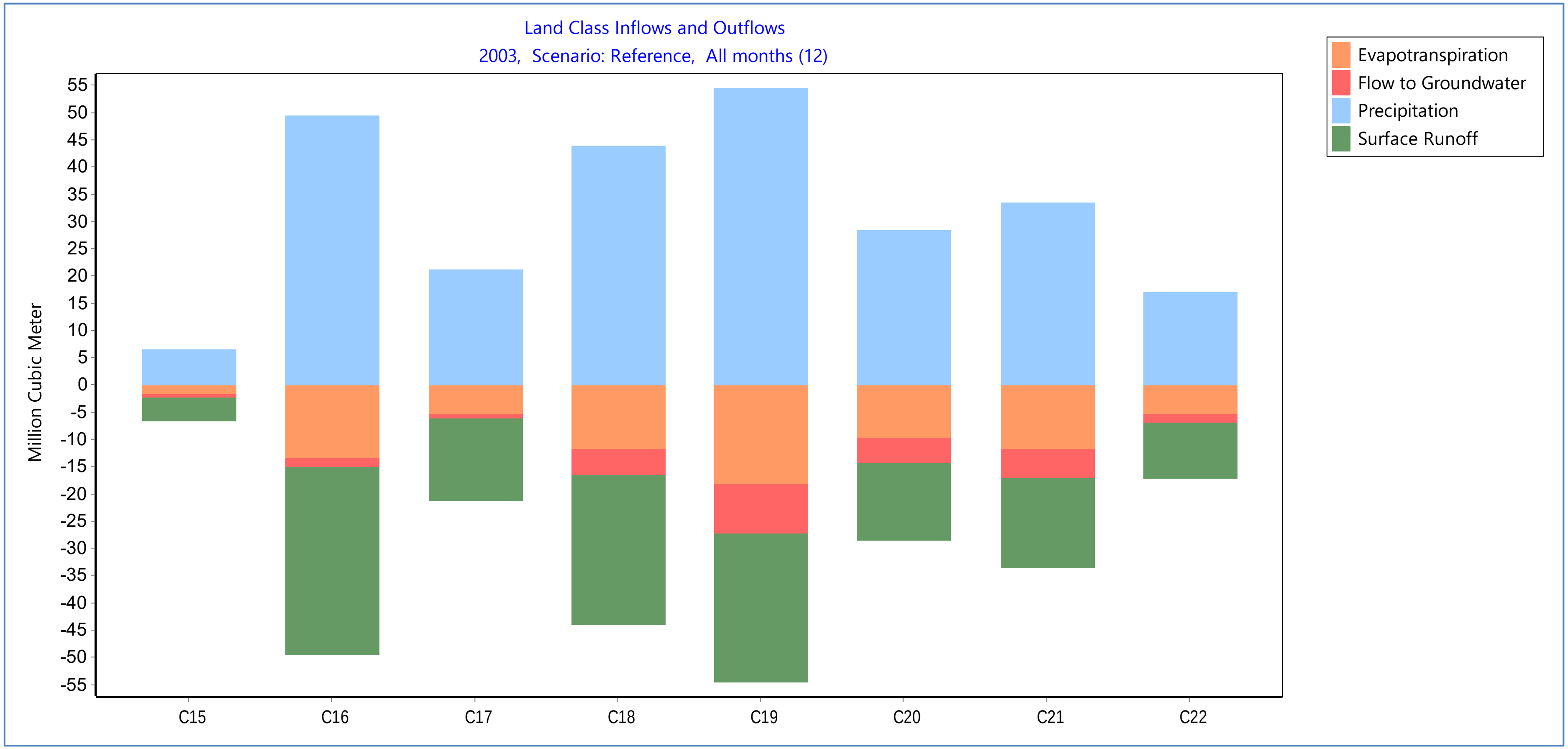


Figure 5-5: Inflows and Outflows (mio m3) per sub-catchment in the Al Ostuan River Basin, for the wet year 2003

Based on the model results the balance between demand and availability is negative, resulting in unmet demand in all the 8 sub-catchments every year. The total annual unmet demand in the Al Ostuan River Basin is presented in

Table **5-3**. It ranges from as low as 8.2 mio m^3 (in 2003) to as high as 22.3 mio m^3 (in 2010), with an average value of 17.3 mio m^3 over the 16-year period 2003-2018. The years with the largest unmet demand are 2010, 2016, 2017, 2008, and 2013 (all the years had annual unmet demand > 19 mio m^3). These values account for around 70% of the supply required, which means that only 30% of the needs were actually met by the water supply during those years. This unmet demand is mainly attributed to the irrigation (agricultural sector), yet the domestic/ urban sector is also affected (Figure 5-6, Figure 5-8). The years with the lowest unmet demand are 2003, 2004 and 2005, yet even in these cases the unmet demand amounted to 32-53% of the water supply required.

Table 5-3: Unmet demand (mio m3) per year in the Al Ostuan River Basin

Year	Supply Required (incl. Losses) (mio m^3)	Total Supply Delivered (mio m^3)	Total Unmet Demand (mio m^3)	Unmet Demand as % of the Supply Required
2003	25.80	17.62	-8.18	-32%
2004	30.23	17.29	-12.93	-43%
2005	26.84	12.63	-14.21	-53%
2006	28.64	12.23	-16.41	-57%
2007	28.69	9.97	-18.72	-65%
2008	27.97	7.99	-19.98	-71%
2009	27.19	10.43	-16.76	-62%
2010	31.59	9.26	-22.33	-71%
2011	27.12	9.12	-18.00	-66%
2012	27.19	11.60	-15.59	-57%
2013	29.47	9.71	-19.76	-67%
2014	26.74	8.19	-18.55	-69%
2015	26.54	8.15	-18.39	-69%
2016	29.72	8.35	-21.37	-72%
2017	29.71	8.86	-20.85	-70%
2018	23.70	8.66	-15.04	-63%
TOTAL	**447.13**	**170.05**	**-277.07**	**-62%**

Year	Supply Required (incl. Losses) (mio m³)	Total Supply Delivered (mio m³)	Total Unmet Demand (mio m³)	Unmet Demand as % of the Supply Required
Average	**27.95**	**10.63**	**-17.32**	**-62%**

The average annual urban unmet demand of the period 2003-2018 was 3.51 mio m³/year (or, assuming a population of ~ 105,000 people living within the ORB, 92 lt/cap/day), varying across the years (Table 5-4). The years with the highest unmet demand in the urban sector were 2016 (with 4.9 mio m³ of urban unmet demand, or ~ 128 lt/cap/day), 2010 (with 4.8 mio m³ of urban unmet demand), 2017 and 2008 (each with with 4.7 mio m³ of urban unmet demand), and 2014 (with 4.63 mio m³ of urban unmet demand). The years with the lowest unmet demand in the urban sector were 2003 (with ~0.6 mio m³ of urban unmet demand, or ~15 lt/cap/day), and 2004 (with 1.2 mio m³ of urban unmet demand, or ~32 lt/cap/day).

Table 5-4: Urban unmet demand (in mio m³ and lt/cap/day) per year in the Al Ostuan River Basin

Year	Total Urban Unmet Demand (mio m³)	Total Urban Unmet Demand (m³/day)	Total Urban Unmet Demand (lt/cap/day)
2003	0.57	1,562.15	14.94
2004	1.23	3,370.89	32.25
2005	2.41	6,606.19	63.19
2006	2.92	7,988.10	76.41
2007	3.60	9,864.15	94.36
2008	4.73	12,951.36	123.89
2009	3.64	9,964.87	95.32
2010	4.81	13,173.27	126.01
2011	3.63	9,940.30	95.09
2012	2.91	7,965.61	76.20
2013	4.03	11,028.39	105.50
2014	4.44	12,166.61	116.38
2015	4.31	11,814.79	113.02
2016	4.90	13,426.58	128.44
2017	4.73	12,965.26	124.02
2018	3.33	9,126.63	87.30

Year	Total Urban Unmet Demand (mio m^3)	Total Urban Unmet Demand (m^3/day)	Total Urban Unmet Demand (lt/cap/day)
TOTAL	**56.18**	153,915.15	**1,472.34**
Average	**3.51**	9,619.70	**92.02**

Looking at the different urban demand nodes (Figure 5-6), the ones with the higher unmet demand, are UD_16_Kob.Daouce (with an annual average unmet demand of 0.69 mio m^3/year, or 1,880 m^3/day, or 18 lt/cap/day), and UD_16_Kob.Charbila (with an annual average unmet demand of 0.60 mio m^3/year, or 1,643 m^3/day, or ~16 lt/cap/day). The villages (Figure 5-7) that are grouped in these 2 nodes are:

- UD_16_Kob.Daouce: El-Kouachra, Daouce et Baghdadi, Denke et El-Amriyeh, El-Bire
- UD_16_Kob.Charbila: Charbila, Ain El-Zeit, El-Daghle, Kherbet Daoud, El-Msalle, Kefr El-Ftouh

The above findings are aligned with the 2020 NWSS Update (NWSS 2020, Volume IV, Appendix IV C5 – Water Balances, pages IV C127 – IV C 148). In this Appendix the potable water balances, i.e. water demand vs. existing water resources, are presented in detail for each distribution zone and system in Lebanon (Table 5-5). The villages of the Al-Ostuan River Basin fall within the districts of Qobayate (distribution systems No. 4, 5, 6-7, 11, 13, 17, 19, 20, 22, 23-24-12), Halba (distribution systems No. 1, 2, 3, 5-6A) and Sahel Akkar (distribution systems No. 1B, 1C, 3, 4). It needs to be noticed that there is no one-to-one match between the Al Ostuan villages and the different distribution systems as listed in the NWSS, since these distribution systems also include additional villages outside the Al-Ostuan boundaries in many cases. The calculated balances in the NWSS 2020 have been found negative in all the aforementioned Qobayate distribution systems (except the systems 4 and 5), and in all the aforementioned Halba distribution systems. In the Sahel Akkar distribution systems the balances were found even or slightly positive. The villages of the WEAP nodes UD_16_Kob.Daouce and UD_16_Kob.Charbila, which were found to have the higher urban unmet demands based on the results of the WEAP model, also present high unmet demands in the NWSS 2020 update, as they fall within the Qobayate distribution systems No. 22 (Charbila, Ain El-Zeit, El-Msalle, Kefr El-Ftouh), No. 23-24-12 (El-Daghle, Kherbet Daoud, El-Bire), No. 17 (El-Kouachra) and No. 13 (Daouce et Baghdadi, Denke et El-Amriyeh).

Table 5-5: Water Balances in the NWSS 2020 Update in the NLWE distribution systems which cover parts of the Al-Ostuan River Basin

Distribution System	Water Balance 2020 (m^3/day)
DISTRICT OF QOBAYATE	
Distribution System 4	245
Distribution System 5	4,213
Distribution System 6 & 7	-136
Distribution System 11	-843
Distribution System 13	-336
Distribution System 17	-538
Distribution System 20	-557
Distribution System 22	-1,484
Distribution System 23 & 24 $ 12	-5,672
DISTRICT OF HALBA	
Distribution System 1	-2,840
Distribution System 2	-424
Distribution System 3	-3,555
Distribution System 5 & 6A	-38
DISTRICT OF SAHEL AKKAR	
Distribution System 1B	1,800
Distribution System 1C	5,674
Distribution System 3	415
Distribution System 4	886

Note: This Table is based on the Tables IV B3, and Appendix IVC5 tables of the NWSS 2020 Update Volume IV. There is no one-to-one match between the Al Ostuan villages and the different distribution systems, since these distribution systems also include additional villages outside the Al-Ostuan boundaries in many cases.

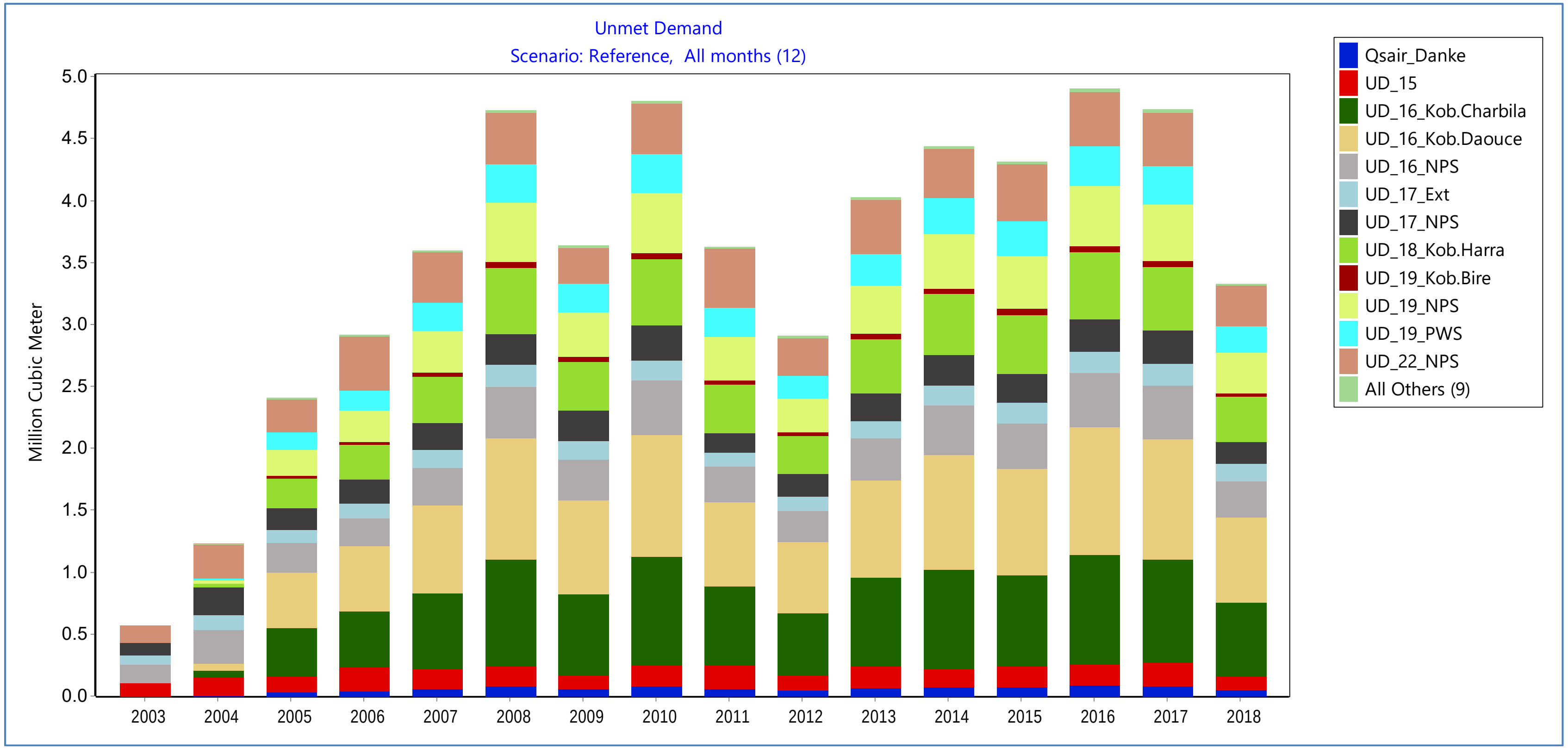


Figure 5-6: Urban unmet demand (mio m3) per year (from 2003-2018) in the 21 urban nodes of the Al Ostuan River Basin

Note: the villages grouped under each urban demand node are presented in the Legend below.

Figure 5-6 Legend:

Urban Demand Node	Villages grouped in the Node (CAD_NAME)	Total Node Population in WEAP, ORB
Qsair- Danke	Fixed exported volume (0.04 mio m³ per year on average)	
UD_15	Halba, Tal Abbas El-Gharbie, Koueikhat, Tal Abbas El-Charkie, Al-Massoudie, Al-Khraibe	3,009
UD_16_Kob.Charbila	Charbila, Ain El-Zeit, El-Daghle, Kherbet Daoud, El-Msalle, Kefr El-Ftouh	13,468
UD_16_Kod.Daouce	El-Kouachra, Daouce et Baghdadi, Denke et El-Amriyeh, El-Bire	15,658
UD_16_NPS	Katte, Al-Rihanie, El-Tleil, Omar el-Beikate, El-Haouchab, Hmais, Saidnaya, Al-Khraibe	6,652
UD_17_Ext	Dahr-Leycine, Machha, Hayzouk	7,614
UD_17_NPS	Al-Souaisse, Dahr el-Kneisse, Al-Khraibe	4,401
UD_18_Kob.Harra	El-Hed, Deir-Janine, Sfeinite El-Dreibe, Kherbet Char. Fseikine et Ain Achma, Barbara, Mazraat Balde	8,239
UD_19_Kob.Bire	Sindianet Zeidan	744
UD_19_NPS	Majdel, Daoura. Andeket, Akkar El-Atika	7,412
UD_19_PWS	El-Koubayat	4,876
UD_22_NPS	Al-Kleiat, Cheikh Zennad Tal Bibe, Al-Kneisse, Al Moghrak, Tal Kerri, Al-Hissa, Al-Massoudie	7,190
All Others (9 nodes)	UD_17_Kob.Harra (Kfar Harra), UD_18_Kob.Charbila (Ain Tanta, Douair Adouiye), UD_18_Ext (Beino), UD_18_NPS (Majdel), UD_20_NPS (Andeket), UD_20_PWS (Akkar El-Atika), UD_21_KobVillage_Jawz (El-Koubayet), UD_21_Qatlabah_Hamade (El-Koubayet), UD_21_NPS (Akkar El-Atika)	25,265

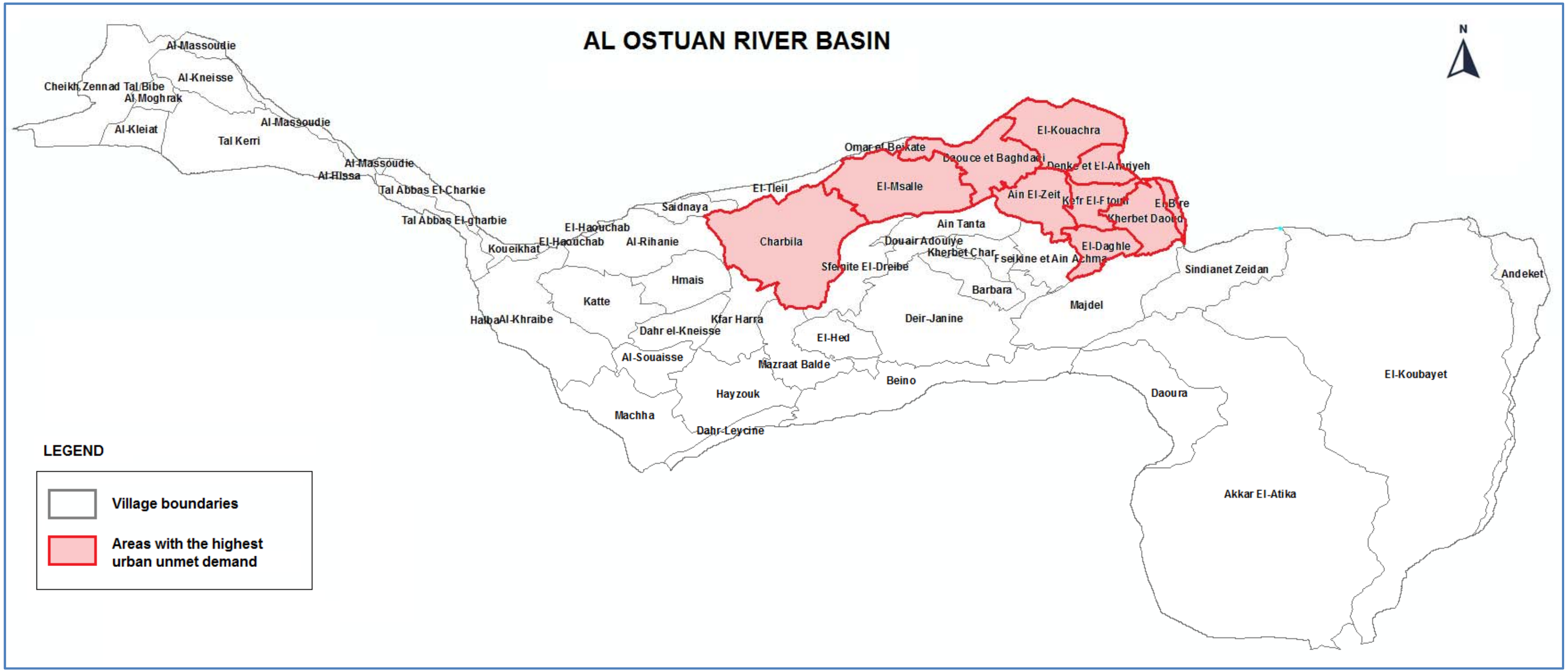


Figure 5-7: Villages with the highest Urban unmet demand (mio m3) per year (from 2003-2018) the Al Ostuan River Basin

The agricultural unmet demand is more pronounced than the domestic sector. The average annual irrigation unmet demand of the period 2003-2018 was 13.8 mio m^3/year (i.e. 76% of the average irrigation supply required), varying across the years (Table 5-6). The years with the highest unmet demand in the agricultural sector were 2010 (with ~17.5 mio m^3 of irrigation unmet demand), 2016 (with ~16.5 mio m^3 of irrigation unmet demand), and 2017 (with 16 mio m^3 of irrigation unmet demand). The years with the lowest unmet demand in the agricultural sector were 2003 (with 7.6 mio m^3 of irrigation unmet demand) and 2004 (with 11.7 mio m^3 of irrigation unmet demand).

Looking at the different irrigation demand nodes (Figure 5-8), the ones with the higher unmet demand, are Agri_15 (with an annual average unmet demand of 5.8 mio m^3/year), and Agri_16 (with an annual average unmet demand of 2.7 mio m^3/year). The villages that are located within these respective sub-catchments (Figure 5-9) are:

- Agri_15: Al-Khraibe, Koueikhat, Tal Abbas El-Charkie, Tal Abbas El-Gharbie, Al-Massoudie, , Halba (very small part of)
- Agri_16: Charbila, Ain El-Zeit, El-Daghle, Kherbet Daoud, El-Msalle, Kefr El-Ftouh, El-Kouachra, Daouce et Baghdadi, Denke et El-Amriyeh, El-Bire, Katte, Al-Rihanie, El-Tleil, Omar el-Beikate, El-Haouchab, Hmais, Saidnaya, Al-Khraibe

Table 5-6: Agricultural (irrigation) unmet demand (mio m3) per year in the Al Ostuan River Basin

Year	Total Agricultural Unmet Demand (mio m^3)	Agricultural Unmet Demand as % of the Total Agricultural Water Supply Required
2003	7.61	47%
2004	11.70	57%
2005	11.80	69%
2006	13.49	71%
2007	15.12	80%
2008	15.25	84%
2009	13.13	75%
2010	17.52	80%
2011	14.37	83%
2012	12.68	73%
2013	15.74	80%
2014	14.11	83%
2015	14.08	84%

Year	Total Agricultural Unmet Demand (mio m^3)	Agricultural Unmet Demand as % of the Total Agricultural Water Supply Required
2016	16.46	82%
2017	16.12	81%
2018	11.71	84%
TOTAL	**220.90**	**76%**
Average	**13.81**	**76%**

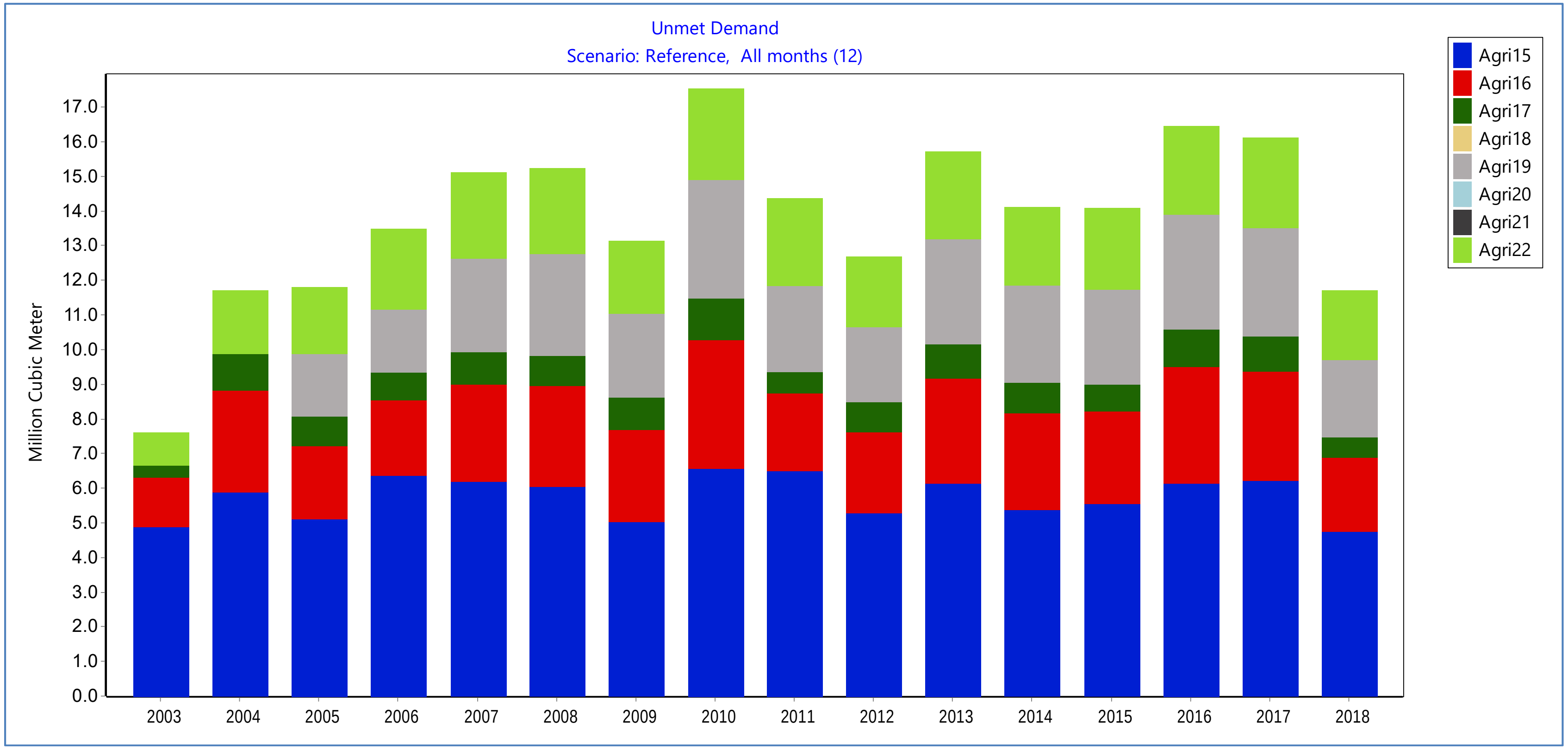


Figure 5-8: Unmet demand (mio m³) for irrigation per year (from 2003-2018) in the 8 agricultural nodes of the Al Ostuan River Basin

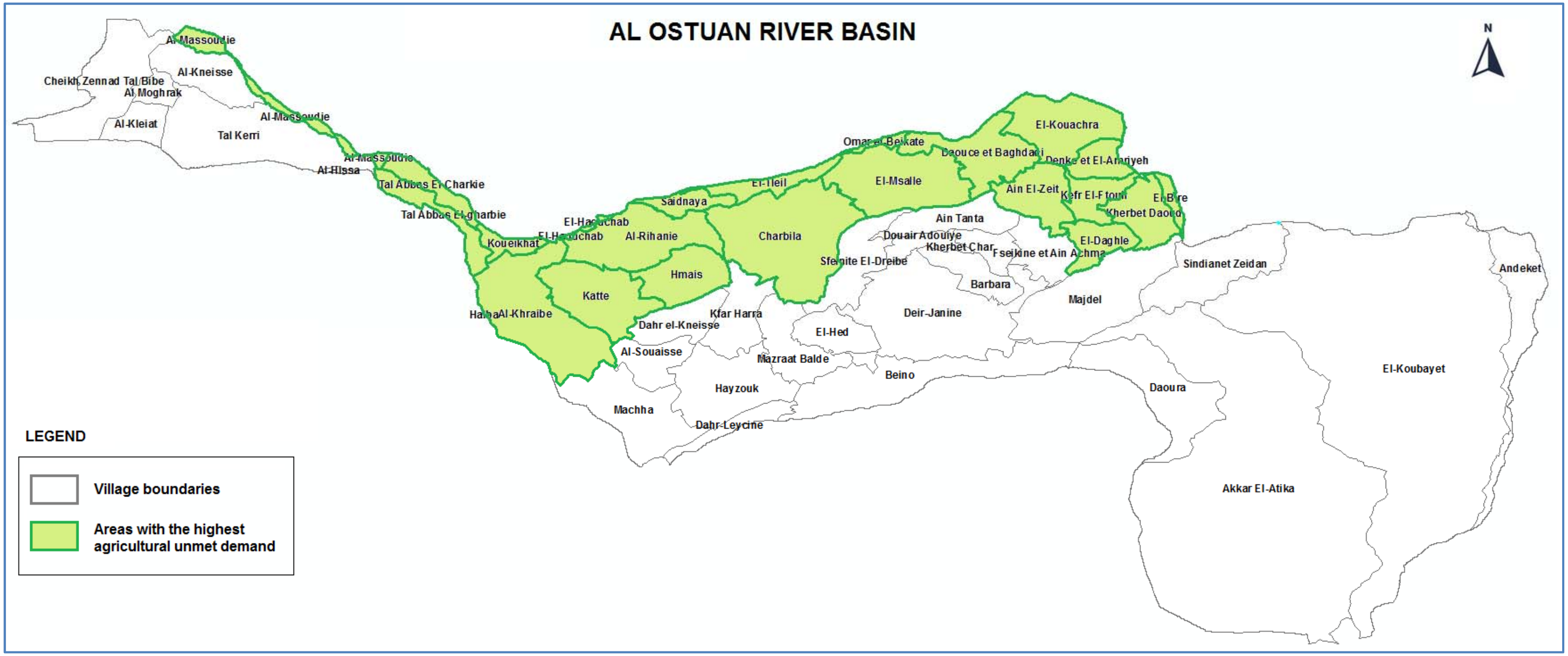


Figure 5-9: Villages with the highest Agricultural unmet demand (mio m3) per year (from 2003-2018) the Al Ostuan River Basin

The Reliability of the system in supplying the requested demand ranges among the uses. Reliability is defined as the percent of the timesteps in which a demand site's demand was fully satisfied. For example, if a demand site has unmet demands in 6 months out of a 10-year scenario, the reliability would be (10 * 12 - 6) / (10 * 12) = 95%.

As domestic use is priority 1, the water allocation to this use has an overall higher reliability comparing to the reliability of the irrigation. The average reliability across all the 21 urban demand nodes is 60%, ranging from as low as ~29% in some sites to 100% in others (

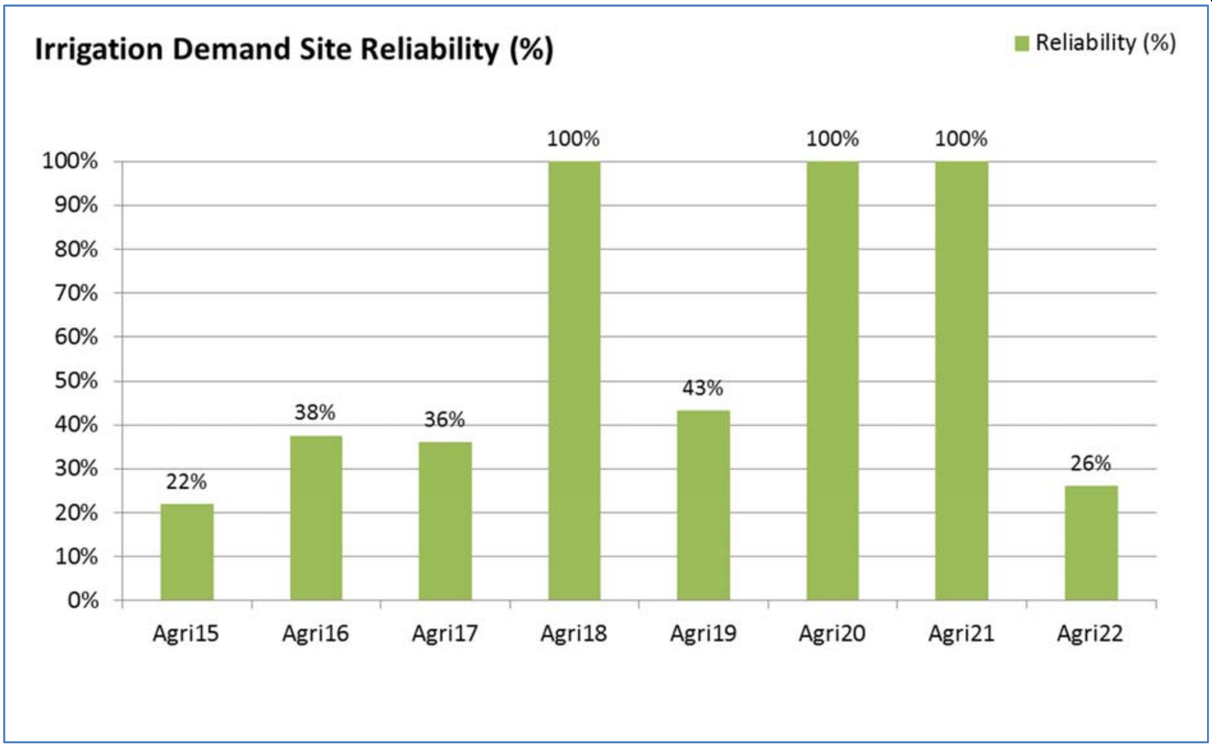


Figure **5-11**). The nodes with the highest water supply reliability are located in the sub-catchments C18, 20 and 21 (i.e. nodes UD_18_Ext, UD_18_Kob.Charbila, UD_18_NPS, UD_20_NPS, UD_20_PWS, UD_21_KobVillage_Jawz, UD_21_NPS, and UD_21_Qatlabah_Hamade) and have all 100% reliability. These nodes include the following villages: Ain Tanta, Douair Adouiye, Beino, Majdel, Andeket, Akkar El-Atika, El-Koubayet. On the other hand, the nodes UD_15, UD_17_Ext, UD_17_NPS, UD_22_NPS and UD_16_NPS exhibit less than 35% reliability. The later include the following villages: Katte, Al-Rihanie, El-Tleil, Omar el-Beikate, El-Haouchab, Hmais, Saidnaya, Al-Khraibe, Al-Kleiat, Cheikh Zennad Tal Bibe, Al-Kneisse, Al Moghrak, Tal Kerri, Al-Hissa, Al-Massoudie , Dahr-Leycine, Machha, Hayzouk, Al-Souaisse, Dahr el-Kneisse, Al-Khraibe, Koueikhat, Tal Abbas El-Charkie, Tal Abbas El-Gharbie, Al-Massoudie, Halba (very small part of).

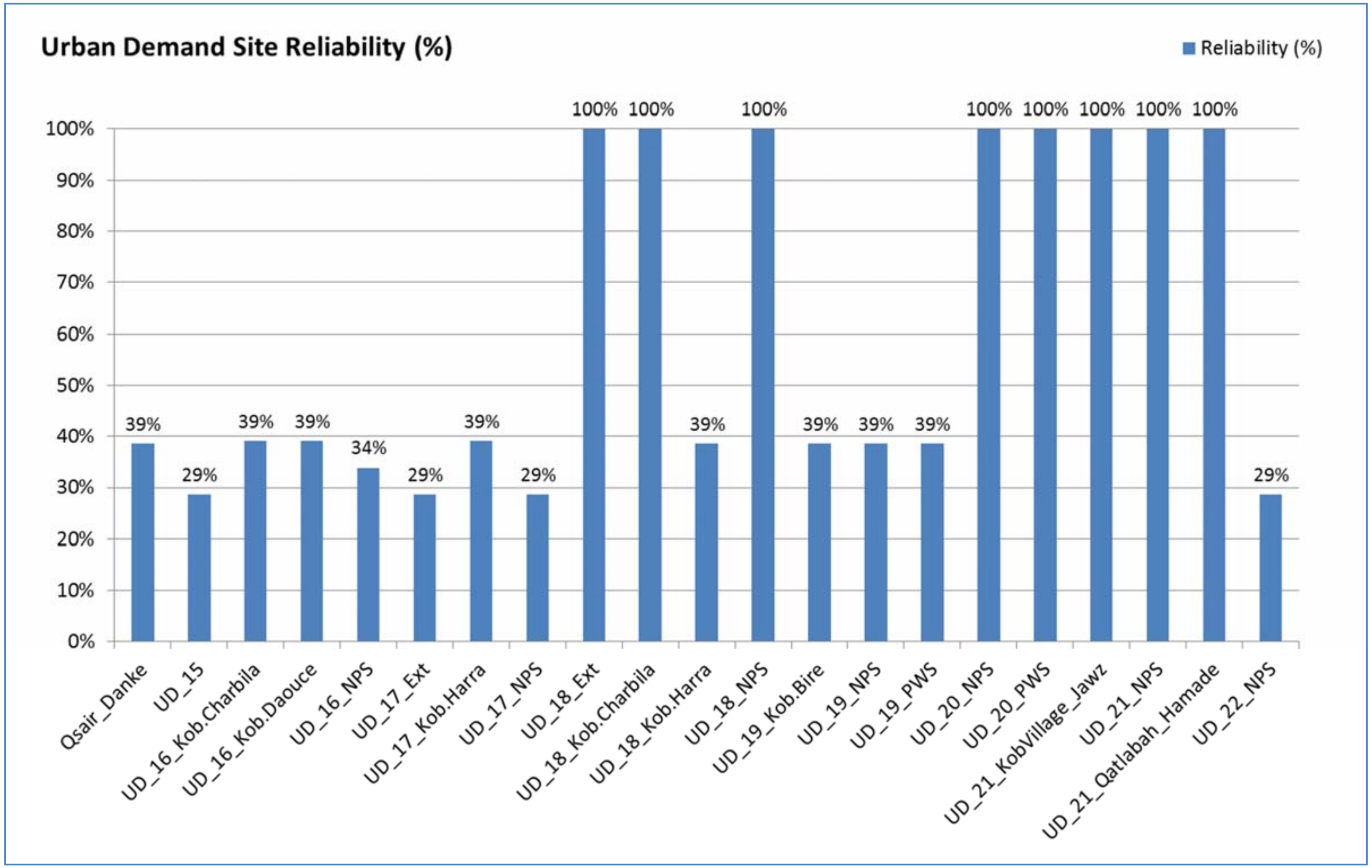


Figure 5-10: Reliability (%) of each urban demand site in the Al Ostuan River Basin

Reliability in the provision of water for irrigation is a bit lower than in the urban sector. The average reliability across all the 8 agricultural demand nodes is 58%, ranging from as low as 22% in some sites to 100% in others (

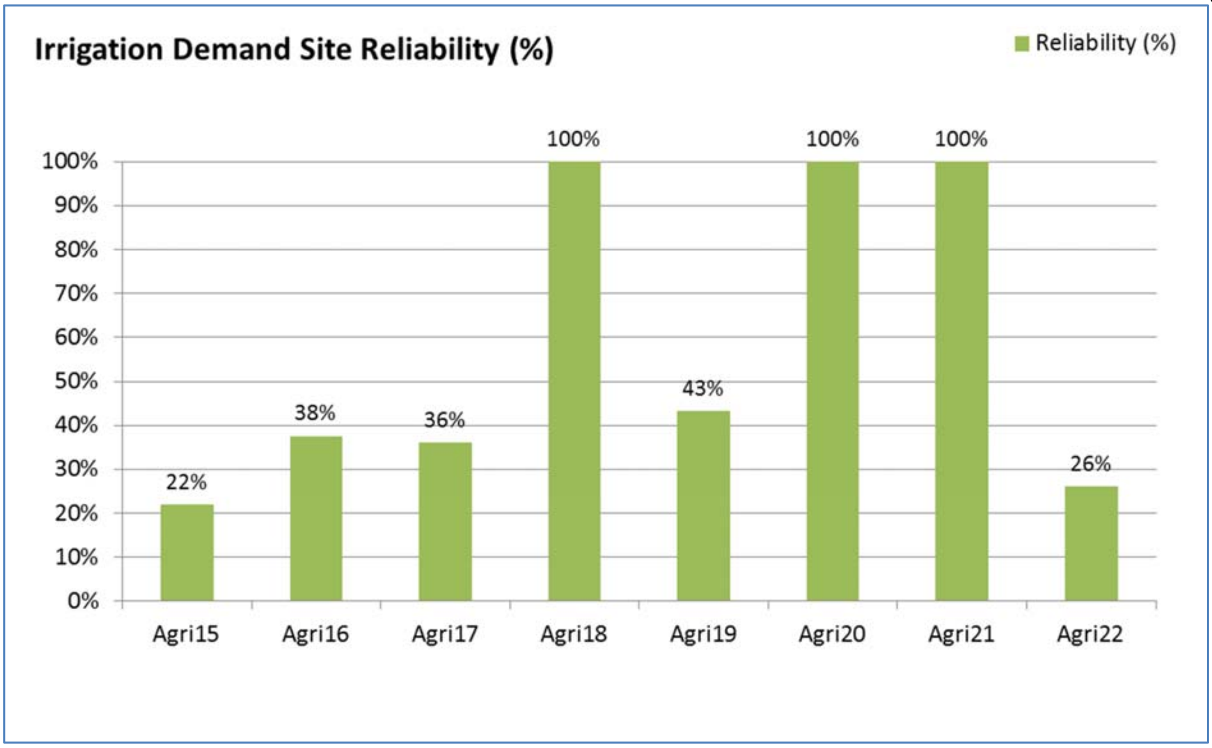


Figure **5-11**). The nodes with the highest water supply reliability are also located in the sub-catchments C18, 20 and 21 (i.e. nodes Agri18, Agri20, Agri21) and have all 100% reliability. These nodes include the following villages: Ain Tanta, Douair Adouiye, El-Hed, Deir-Janine, Sfeinite El-Dreibe, Kherbet Char, Fseikine et Ain Achma, Barbara, Mazraat Balbe, Beino, Majdel, Andeket, Akkar El-Atika, El-Koubayet. On the other hand, the nodes located in the sub-catchments C15, C22, C17, and C16. The lowest reliability (22%) is observed in Agri15 node in the sub-catchment C15 which includes the villages of Al-Khraibe, Koueikhat, Tal Abbas El-Charkie, Tal Abbas El-Gharbie, Al-Massoudie, Halba (very small part of). The node Agri22 in the sub-catchment C22 also exhibits very low reliability of 26% (includes the villages of Al-Kleiat, Cheikh Zennad Tal Bibe, Al-Kneisse, Al Moghrak, Tal Kerri, Al-Hissa, Al-Massoudie).

Table 5-7 summarizes the number of sites (nodes) per water use that fall under different reliability categories. The reliability categories have been defined as very high (>95%), high (80-95%), medium (60-80%), low (40-60%), and very low (<40%). Within the urban sector, 62% of the users have very low reliability of water supply. Only 38% have very high reliability. Within the agricultural sector, 50% of the users have very low reliability of irrigation, 12.5% low, and only 37.5% have very high reliability.

Table 5-7: Percent (%) of user for each use category (domestic, irrigation) that fall under the 5 reliability classes (very low, low, medium, high, very high) for the 16-year period 2003-2018

Reliability	Urban users	Irrigation users
Very High (>95%)	38%	37.5%
High (80-95%)	0%	0%
Medium (60-80%)	0%	0%
Low (40-60%)	0%	12.5%
Very Low (<40%)	62%	50%

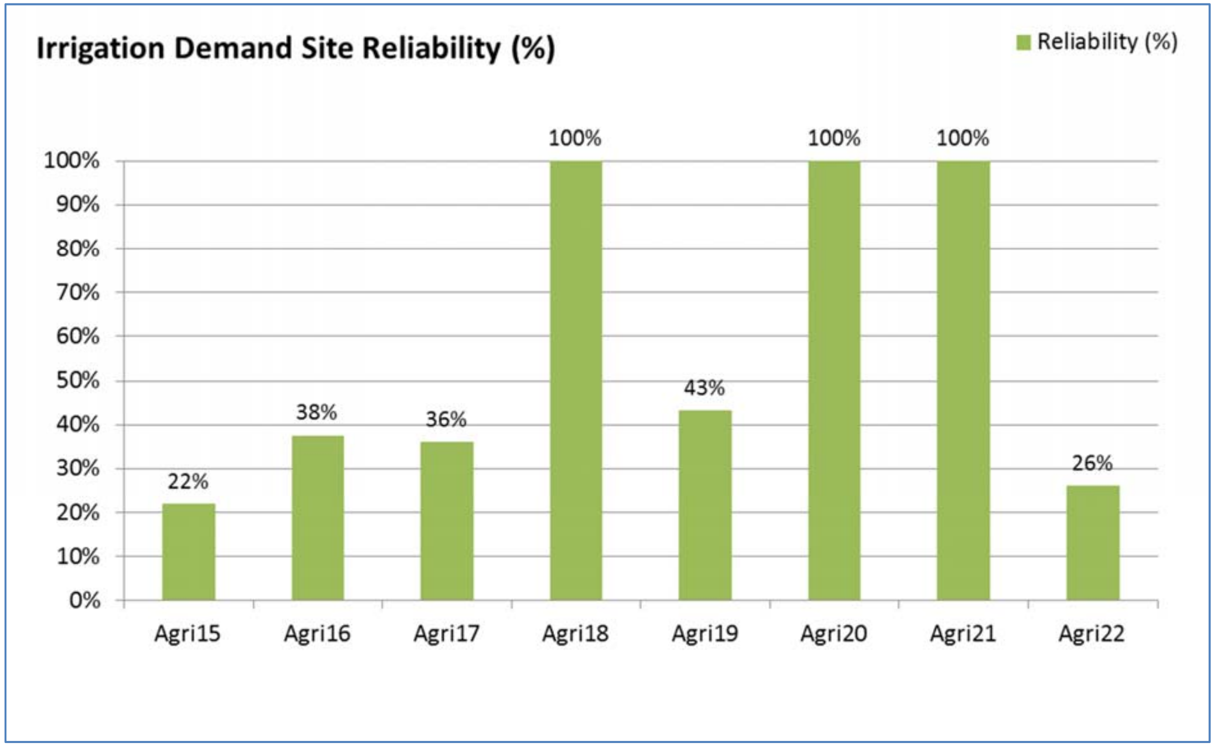


Figure 5-11: Reliability (%) of each agricultural demand site in the Al Ostuan River Basin

6 WATER POLLUTION ASSESSMENT IN THE AL OSTUAN RIVER BASIN

6.1 BACKGROUND AND OBJECTIVES OF THE WATER POLLUTION ASSESSMENT

There are multiple sources for the water contamination in the Ostuan River Basin, which has been identified as one of the polluted rivers in Akkar region in Northern Lebanon. The direct discharge of untreated wastewater from municipal areas and households has been identified as one of the major causes of environmental pollution. Moreover, outflows from the agricultural and farmlands to the Ostuan River or its tributaries can also be observed and are correlated particularly to the contamination of the water with heavy metals.

The lack of correct public networks and waste water treatment plants, increase the rate of pollution and contamination in the Al Ostuan River Basin since the untreated waste water is directly released to the river. Thus, the communities living in the Ostuan River basin consider improving the health of the river in parallel to addressing water scarcity as a priority since it directly impacts the health and wellbeing of the communities, the local agriculture, and the tourism sector.

Previous water quality studies that have been conducted in the past two decades in the area have revealed significant contamination levels in the water resources of the river basin due to microbiological and chemical contaminants, including heavy metals (Baroudi et al., 2012; Bouaoun and Nabbout, 2016). All these parameters can cause serious effect on human health and the ecosystem itself; therefore, their assessment and monitoring in the water resources of Ostuan river basin is of great environmental importance. The objective of the current work is to assess and provide a preliminary baseline for the surface water quality of the Ostuan river basin. Moreover, this work will assist in the data collection process for the Ostuan river by collecting and implementing information and data on the major water supply sources and the water abstraction points (springs, wells, etc.). In this context, a field investigation for the dry season was conducted on October 3rd, 2019 to select sampling points in terms of their representativeness to the major sources of the river. Following this field investigation, two water quality sampling campaign have been conducted (during the dry season in October 2019 and during the wet season in February 2021) where samples were collected from 17 sampling sites and analyzed in the laboratory of the University of Balamand.

The sites were selected to cover the upper area of the river where the river outflows. Condensed sampling was done in the middle of the river where it is mostly populated, and was followed by various sampling points at the vicinity of the outflow of uncontrolled and untreated wastewater discharge, near the most populated area at the bottom of the river. The samples were properly collected and preserved, and transported to the Environmental Engineering Laboratory (EEL) at the University of Balamand for analysis. Thirty one water quality parameters were analyzed; pH, water temperature, electric conductivity (EC), salinity, total dissolved solids (TDS), turbidity, and dissolved oxygen (DO) were measured on site using a HORIBA multi-parameter water checker model U-52. The analysis of ions such as chloride (Cl^-), sulphate ($SO4^{2-}$), fluoride (F^-), nitrate ($NO^-{}_3$), calcium (Ca^{2+}), phosphate (PO_4^{2-}), magnesium (Mg^{2+}), potassium (K^+), sodium (Na^+), and ammonium (NH^{4+}) was performed by Ion Chromatography and calcium carbonate. Furthermore, the heavy metals were analyzed by Inductively Coupled Plasma/Mass Spectrometry (ICP/MS) following EPA method 200-8. This study comprises also the analysis of the microbiology parameters such as biochemical oxygen demand (BOD_5), total coliforms, and Escherichia Coli (*E.Coli*). This information was embodied in GIS (Geographic Information System) by adding up all the data in consecutive layers (hydrogeology, irrigated land, crops, chemical, physical, and microbiological parameters) to better assess the Ostuan river basin.

In line with the current work, the specific objectives of this high-level policy-relevant water pollution assessment are to:

(1) evaluate the water quality of the Ostuan River located in the governorate of Akkar, North Lebanon,

(2) estimate the possible sources of pollution,

(3) define and map the critical sites based on the level of contamination,

(4) establish a full profile database on the water quality in the tested area, and

(5) develop an action plan and find effective suggestions for water treatment.

6.2 FIELD SAMPLING AND TESTING PROCEDURES

The sampling activities covered the different locations along the Ostuan river. Water samples were collected from 17 sampling points for both wet and dry season. Their respective coordinates and labeling are illustrated in Table 6-1 and Figure 6-1.

Table 6-1: Coordinates of the sampling points

Number	X	Y	Side ID
S1	36.2336	34.5032	Nabaa El Chouh El Ali
S2	36.2339	34.504	Nabaa El Chouh El Wati
S3	36.2367	34.5068	Nabaa El Jaouz
S4	36.2486	34.5154	Nabaa El Cheikh Jneid
S5	36.2508	34.5143	Nabaa Omar Kaylo
S6	36.245	34.539	Ain I Watyeh
S7	36.2422	34.5296	Ain I Homsiyeh
S8	36.265	34.5471	Ain El Abiad
S9	36.2747	34.5337	Nabaa Hmadeh
S10	36.117	34.5543	Ain I Fouar
S11	36.0964	34.5729	Nabaa El Qolqas
S12	36.2353	34.5274	Nabaa El Tine
S13	36.2378	34.5224	Ain Taqiyeh
S14	36.2808	34.5565	Ain El Set
S15	36.0986	34.5721	Nabaa Abou Chawkat
S16	36.2562	34.5597	Ain El Hajal
S17	36.2365	34.514	Ain Taba

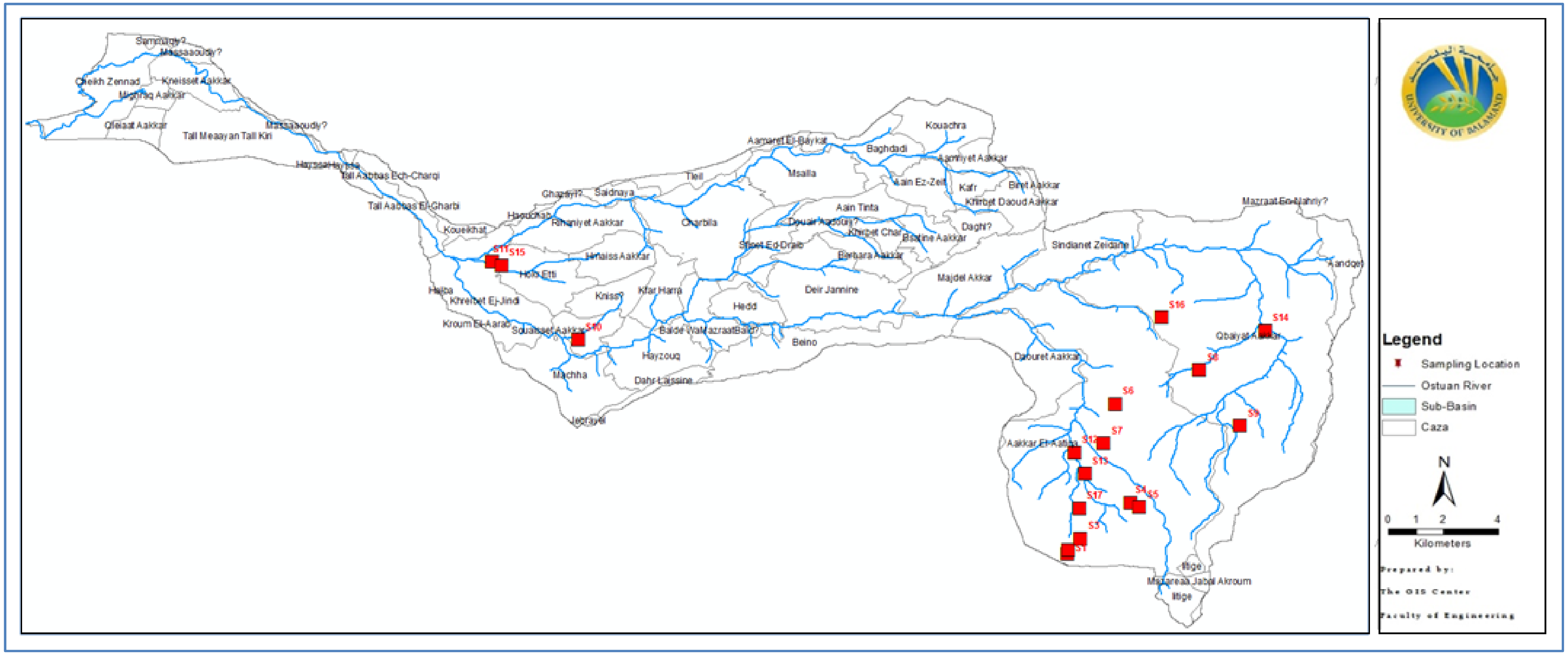


Figure 6-1: Location of the sampling points

Before the sampling campaign, a brief preparation for the water quality sampling was done. All the sampling and processing equipment were systematically cleaned. Samples were collected in one time using 500 ml polyethylene bottles for the physical and chemical analysis and 100 ml sterile cups for the microbiological analysis. Samples were stored at 4°C from the time of collection until the analysis. Afterward, the samples were transported to the Environmental Engineering Laboratory (EEL) at the University of Balamand for analysis. The pH, water temperature, electric conductivity (EC), salinity, total dissolved solids (TDS), turbidity, and dissolved oxygen (DO) were measured on site using a HORIBA multi-parameter water checker model U-52. The analysis of ions such as chloride (Cl-), sulphate (SO42-), fluoride (F-), nitrate (NO- 3), calcium (Ca2+), phosphate (PO42-), magnesium (Mg2+), potassium (K+), sodium (Na+), and ammonium (NH4+) were performed by Ion Chromatography and calcium carbonate. Furthermore, the heavy metals were analyzed by Inductively Coupled Plasma/Mass Spectrometry (ICP/MS) following EPA method 200-8. This study comprises also the analysis of the microbiology parameters such as biochemical oxygen demand (BOD5), total coliforms, and Escherichia Coli (E.Coli). Finally, the results obtained were analyzed and were illustrated by using the geographical information systems (GIS), thus producing decisive maps in terms of the water quality of each studied sampling sites. Additionally, these results were compared with the WHO, Lebanese and European standards for drinking water quality as seen in Appendix 1, 2 and 3.

6.3 RESULTS AND ANALYSIS OF WATER POLLUTION

A complete environmental data collection was performed for the dry season and the wet season for the Ostuan River, which allowed us to achieve a complete and proper monitoring of the water quality with the implementation of GIS maps to help in the mitigation steps. The sampling covered the chemical, physical, and microbiological parameters. The state of the water quality is the result of complex natural and man-made conditions and the consequent interactions in both time and space. Consequently, the monitoring and assessment of the surface water was performed to generally investigate whether the source of pollution is a point source or non-point source in case detected.

The water quality is normally assessed by measuring a broad range of parameters i.e. temperature, pH, electric conductivity, total dissolved solids, and the concentrations of the heavy metals. Time series of water quality parameters such as temperature, pH, EC, DO, and nutrients (N, P) can provide valuable information on the quality of the water, the likely sources of the variation, and their impacts on the functioning of the reservoir. In this study, water samples were analyzed for thirty-one different water parameters. Four parameters such as pH, dissolved oxygen, biochemical oxygen demand, and fecal coliform were used for the calculation of the water quality index following MPCB Water Quality Standards for best designated use. The analysis showed that river points collected during the dry sampling periods were in an average category with certainty level ranging above the WHO and Lebanese standards (Appendix 1,2 and 3), thus, being unsuitable for drinking purposes.

The results of the physical parameters of the dry sampling campaign are illustrated in Table 6-2. The results of the soluble ions and carbonates concentrations, pH and DO of the dry sampling campaign are illustrated in

Table 6-3. The results of the heavy metals concentrations of the dry sampling campaign are illustrated in Table 6-4. The results of the microbiological parameters of the dry sampling campaign are illustrated in Table 6-5.

Table 6-2: Results of the physical parameters of the dry sampling campaign

Sample	X	Y	Temperature °C	Conductivity µS/cm	Salinity %	TDS ppm
S1	36.2336	34.5032	14.25	391	0.02	255
S2	36.2339	34.504	12.58	399	0.02	258
S3	36.2367	34.5068	11.12	416	0.02	271
S4	36.2486	34.5154	14.18	598	0.03	383
S5	36.2508	34.5143	14.21	506	0.02	324
S6	36.245	34.539	15.02	538	0.03	344
S7	36.2422	34.5296	10.57	452	0.02	299
S8	36.265	34.5471	11.38	444	0.02	287
S9	36.2747	34.5337	14.63	640	0.03	409
S10	36.117	34.5543	16.01	661	0.03	423
S11	36.0964	34.5729	14.69	772	0.04	494
S12	36.2353	34.5274	15.13	707	0.03	455
S13	36.2378	34.5224	14.43	698	0.01	1001
S14	36.2808	34.5565	19.21	625	0.03	400
S15	36.0986	34.5721	19.3	617	0.03	395
S16	36.2562	34.5597	30.79	523	0.03	336
S17	36.2365	34.514	23.43	650	0.03	416
Max			**30.79**	**772**	**0.04**	**1001**
Min			**10.57**	**391**	**0.01**	**255**
Avg			**15.94**	**566.88**	**0.03**	**397.06**

Table 6-3: Results of the soluble ions and carbonates concentrations, pH and DO of the dry sampling campaign

Sample	Carbonates mg/L	Avg Flu mg/L	Avg Cl mg/L	Avg-SO4 mg/L	Avg NO3 mg/L	Avg NO2 mg/L	Avg Na mg/L	Avg K mg/L	Avg Mg mg/L	Avg Cal mg/L	pH (n.u)	DO mg/L
S1	197.91	0.11	5.22	4.58	8.10	1.39	3.71	0.37	25.05	66.51	8.19	5.62
S2	185.08	0.10	5.48	4.59	8.43	1.40	3.88	0.36	24.98	66.69	8.51	6.23
S3	190.42	0.10	5.63	4.82	8.86	1.66	4.13	0.38	26.72	69.28	8.38	6.32
S4	224.66	0.03	12.55	11.66	11.21	7.35	7.90	0.72	27.61	102.50	8.15	5.22
S5	246.05	0.08	9.61	15.06	9.15	9.69	6.53	0.82	24.73	83.94	8.13	5.13
S6	213.96	0.08	9.75	15.16	9.90	10.23	6.67	0.80	24.89	89.49	8.16	6.41
S7	214.60	0.08	7.62	5.66	9.45	2.65	4.88	0.52	25.81	72.17	8.41	6.12
S8	203.80	0.08	7.30	5.07	9.32	2.28	4.70	0.42	27.43	73.75	7.86	5.66
S9	254.61	0.07	14.94	9.52	11.29	4.49	9.60	0.75	41.32	88.23	8.11	6.27
S10	202.19	0.10	19.68	14.98	11.59	15.01	13.67	2.38	41.75	87.53	8.34	5.71
S11	215.03	0.12	17.01	61.88	11.97	19.02	11.30	2.07	37.42	123.63	7.76	4.81
S12	227.87	0.11	19.48	11.62	13.58	5.19	12.54	1.34	40.70	102.69	7.93	5.11
S13	230.01	0.08	16.27	8.13	13.22	2.41	9.67	0.57	30.94	112.62	7.80	6.56
S14	267.45	0.15	21.70	16.47	11.14	7.97	16.58	1.90	30.49	99.65	8.32	4.98
S15	213.43	0.10	21.00	16.67	11.08	7.56	16.35	1.82	30.50	96.83	8.25	5.62
S16	201.12	0.12	32.47	8.98	8.85	6.81	30.57	0.54	27.22	59.00	8.44	6.01
S17	234.29	0.08	29.05	22.05	11.18	12.06	24.47	0.18	2.36	91.67	8.02	5.78
Max	**267.45**	**0.15**	**32.47**	**61.875**	**13.58**	**19.015**	**30.565**	**2.375**	**41.75**	**123.63**	**8.51**	**6.56**
Min	**185.07**	**0.03**	**5.22**	**4.58**	**8.1**	**1.385**	**3.705**	**0.175**	**2.36**	**59**	**7.76**	**4.81**
Avg	**218.97**	**0.09**	**14.98**	**13.93**	**10.49**	**6.89**	**11.01**	**0.94**	**28.82**	**87.42**	**8.16**	**5.74**

Table 6-4: Results of the heavy metals concentrations of the dry sampling campaign

Sample	27Al µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L	59Co µg/L	60Ni µg/L	63Cu µg/L	66Zn µg/L	111Cd µg/L	201Hg µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L
S1	19.872	0.419	0.308	8.692	0.047	0.898	46.268	41.772	0.015	16.744	2.713	2.781	2.732
S2	23.271	0.972	0.514	10.929	0.049	1.159	58.197	52.705	0.038	26.982	3.44	3.444	3.425
S3	17.519	0.337	0.283	10.271	0.053	1.093	56.814	50.19	0.03	21.424	3.258	3.373	3.349
S4	14.381	0.527	0.72	9.075	0.076	2.057	36.845	36.27	0.023	17.256	2.425	2.277	2.418
S5	20.657	0.363	0.368	11.618	0.06	1.255	59.605	55.786	0.023	17.037	3.665	3.437	3.62
S6	22.748	0.392	0.463	12.186	0.073	1.258	57.352	62.14	0.053	16.598	3.424	3.444	3.389
S7	24.579	3.188	0.505	11.178	0.057	0.927	60.423	83.068	0.038	16.526	3.626	3.533	3.588
S8	23.271	0.378	0.505	23.968	0.037	1.097	59.583	72.598	0.015	14.112	3.526	3.533	3.509
S9	25.888	0.489	0.471	13.49	0.059	1.203	56.277	77.974	0.03	12.796	3.267	3.291	3.29

Sample	27Al µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L	59Co µg/L	60Ni µg/L	63Cu µg/L	66Zn µg/L	111Cd µg/L	201Hg µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L
S10	20.918	0.359	0.291	10.792	0.062	0.821	58.129	76.903	0.046	11.845	3.33	3.281	3.336
S11	22.226	0.426	0.36	11.406	0.05	1.063	61.126	79.761	0.008	11.114	3.532	3.469	3.516
S12	21.964	0.344	0.463	10.637	0.05	1.019	56.853	53.212	0.068	10.821	3.369	3.36	3.368
S13	25.625	0.32	0.368	11.579	0.053	0.916	61.007	63.196	0.015	12.138	3.549	3.624	3.523
S14	25.624	0.274	0.36	12.047	0.048	0.92	60.315	76.153	0.046	13.015	3.486	3.467	3.531
S15	18.042	0.676	0.385	10.697	0.06	1.06	55.92	72.843	0.015	13.966	3.212	3.354	3.286
S16	23.794	0.424	0.36	11.581	0.049	0.861	62.457	68.882	0.053	10.383	3.639	3.644	3.627
S17	25.625	0.407	0.377	11.615	0.058	0.883	63.32	60.593	0.03	10.383	3.577	3.487	3.62
Max	25.888	3.188	0.72	23.968	0.076	2.057	63.32	83.068	0.068	26.982	3.665	3.644	3.627
Min	14.381	0.274	0.283	8.692	0.037	0.821	36.845	36.27	0.008	10.383	2.425	2.277	2.418
Avg	22.12	0.61	0.42	11.87	0.06	1.09	57.09	63.77	0.03	14.89	3.36	3.34	3.36

Table 6-5: Results of the microbiological parameters of the dry sampling campaign

Sample	X	Y	Ecoli MPN	Fecal MPN	BOD mg/L
S1	36.2336	34.5032	250	179	10
S2	36.2339	34.504	212	76	14
S3	36.2367	34.5068	235	94	17
S4	36.2486	34.5154	113	19	17
S5	36.2508	34.5143	289	198	20
S6	36.245	34.539	140	35	32
S7	36.2422	34.5296	64	31	23
S8	36.265	34.5471	94	52	26
S9	36.2747	34.5337	201	15	17
S10	36.117	34.5543	206	20	40
S11	36.0964	34.5729	126	26	18
S12	36.2353	34.5274	118	41	28
S13	36.2378	34.5224	109	14	25
S14	36.2808	34.5565	232	206	48
S15	36.0986	34.5721	201	203	10
S16	36.2562	34.5597	95	0	54
S17	36.2365	34.514	352	212	68
Max			**352**	**212**	**68**

Sample	X	Y	Ecoli MPN	Fecal MPN	BOD mg/L
Min			64	0	10
Avg			178.65	83.59	27.47

6.3.1 TEMPERATURE

Temperature is one of the most important factors for survival of aquatic life. A moderate change in temperature can seriously affect the aquatic environment, including bacteria, algae, invertebrates, and fish. Water temperatures fluctuate naturally both daily as well as seasonally.

The temperature of the studied water samples in the dry season ranged between 10°C and 31°C (Figure 6-2). 70.58% of the water samples were below the standard value set by the EPA (16˚C) and 76.5% of the water samples were below 18˚C, standard value set by the Lebanese decree 1/52 (Lebanese). This sampling campaign was conducted in the dry season which is characterized by high atmospheric temperature leading to the increase in the temperature of the watercourses. The highest temperature values (above 18°C) were recorded at sites S14, S15, S16, and S17. The temperature increase can lead to a reduction in the amount of dissolved oxygen and hence BOD and COD increases. This is in correlation with the BOD values obtained at sites S14 (48 mg L-1), S16 (54 mg L-1), and S17 (68 mg L-1). Moreover, the E.coli results showed high values at S14 (232MPN/ 100mL), S15 (201 MPN/ 100mL), S16 (95 MPN/ 100mL), and S17 (352 MPN/ 100mL).These values were seen to be above the acceptable range set by the different standards either WHO, EPA and Libnor.

The temperature of the studied water samples in the wet season ranged between 8.78°C and 17.33°C (

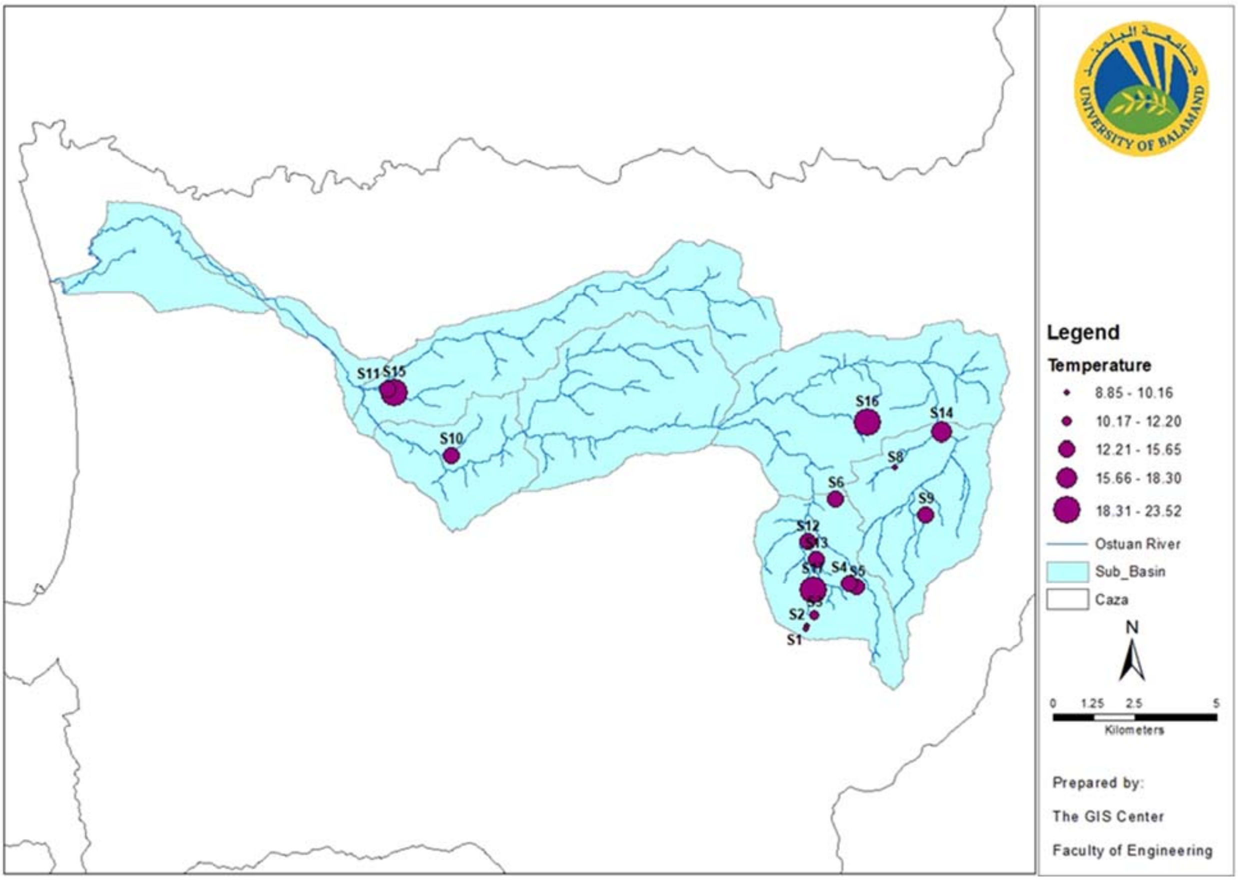


Figure 6-3). 87.5% of the water samples were below the standard value set by the EPA (16˚C) and 100 % of the water samples were below 18˚C, the standard value set by the Lebanese decree 1/52 (Lebanese). This sampling campaign was conducted in the wet season, which is characterized by low atmospheric temperature leading to a decrease in the temperature of the watercourses. The highest temperature values were recorded at sites S15 and S16.The increase in the temperature values is in correlation with the high values of COD obtained at sites S15 (475 mg L^{-1}) and S16 (332 mg L^{-1}) and the high E.Coli values, which were seen to be above 10000 MPN/ 100 mL. These values are above the acceptable range set by the different standards either WHO, EPA, or Libnor.

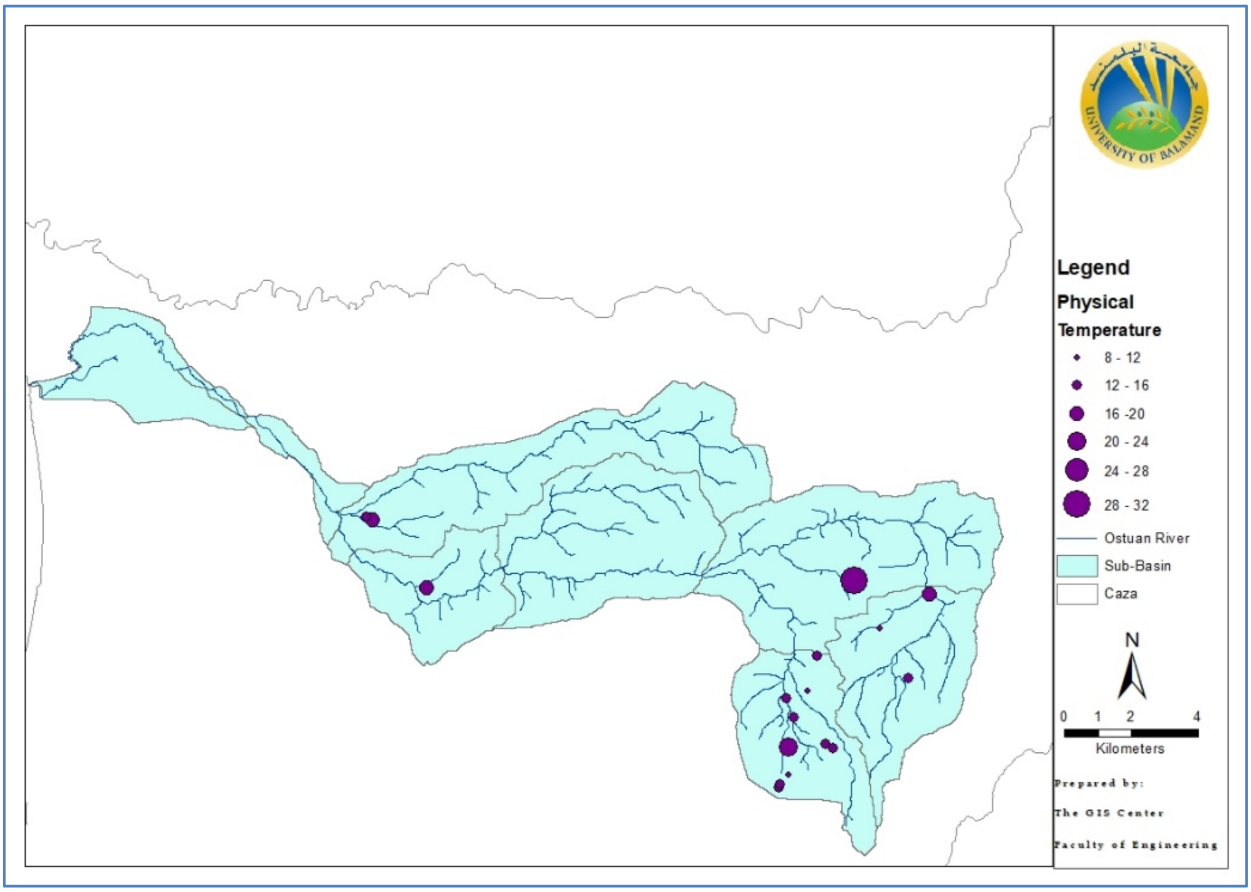


Figure 6-2: Temperature values for the studied sampling sites (dry season)

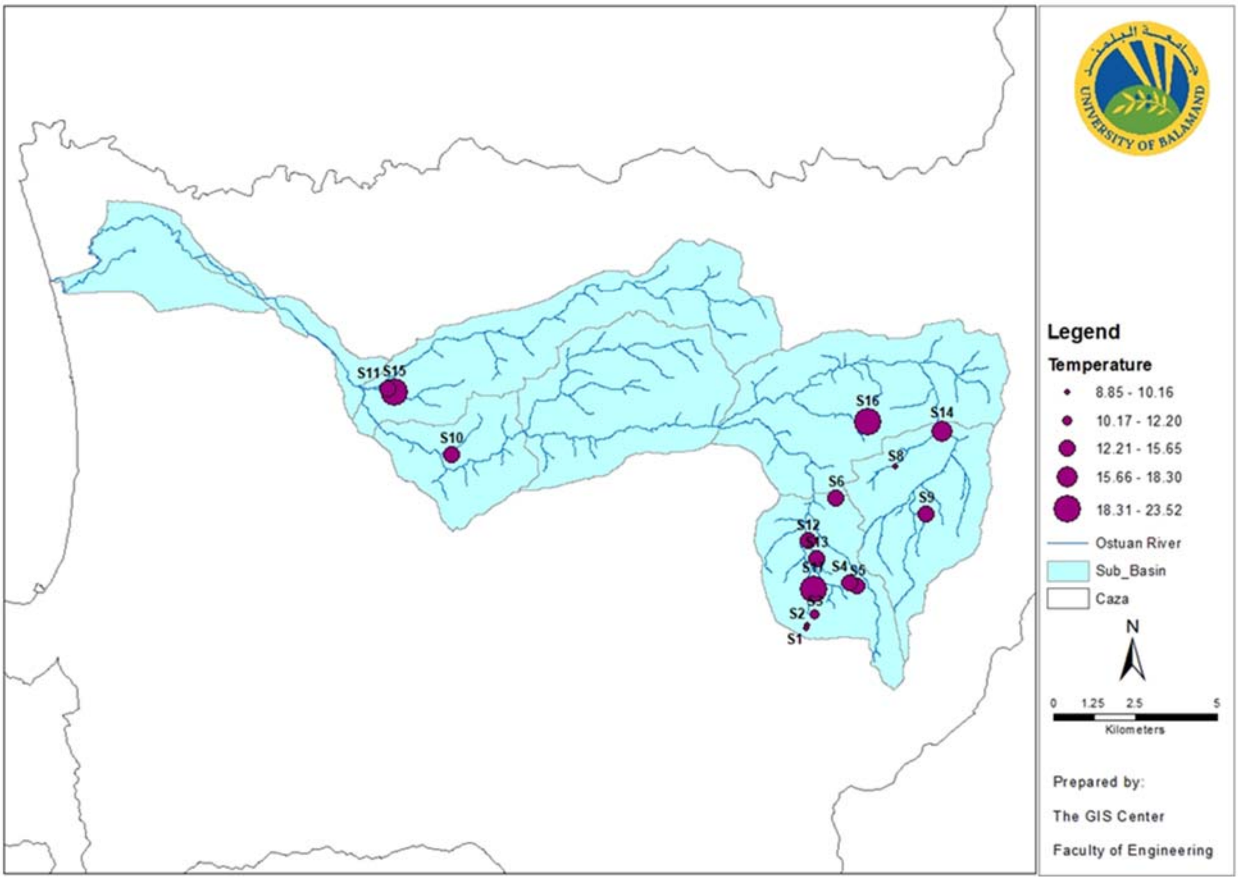


Figure 6-3: Temperature values for the studied sampling sites (wet season)

6.3.2 PH

pH is defined as the concentration of hydrogen ions in a solution. It is the indicator of acidic or alkaline condition of water. The water samples analyzed in the dry season were slightly alkaline with a pH value ranging between 7.8 and 8.5 (Figure 6-4). However, all these values were within the standard values set by the Lebanese decree 1/52 (6.5-8.5) (see Appendix 3). It is important to highlight that alkaline water is strictly toxic to aquatic life. The water samples analysed in the wet season showed higher alkalinity compared to the dry season with pH value ranging between 7.46 and 8.5 (Figure 6-5).

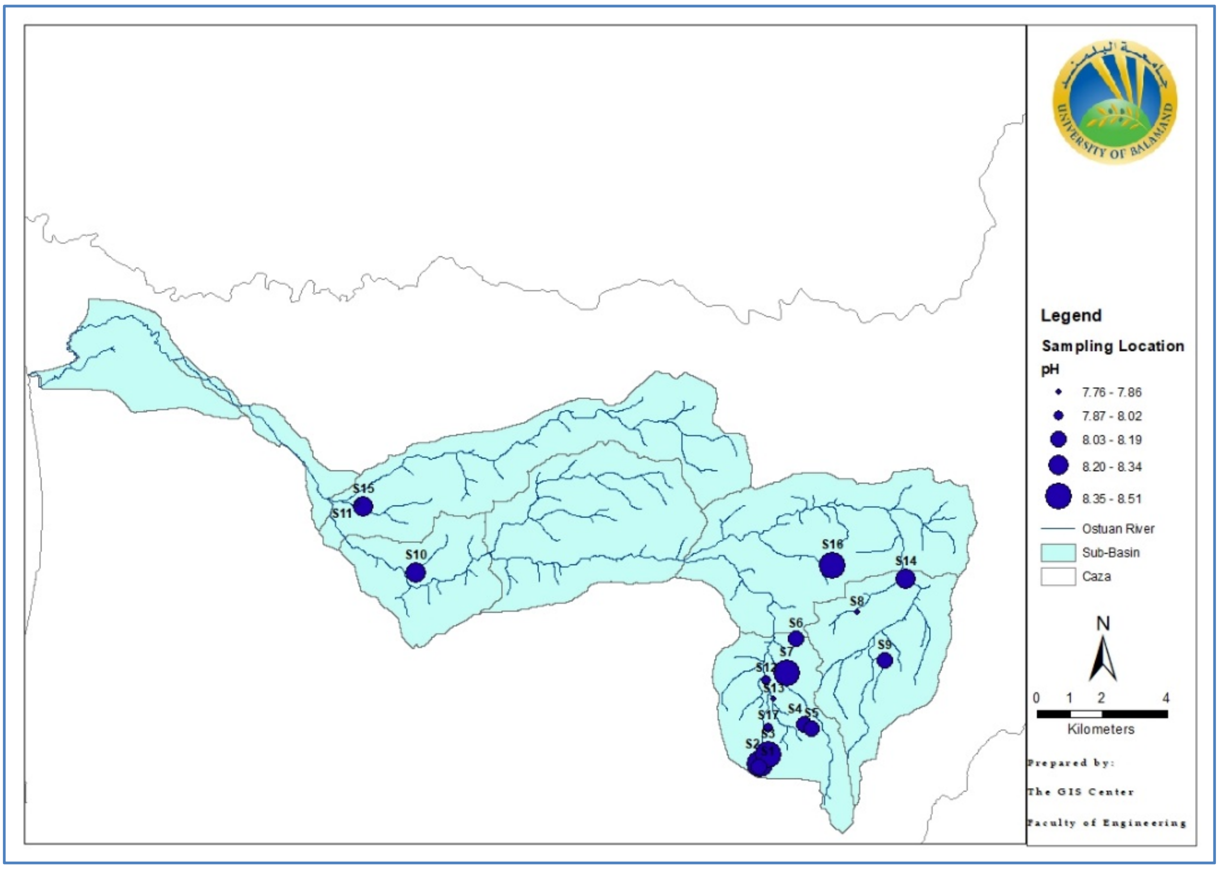


Figure 6-4: Variation of pH in the sampling sites of Ostuan River (dry season)

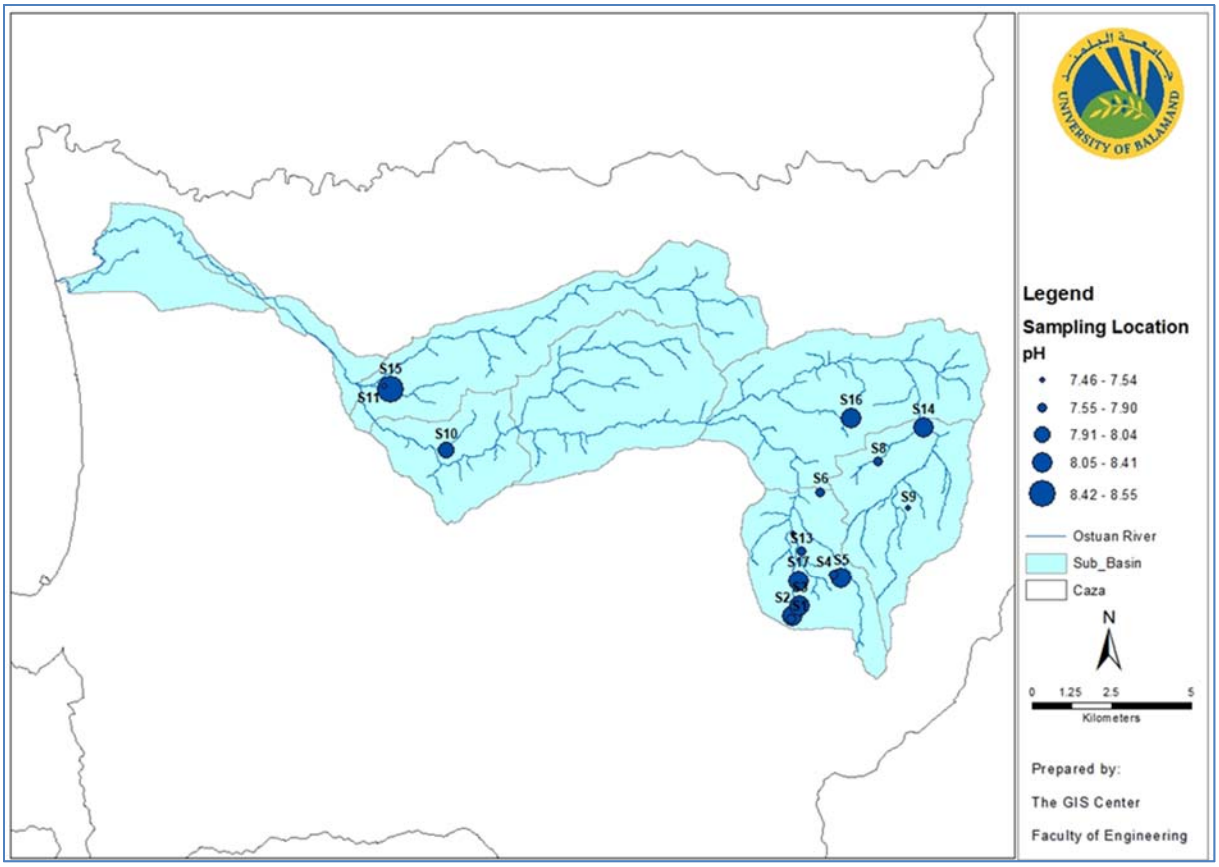


Figure 6-5: Variation of pH in the sampling sites of Ostuan River (wet season)

6.3.3 CARBONATES

Figure 6-6 presents the concentration of CO_3^{2-} in the surface water of Ostuan River during the dry season, ranging from 185.07 mg L^{-1} at S2 to 267.45 mg L^{-1} at S14. Figure 6-7 presents the concentration of CO_3^{2-} in the surface water of the Ostuan River during the wet season, ranging from 205.02 mg $^{L-1}$ at S2 to 367.2 mg $^{L-1}$ at S14In all the studied samples, the amounts of carbonates were higher than the standard value. However, these values are consistent with the geology of the area. Generally, the erosion of limestone rocks leads to an increase in the concentrations of carbonates in water. In return, these high concentrations are responsible for the slight increase in the pH values observed in all the studied sampling sites. The values obtained in the wet season were higher than those of the dry season due to erosion and runoff events.

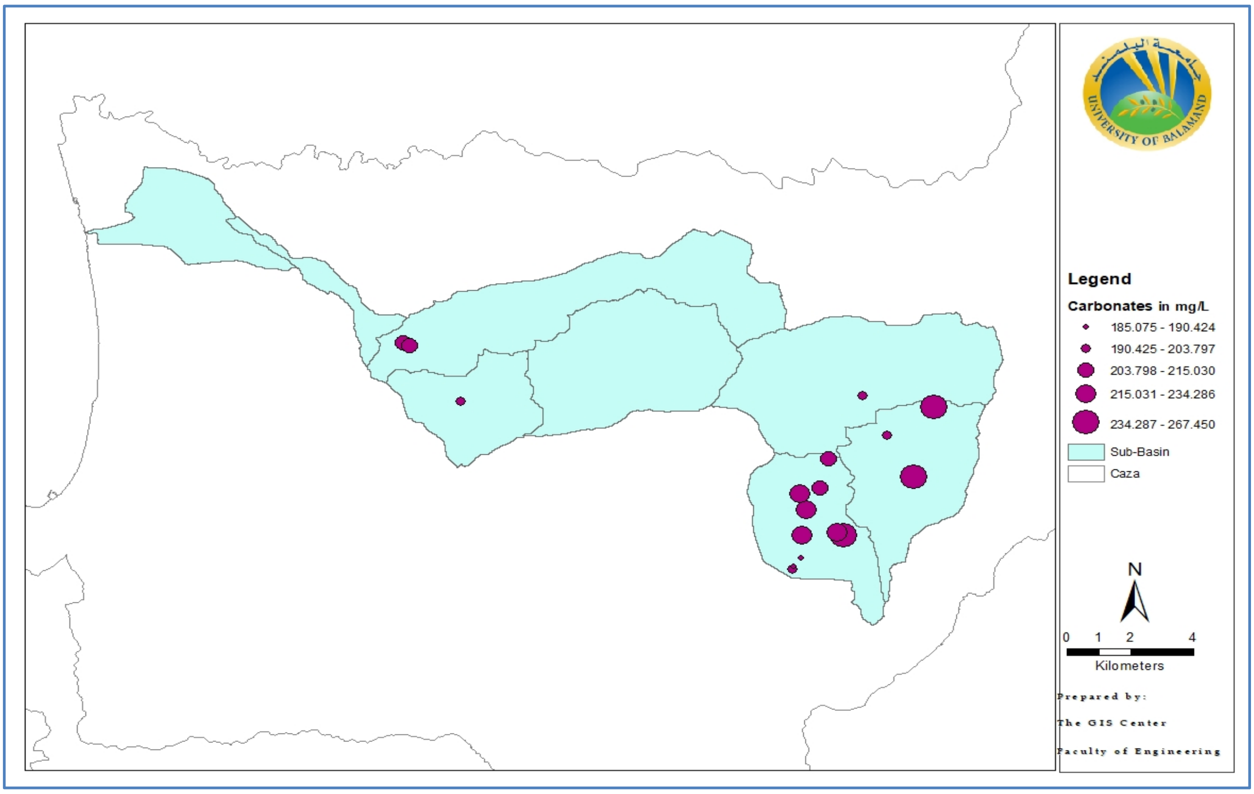


Figure 6-6: Variation of Carbonate in the sampling sites of Ostuan River (dry season)

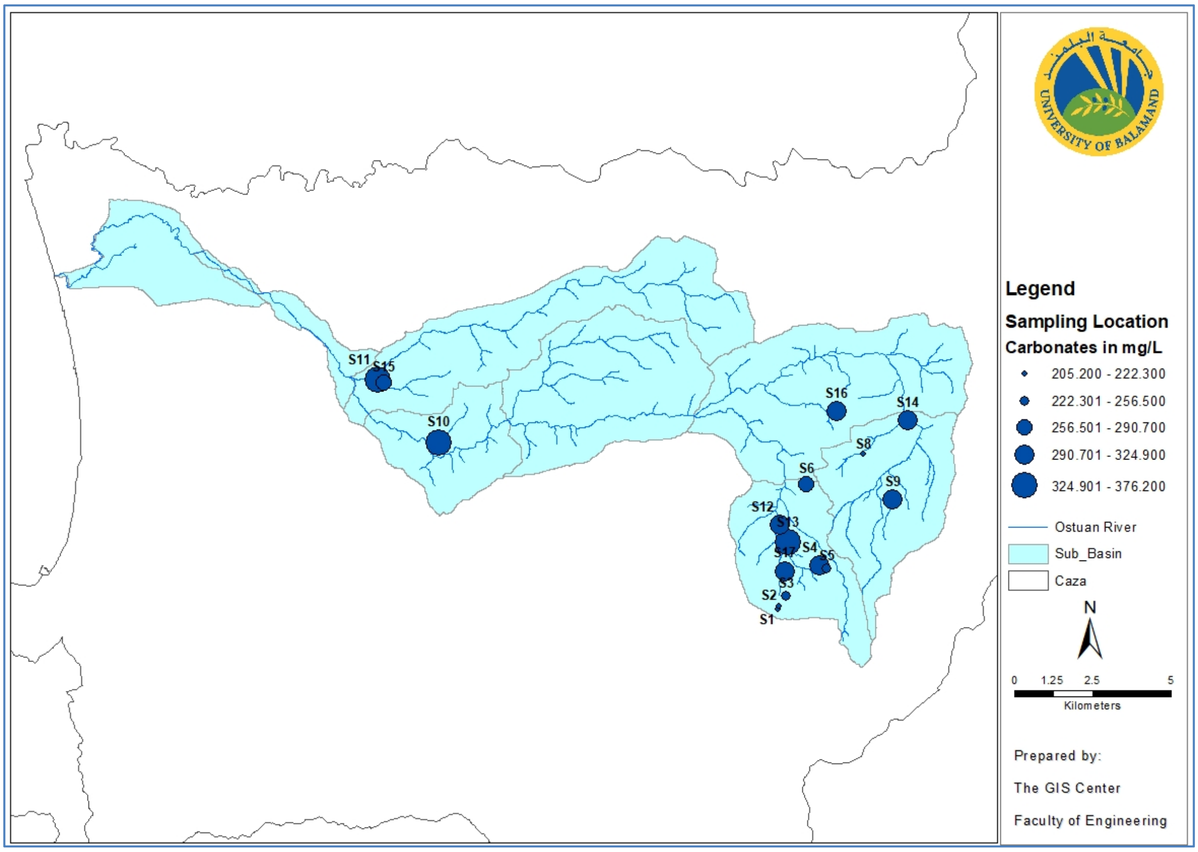


Figure 6-7: Variation of Carbonate in the sampling sites of Ostuan River (wet season)

6.3.4 ELECTRICAL CONDUCTIVITY

Electrical conductivity is a measure of the ability of an aqueous solution to carry an electric current and depends on the presence of ions, on their total concentration, mobility, and temperature. It is associated with major water quality parameters due to the dilution effect of the stream flow and can be used as an indicator in determining the suitability of water for irrigation. The electrical conductivity is also considered to be a rapid and good measure of dissolved solids which reflects the pollution status of the water resources. The low conductivity might be responsible for the soft nature of the water and the significant changes in the conductivity may be an indicator of a discharge or implication of other sources of pollution into the stream. The electrical conductivity is in direct correlation with the temperature; thus the increase in temperature leads to an increase in the conductivity. Figure 6-8 illustrates the variation of the conductivity of the samples during the dry seasons. These values ranged between 391 and 772 µS/cm. The highest values were observed at sites S11 (772 µS/cm), S12 (707 µS/cm), and S13 (698 µS/cm). These values are associated with the high concentrations of ionic compounds observed in the water of these sampling sites S11 (Ca: 123.7 mg L^{-1}, Mg: 37.5 mg L^{-1}), S12 (Ca: 102.7 mg L^{-1}, Mg: 40.7 mg L^{-1}), and S13 (Ca: 112.6 mg L^{-1}, Mg: 30.9 mg L^{-1}). The values for conductivity were below the Maximum Contaminant Level (MCL) (1500 µS/cm).

The values for the electrical conductivity obtained for the wet season were similar to those obtained during the dry season (Figure 6-15). These values ranged between 384 and 776 µS/cm. The highest values were observed at sites S11 (776 µS/cm), S16 (694 µS/cm), S13 (681 µS/cm), and S12 (670 µS/cm).

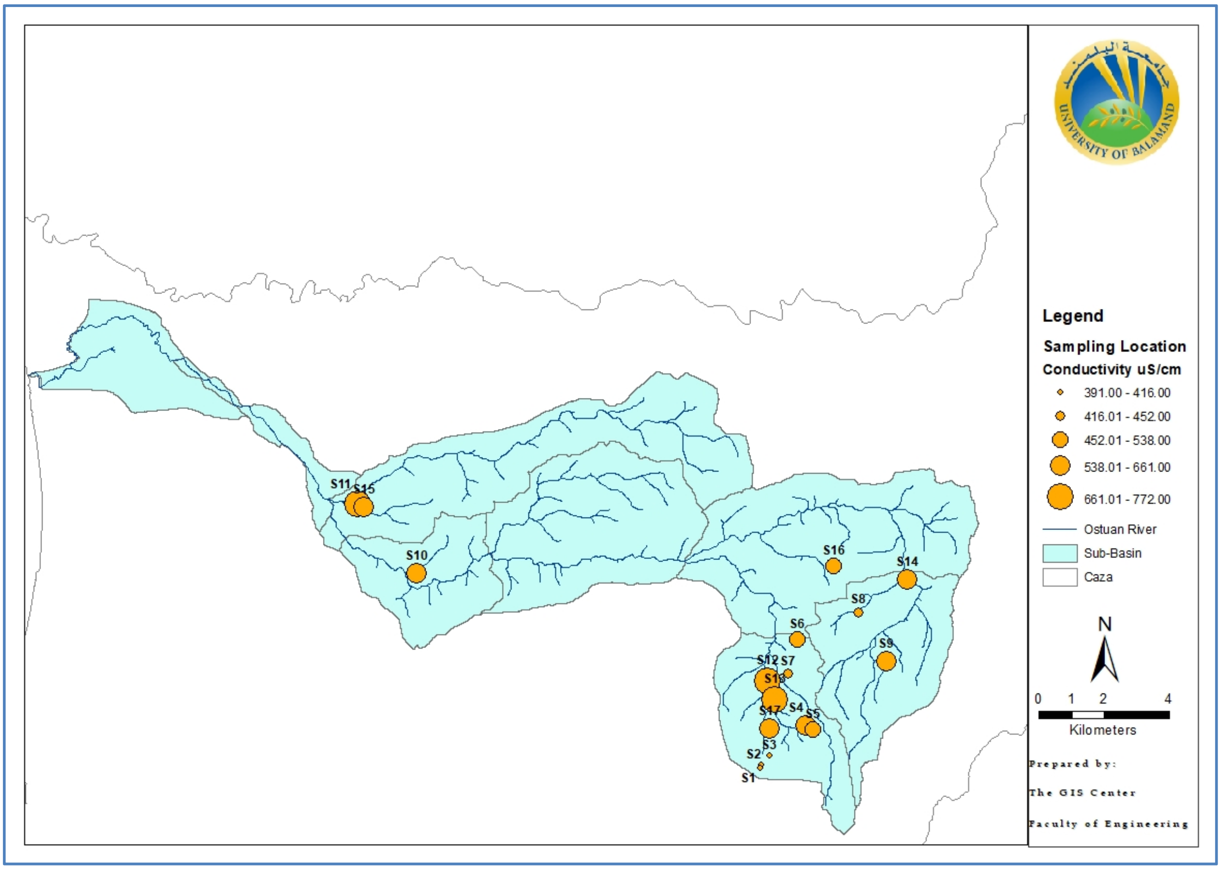


Figure 6-8: Variation of Conductivity in the sampling sites of Ostuan River (dry season)

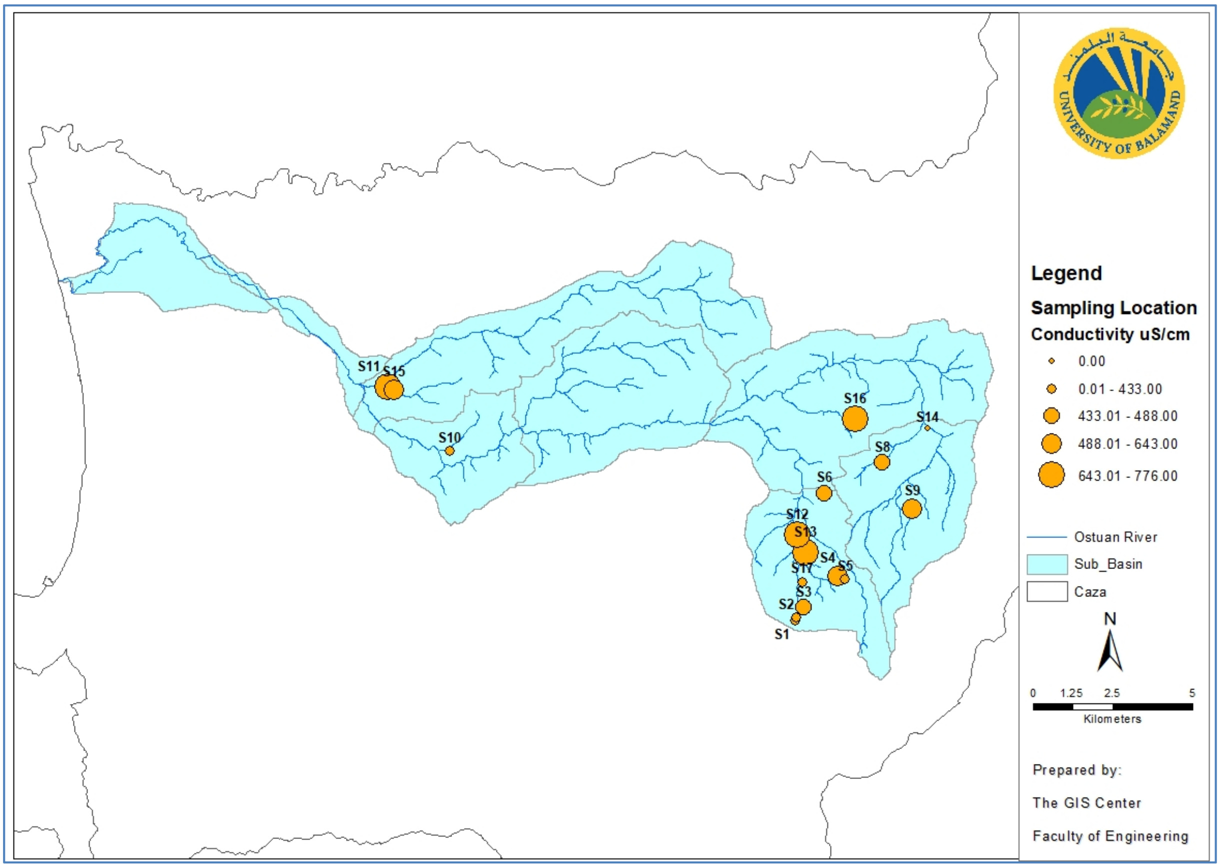


Figure 6-9: Variation of Conductivity in the sampling sites of Ostuan River (wet season)

6.3.5 TOTAL DISSOLVED SOLIDS (TDS)

The Total Dissolved Solids (TDS) is considered as an important parameter when determining the suitability of water for irrigation, drinking, and industrial usages. TDS indicates the general nature of the salinity of water (a high value means that water has a salty taste). For irrigation purposes, the water dissolved solid is a very important criterion as the gradual accumulation of solids results in the salinization of the soil, thus, rendering the agricultural land non-productive. The variation of the salinity below or above the standard range can cause negative effect to the aquatic species and aquatic plants. The results obtained for the dry sampling campaign showed that only 1 sample of 17 exhibited a TDS value above 500 mg/L (S13: 1001 mg/L). The variation of TDS among the sampling sites is represented in Figure 6-10.

The results obtained for the wet sampling campaign revealed a minimum of 252 mg L^{-1} and a maximum of 499 mg L^{-1} (**Figure 6-11**), thus all the values were within the standard set by the Lebanese Decree 1/52 (500 mg/L). The TDS values obtained for the wet season all below those obtained for the dry season and that is related to the variation of the flow of the river and the dilution factor.

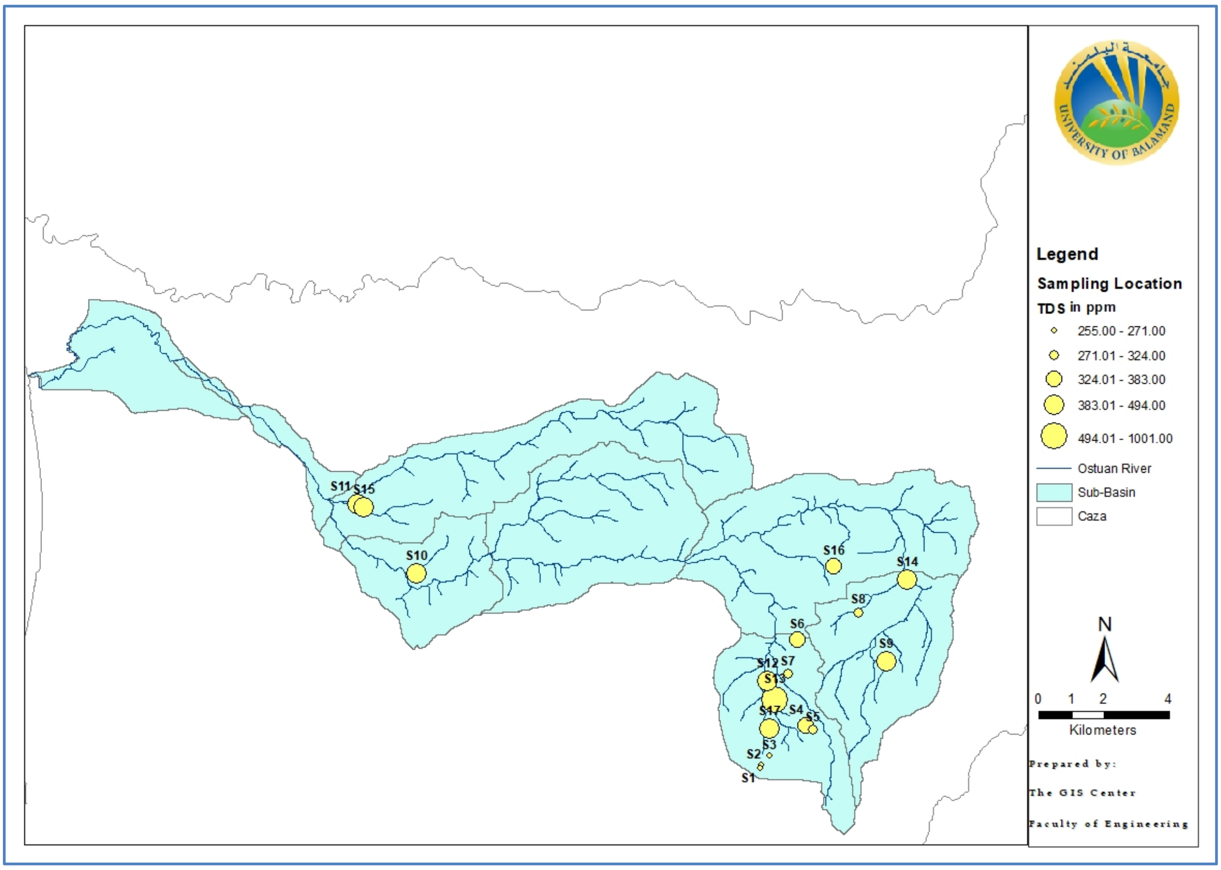


Figure 6-10: Variation of TDS in the sampling sites of Ostuan River (dry season)

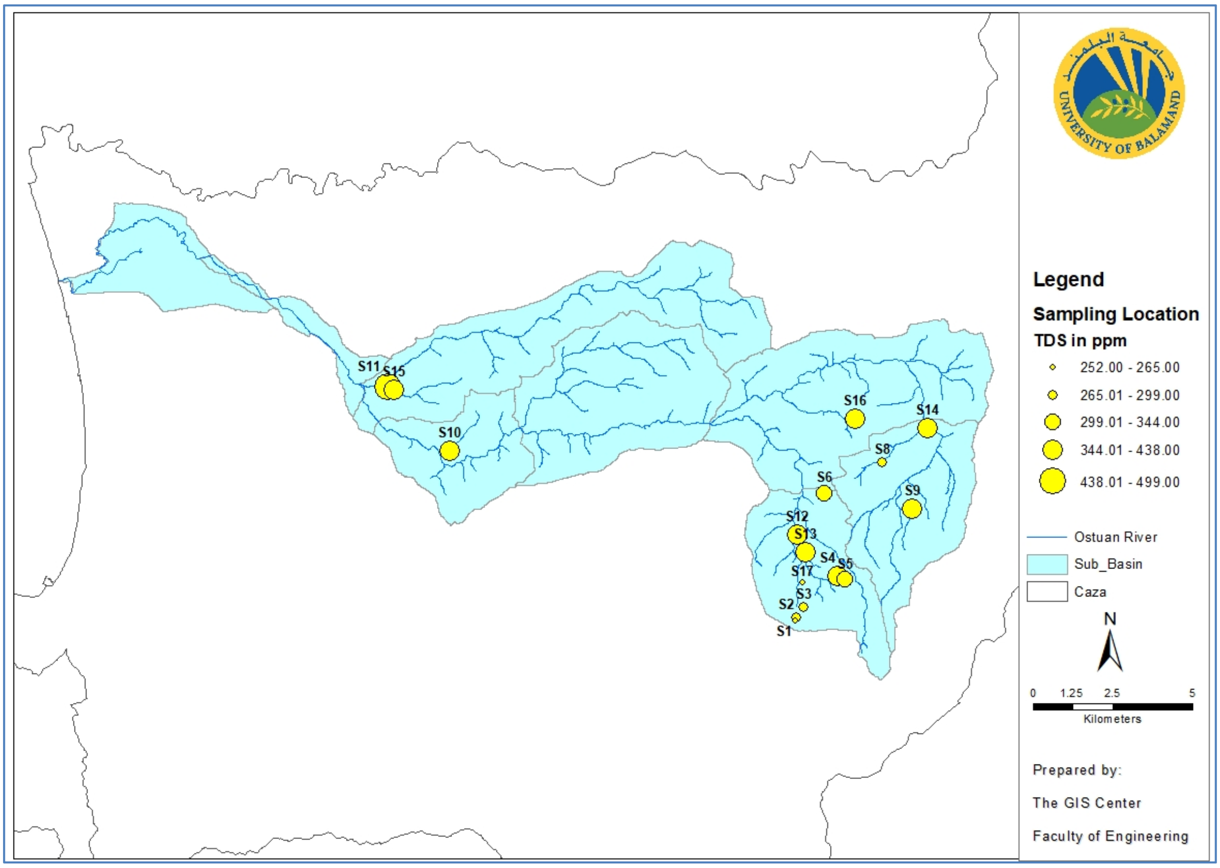


Figure 6-11: Variation of TDS in the sampling sites of Ostuan River (wet season)

6.3.6 BIOLOGICAL OXYGEN DEMAND (BOD_5)

The biological oxygen demand BOD_5 is defined as the measure of the extent of pollutant in the water body. The water that has a BOD_5 of 2 mg L^{-1} or less can be considered as a drinking water source without conventional treatment following a disinfection process. High levels of BOD_5 are related to the discharge of untreated municipal and domestic waste in water bodies leading to a boost in the amount of organic content. The BOD^5 of the dry season samples ranged between 10 mg L^{-1} at S1 and 68 mg L^{-1} at S17 (Figure 6-12). The highest values were observed at S10 (wastewater treatment plants WWTP of Jebrayel), S14 (open dumps), S16 (Qoubayat el Gharbiyeh WWTP and open dumps), and S17 (Akkar el Attika WWTP).

The BOD_5 of the wet season samples ranged between 0 mg L^{-1} at S1 and 125 mg L^{-1} at S17. As observed in Figure 6-13, the highest values were observed at S7 (Cheikh Jneid), S16 (Qoubayat el Gharbiyeh WWTP and open dumps), and S17 (Akkar el Attika WWTP). The values obtained for the wet season were lower than those observed for the dry season in all the sampling sites, except those affected by intense agricultural activities (S7, S15, and S17).

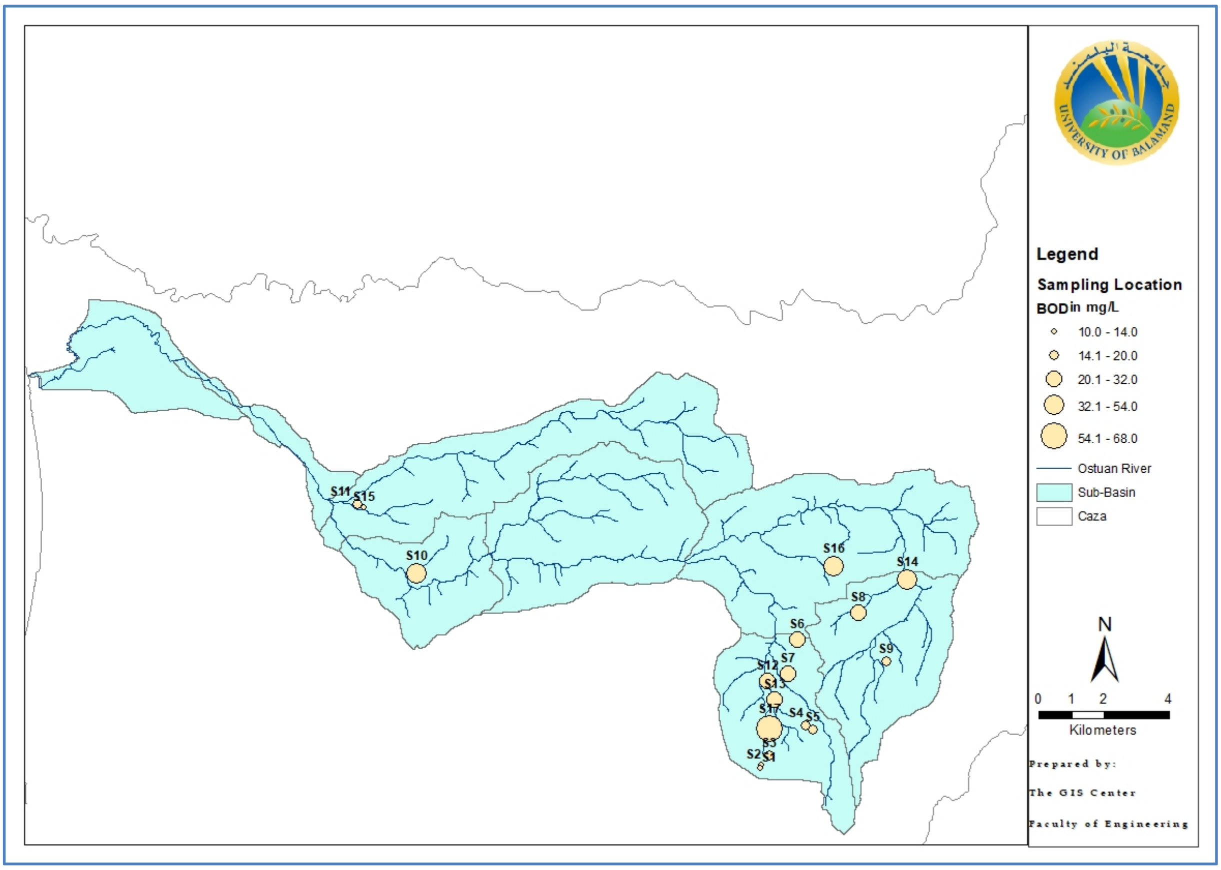


Figure 6-12: Variation of BOD_5 in the sampling sites of Ostuan River (dry season)

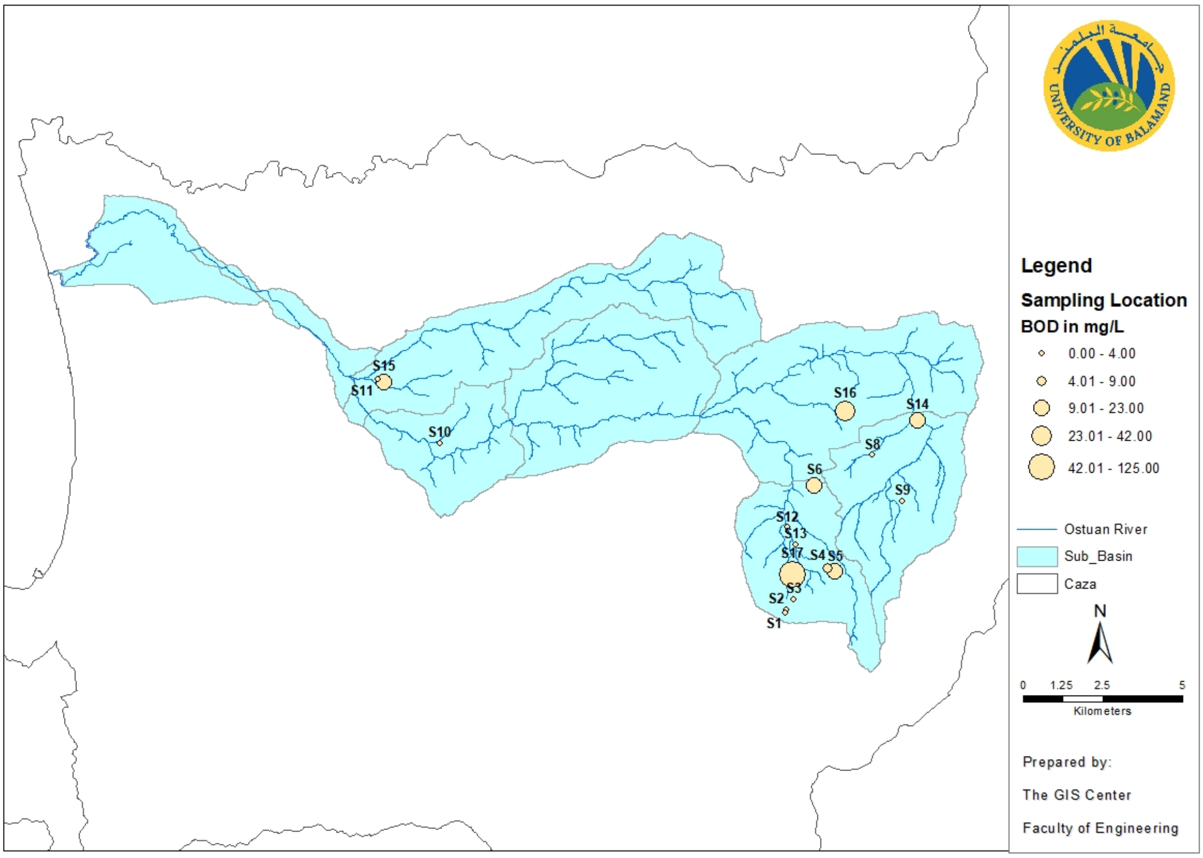


Figure 6-13: Variation of BOD_5 in the sampling sites of Ostuan River (wet season)

6.3.7 DISSOLVED OXYGEN (DO)

Dissolved Oxygen (DO) is an important indicator of the water quality, ecological status, productivity, and health of a water bodies. The amounts of dissolved oxygen in the studied sampling sites during the dry season varied between 4.8 and 6.6 mg of O2 L^{-1} (Figure 6-14), while, according to the EPA, WHO, and Lebanese decree (Appendix 1,2 and 3), DO should be above 8 mg of O2 L^{-1}. The results obtained for DO confirm the contamination of water by untreated wastewater discharge and open dumping activities scattered all over the area of the River basin.

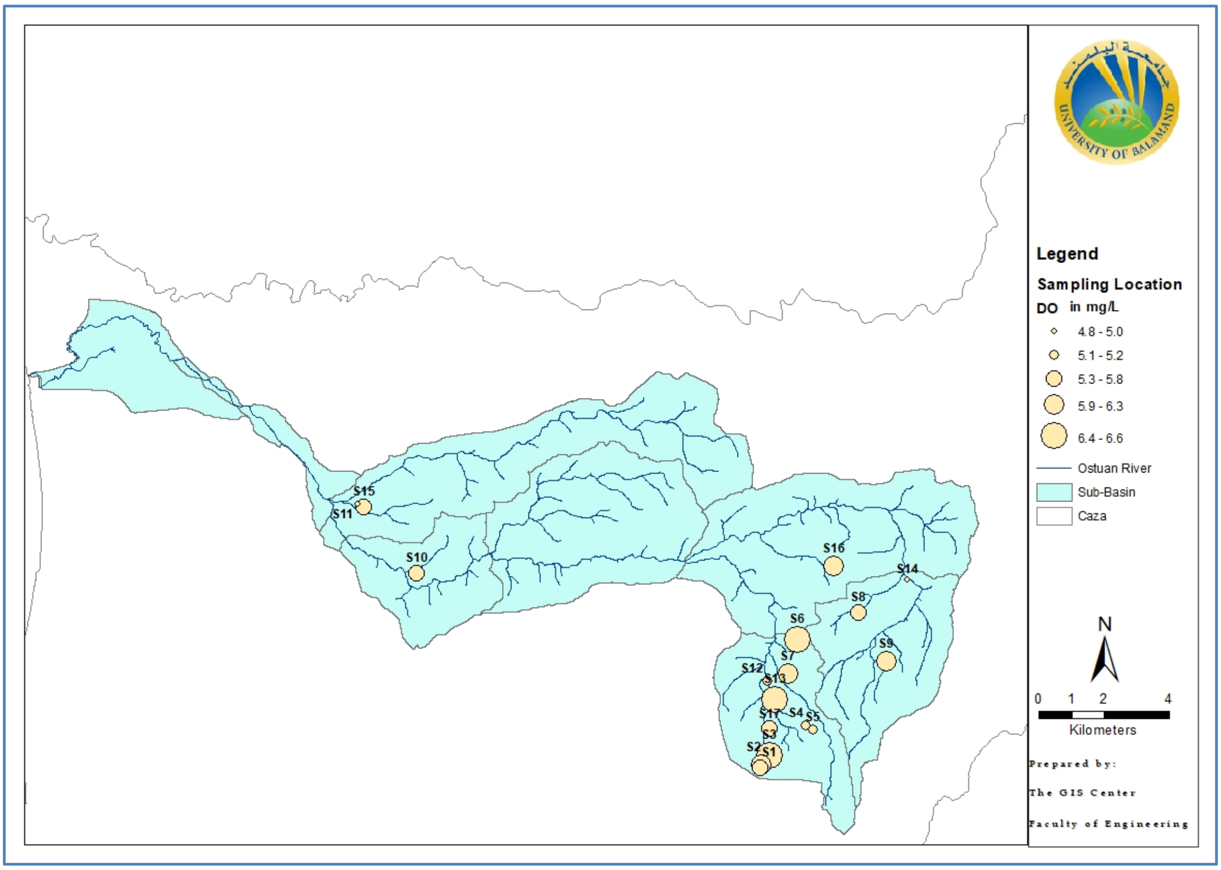


Figure 6-14: Variation of DO in the sampling sites of Ostuan River (dry season)

6.3.8 SALINITY

Salinity is an important parameter of the hardness of water. It is not a pollution parameter but generally indicates the salinity expressed by the presence of calcium and magnesium ions. The water samples measured onsite during the dry season showed that all the values for salinity were below the MCL (<0.05%) as illustrated in Figure 6-15.

The water samples measured onsite during the wet season showed that all the values for salinity were below the MCL (<0.05%) except for site S11 (Ain Bet el Khattib) as illustrated in Figure 6-15. Nevertheless, the average as recorded in the wet season (0.0519%) was found to be higher than the dry season average set to 0.0259 %. This is mainly related to the increase of carbonate values due to heavy erosions occurring drying wet season, the heavy agricultural activities, and the disposal of untreated wastewater into the river and streams.

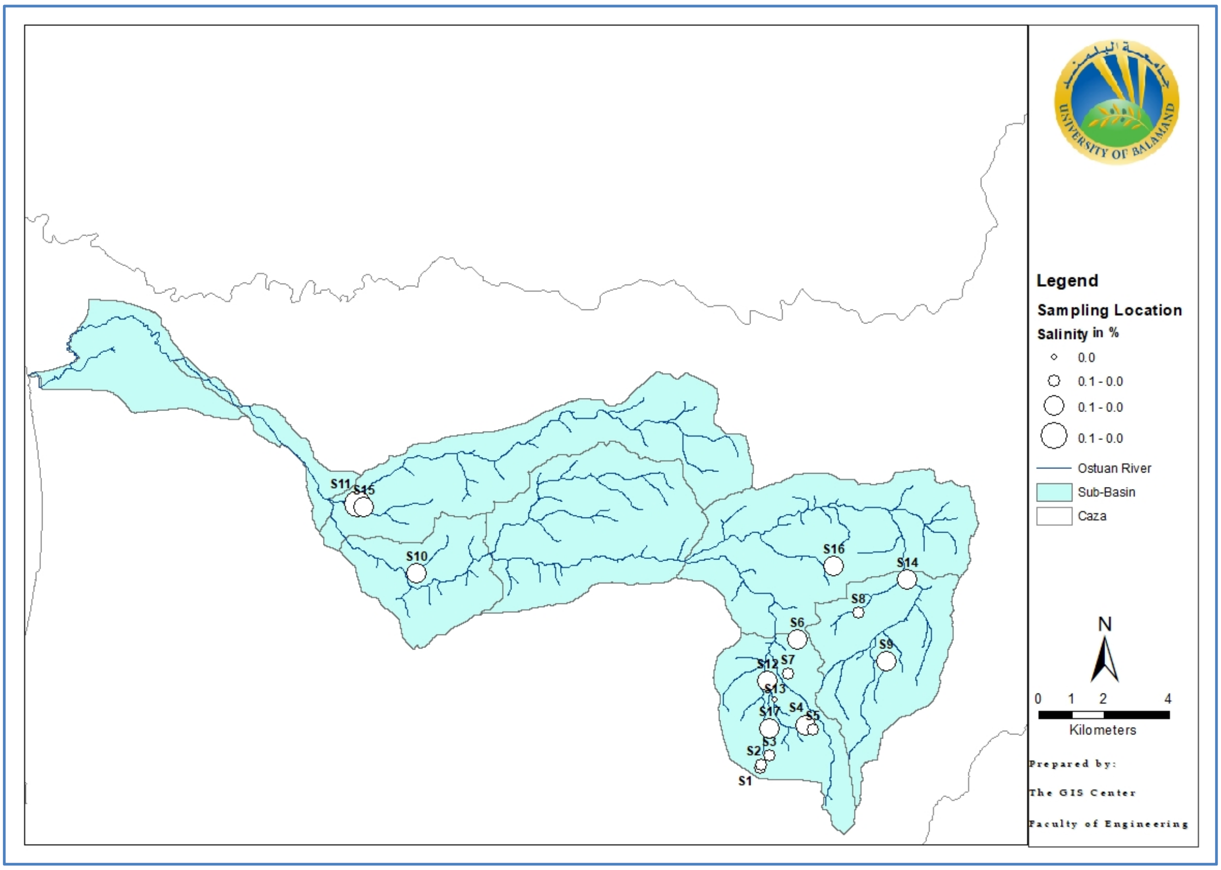


Figure 6-15: Variation of Salinity in the sampling sites of Ostuan River (dry season)

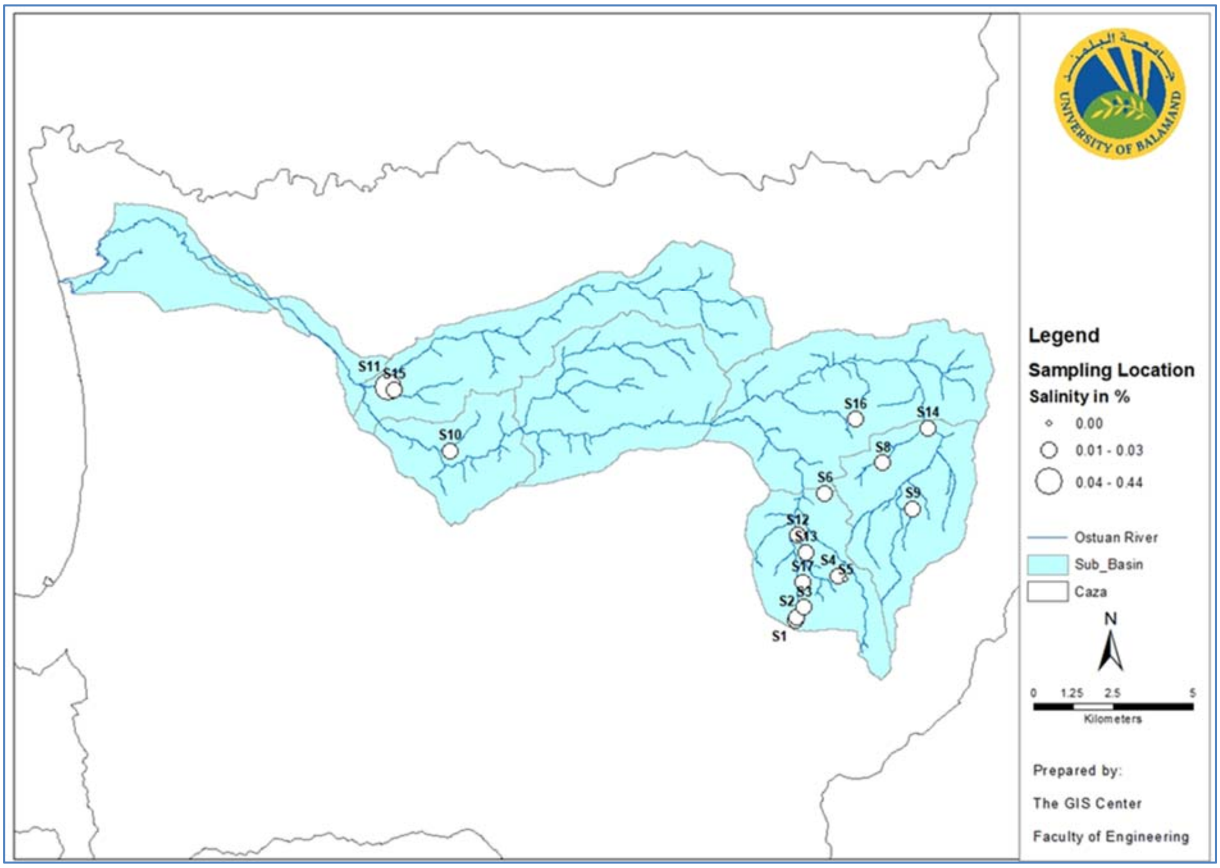


Figure 6-16: Variation of Salinity in the sampling sites of Ostuan River (wet season)

6.3.9 CHLORIDE

The high concentrations of chloride in water may be an indicator of water pollution caused by sewage, industrial wastes, and intrusion of seawater. Figure 6-17 shows that the concentrations of chlorides during the dry season fluctuated between 5.22 mg L-1 (at site S1) and 32.5 mg L-1 (at site S16). However, all the values obtained were below the MCL set by the Lebanese decree 52/1 (200 mg L-1). Figure 6-18 shows that the concentrations of chlorides during the wet season varied between 5.5 mg L^{-1} (at site S1) and 106.81 mg L^{-1} (at site S15). However, all the values obtained were below the MCL set by the Lebanese decree 52/1 (200 mg L^{-1}).

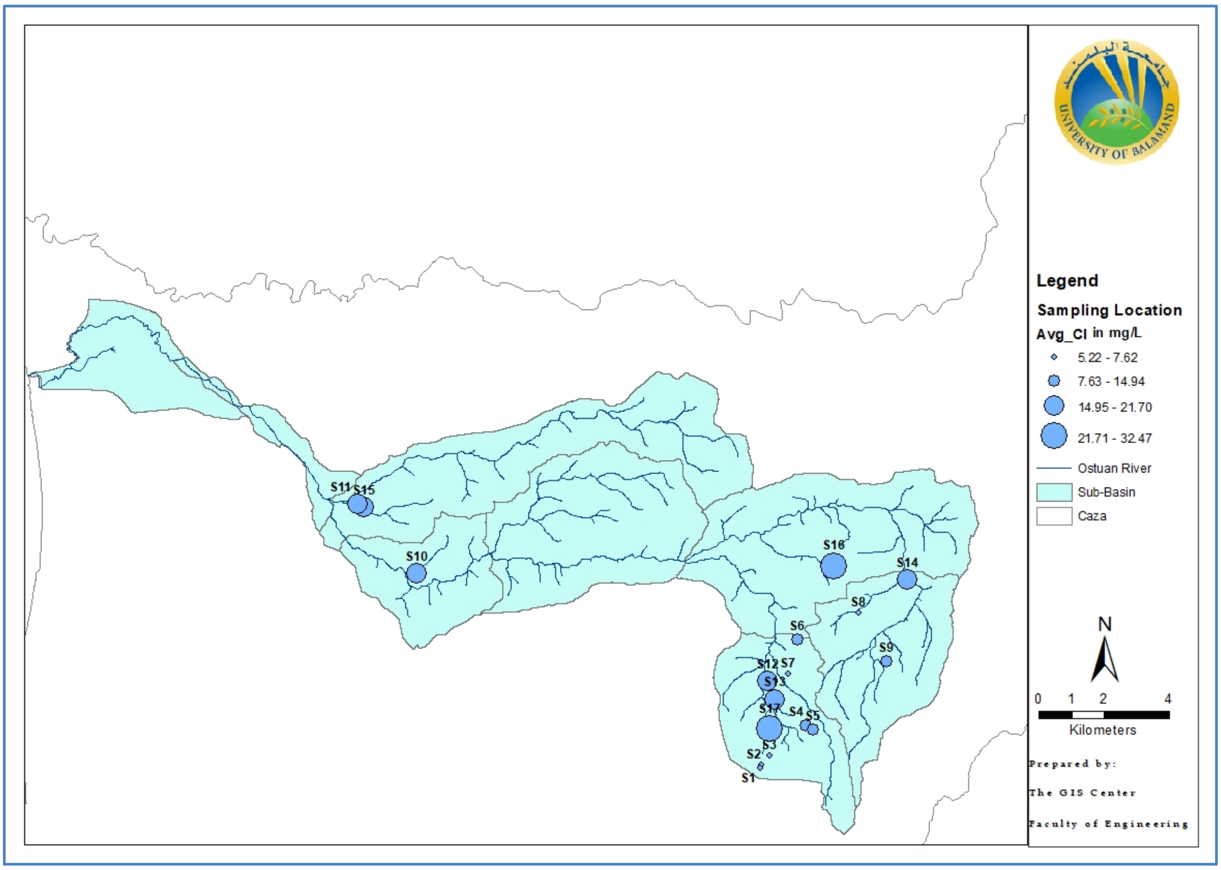


Figure 6-17: Variation of Chloride concentrations in the sampling sites of Ostuan River

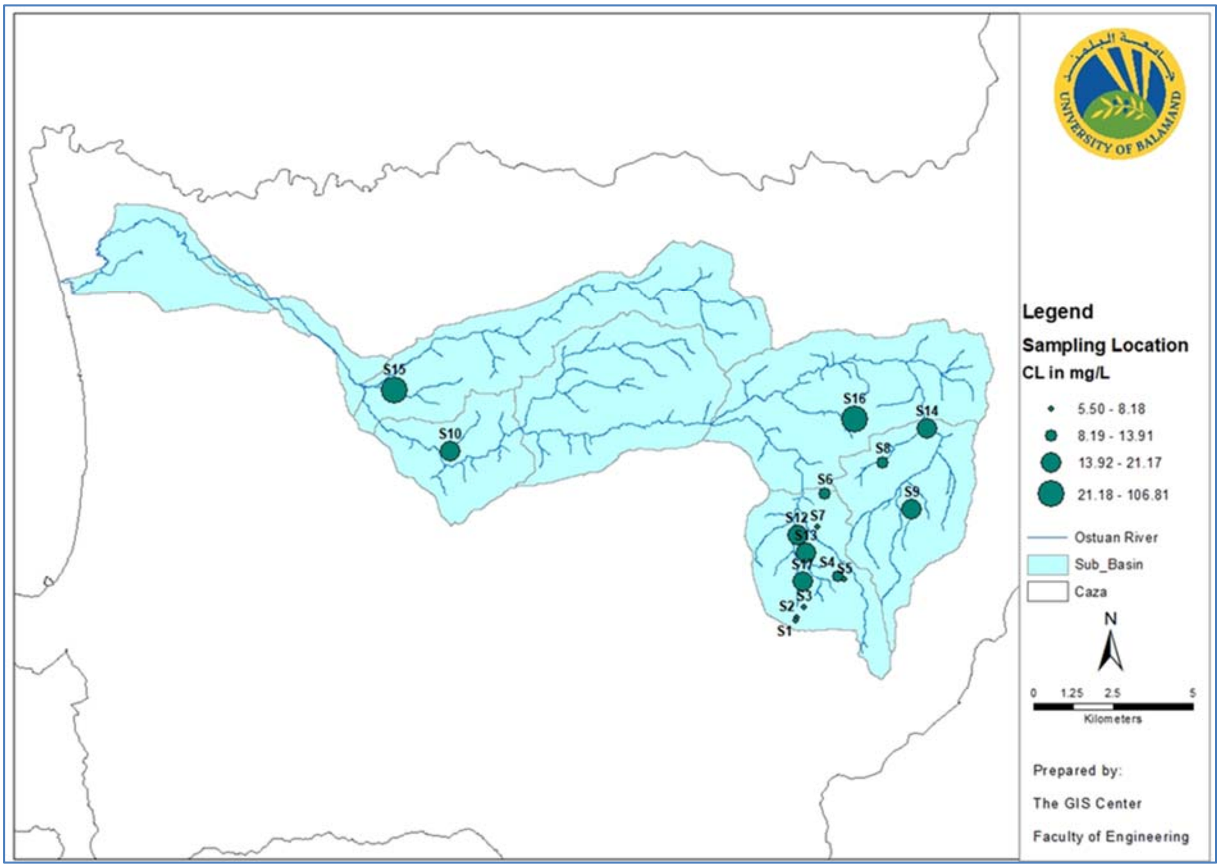


Figure 6-18: Variation of Chloride concentrations in the sampling sites of Ostuan River

6.3.10 CALCIUM, POTASSIUM, AND MAGNESIUM

Calcium, potassium, and magnesium are the main sources of hard in natural water. Their concentration is consistent with the types of rocks, industrial waste, and sewage. Water with calcium levels below 10 mg L^{-1} is usually considered oligotrophic, while those above 25 mg L^{-1} is considered eutrophic. Higher concentrations of magnesium make the water unpalatable and act as laxative to human beings. In the studied water samples of the dry season, the Calcium concentrations values were in consistence with the rocks types of Akkar that are known to be rich in calcium. Figure 6-19, Figure 6-21 and Figure 6-23 describe respectively the concentrations of Ca^{2+}, K^{+} and Mg^{2+} in the waters of the Ostuan River (ranging between 59 mg L^{-1} at S16 and 123.7 mg L^{-1} at S11 for Ca^{2+}, between 0.2 mg L^{-1} and 2.4 mg L^{-1} for K^{+}, and between 2.4 mg L^{-1} and 41.7 mg L^{-1} for Mg^{2+}). The levels remained below the limit value set by the Lebanese decree 52/1 (refer to Appendix 3) for all the samples.

Figure 6-20, Figure 6-22 and Figure 6-24 show the concentrations of Ca^{2+}, K^{+}, and Mg^{2+} in the waters of the Al Ostuan river during the wet season, respectively ranging between 56.12 mg L^{-1} at S13 and 140.81 mg L^{-1} at S16 for Ca^{2+}, between 0.10 mg L^{-1} at S1 and 13.60 mg L^{-1} at S15 for K^{+}, and between 2.36 at S17 mg L^{-1} and 41.75 at S10 mg L^{-1} for Mg^{2+}. The levels remained below the limit value set by the Lebanese decree 52/1 (refer to Appendix 3) for all the samples and considering all the parameters except for sample S15 in which the value for potassium was found to be above 12 mg L^{-1}. This could be due to the erosion events occurring in clay-based formations that increased the levels of non-ferromagnesium ions in the water.

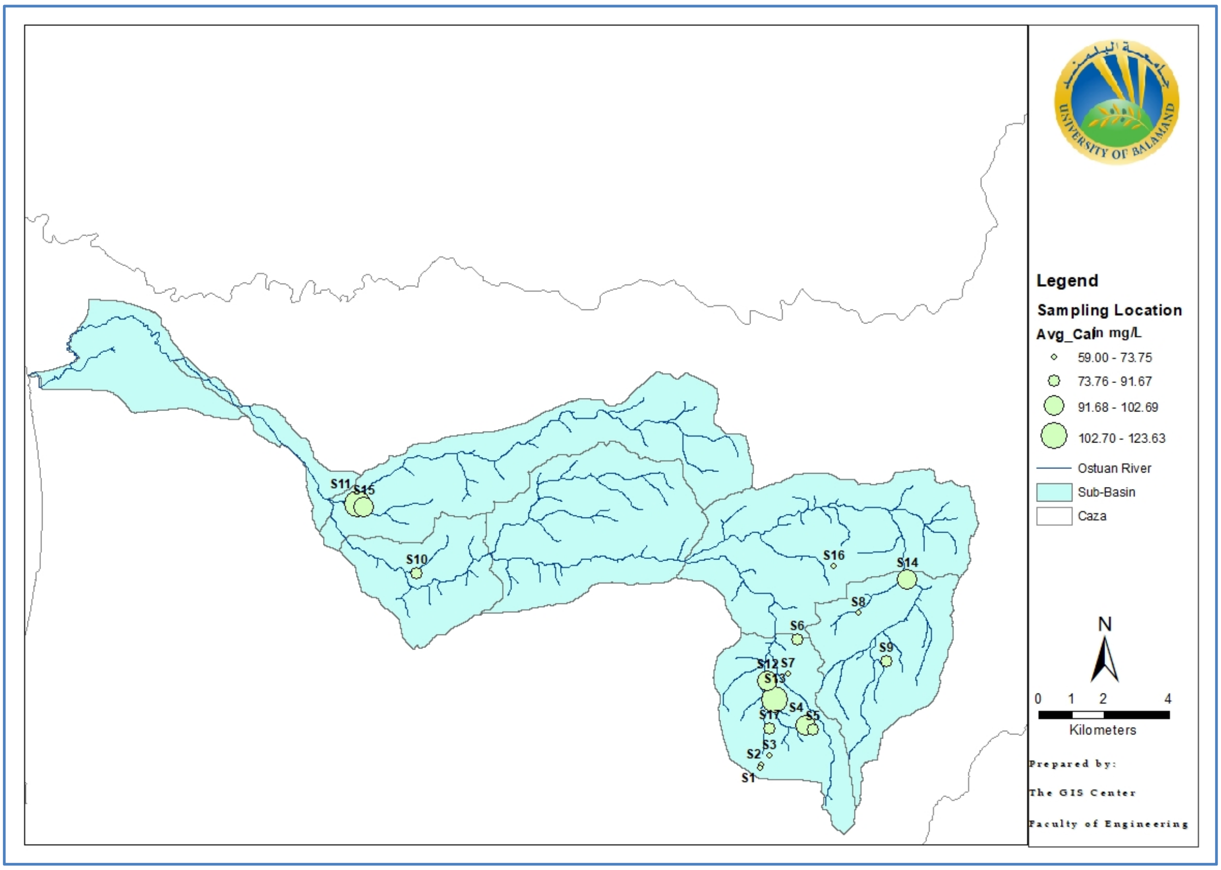


Figure 6-19: Variation of Calcium concentrations in the sampling sites of Ostuan River (dry season)

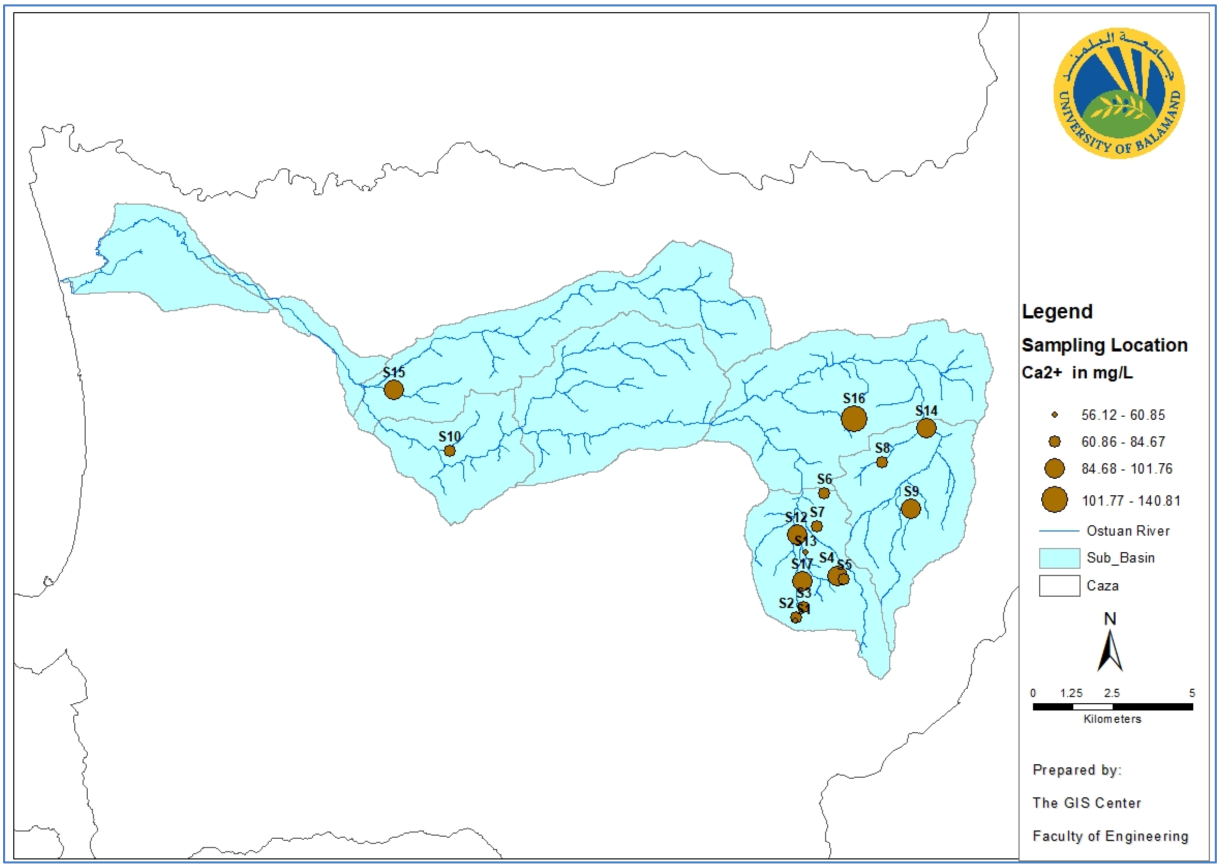


Figure 6-20: Variation of Calcium concentrations in the sampling sites of Ostuan River (wet season)

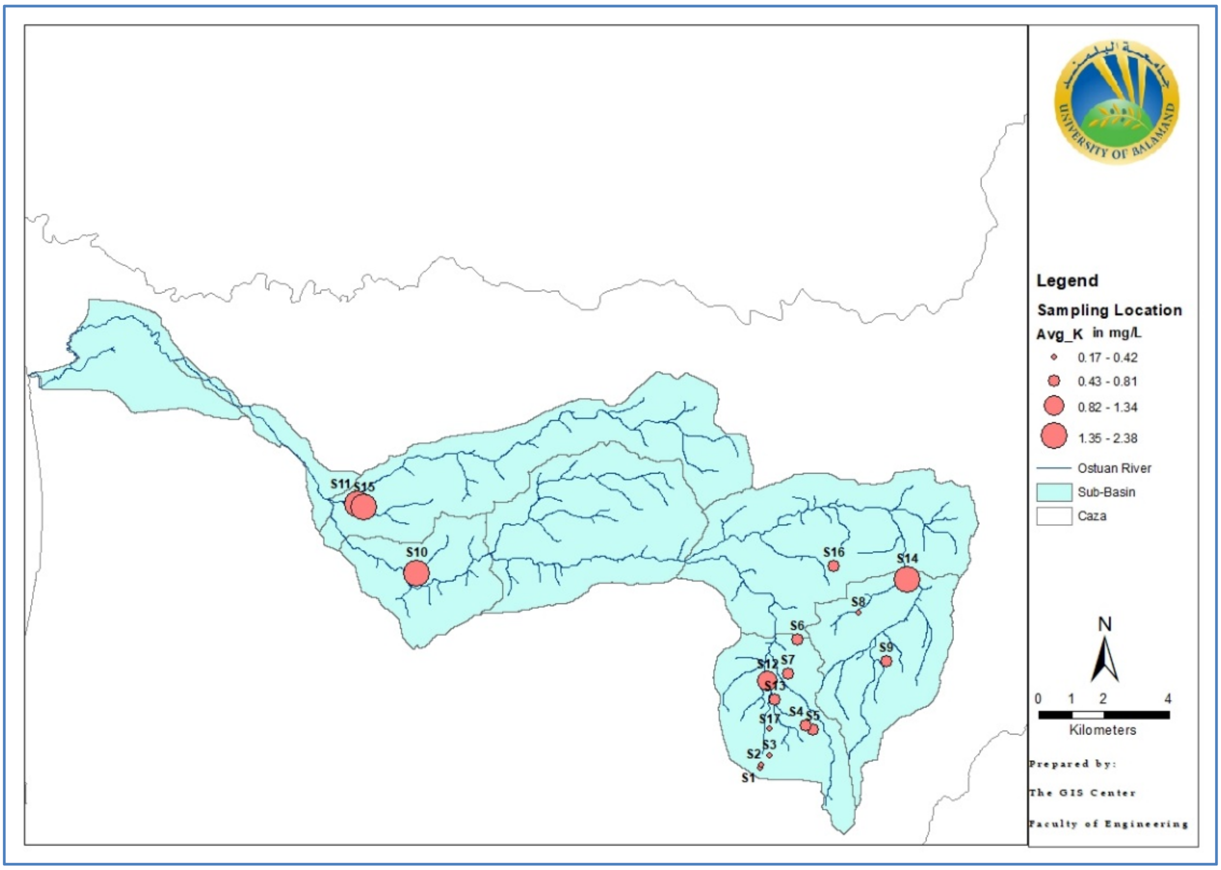


Figure 6-21: Variation of Potassium concentrations in the sampling sites of Ostuan River (dry season)

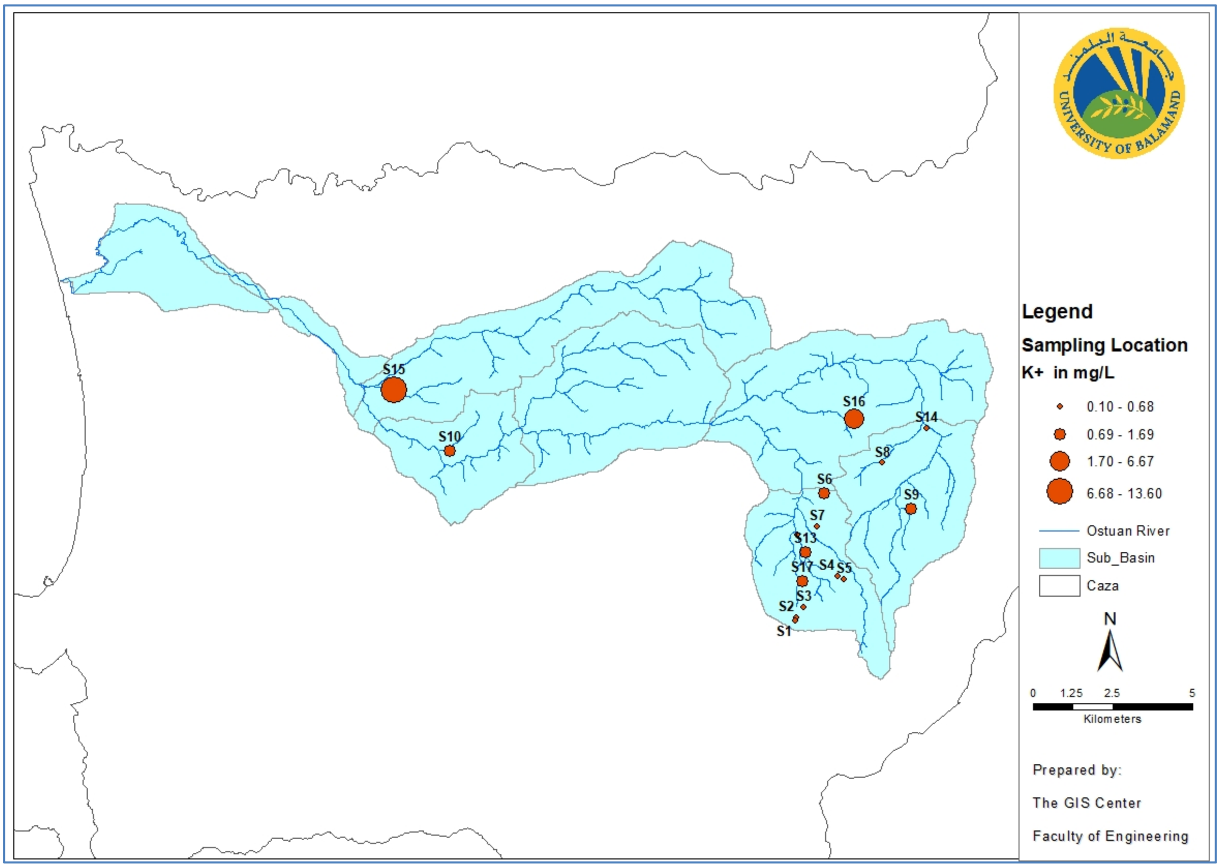


Figure 6-22: Variation of Potassium concentrations in the sampling sites of Ostuan River (wet season)

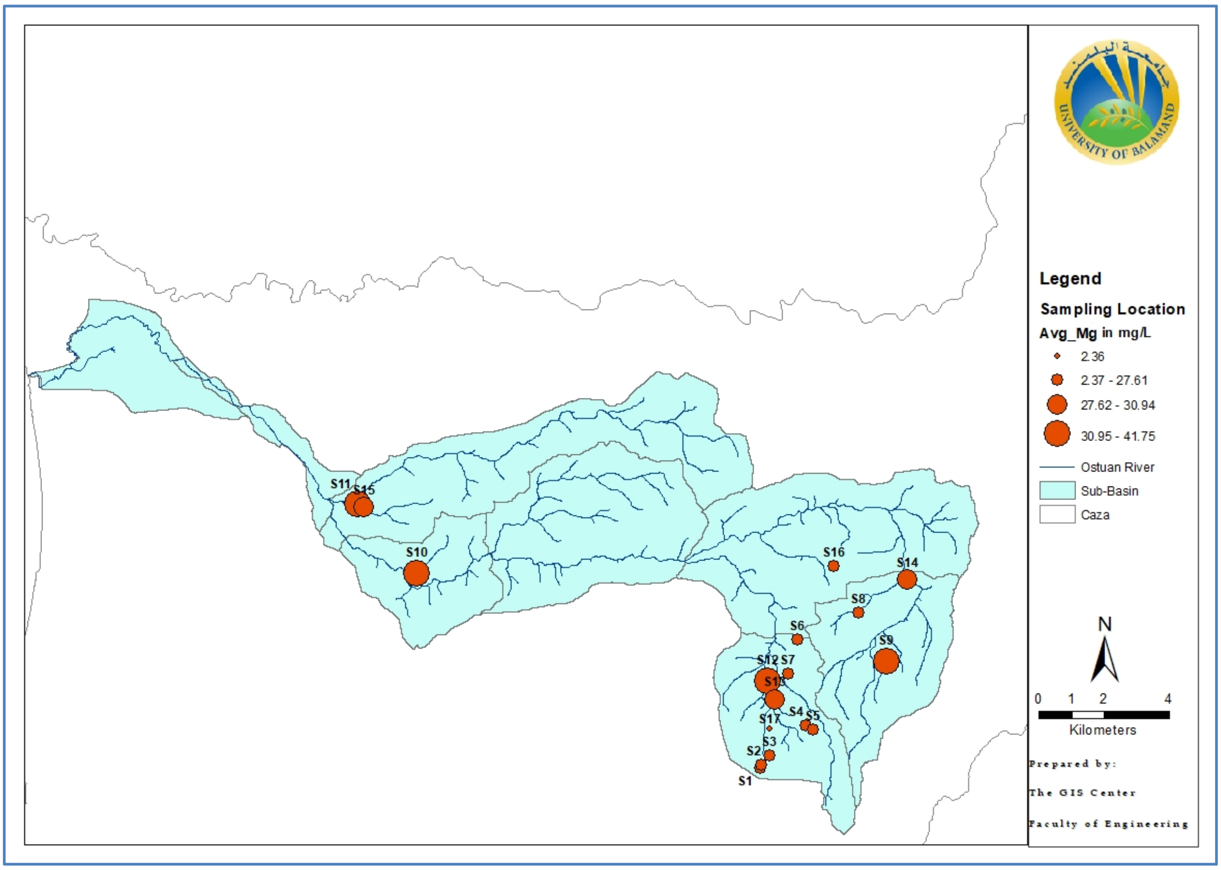


Figure 6-23: Variation of Magnesium concentrations in the sampling sites of Ostuan River (dry season)

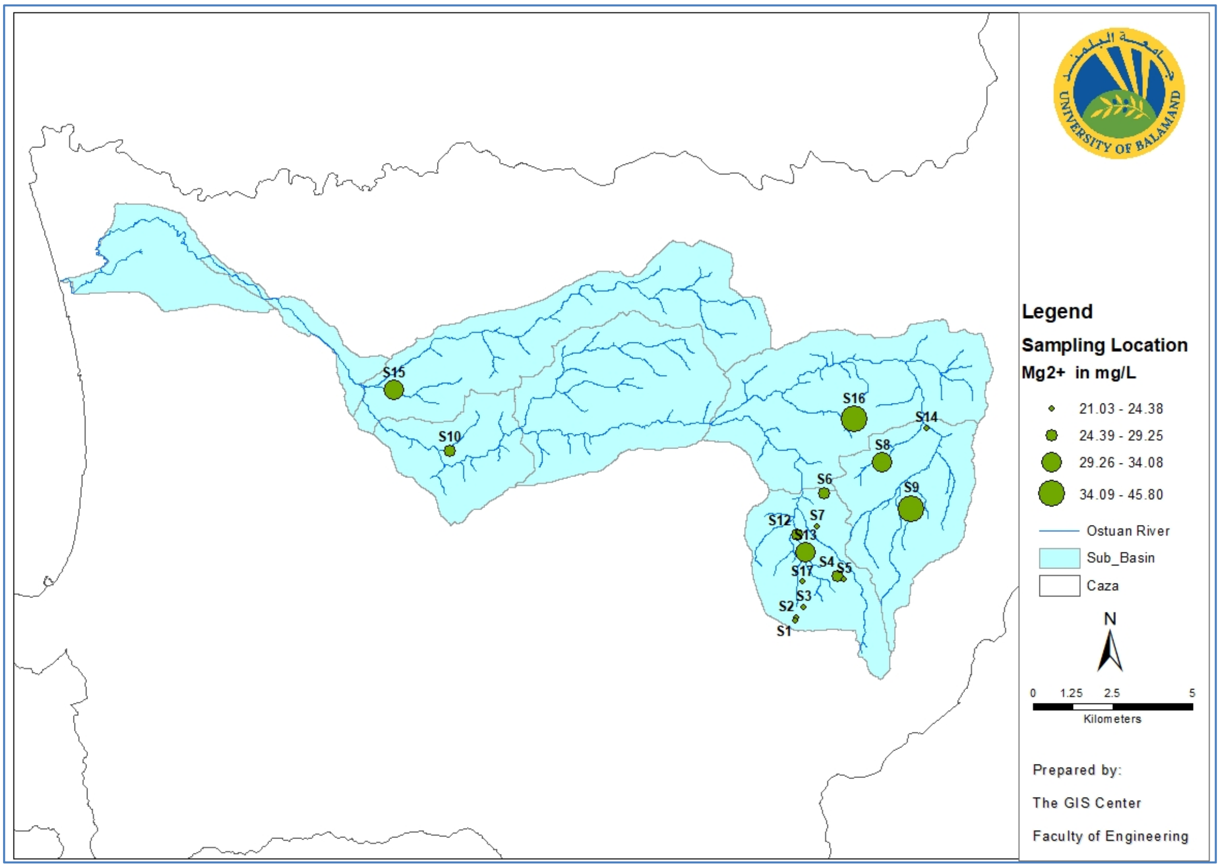


Figure 6-24: Variation of Magnesium concentrations in the sampling sites of Ostuan River (wet season)

6.3.11 SULPHATE

Sulphate occurs in natural water with concentration ranging between few milligrams per litre and several thousand milligrams per litre. Figure 6-25 presents the fluctuation of sulphate concentrations during the dry seaso,n ranging between 4.6 mg L^{-1} at site S1 and 67.8 mg L^{-1} at site S11. All the registered values were below the MC set by the Lebanese decree 52/1 (Appendix 3). Figure 6-26 presents the fluctuation of sulfate concentrations during the wet season, ranging between 5.49 mg L^{-1} at S2 and 112.45 mg L^{-1} at S16. All the registered values were below the MC set by the Lebanese decree 52/1 (Appendix 3). The concentrations of sulfate recorded for the wet season were relatively higher than the values obtained for the dry season and this is related to the rainfall events. Nevertheless, the highest values obtained at sites S8, S15, and S16 are relatively related to geogenic sulphate that increases with the increasing distance of the water flow through rocks in the river

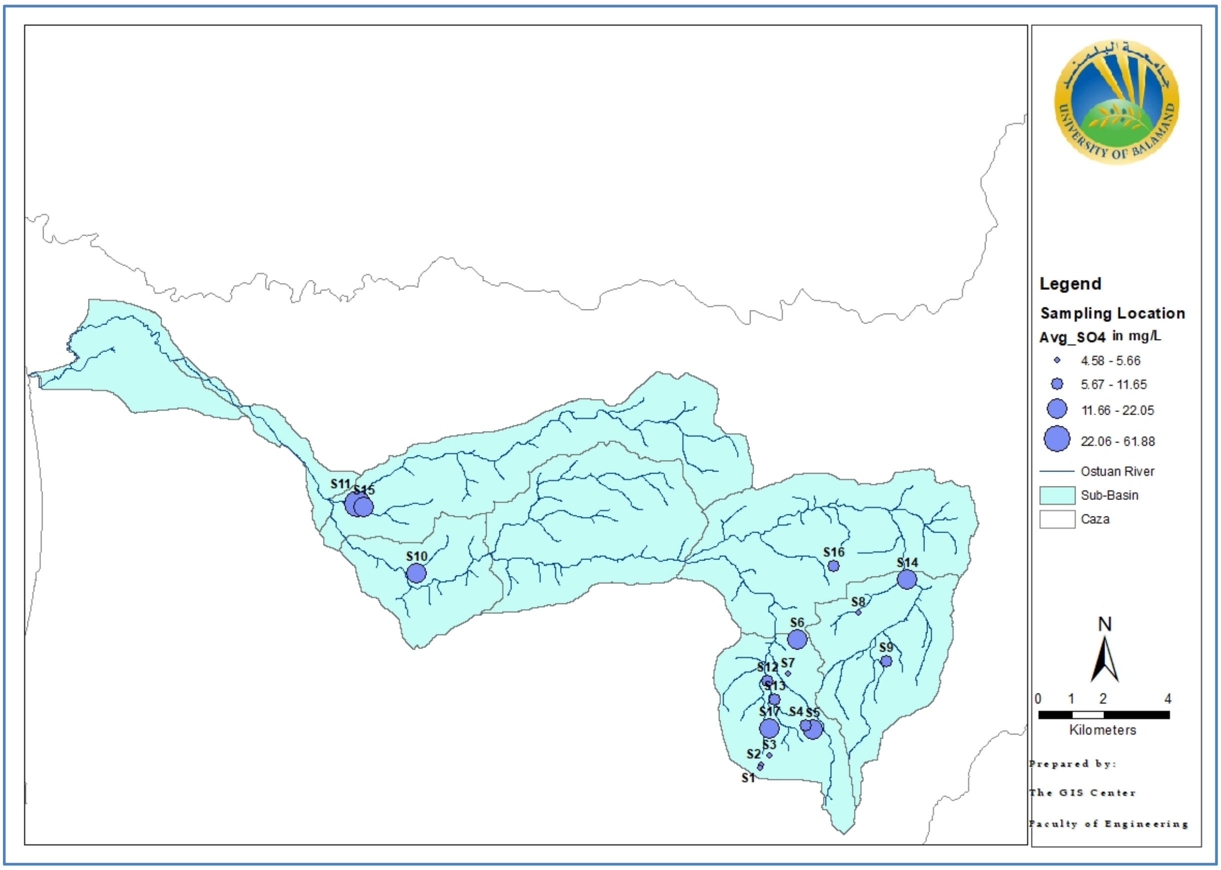


Figure 6-25: Variation of Sulphate concentrations in the sampling sites of Ostuan River (dry season)

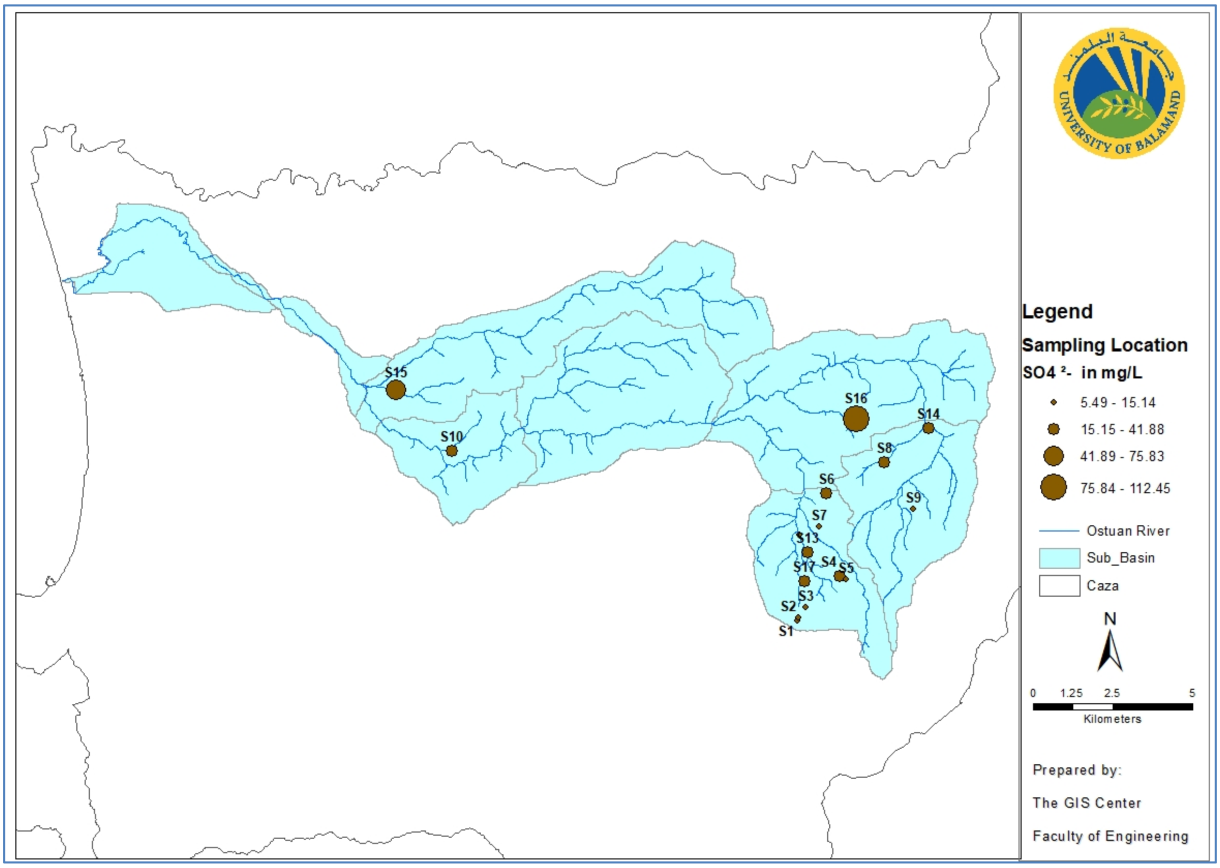


Figure 6-26: Variation of Sulphate concentrations in the sampling sites of Ostuan River (wet season)

6.3.12 NITRATE

Nitrate (NO^{3-}) is the essential nutrient for many photosynthetic autotrophs and generally occurs in trace quantities in surface water. Nitrate is a less serious environmental problem. However, when nitrate concentrations become excessive and other essential nutrient factors are present, eutrophication and associated algal blooms may be become a problem. The main sources of nitrate in water are human and animal waste, industrial effluent, use of fertilizers and chemicals, and silage through drainage system.

Figure 6-27 presents the fluctuation of Nitrate all over the Ostuan River during the dry season of the study. Nitrate values ranged between 8.1 mg L^{-1} at site S1 and 13.58 mg L^{-1} at site S12. It is of note that all the values obtained for nitrate were below the MCL set by the EPA (50 mg L^{-1}) as seen in Appendix 1. The low concentrations of nitrates observed in these sampling sites can be linked to the water dilution effect. Figure 6-28 presents the distribution of Nitrate all over the Al Ostuan river during the wet season of the study. The Nitrate values ranged between 0.99 mg L^{-1} at site S2 and 78.99 mg L^{-1} at site S16. It is of note that all the values obtained for the Nitrates were below the MCL set by the EPA (50 mg L^{-1})

except for S16 and this is because of the agricultural runoff and direct discharge of untreated wastewater. The low concentrations of Nitrates observed in the remaing sampling sites can be linked to the water dilution effect.

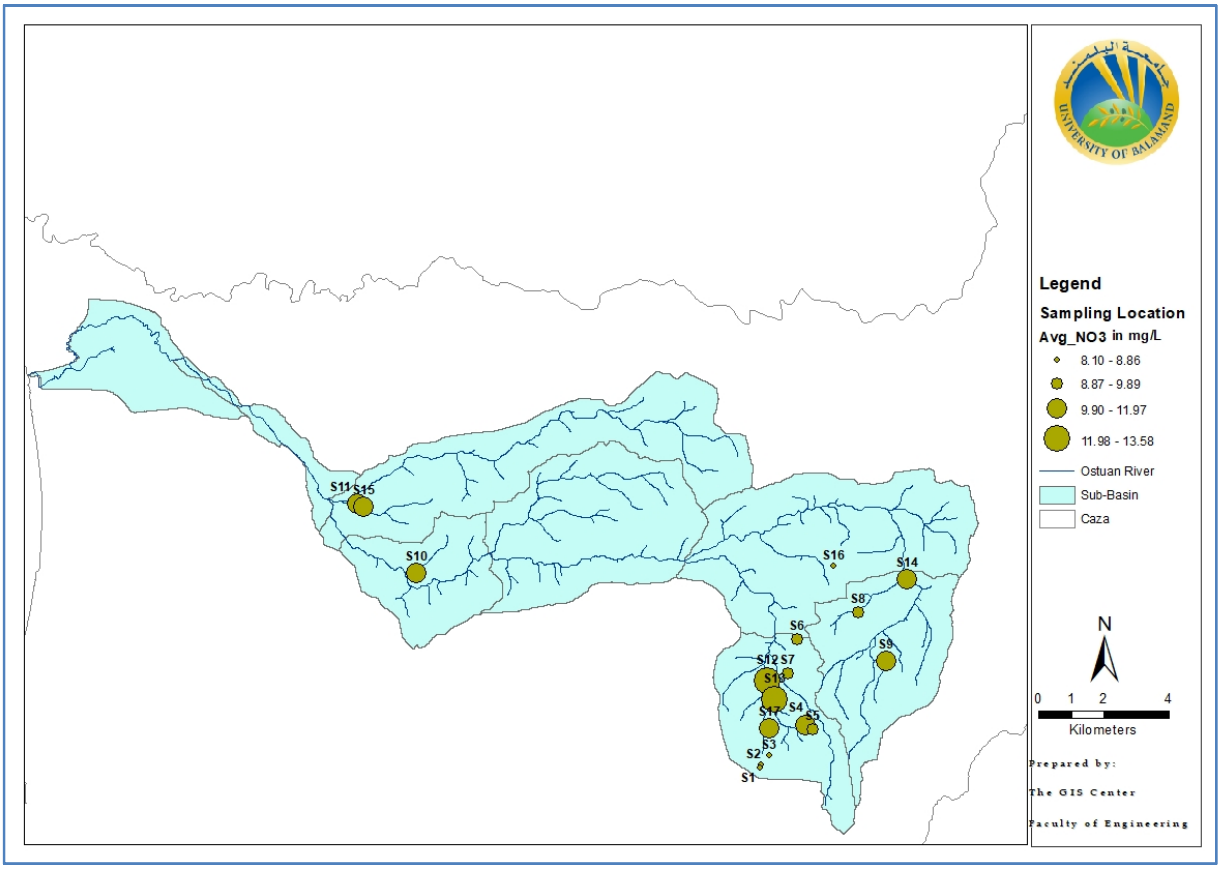


Figure 6-27: Variation of Nitrate concentrations in the sampling sites of Ostuan River (dry season)

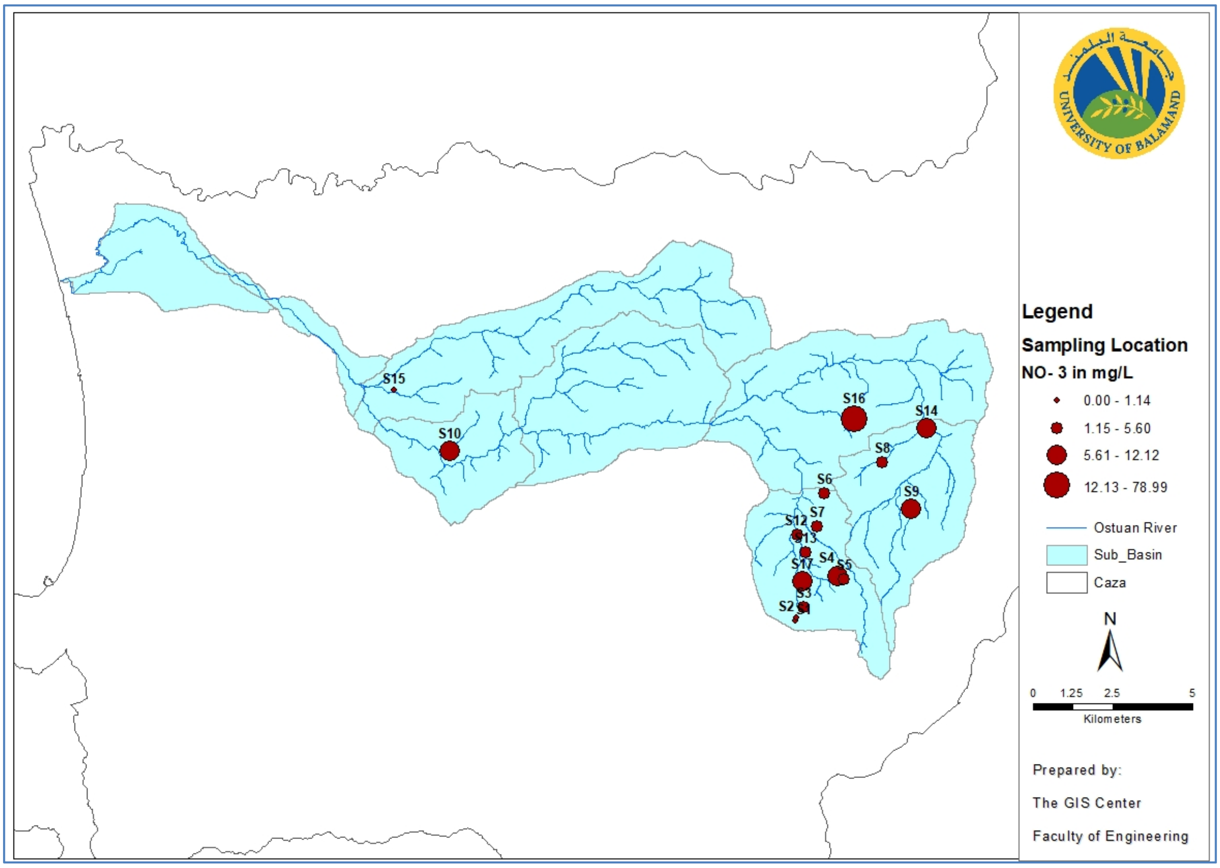


Figure 6-28: Variation of Nitrate concentrations in the sampling sites of Ostuan River (wet season)

6.3.13 NITRITE

Nitrite (NO^{2-}) is known to be extremely toxic to aquatic life. This compound is usually present in trace amounts in almost all the natural freshwater systems because it is rapidly oxidized into nitrate. The conversion process is affected by several factors, including pH, temperature and DO, number of nitrifying bacteria, and the presence of inhibiting compounds. If the pH of the solution increases either naturally or by the addition of a base, the concentration of unionized NH3 increases. As the pH increases, the toxicity in terms of NO^{2-} as N decreases while the toxicity in terms of HNO_2 as N increases. In this context, Figure 6-29 shows that all the values obtained for nitrite during the dry season were above the MCL levels set by all the common standards: WHO, EPA and the Lebanese decree (Appendix 1, 2 and 3). The high values obtained may be correlated to the alkaline conditions of the river water.

All the values obtained for the Nitrites during the wet season (Figure 6-30) were below the MCL levels set by all the common standards: WHO, EPA, and the Lebanese decree (Appendices 1, 2, and 3). Similar to the Nitrates, the value of the Nitrites has reached a high concentration of 5.32 mg/L at site S16 which confirms the source of pollution.

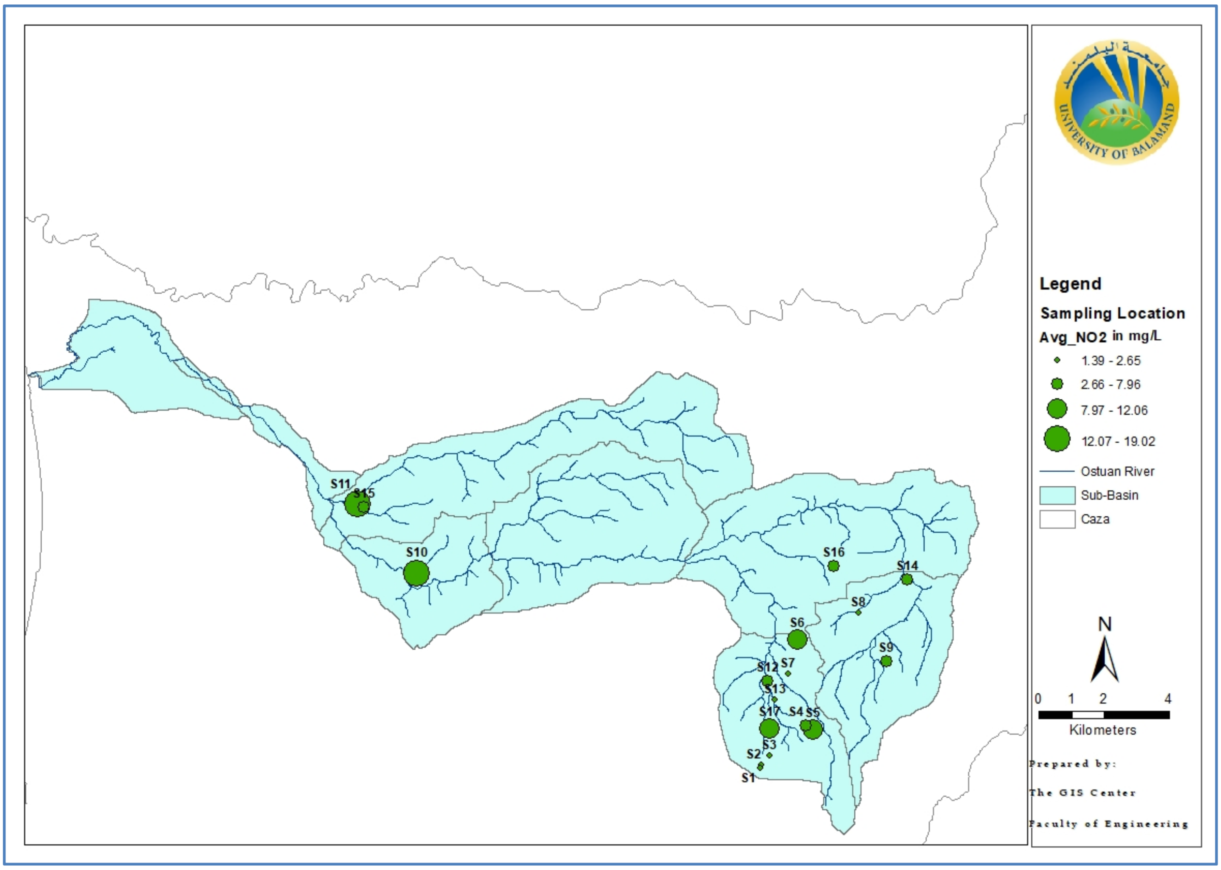


Figure 6-29: Variation of Nitrite concentrations in the sampling sites of Ostuan River (wet season)

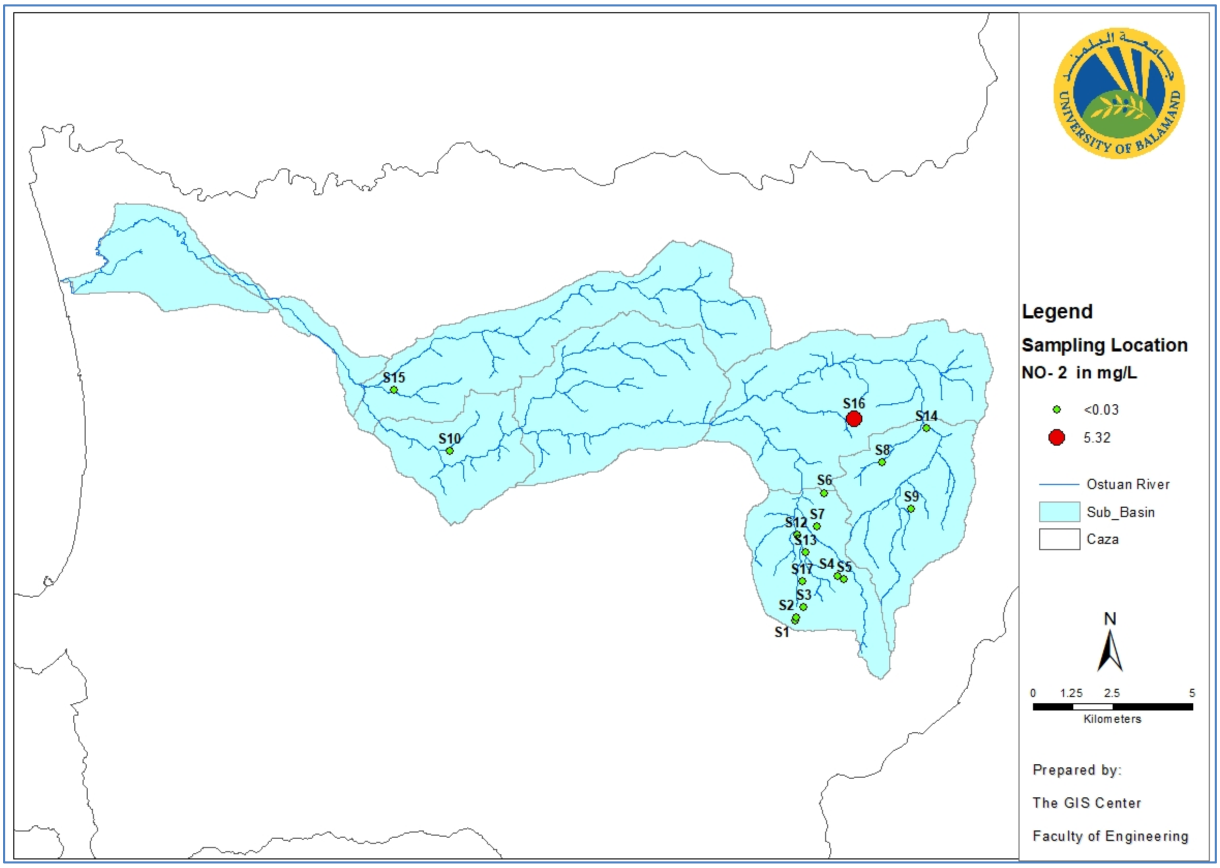


Figure 6-30: Variation of Nitrite concentrations in the sampling sites of Ostuan River (dry season)

6.3.14 HEAVY METALS

In this study, the surface water samples were analyzed for: Al, Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd, Hg, and Pb. In Table 6-4 and Figure 6-31 to Figure 6-52, the heavy metal data for the 17 sampling sites for the dry season and wet season are listed.

The presence of heavy metals in waterways may result from the leaching from agricultural lands. The direct release of fertilizers and industrial effluent into water bodies results in the contamination of the ecosystem with heavy metals. These compounds are considered as harmful to the ecosystem and human health as they tend to accumulate in the environment. The results obtained revealed negligible heavy metals contamination for almost all the tested parameters. These findings are consistent with the absence of big industries in the area and the alkaline conditions of the studied water samples. Only Hg and Pb exhibited concentrations above the maximum contaminant levels (MCL) at all sampling sites during the dry season. These compounds reached a maximum concentration of 27 μg L^{-1} and 3.7 μg L^{-1} for Hg and Pb, respectively during the dry season.

The heavy metals values (Al, Cd, Cr, Co, Cu, Fe, Pb, Mn, Hg, Ni, Zn) have shown some visible changes from the dry season (October 2019) to the wet season (February 2021). Several elements have shown no visible change, nevertheless, the majority has shown a visible increase in their concentrations, and all of the obtained results exceeded the acceptable standards. More specifically, Al, Cr, Mn, Fe, Co, and Hg have shown a remarkable increase in their concentration. These high values are due to the agricultural activities and the uncontrolled use of fertilizers that is related to the abundance of the crop. Another major factor that influences these high values is the lack of wastewater treatment plants that increases their content in surface waters. This is directly related to the fertilizers effluents that expel heavy metals directly into the ecosystem. These high concentrations were heavily observed in the lowest locations of the river basin where the agricultural activities are quite developed and the non-treated wastewater effluent clearly infulences the water quality of the river. The heavy metals that showed invariant concentrations were Ni, Cu, Zn, Cd, and Pb.

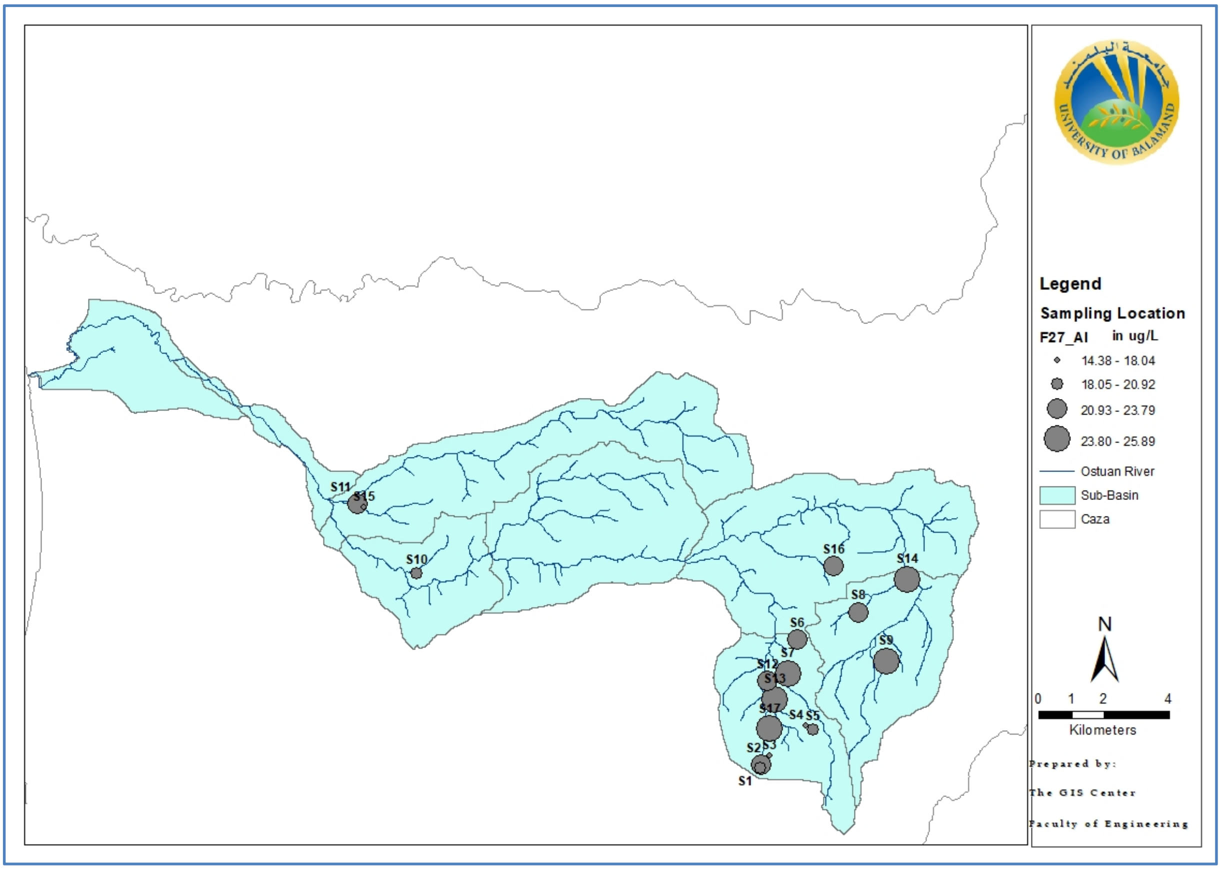


Figure 6-31: Variation of Aluminum concentrations in the sampling sites of Ostuan River (dry season)

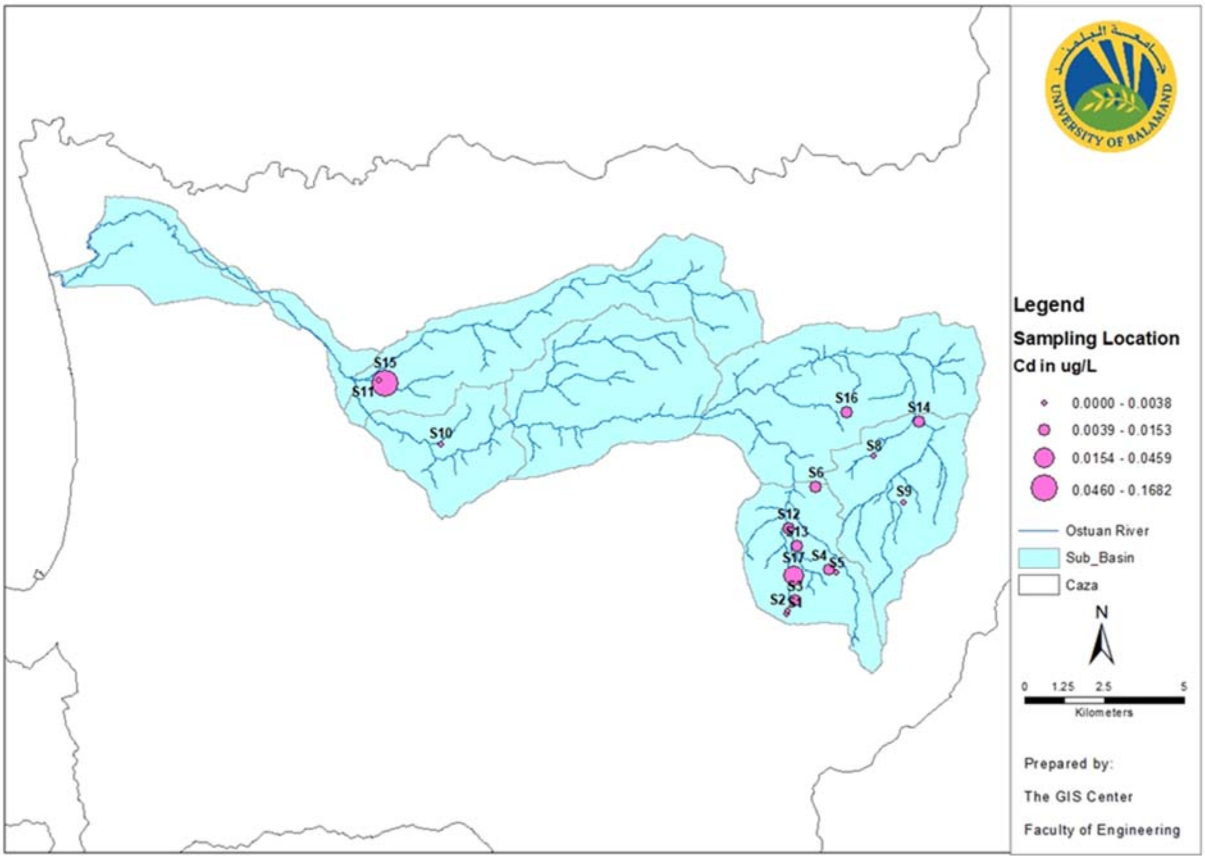


Figure 6-32: Variation of Aluminum concentrations in the sampling sites of Ostuan River (wet season)

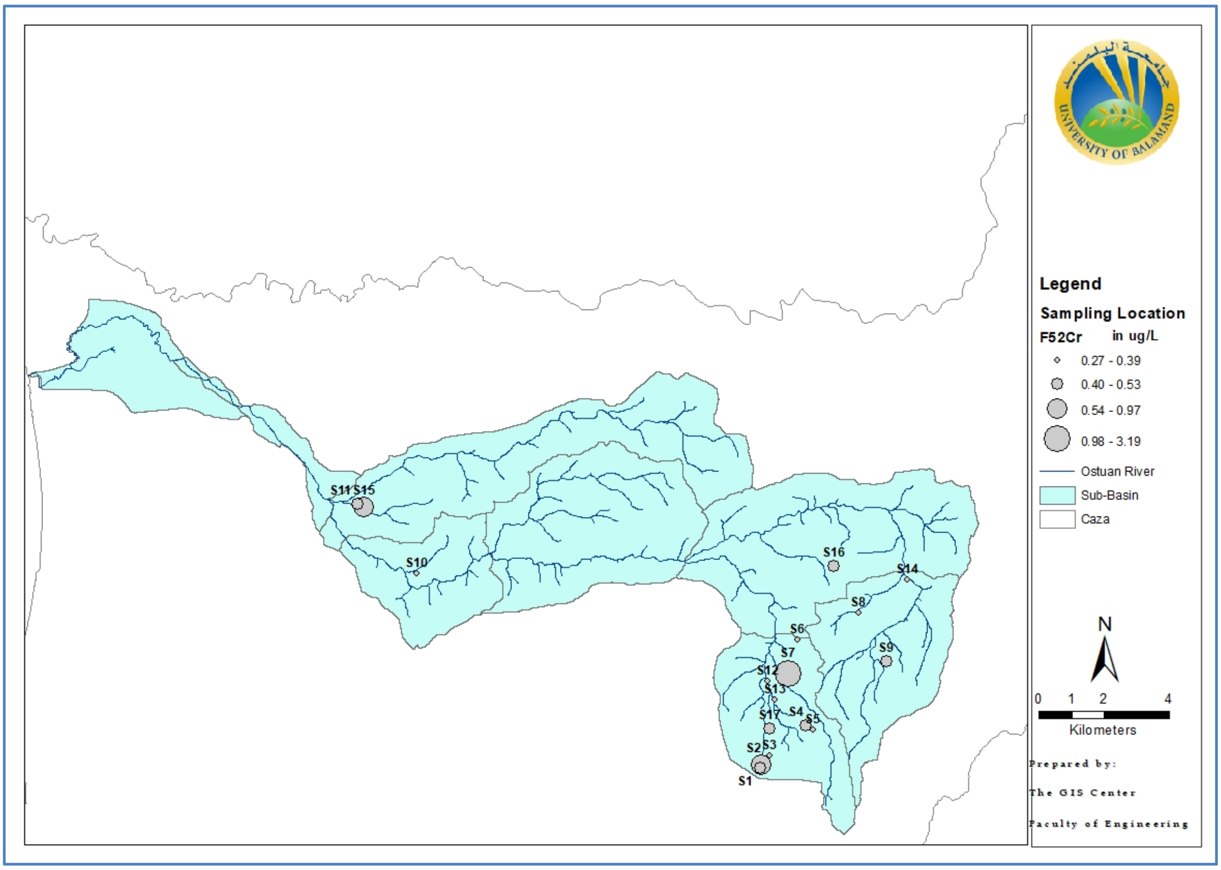


Figure 6-33: Variation of Chromium concentrations in the sampling sites of Ostuan River (dry season)

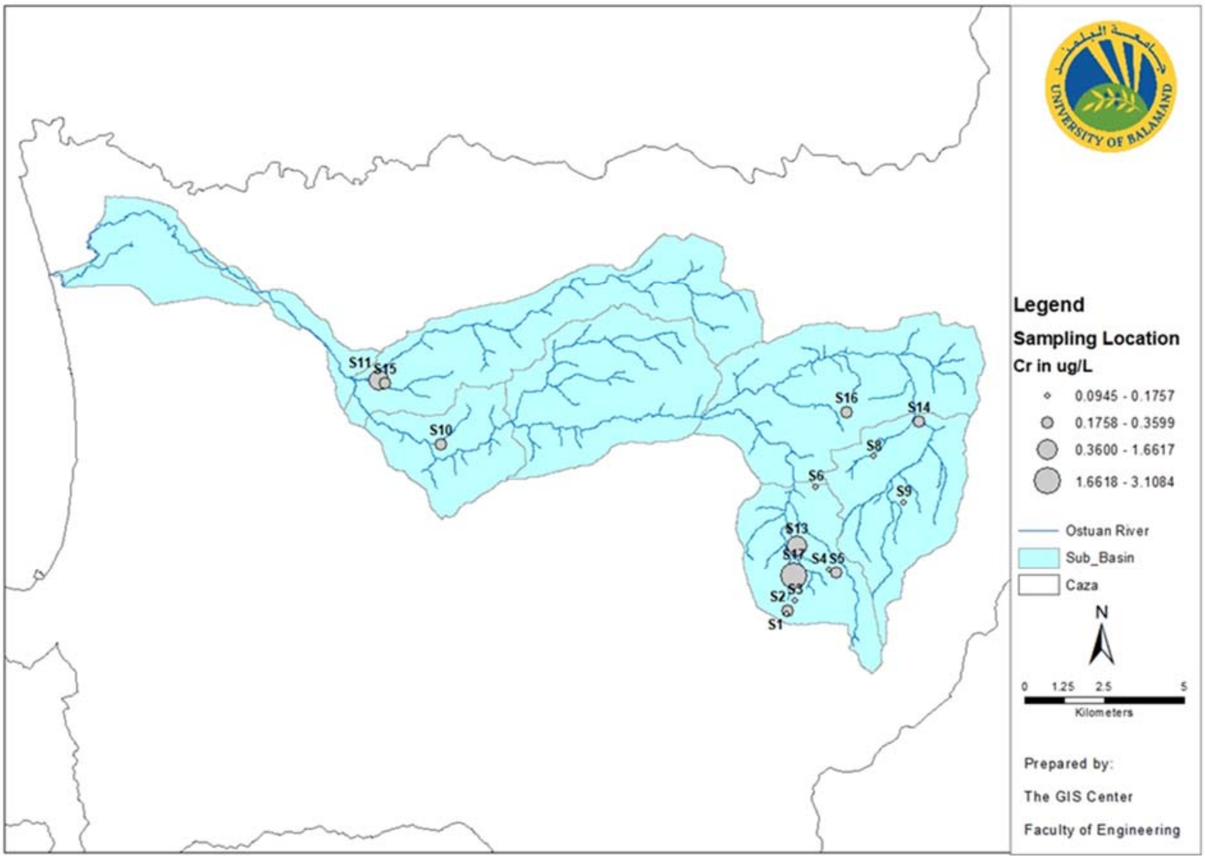


Figure 6-34: Variation of Chromium concentrations in the sampling sites of Ostuan River (wet season)

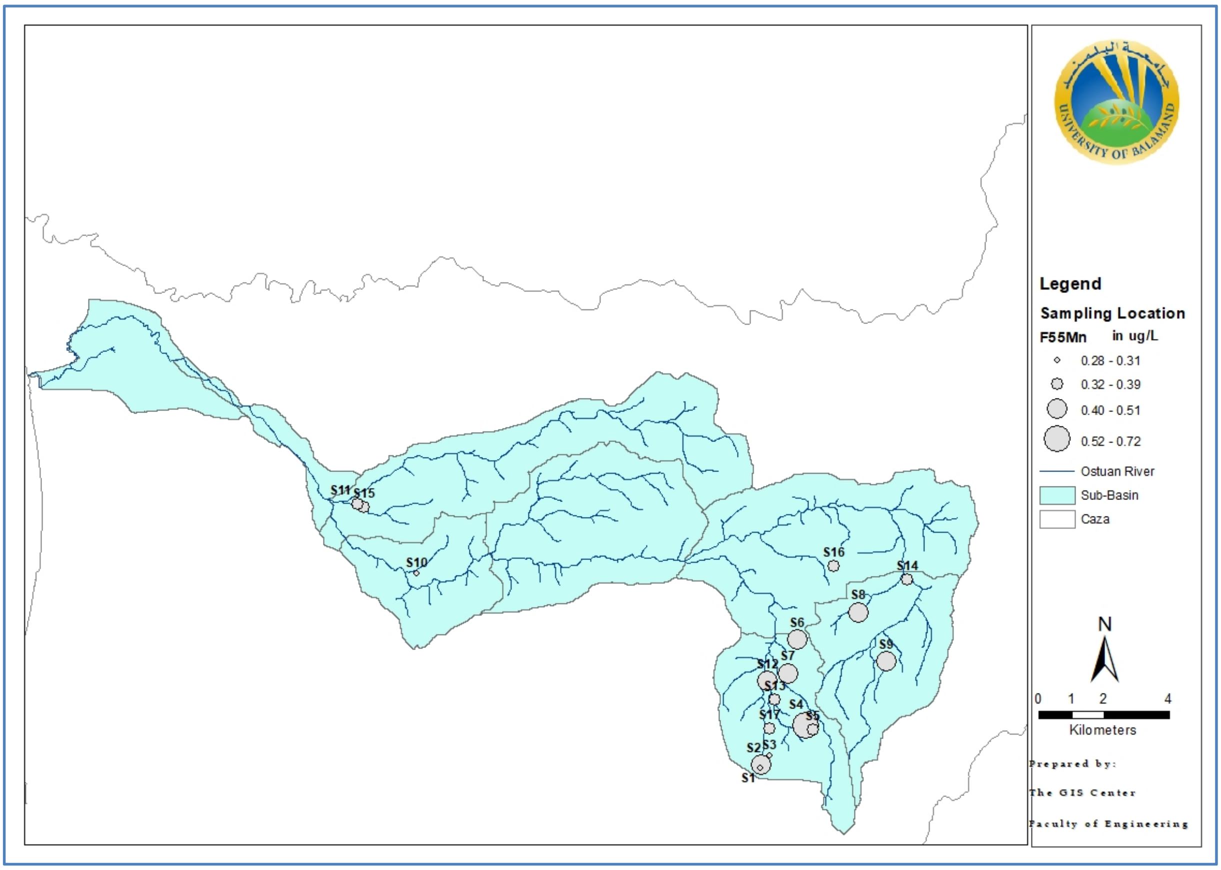


Figure 6-35: Variation of Manganese concentrations in the sampling sites of Ostuan River (dry season)

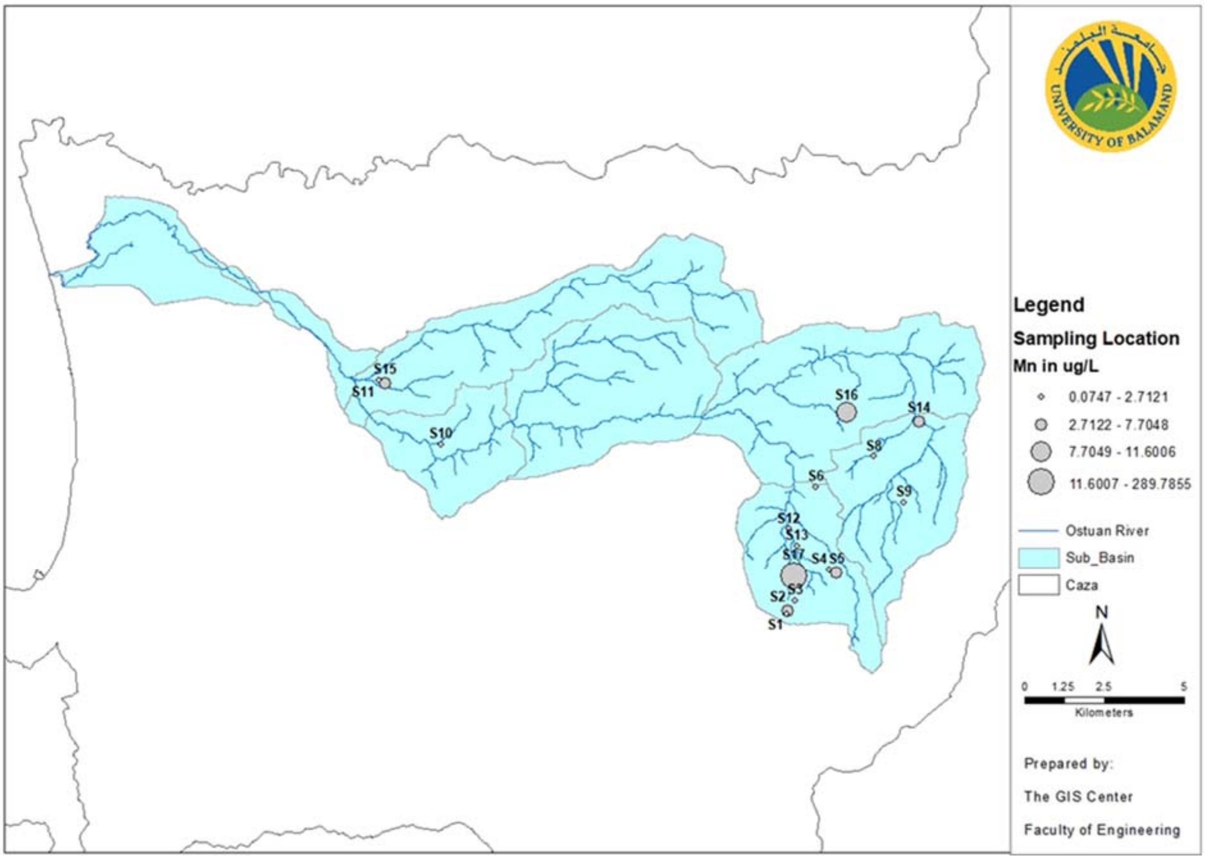


Figure 6-36: Variation of Manganese concentrations in the sampling sites of Ostuan River (wet season)

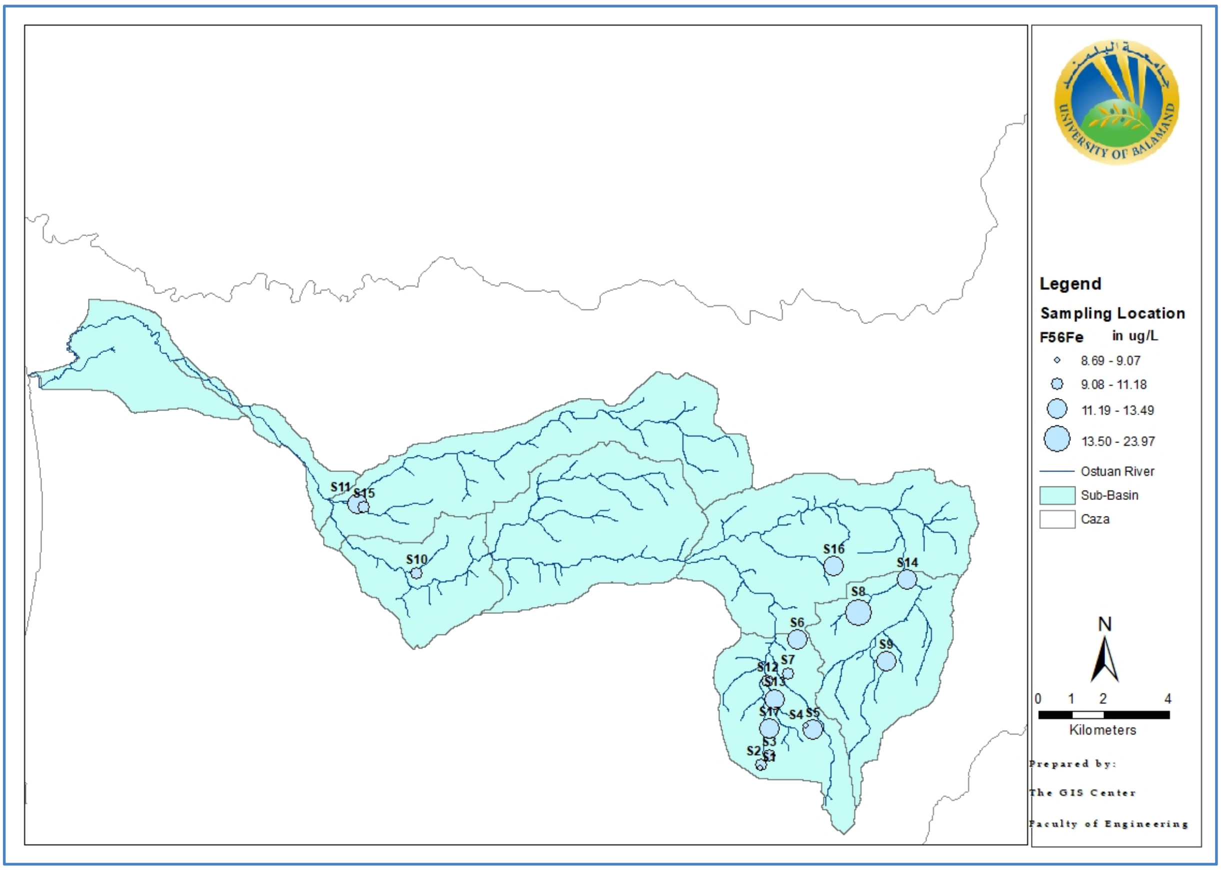


Figure 6-37: Variation of Iron concentrations in the sampling sites of Ostuan River (dry season)

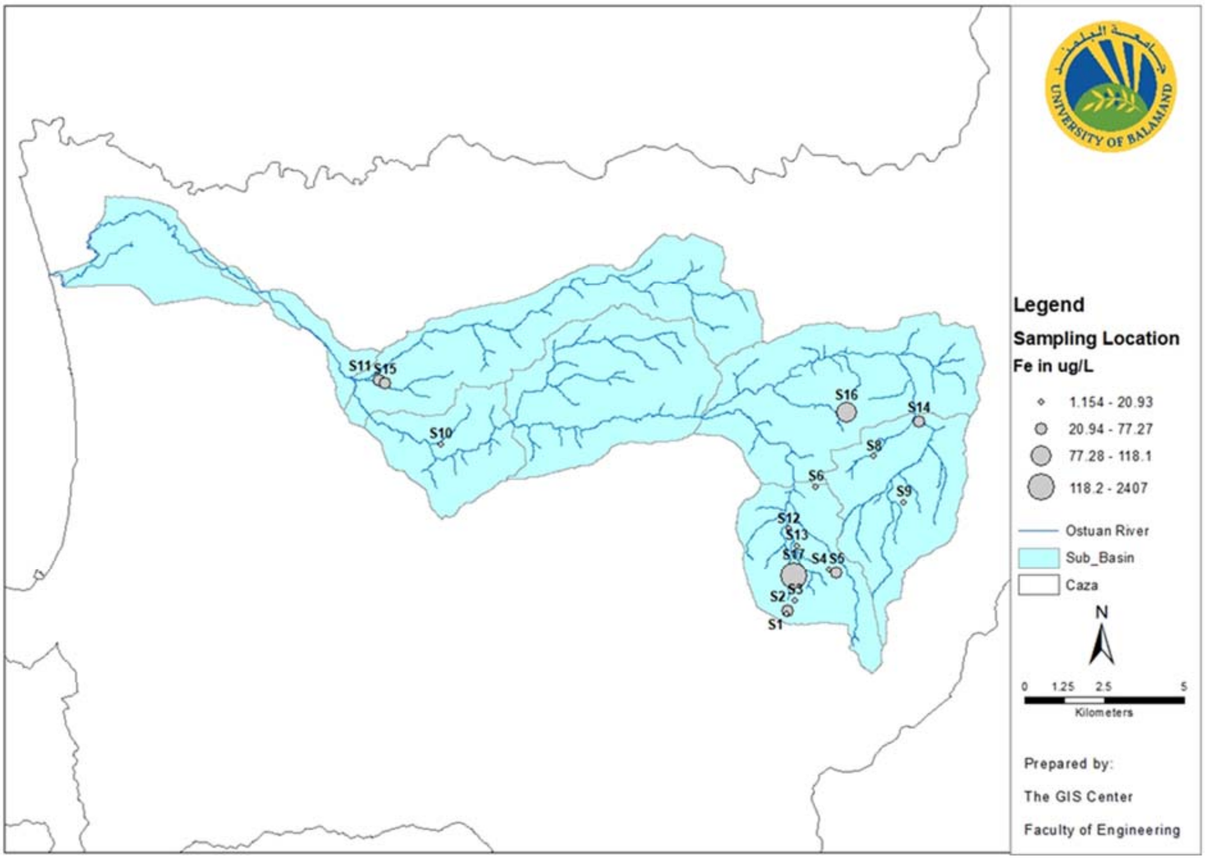


Figure 6-38: Variation of Iron concentrations in the sampling sites of Ostuan River (wet season)

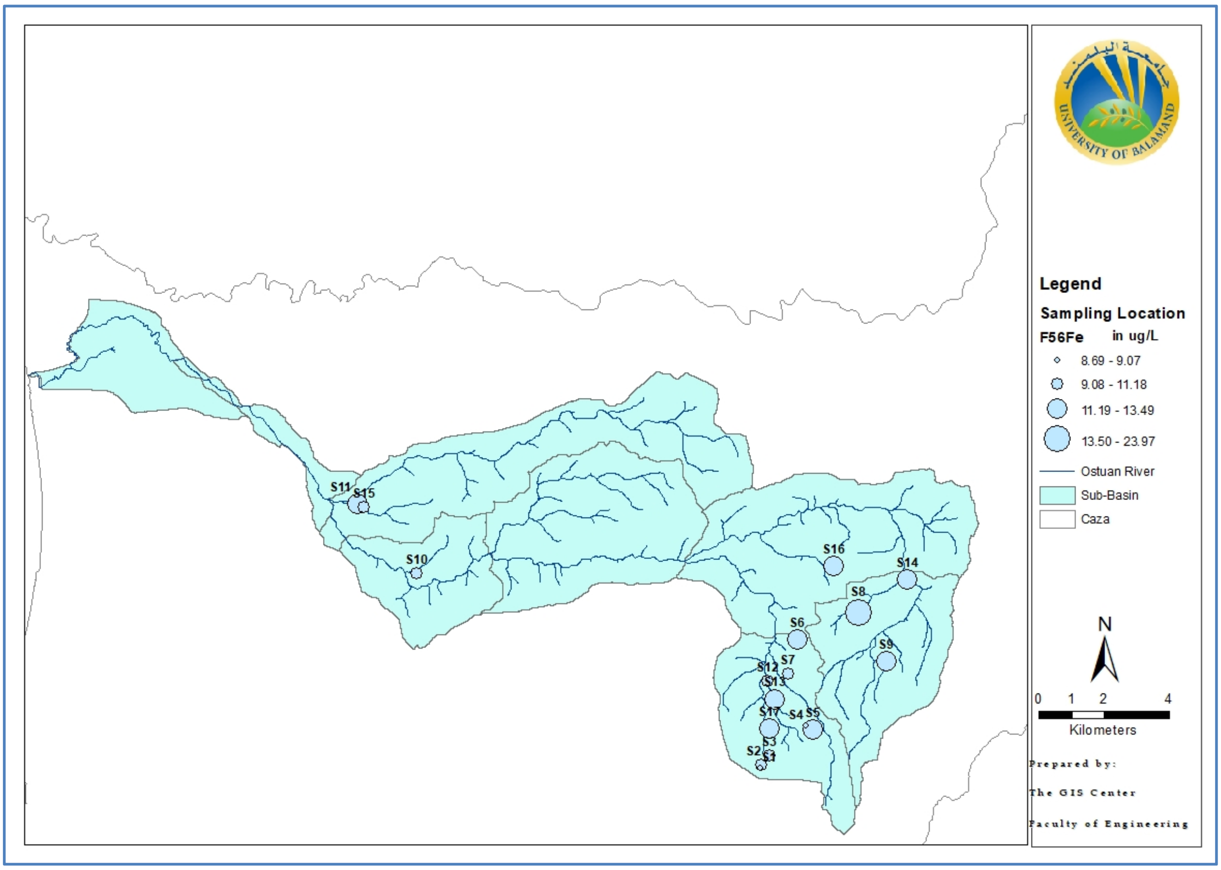


Figure 6-39: Variation of Cobalt concentrations in the sampling sites of Ostuan River (dry season)

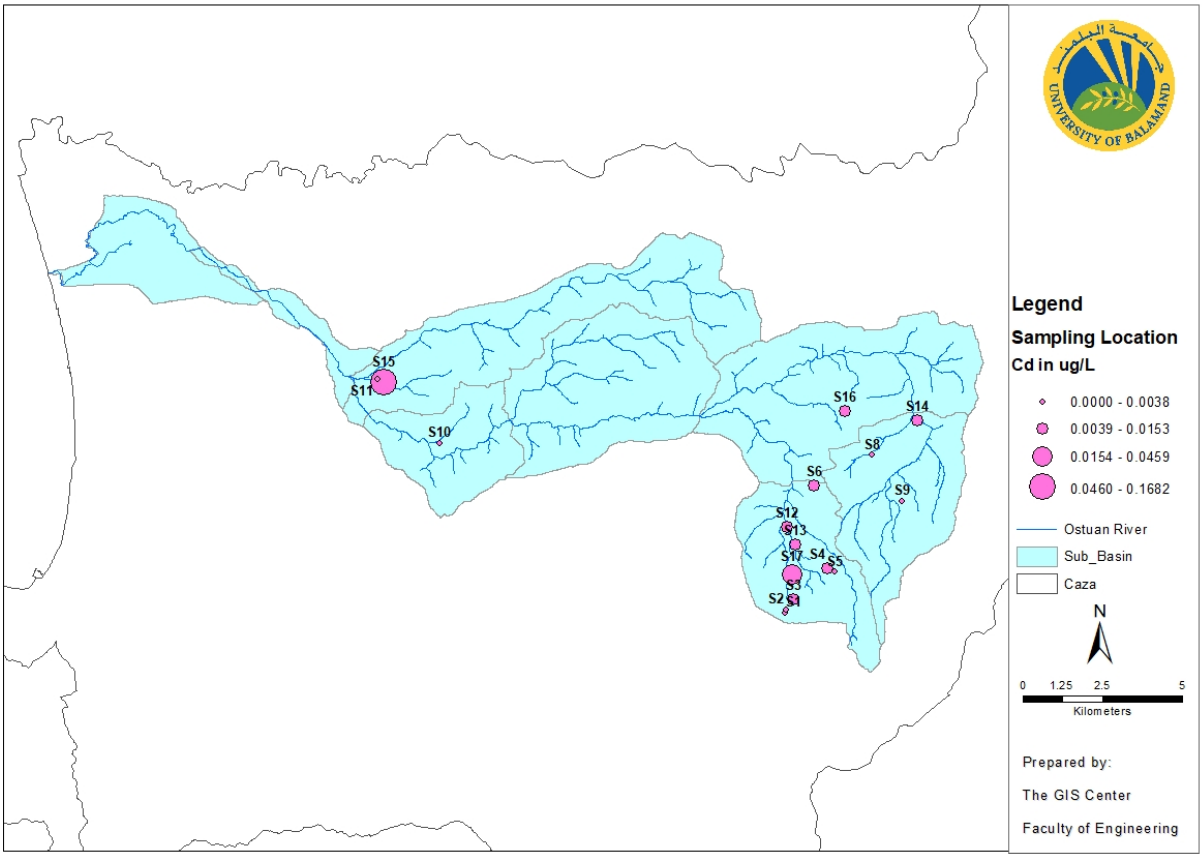


Figure 6-40: Variation of Cobalt concentrations in the sampling sites of Ostuan River (wet season)

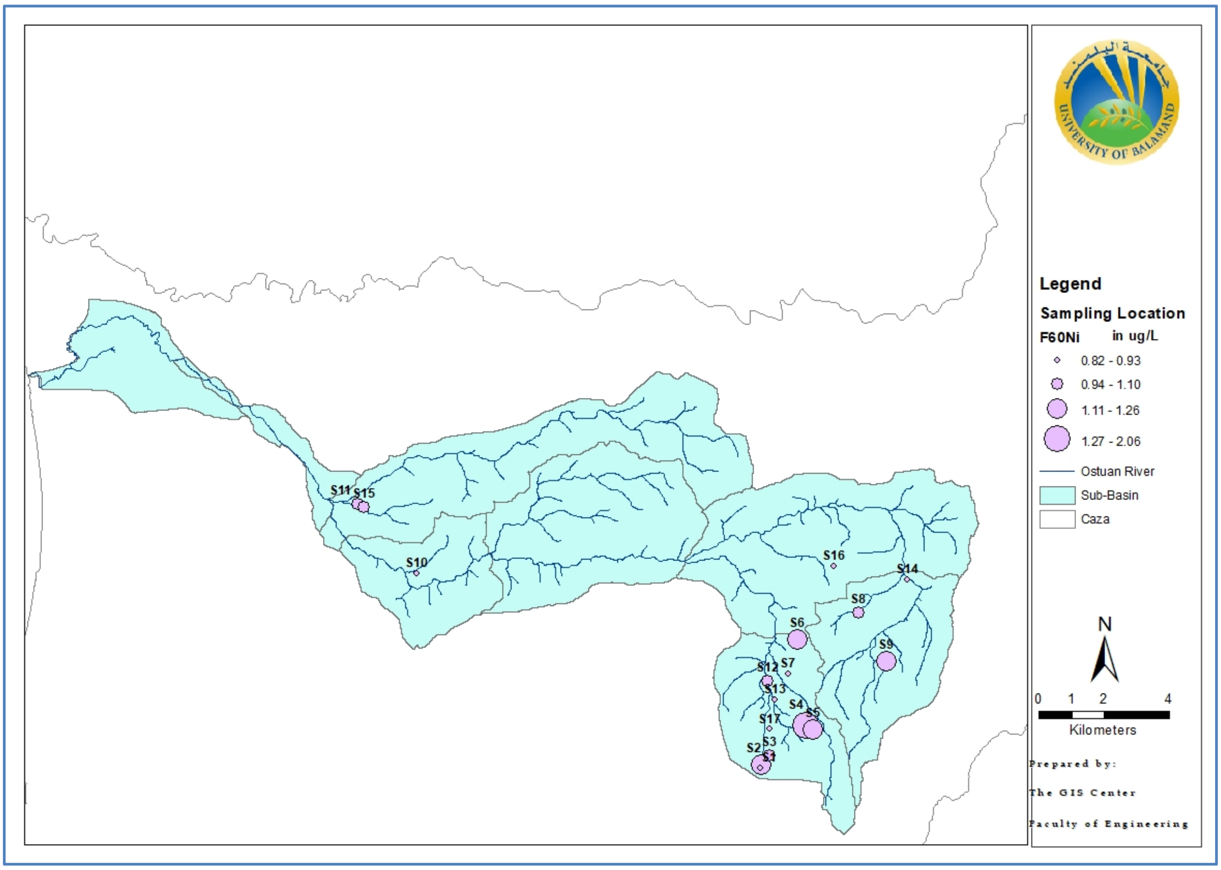


Figure 6-41: Variation of Nickel concentrations in the sampling sites of Ostuan River (dry season)

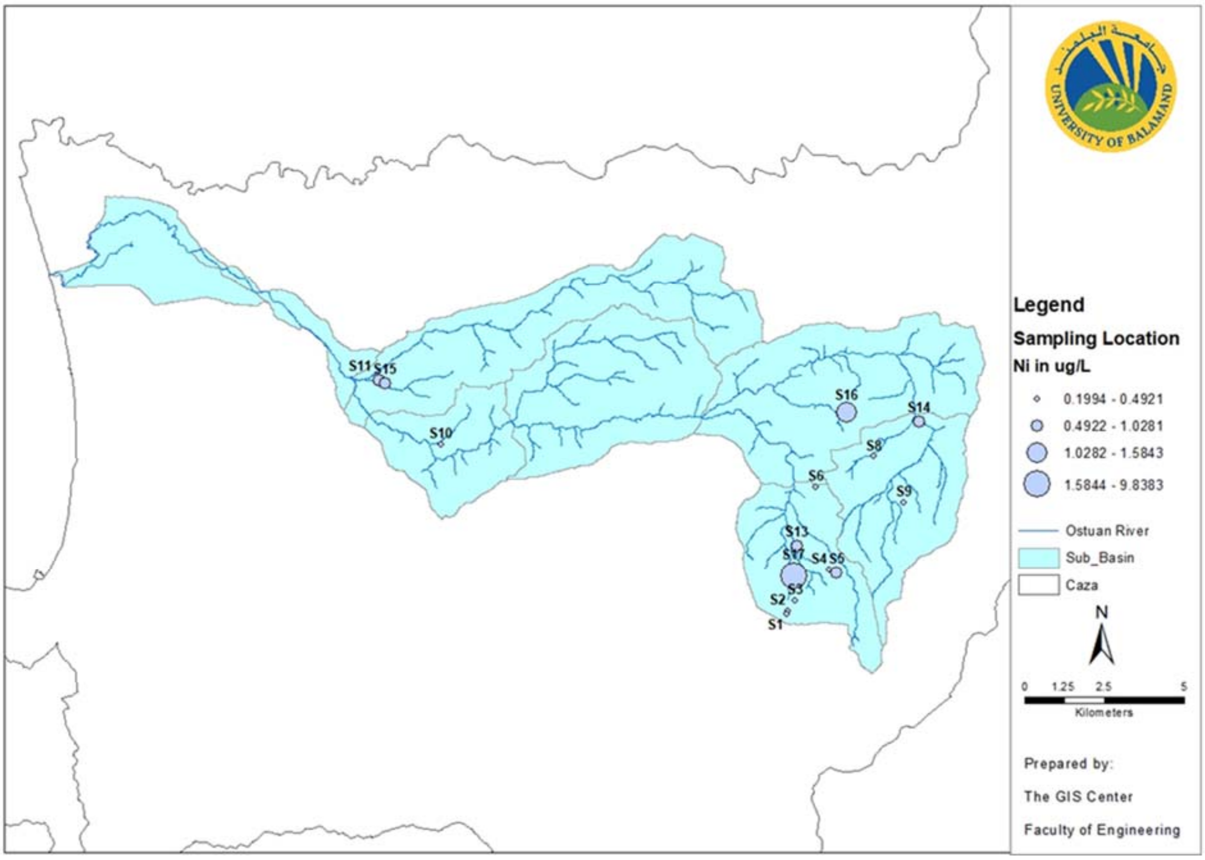


Figure 6-42: Variation of Nickel concentrations in the sampling sites of Ostuan River (wet season)

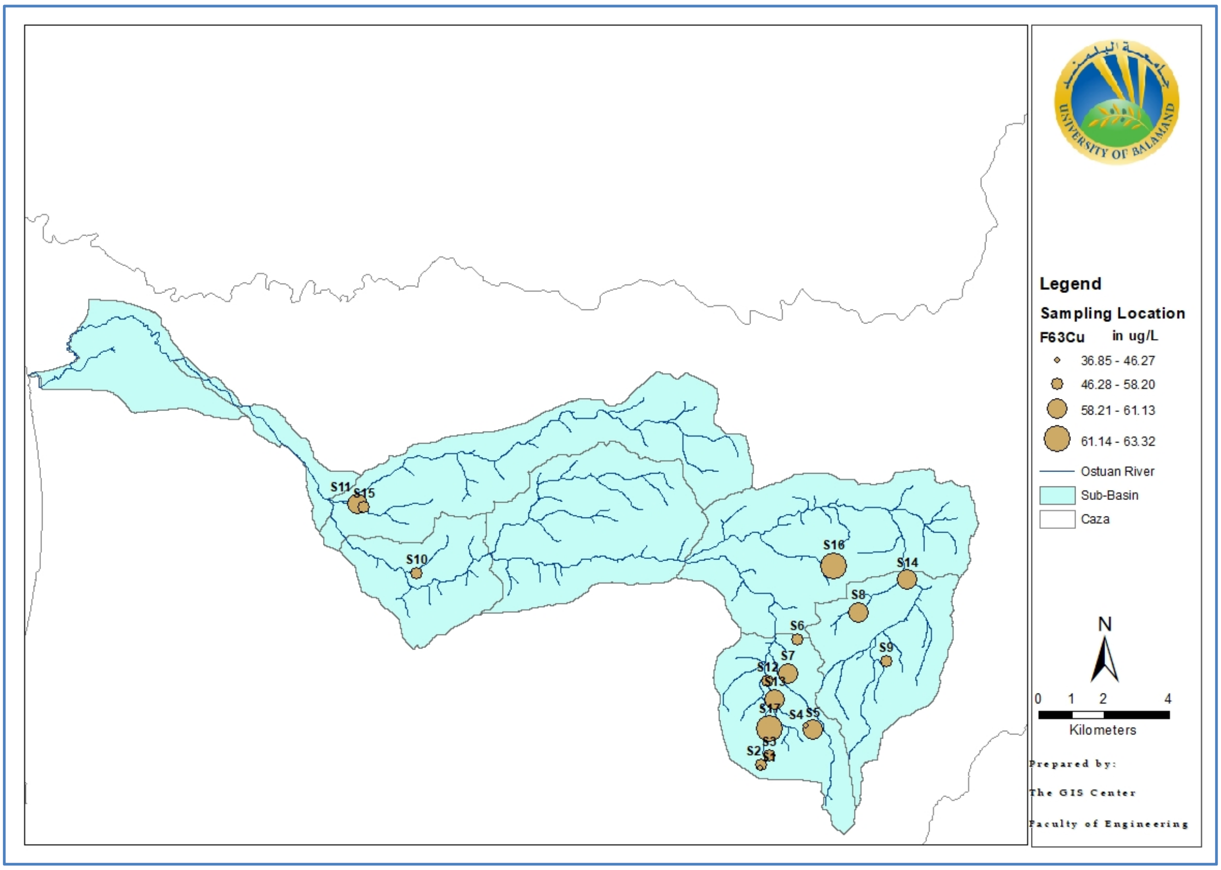


Figure 6-43: Variation of Copper concentrations in the sampling sites of Ostuan River (dry season)

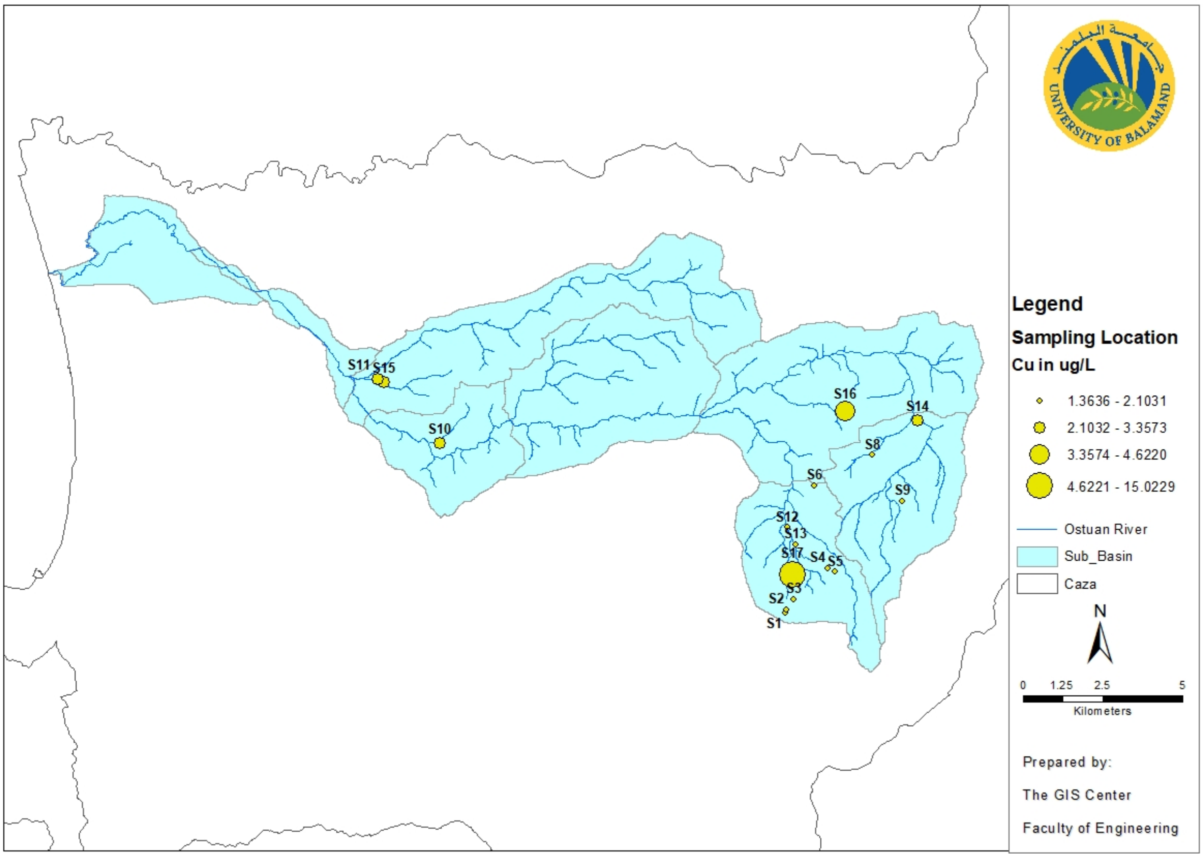


Figure 6-44: Variation of Copper concentrations in the sampling sites of Ostuan River (wet season)

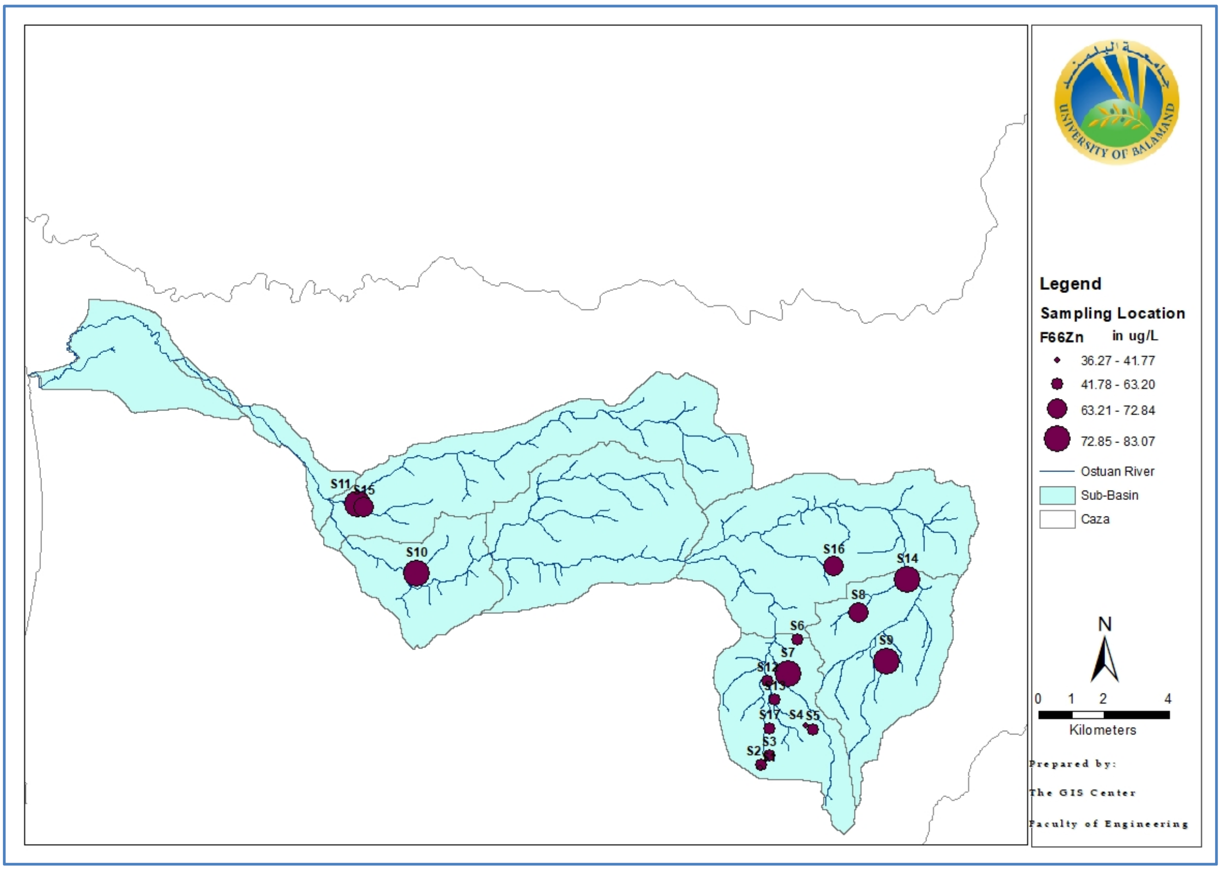


Figure 6-45: Variation of Zinc concentrations in the sampling sites of Ostuan River (dry season)

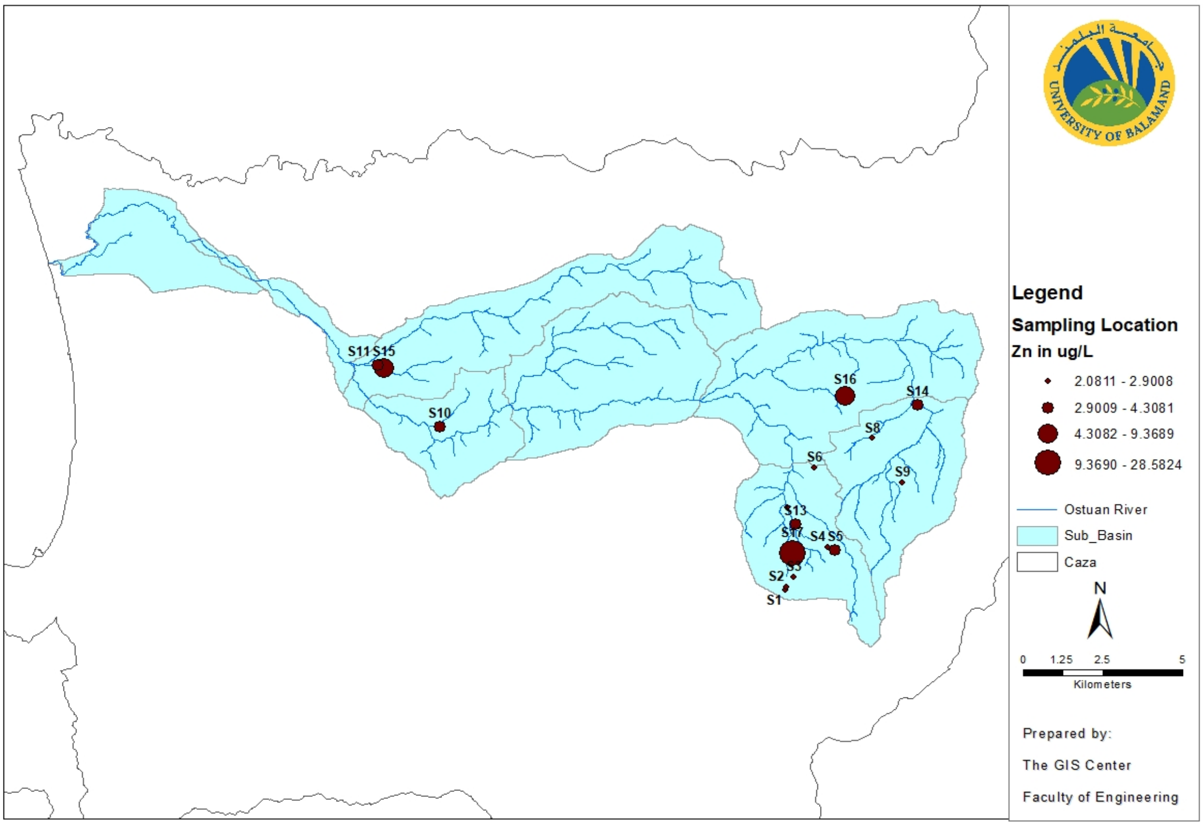


Figure 6-46: Variation of Zinc concentrations in the sampling sites of Ostuan River (wet season)

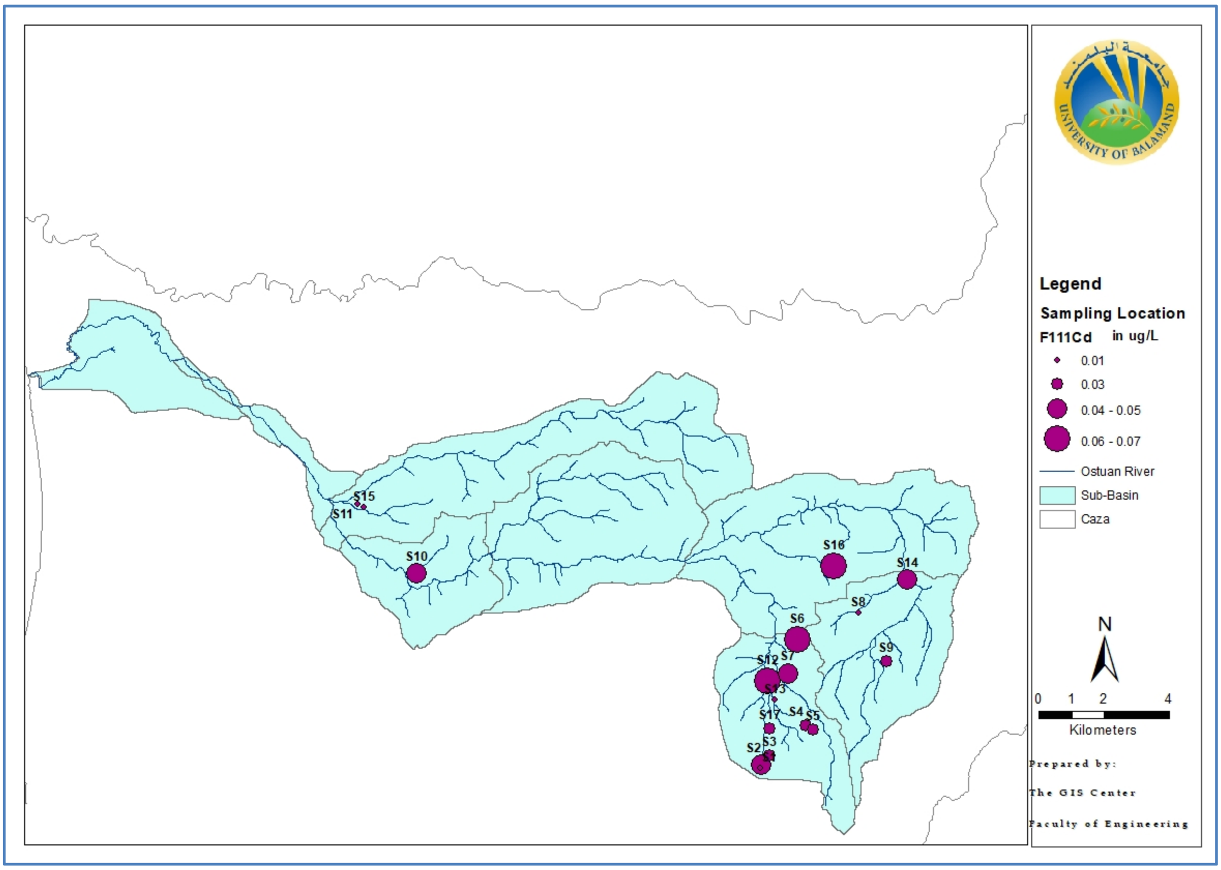


Figure 6-47: Variation of Cadmium concentrations in the sampling sites of Ostuan River (dry season)

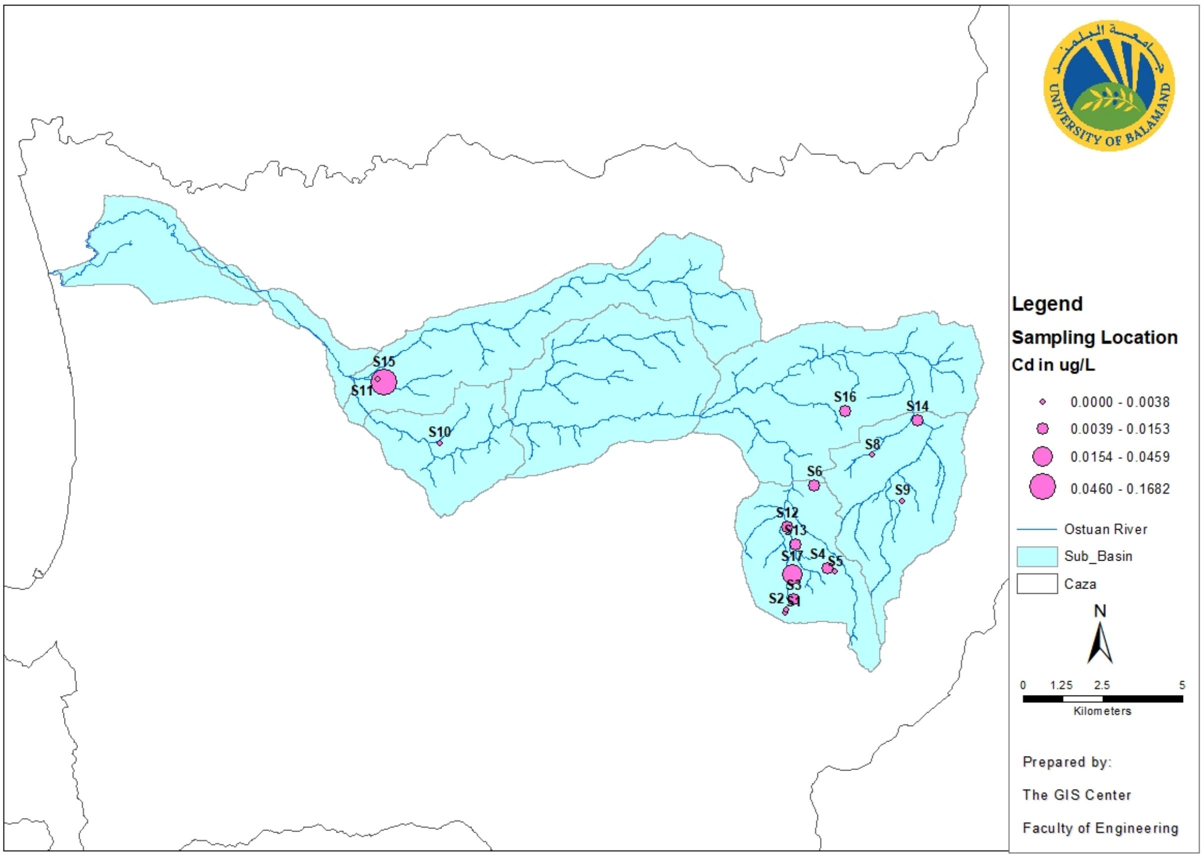


Figure 6-48: Variation of Cadmium concentrations in the sampling sites of Ostuan River (wet season)

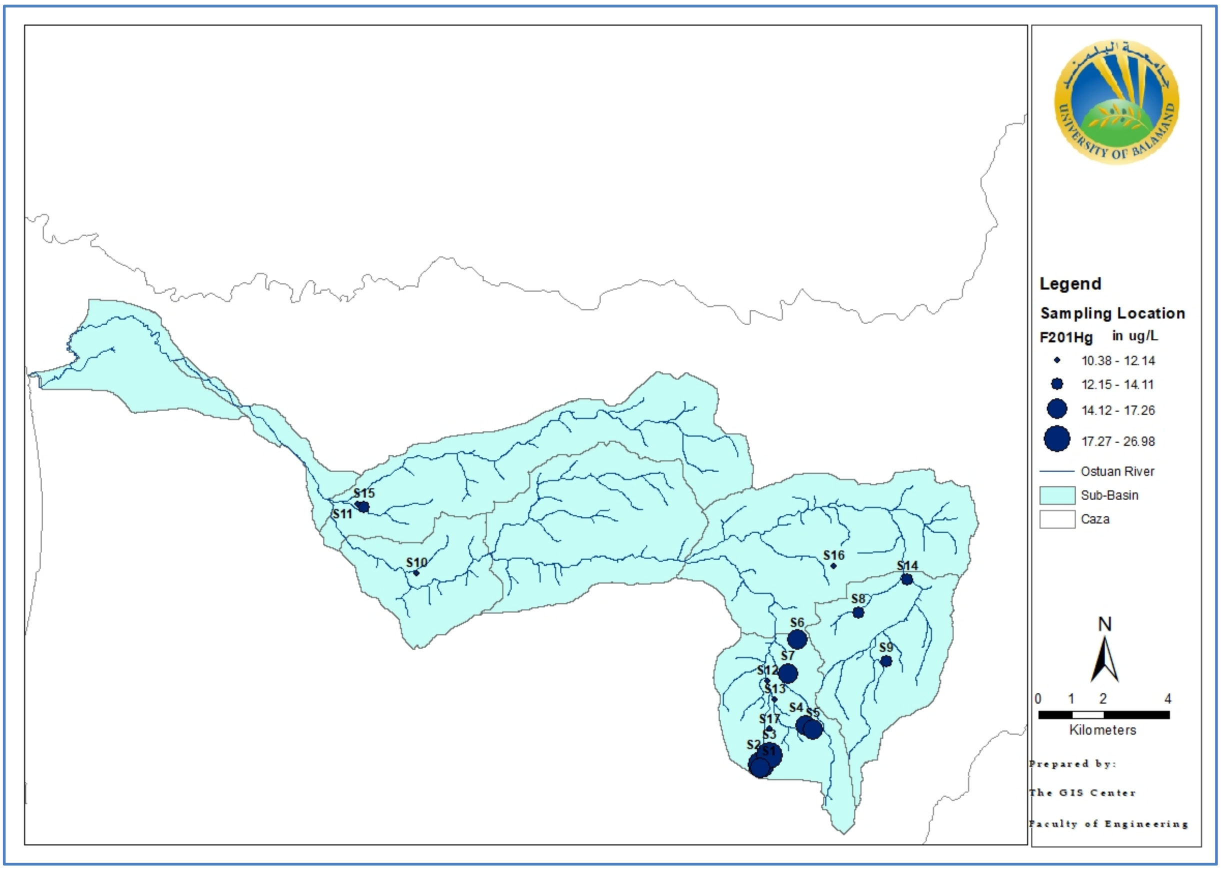


Figure 6-49: Variation of Mercury concentrations in the sampling sites of Ostuan River (dry season)

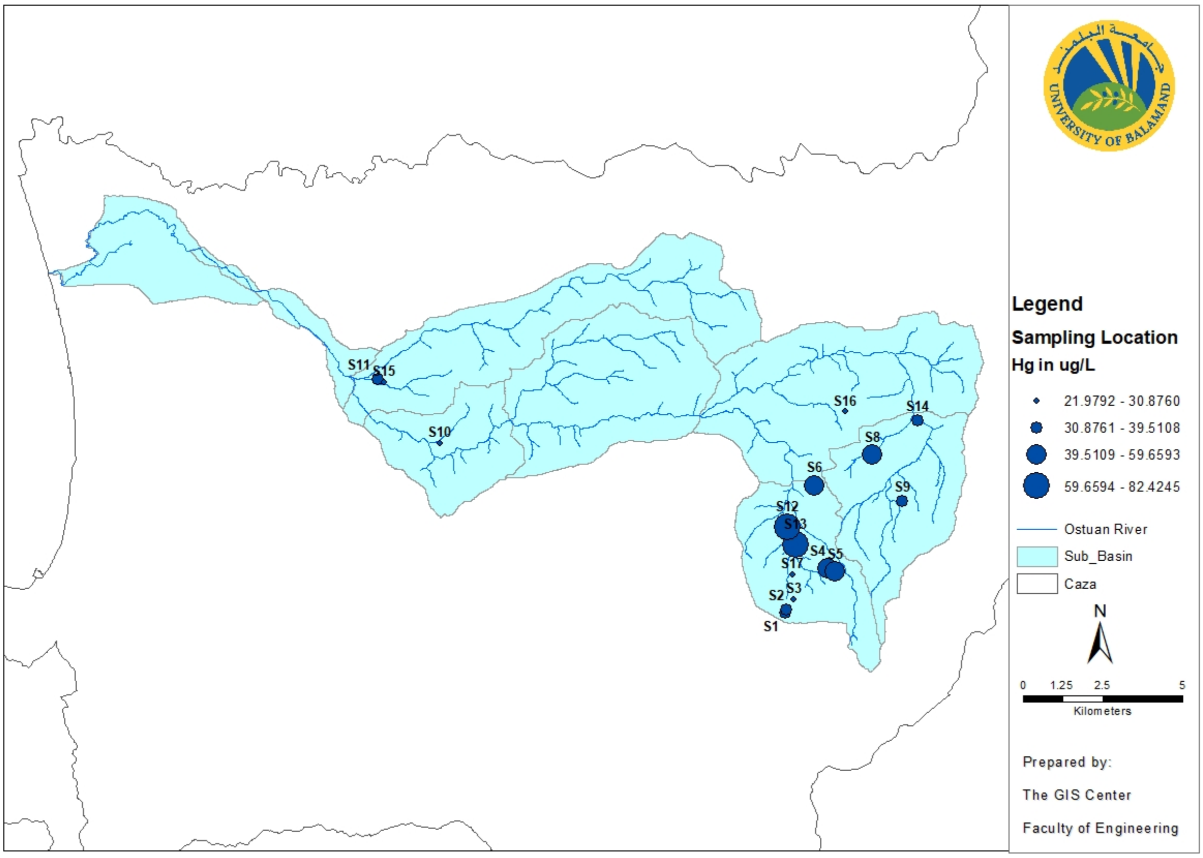


Figure 6-50: Variation of Mercury concentrations in the sampling sites of Ostuan River (wet season)

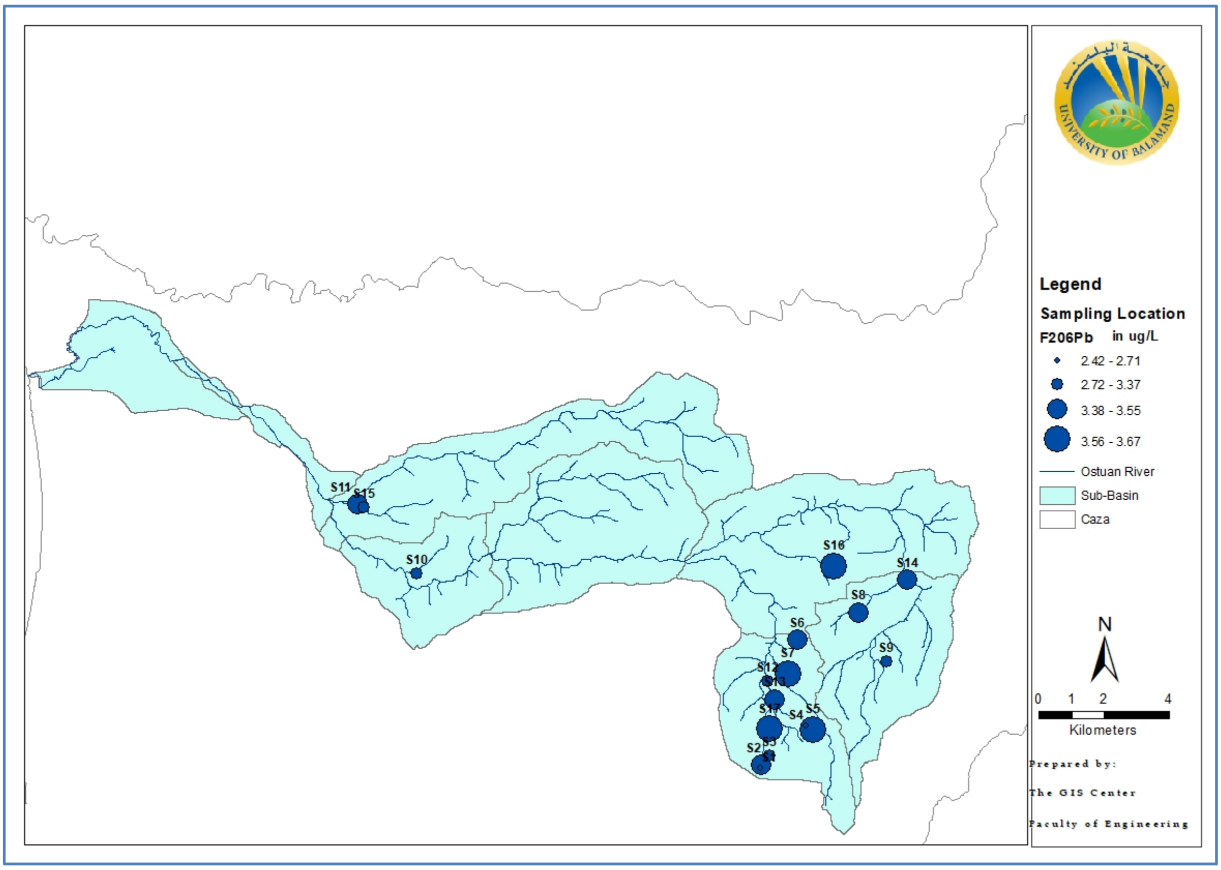


Figure 6-51: Variation of Lead concentrations in the sampling sites of Ostuan River (dry season)

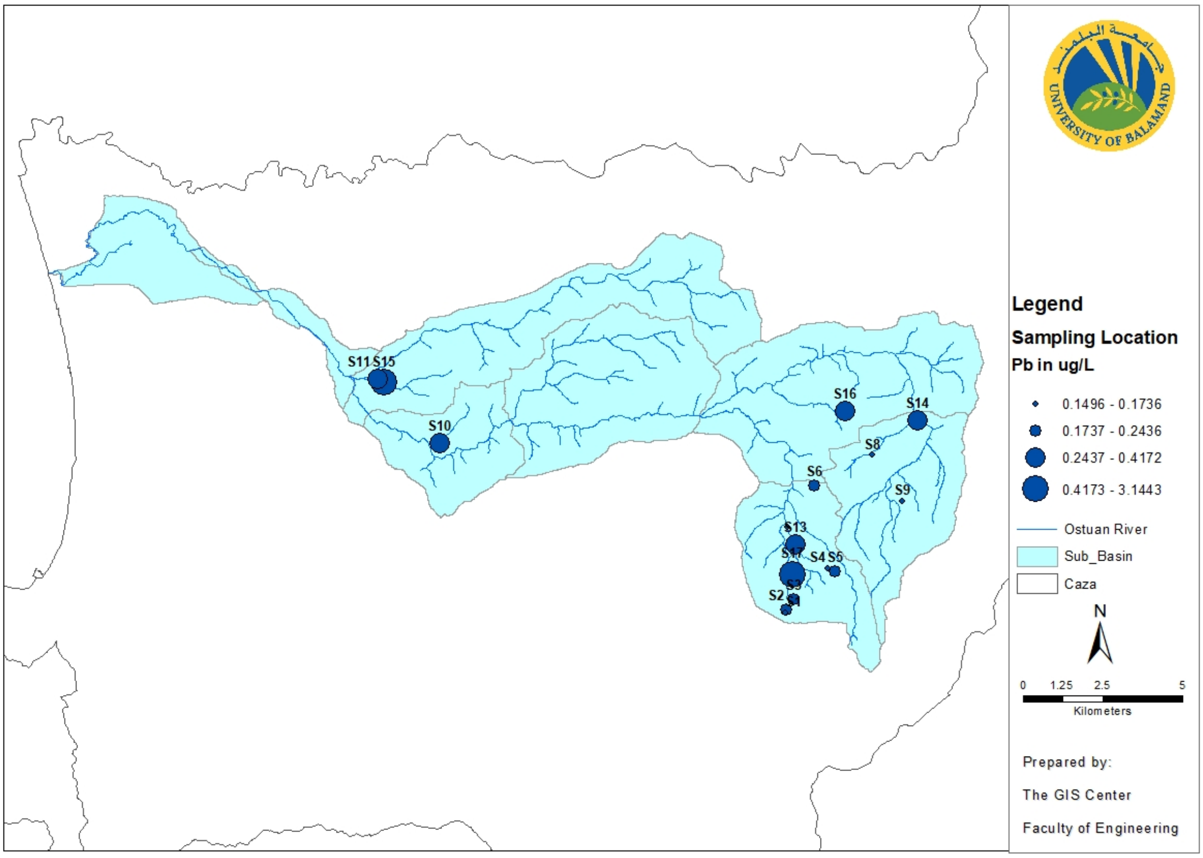


Figure 6-52: Variation of Lead concentrations in the sampling sites of Ostuan River (wet season)

6.3.15 MICROBIOLOGICAL PARAMETERS

The results obtained revealed the presence of fecal coliforms and E.coli in all the studied sampling sites. The values seen in Figure 6-53 through Figure 6-56 are far above the MCL value set by the WHO (0 MPN/ 100 mL) (Appendix 1). These findings confirm the essential contribution of wastewater discharge in the pollution of the water resources of Al Ostuan River.

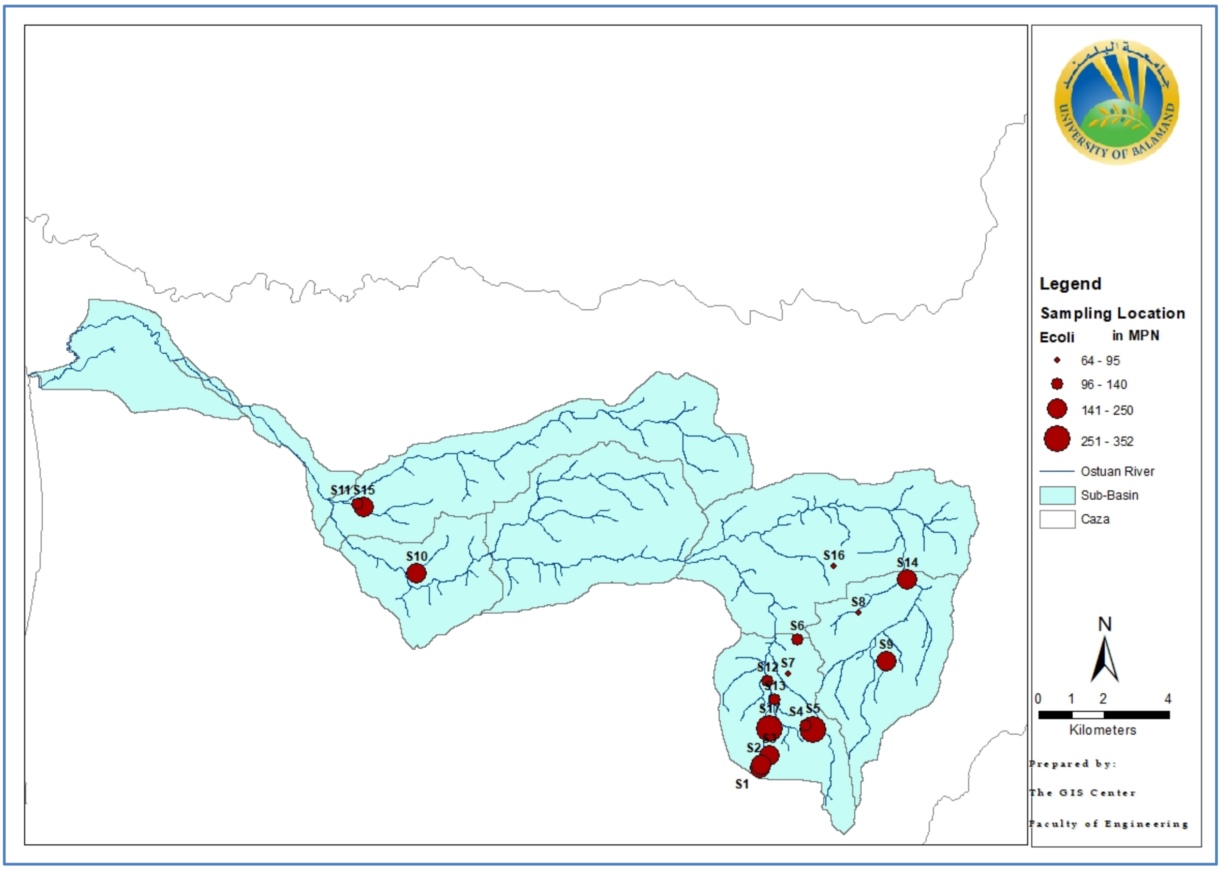


Figure 6-53: Variation of E.Coli in MPN/ 100 mL the sampling sites of Ostuan River (dry season)

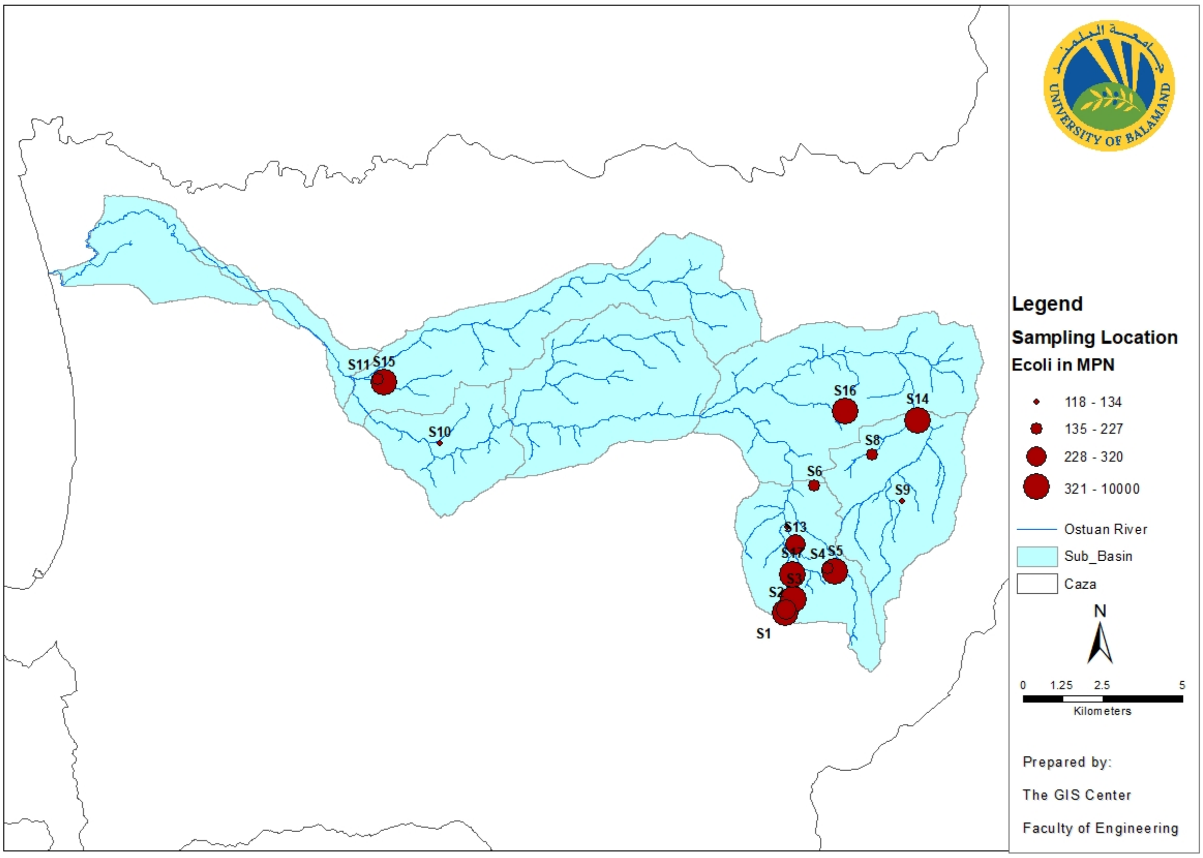


Figure 6-54: Variation of E.Coli in MPN/ 100 mL the sampling sites of Ostuan River (wet season)

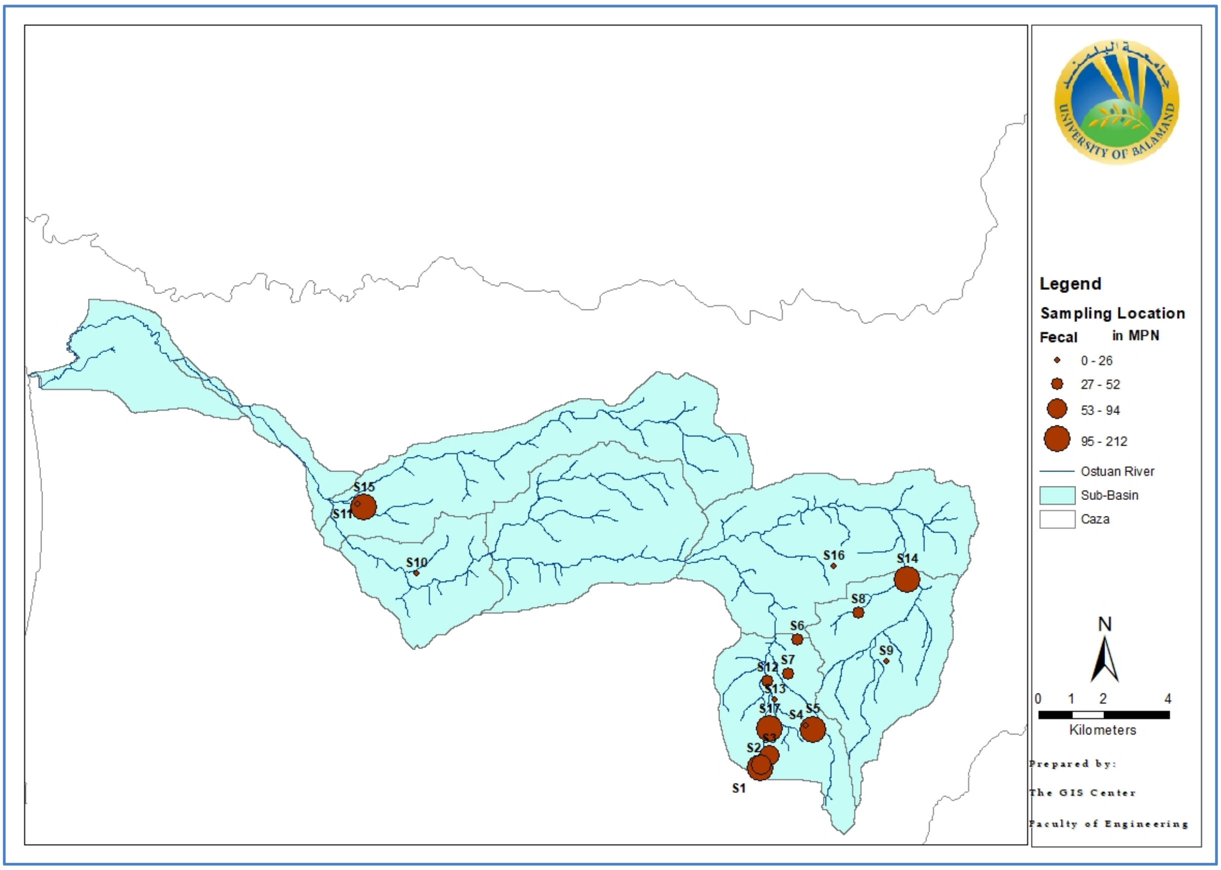


Figure 6-55: Variation of Coliforms in MPN/ 100 mL in the sampling sites of Ostuan River (dry season)

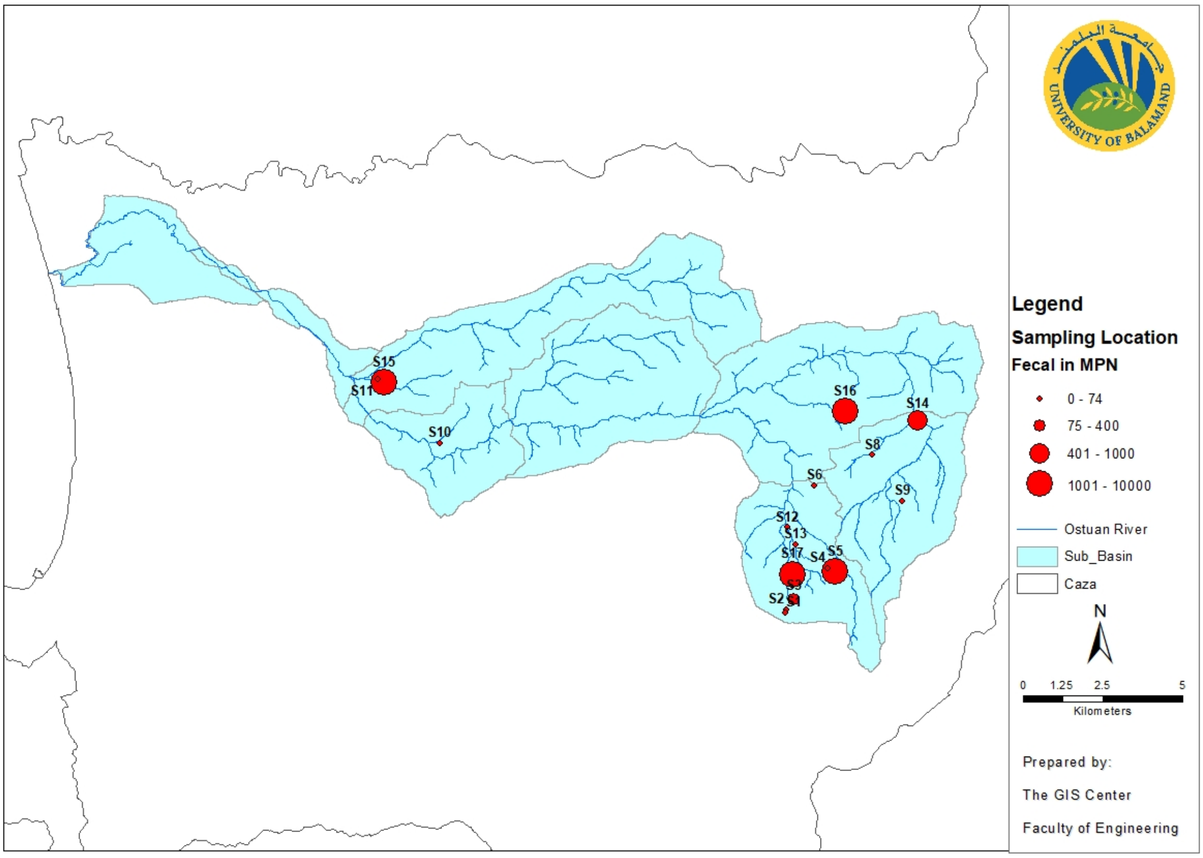


Figure 6-56: Variation of Coliforms in MPN/ 100 mL in the sampling sites of Ostuan River (wet season)

7 CONCLUSIONS

7.1 CONCLUSIONS OF THE WATER BALANCE ASSESSMENT

A detailed water balance model has been developed for the Al Ostuan River Basin in Lebanon for the period 2003-2018, allowing the representation of the components of the hydrological cycle and catchment process along with the water demand and use aspects in the catchment. All model features have been calculated at monthly timestep, for each of the 8 sub-catchments and 29 demand sites, allowing the identification of opening and closing stock, and exchange in flows, the assessment of the water availability and water demands, and thus the prevailing water balance in the entire River Basin and at sub-catchment level. The model also allowed for the identification of the unmet demand (i.e. the difference between the water demand and the supply provided) at the node-based level, for all urban and agricultural demand sites.

The long-term annual average precipitation is in the basin is about 121 Mm^3, of which 50% is lost due to evapotranspiration, about 42% is turned into surface runoff and about 8% infiltrates in the groundwater. It was observed that the years 2010, 2016, 2017 and 2008 have been dry, while 2003, 2004, 2005, and 2018 have been wet. Variability in the precipitation is observed across the river basin, with the western part of the basin receiving (sub-catchments C15, C22) lower precipitation level. The highest groundwater infiltration rates and groundwater potential have been observed in the central and central-eastern part of the basin (sub-catchments C19, C18) which are located in within the aquifers C4-C6 (North Lebanon Cretaceous Basin [18] and Mount Lebanon-Bekaa Cretaceous Basin [3]). The higher surface runoff is observed in sub-catchment C16 in the northern part of the basin (~ 33 Mm3/year on average, representing 53% of the precipitation).

The primary water demands in the Al Ostuan basin are for urban and irrigation purposes, and sum up to ~7 Mm^3/year and 11 Mm^3/year respectively (average of the 2003-2018 period). The irrigation demand is highly dependent on the precipitation and thus varies across the years from 8 to 13 Mm^3/year. The urban demand is mainly for domestic purposes (90%) and also includes a small share (~10%) for industrial purposes. The water supply requirements are in fact higher than the actual water demand due to network losses and irrigation practices' efficiency. The losses in the urban water supply network are 30%, while the overall combined irrigation efficiency is 60% since most irrigation networks are local and individual. The efficiency of the collective networks is very low, around 45%, since these are dominantly open channels, while furrow (surface) irrigation is extensively used.

Based on the model results, the balance between demand and availability is negative, resulting in unmet demand in all the 8 sub-catchments of the Al Ostuan River Basin every year. The total annual unmet demand in the Al Ostuan River Basin is, on average, 17 million m^3/year (which represents 62% of the water supply required) over the 16-year period 2003-2018, ranging from as low as 8 Mm^3 (in 2003) to as high as 22 Mm^3 (in 2010). This basically means that, on average, only 42% of the water needs are covered by the water availability and supply in Al Ostuan. The years with the largest unmet demand are 2010, 2016, 2017, 2008, and 2013 (all these years had annual unmet demand > 19.5 Mm^3/year, and only ~30% of the needs were actually met). The years with the lowest unmet demand were 2003, 2004 and 2005, yet even in these cases the unmet demand amounted to 32-53% of the water supply required.

This unmet demand is mainly attributed to the irrigation: ~13.8 million m3/year on average, with maximum 16-17.5 million m3 observed in 2010, 2017, 2016, 2010. Nevertheless, the domestic/ urban sector is also highly affected: the average urban unmet demand is ~3.5 million m3/year (or 9,620 m3/day, or 92 lt/cap/day), with maximum ~5 million m3 observed in 2016, 2010, 2017 and 2008.

The urban nodes (demand sites) with the higher unmet demand, are UD_16_Kob.Daouce (with an annual average unmet demand of 0.69 mio m^3/year, or 1,880 m^3/day, or 18 lt/cap/day), and UD_16_Kob.Charbila (with an annual average unmet demand of 0.60 mio m^3/year, or 1,643 m^3/day, or ~16 lt/cap/day). The villages that are grouped in these 2 nodes are: El-Kouachra, Daouce et Baghdadi, Denke et El-Amriyeh, El-Bire, Charbila, Ain El-Zeit, El-Daghle, Kherbet Daoud, El-Msalle, Kefr El-Ftouh. All these villages are supplied by the NLWE Qoubayat Branch (system of Qoubayat wells 1/3, 2/3, 3/3) Daouce and Charbila lines. It is concluded that the supply provided by the Qoubayat wells cannot meet all the current needs of these villages. The above findings are aligned with the 2020 NWSS Update (NWSS 2020, Volume IV, Appendix IV C5 – Water Balances, pages IV C127 – IV C 148). The calculated balances in the NWSS 2020 have been found negative within the Qobayate distribution systems No. 22 (Charbila, Ain El-Zeit, El-Msalle, Kefr El-Ftouh), No. 23-24-12 (El-Daghle, Kherbet Daoud, El-Bire), No. 17 (El-Kouachra) and No. 13 (Daouce et Baghdadi, Denke et El-Amriyeh).

The agricultural nodes (demand sites) with the higher unmet demand, are Agri_15 (with an annual average unmet demand of 5.8 mio m^3/year), and Agri_16 (with an annual average unmet demand of 2.7 mio m^3/year).In Agri_15 there are extensive irrigation areas, about 3 km^2, covering 75% of the total sub-catchment area, dominated with field crops in medium to large terraces (68% of the irrigated area) and citrus fruit trees (27% of the irrigated area). The available water cannot cover all these irrigation needs. The farms affected are within the villages of Al-Khraibe, Koueikhat, Tal Abbas El-Charkie, Tal Abbas El-Gharbie, Al-Massoudie. In Agri_16 there are extensive irrigation areas, about 18 km^2, covering 63% of the total sub-catchment area, dominated with olives (62% of the irrigated area), and field crops in medium to large terraces (35% of the irrigated area). The available water cannot cover all these irrigation needs. The farms affected are within the villages of Charbila, Ain El-Zeit, El-Daghle, Kherbet Daoud, El-Msalle, Kefr El-Ftouh, El-Kouachra, Daouce et Baghdadi, Denke et El-Amriyeh, El-Bire, Katte, Al-Rihanie, El-Tleil, Omar el-Beikate, El-Haouchab, Hmais, Saidnaya, Al-Khraibe.

The Reliability of the system in supplying the requested demand ranges among the uses. Reliability is defined as the percent of the timesteps in which a demand site's demand was fully satisfied. For example, if a demand site has unmet demands in 6 months out of a 10-year scenario, the reliability would be (10 * 12 - 6) / (10 * 12) = 95%. As domestic use is priority 1, the water allocation to this use has an overall higher reliability (60% on average across all the 21 urban demand nodes) comparing to the reliability of the irrigation (58% on average across all the 8 agricultural demand nodes).

The reliability in the urban water supply ranges from as low as ~29% in some sites (Katte, Al-Rihanie, El-Tleil, Omar el-Beikate, El-Haouchab, Hmais, Saidnaya, Al-Khraibe, Al-Kleiat, Cheikh Zennad Tal Bibe, Al-Kneisse, Al Moghrak, Tal Kerri, Al-Hissa, Al-Massoudie , Dahr-Leycine, Machha, Hayzouk, Al-Souaisse, Dahr el-Kneisse, Al-Khraibe, Koueikhat, Tal Abbas El-Charkie, Tal Abbas El-Gharbie, Al-Massoudie), to 100% in others (Ain Tanta, Douair Adouiye, Beino, Majdel, Andeket, Akkar El-Atika, El-Koubayet). Overall, within the urban sector, 32% of the users have very low reliability (i.e. 40% reliability) of water supply, while only 38% have very high (i.e. >95% reliability).

The reliability in the irrigation water supply ranges from as low as ~22% in some sites (Al-Khraibe, Koueikhat, Tal Abbas El-Charkie, Tal Abbas El-Gharbie, Al-Massoudie, Al-Kleiat, Cheikh Zennad Tal Bibe, Al-Kneisse, Al Moghrak, Tal Kerri, Al-Hissa, Al-Massoudie), to 100% in others (Ain Tanta, Douair Adouiye, El-Hed, Deir-Janine, Sfeinite El-Dreibe, Kherbet Char, Fseikine et Ain Achma, Barbara, Mazraat Balbe, Beino, Majdel, Andeket, Akkar El-Atika, El-Koubayet). Overall, within the agricultural sector, 50% of the users have very low reliability of water supply (i.e. <40% reliability), 12.5% have low (i.e. 40-60% reliability), while only 37.5% have very high (i.e. >95% reliability).

Among the major limitations encountered during the model setup are those related to data availability. The lack of water use data for the urban, industrial and agricultural sectors at different spatial and temporal scales required a number of aggregation and assumptions, and relevant proxies. Only limited data was available for validating streamflow. Groundwater observations remains missing. Up-to-date information about the status of the water supply network was not available for all lines. Information on irrigation efficiency and losses (conveyance losses in the irrigation networks, field application efficiency and practices in irrigated areas) are not available. The lack of these data can lead to over-estimation or under-estimation of the water supply required in the model, since this is strongly linked to the prevailing losses (open channels vs. closed pipes) and irrigation practices (% drip, sprinklers, surface).Data consistency issues were also prominent, adding difficulties to the proxy calculations (e.g. data on the number of population per village were incompatible among different data providers).

Concluding the baseline assessment of water resources' availability in the Al Ostuan River Basin for the period 2003-2018, it is observed that the current water supply cannot meet the water demand in the Al Ostuan River Basin, resulting in unmet demands in both the urban and agricultural sector every year. The "exploitable" precipitation in the basin (i.e. total precipitation minus evapotranspiration) is on an annual average basis about 61 mio m^3, of which ~62 mio m^3 becomes surface runoff and the remaining 9 mio m^3 infiltrate to the groundwater. The supply required (including the 30% losses in the urban supply network and 40% in irrigation) on the other hand is ~28 mio m^3 on an annual average basis. This means that the "exploitable" precipitation could in fact cover all demands if adequately captured and exploited, and still leave an adequate volume for the environmental water requirements. Yet, the current supply delivered is only ~10.6 mio m^3 (and fails to cover all demands) simply because only the groundwater is exploited in the basin. The surface water of the river is too polluted to be exploited, especially for drinking purposes. It becomes thus clear, that the water pollution of the river, highly attributed to the direct disposal of sewage waste in the river, impedes the exploitation of the surface water.

This condition will be exacerbated in the future, as population growth projection and climate variability will increase the current water demands. It is thus important that demand management is promoted and practiced at the basin, i.e. the adoption of various interventions and measures (technological, legislative, regulatory, financial, etc.) to achieve efficient water use by all sectors of the community (urban/ domestic, agricultural, industrial, etc.). These measures should target to reduce demand and/or introduce water conservation [For example: reduce leakage, install water saving fixtures, increase irrigation conveyance and field application efficiency, create incentives, water tariffs, water markets, taxes, etc.], while in parallel can target to increase water supply and the water available for use (for example: greywater and wastewater reuse, water recycling, desalination, rainwater and stormwater harvesting, natural water retention measures). Caution to potential adverse environmental impacts is important in any case.

7.2 CONCLUSIONS OF THE WATER POLLUTION ASSESSMENT

A water quality assessment can be deduced based on the results of the water quality sampling campaign during the dry and wet period. An overview of the water pollution in the Al Ostuan River Basin (as assessed by the water quality sampling and analysis) is presented in

Table **7-1** below.

Table 7-1: Al Ostuan River Basin Water Pollution Overview

Sampling Site	Village (CAD_Name)	Nearby landmark	Temperature	Conductivity	Salinity	TDS	Fluoride	Chloride	Sulfate	Nitrate	Nitrite	Sodium	Potassium	Magnesium	Calcium	pH	DO	Heavy Metals (Al, Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd)	Heavy Metals (Hg, Pb)	E.coli	Fecal	BOD
S1	Akkar El-Aatiqa	Crops or animals all around the area																				
S2	Nabaa El Chouh El Ali	Green Area																				
S3	Nabaa El Chouh El Wati	Canal																				

Sampling Site	Village (CAD_Name)	Nearby landmark	Temperature	Conductivity	Salinity	TDS	Fluoride	Chloride	Sulfate	Nitrate	Nitrite	Sodium	Potassium	Magnesium	Calcium	pH	DO	Heavy Metals (Al, Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd)	Heavy Metals (Hg, Pb)	E.coli	Fecal	BOD
S4	Nabaa El Jaouz	Chicken breading all around																				
S5	Nabaa El Cheikh Jneid																					
S6	Nabaa Omar Kaylo	Tap/ Origin Ain Tayea																				
S7	Ain I Watyeh	Karst																				
S8	Ain I homsiyeh																					
S9	Ain El Abiad																					
S10	Nabaa Hmadeh																					
S11	Ain I Fouar																					
S12	Nabaa El Qolqas																					
S13	Nabaa El Tine																					
S14	Ain Taqiyeh	Mazeret El Baldeh/ In the middle of the river																				
S15	Nabaa Abou Chawkat																					
S16	Ain El Hajal																					
S17	Ain Taba																					

*<u>Note</u>: *Results based on field sampling and analysis conducted on October 3rd, 2019*
***Red** cells show concentration **above** the limits; **Green** cells show a concentration **below** the limits*

It is observed that the physical parameters such as temperature, pH, and electrical conductivity were all observed to be acceptable levels (lower than the values in the referred standards: Libnor Water standards);

As for the chemical parameters, values related to the basic water quality such as the anions and cations were all seen to be below the water norms in the exception of Nitrate and Nitrite. The presence of these two parameters is due to the agricultural activities and the uncontrolled use of fertilizers that is related to the crops abundance. Another major factor that influences the high amounts of Nitrate and Nitrite is the lack of wastewater treatment plants that increases the values of these parameters in surface waters. As for the heavy metals, all the levels obtained exceeded the accepted standards. This is directly related to the fertilizers and industrial effluents that expel heavy metals directly into the ecosystem. Last but not least, since untreated wastewater effluents are discharges and uncontrolled agricultural activities are occurring, the microbiological parameters (fecal coliforms and E.Coli) were all found to be above the acceptable limits.

The major variation that occurred between the dry and wet seasons is due to two major factors. The first factor is related to the location of the sampling points: if the samples were taken at the upper side of the river, lower concentrations of pollutants have been observed (physical, chemical, and microbial). The samples taken near the discharge point of the river (i.e. the closer to the sea) were found to be contaminated by the untreated and uncontrolled wastewater that is directly discharged into the Al Ostuan River without being treated, and by the visible accumulation of refugees and developed agricultural activities around the river bed. The second factor that affected the concentration of the chemical and physical values was the visible erosion that occurred in the wet season in the riverbed of the Al Ostuan river. It was observed that the samples that were collected from the lower basin of the river carried sediments and endured, therefore, higher salinity and carbonates values.

As for the chemical parameters, heavy metals values (Al, Cd, Cr, Co, Cu, Fe, Pb, Mn, Hg, Ni, Zn) have shown some visible changes from the dry season 2019 to the wet season 2020. Several elements as discussed below have shown no visible change, nevertheless, a majority has shown a visible increase in their concentrations, and all of the obtained results exceeded the acceptable standards. Al, Cr, Mn, Fe, Co, and Hg have shown a remarkable increase in their concentration. These high values are due to the agricultural activities and the uncontrolled use of fertilizers that is related to the abundance of the crop. Another major factor that influences the high amounts is the lack of wastewater treatment plants that increases their content in surface waters. This is directly related to the fertilizers effluents that expel heavy metals directly into the ecosystem. These high concentrations were heavily seen in the lowest locations of the river basin where the agricultural activities were quite developed and the effluent non-treated wastewater was observed in the water quality of the river. The heavy metals that showed invariant concentrations were Ni, Cu, Zn, Cd, and Pb.

In order to have a full assessment of the water quality in the Akkar governorate, a broader surface water quality study of the Al Ostuan river with major analysis of fertilizers and pesticides availability in the water should be performed in the near future.

The major sources of water pollution in the Ostuan river basin can be described as follows:

- The lack of urban development planning that increases flash flooding and water pollution
- The lack of Wastewater Treatment Plants (WWTPs)

- The direct disposal of domestic sewage into the river without any treatment from municipal councils & villages located near the river
- The uncontrolled solid waste dumping in the river which increases especially microbiological contamination as well as heavy metals
- The re-surfacing of previously deposited pollutants
- The uncontrolled human activities such as large agricultural activities, local farming, livestock breeding, vehicle washing

The short terms mitigation measures for the Al Ostuan River Basin are listed below:

- Treatment facilities should be adopted at the source as the first step for decentralised and small cluster services
- Effective implementation, operation and maintenance of waste water treatment plants
- Control over solid waste dumping
- Effective collection and transfer mechanism for sewage; otherwise, source wastewater shall be implemented and connected to proposed treatment facilities via sewer lines

8 LIST OF REFERENCES

Allen, R., Pereira, L., Raes, D., Smith, M., 1998. **Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements**. United Nations Food and Agriculture Organization (FAO), Irrigation and Drainage Paper 56, Rome, Italy, 300 p. Available online: http://www.fao.org/docrep/x0490e/x0490e00.htm

Baroudi. M., Bakkour. H., Halwani, J., Taha, S., El Osmani, R., Mouneimne A.H., 2012. **Determination of pesticides, Nitrates and Nitrites level in Groundwater of Akkar plain in Northern Lebanon**. J. Appl. Sci. Res., 8(8): 4663-4667, 2012

Bouaoun, D., Nabbout, R., 2016. **Study of Physical and Chemical Parameters of Oustouan River, North Lebanon**. J Coast Zone Manag 19:430. doi:10.4172/2473-3350.1000430

CDR, 2005. **National Physical Master Plan of the Lebanese Territory Final Report (NPMPLT).** Council for Development and Reconstruction (CDR), 2005, http://www.cdr.gov.lb/study/sdatl/English/NPMPLT-TOC.PDF

Comair, F., 2007. **Water sector in Lebanon: An operational framework for undertaking legislative and institutional reforms.** United Nations Economic and Social Commission for Western Asia

Doorenbos, J., Kassam, A.H., 1979. **Yield response to Water**. FAO Irrigation and Drainage Paper No. 33. Rome, FAO.

El-Fadel, M., Zeinati, M. & Jamali, D. (2000). **Water resources in Lebanon: Characterization, water balance and constraints**. Water Resources Development, 16, 619–642.

Halawani, J., B. Ouddane, M. Baroudi and M. Wartel, 1999. **Contamination par les nitrates des eaux souterraines de la plaine d'Akkar au Liban du Nord**. Cahiers Santé, 9: 219-223

Karaa, K., Karam, F., Raad, R., 2009. **Modernization of irrigation systems: measures to reduce pressure on water demand in Lebanon**. Options Méditerranéennes, A n° 88, 2009 - Technological Perspectives for Rational Use of Water Resources in the Mediterranean Region.

Kossida, M. (2015). **Methods and tools supporting operational drought risk management in water stressed areas**. PhD Dissertation, National Technical University of Athens (NTUA), http://hdl.handle.net/10442/hedi/43161

Kossida, M., Fayad, A. 2019. **Report on the assessment of the water resources/ balance in Nahr El-Kelb River Basin, based on the outputs of the WEAP model (under current and future scenarios), including a brief on the scenarios**. Project Deliverable D1.2 & D.1.3, SWIM-H2020 SM Expert Facility Activity EFS-LB-1, Task 1, SWIM-H2020 Project, February 2019.

Ministry of Energy and Water (MEW), 2020. **National Water Sector Strategy Update – 2020: Volume I: Executive Summary**: Volume II: Water Sector Governance; Volume III: Water Resources Management; Volume IV: water sector current situation; Volume V: proposed projects; Volume VI: drawings.

MOE, LEDO, 2001. **State of the Environment report in Lebanon, Chapter 8**. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=5&cad=rja&uact=8&ved=2ahUKEwjBjdLHqrPmAhVE1qYKHULJBlgQFjAEegQIAhAC&url=http%3A%2F%2Fwww.databank.com.lb%2Fdocs%2FWater-State%2520of%2520the%2520environment%2520report-MOE-2000.pdf&usg=AOvVaw3zAPrXxvixDfs8eceS3hZt

MOE, UND, ECODIT, 2011. **State of the Environment report in Lebanon**. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=2ahUKEwjBjdLHqrPmAhVE1qYKHULJBlgQFjAAegQIBRAC&url=http%3A%2F%2Fwww.undp.org.lb%2Fcommunication%2Fpublications%2Fdownloads%2FSOER_en.pdf&usg=AOvVaw16g1cwmFcTW5DEuAJ7iuiD

Mouchref, A. 2008. **Forgotten Akkar, Socio-Economic Reality of the Akkar Region, Mada Association**, January 2008

SISSAF, 2017. **Water Supply Master Plan for North Lebanon, Chapter 10 Akkar Water Master Plan**.

SISSAF, 2017. **Water Supply Master Plan for North Lebanon, Chapter 12 Socioeconomic Study**.

Stockholm Environment Institute (SEI), 2015. **WEAP Water Evaluation And Planning System. User Guide for WEAP 2015**, SEI, August 2015.

Tegos, A., Malamos, N., Efstratiadis, A., Tsoukalas, I., Karanasios, A., & Koutsoyiannis, D., 2017. **Parametric Modelling of Potential Evapotranspiration: A Global Survey**. Water, 9(12), 795. https://doi.org/10.3390/w9100795

Tsoukalas, I., 2019. **Modelling and simulation of non-Gaussian stochastic processes for optimization of water-systems under uncertainty**. PhD Thesis, Department of Water Resources and Environmental Engineering, National Technical University of Athens (Defence date: 20 December 2018).

Tsoukalas, I., Efstratiadis, A., & Makropoulos, C, 2019. **Building a puzzle to solve a riddle: A multi-scale disaggregation approach for multivariate stochastic processes with any marginal**

distribution and correlation structure. Journal of Hydrology, 575, 354–380. https://doi.org/10.1016/j.jhydrol.2019.05.017

Tsoukalas, I., Makropoulos, C., & Koutsoyiannis, D., 2018. **Simulation of stochastic processes exhibiting any-range dependence and arbitrary marginal distributions**. Water Resources Research. https://doi.org/10.1029/2017WR022462

UNDP, 2014. **Nationwide Assessment of Groundwater Resources Across Lebanon, Groundwater Modeling Within The Akkar Basin, Deliverable No. 14**, Prepared by ELARD in association with BURGEAP-IGIP-RIBEKA.

UNDP, 2014. **Nationwide Assessment of Groundwater Resources Across Lebanon, Data Collection and Field Assessment Campaign of Groundwater Resources across Lebanon, Preliminary Baseline Data Assessment (Private Wells Survey Report), Deliverable No. 6b**, Prepared by ELARD in association with BURGEAP-IGIP-RIBEKA.

UNDP, 2014. **Nationwide Assessment of Groundwater Resources Across Lebanon, Data Synthesis & Basin Water Resources Characterization Report, II. Groundwater Basins-Boundaries and Geology , Part of Deliverable No.9,** Prepared by ELARD in association with BURGEAP-IGIP-RIBEKA.

World Bank, 2003. **Republic of Lebanon Policy Note on Irrigation Sector Sustainability**, Report No. 28766 – LE, November 2003

9 ANNEXES

9.1 ANNEX 1: SURFACE WATER QUALITY STANDARDS (WHO, EPA)

	WHO[a]	Remark	GB5749[b]	Remark	GB3838[c]		Remark
					Grade I	Grade II	
pH	No	Optimum: 6.5–8.5	6.5–8.5		6–9	6–9	
TDS	No		1000		–	–	
Turbidity	5						
EC							
Total alkalinity							
SO_4^{2-}	No		250		–	250	
Ag	No		0.05		–	–	
Al	0.2	Practicable level	0.2		–	–	
As	0.01 (P)		0.01		0.05	0.05	
B	0.5 (T)						
Ba	0.7						
Bi							
Ca					–	–	
Cd	0.003		0.005		0.001	0.005	
Cl	0.05 (P)	For total chromium					
Co	–		–		–	1	
Cr	0.05 (P)	For total chromium	0.05	For Cr(+6)	0.01	0.05	For Cr(+6)
Cu	2		1		0.01	1	
Fe	No		0.3		–	0.3	
Hg	0.001	For total mercury	0.001		0.00005	0.00005	
K							
Li							
Mg							
Mn	0.4 (C)		0.1		–	0.1	Mn
Mo	0.07		0.07		–	0.07	
Na	No		200		–	–	
Ni	0.02 (P)		0.02		–	0.02	
Pb	0.01		0.01		0.01	0.01	
Rb							
S	No						
Sb							
Sr							
Ti	–		–		–	0.1	
Tl							
V							
Zn	No		1		0.05	1	Zn

Parameter	WHO	EPA
	1973	1982
Phosphate (mg/L)	10	-
Nitrate (mg/L)	0.05	-
Ammonia (mg/L)	0.5	-
Chl-a (µg/L)	20	-
DO(mg/L) (mg/L)	0.17	5
Transparency (cm)	10	-
pH	6-8.5	6.5-9.00
Temperature (℃)	-	16-32
Salinity	-	-
BOD (mg/L)	-	-
COD (mg/L)	-	-

Sl No.	Parameter and Unit	Class A	Class B	Class C	Class D	Class E
		Drinking water without treatment but after disinfection	Water for outdoor bathing	Drinking water with conventional treatment followed by disinfection	Water for fish culture and wild life propagation	Water for Irrigation, industrial cooling and controlled waste disposal
1	pH (min : 6.5)	8.5	8.5	8.5	8.5	-
2	Conductivity (25°C) µS/cm	-	-	-	1000	2250
3	DO (mg/L)(minimum)	6	5	4	4	-
4	BOD (3d, 27°C) (mg/L)	2	3	3	-	-
5	Total Hardness (mg/L as $CaCO_3$)	300	-	-	-	-
6	Calcium (mg/L)	80.10	-	-	-	-
7	Magnesium (mg/L)	24.28	-	-	-	-
8	Chlorides (mg/L as Cl)	250	-	600	-	600
9	Nitrates (mg/L as NO_3)	20	-	50	-	-
10	Free NH_3 (mg/L as N)	-	-	-	1.2	-
11	Sodium Absorption Ratio	-	-	-	-	26

Surface water quality standards (IS: 2296)

Parameter	Units	Standard Value for Class					
		1	2	3	4	5	6
Floatable solids	–	Not objectionable					
Color	Forel-Ule scale	Not objectionable					
Odor	–	Not objectionable					
Temperature	°C from ambient	↑ <1	n	↑ <1		↑ <2	
pH	–	7.0 – 8.5					
Transparency	–	↓ <10% of the lowest ambient value					
Suspended solids	mg/l	↑ less than (average + standard deviation)					
Salinity	–	↓ <10% of the lowest ambient value					
Floatable Oil & Grease		not visible					
DDPH	µg/l (chrysene eq.)		<0.5		<1	<5	
Dissolved Oxygen	mg/l	>4	>6		>4		
Total coliform bacteria	MPN/100 ml	<1,000					
Fecal coliform	CFU/100 ml		<70			<100	
Enterococci bacteria	CFU/100 ml	–	<35	–	<35	–	–
Nitrate	µg-N/l	<20			<60		
Ammonia	µg-N/l	<70		<100		<70	
Phosphate	µg-P/l	<15		<45	<15	<45	
Total Mercury	µg/l	<0.1					
Cadmium	µg/l	<5					
Total Chromium	µg/l	<100					
Chromium (VI)	µg/l	<50					
Lead	µg/l	<8.5					
Copper	µg/l	<8					
Manganese	µg/l	<100					
Zinc	µg/l	<50					
Iron	µg/l	<300					
Arsenic	µg/l	<10					
Fluoride	µg/l	<1					
Residual chlorine	µg/l	–	–	–	–	<0.01	
Phenols	µg/l	<0.03					
Sulfide	µg/l	<10					
Cyanide	µg/l	<7					
PCBs	µg/l	nil					
TBT	ng/l	<10					
Radioactivity							
α Gross	Bq/l	<0.1					
β Gross (excl. K-40)	Bq/l	<1.0					
Total organochlorine pesticides							
Aldrin		<1.3					
Chlordane		<0.004					
DDT		<0.001					
Dieldrin	µg/l	<0.0019					
Endrin		<0.0023					
Endosulfan		<0.0087					
Heptachlor		<0.0036					
Lindane		<0.16					
Others*		Not detected					

* Include: Alachlor, Ametryn, Atrazine, Carbaryl, Carbendazim, Chlorpyrifos, Cypermethrin, 2,4-D, Diuron Glyphosate, Malathion, Mancozeb, Methyl parathion, Parathion, Propanil

National and international quality standards for drinking water surface water quality (in mg/L)

9.2 ANNEX 2: DRINKING WATER QUALITY GUIDELINES : WHO AND LIBNOR STANDARDS (2016)

Level	Parameter	Recommended frequency/location	WHO Guideline (mg/L)	Libnor standard (mg/L)
Level 3 tests	*All Level 1 and 2 tests* (and see notes below on selecting parameters)			
	magnesium (Mg)	when investigating new source	no guideline	50
	phenolic compounds, as phenol (exception natural phenols unreacted with chlorine)	when investigating new source	-	0.001
	mineral oils	when investigating new source	no guideline	Nil
	carbon chloroform extract	when investigating new source	no guideline	0.2
	surface active agents (alkyl benzene sulfonate)	when investigating new source	no guideline	Nil
	ammonia	when investigating new source	no guideline	Nil
	phosphates (P2O5)	when investigating new source	no guideline	1
	organic matter	when investigating new source	no guideline	0.5
	hydrogen sulfide (H2S)	when investigating new source	no guideline	0.05
	sodium (Na)	when investigating new source	no guideline	150
	potassium (K)	when investigating new source	no guideline	12
	aluminium (Al)	when investigating new source	0.2	0.2
	cadmium (Cd)	when investigating new source	0.003	0.005
	cyanide (CN)	when investigating new source	no guideline	0.05
	mercury (Hg)	when investigating new source	0.006	0.001
	selenium (Se)	when investigating new source	0.04	0.01
	lead (Pb)	when investigating new source	0.01	0.01
	hexavalent chromium (Cr)	when investigating new source	0.05	0.05
	barium (Ba)	when investigating new source	0.7	0.5
	silver (Ag)	when investigating new source	no guideline	0.01
	nickel (Ni)	when investigating new source	0.07	0.02
	polynuclear aromatic hydrocarbons - fluoranthene	when investigating new source	no guideline	0.0002
	polynuclear aromatic hydrocarbons - Benzo (3,4) fluoranthene	when investigating new source	no guideline	0.0002
	polynuclear aromatic hydrocarbons - Benzo (11,12) fluoranthene	when investigating new source	no guideline	0.0001(single) 0.0002 (combined)
	polynuclear aromatic hydrocarbons - Benzo (3,4) pyrene	when investigating new source	0.0007	0.00001
	polynuclear aromatic hydrocarbons - Benzo (1,12) perylene	when investigating new source	no guideline	0.0002
	polynuclear aromatic hydrocarbons - Indino (1,2,3 – cd) pyrene	when investigating new source	no guideline	0.0002

Level	Parameter	Recommended frequency/location	WHO Guideline (mg/L)	Libnor standard (mg/L)
Level 3 tests *(continued)*	chlorinated organic compounds	when investigating new source	See fact sheets	0.06
	chloroform	when investigating new source	0.3	0.1
	Pesticides, according to use and risk-assessment, including:			
	aldrin and dieldrin	when investigating new source	0.00003	0.00002
	lindane	when investigating new source	0.002	0.0002
	methoxychlor	when investigating new source	0.02	0.02
	toxaphene	when investigating new source	no guideline	0.003
	2,4- dichlorophenoxy acetic acid	when investigating new source	0.03	0.03
	2,4,5- trichlorophenoxy propionic acid	when investigating new source	0.009	0.009

Notes to Table 1:

1. Table 1 provides a guide only and is derived from *Ministry of Public Health Decree 1039/1999* Drinking Water Specifications, Lebanese Standards Institution (LIBNOR), and WHO *Guidelines for Drinking-Water Quality*.

2. Generally the WHO does not establish a guideline value for a parameter if there is no health concern at the concentrations typically found in drinking water. However, the WHO provides fact sheets and additional guidance for some paratmeters including targets for aesthetic quality. For more information see the *Guidelines for Drinking-Water Quality* (WHO 2011).

3. **Selection of parameters.** Water sources should be assessed for parameters of known health and aesthetic quality (WHO 2011, UNICEF 2008). It is expensive, time consuming, difficult and largely unnecessary to routinely test for multiple parameters, unless they are likely to be present and affect health or aesthetic quality (acceptability). When selecting parameters WASH agencies should consider the seriousness of the health impact, the findings of previous surveys and whether a parameter is known (or suspected) to be present in the region and human activities that potentially cause pollution.

4. **Nitrate.** The WHO guideline value for nitrate (50 mg/L) is based on a test for the nitrate ion. If the sample is tested for nitrate-nitrogen (rather than the nitrate ion) the equivalent guideline is 11 mg/L.

Table 2 Drinking Water Quality Assessment – by sampling location

Site	Parameter	Recommended frequency	Target or WHO Guideline (mg/L)	Libnor standard (mg/L)
Water source (Level 1 test)	*E. coli*/thermotolerant coliforms	monthly	0	0
	conductivity	monthly	No guideline	1500 microSiemens/cm
	pH	monthly	6.5 – 8.5	6.5 – 8.5
	turbidity	monthly	<1 NTU (and preferably much lower)	10 JTU
	nitrate	2 times per year (according to risk assessment)	50	45
	arsenic	2 times per year (unless known to be absent)	0.01	0.05
	fluoride	2 times per year (unless known to be absent)	1.5	1.5 (at 8-12°C), 0.7 (at 25-30°C)
Water source (Level 2 test)	total dissolved solids	2 times per year	<600 good, >1000 unacceptable	500
	iron	2 times per year	>0.3 causes staining	0.3
	manganese	2 times per year	no guideline	0.05
	nitrite	2 times per year	3	0.05
	sulfate	2 times per year	>250, causes taste	250
	zinc	2 times per year	no guideline	5
	calcium	2 times per year	no guideline	200
	chloride	2 times per year	>250, causes taste	200
	hardness	2 times per year	>200 causes scale	250
Water truck	chlorine (free chlorine)	daily, 30 minutes after added to truck	>0.5 mg/L after 30 min contact, pH <8	no guideline
	chlorine (free chlorine)	daily on delivery	0.2 – 0.5 mg/L	no guideline
	E. coli/thermotolerant coliforms	monthly on delivery	0	0
	turbidity	monthly on delivery	<1 NTU (and preferably much lower)	10 JTU
	colour, appearance, taste, odour	daily on delivery	not objectionable	not objectionable
Household	*E. coli*/thermotolerant coliforms	monthly	0	0
	chlorine (free chlorine)	monthly	>0.1 mg/L	no guideline
	colour, appearance, taste, odour	monthly	not objectionable	not objectionable

Notes to Table 2:

1. **Water source.** Test source before use and then periodically according to the recommended frequency.
2. **Water truck testing.** If chlorine tests are consistently good then monthly bacteria testing may not be necessary. However, the bacteria test should be carried out if there is any concern about the adequacy of chlorine disinfection.
3. **Household testing.** Household chlorine target (>0.1 mg/L) may be difficult to control due to storage conditions and cleanliness of containers. Ideally clean drinking water and washing water (e.g. 'undrinkable' well water) should not be stored or mixed in the same container. Each month a representative sample of ITS (and households within the ITS) should be selected for household monitoring on a rotating basis. Targeted sampling may also be carried out in response to concerns or complaints regarding water quality, or where there is an issue with source water quality.

9.3 ANNEX 3: LEBANEESE DECREE 52-1

Contact Name for this Assignment:
Mr. Costis Nicolopoulos
TEL: +30-210-8196753
EMAIL: cni@ldk.gr

HEADQUARTERS
Off 21, Thivaidos St., GR-145 64 Kifissia, GREECE
Tel: +30 210 8196700, Fax: +30 210 8196709
email: main@ldk.gr
www.ldk.gr