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Protection of Jeita Spring

Technical Report 7

Groundwater Vulnerability in the Groundwater Catchment of Jeita Spring and Delineation of Groundwater Protection Zones Using the COP Method

Raifoun
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Technical Report No. 7: Groundwater Vulnerability in the Groundwater Catchment of Jeita Spring and Delineation of Groundwater Protection Zones using the COP Method

Author:	Dr. Armin Margane & Philip Schuler, MSc., both BGR
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List of Abbreviations

ACSAD	Arab Center for Arid Zones and Dry Lands
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources)
BMZ	Bundesministerium für Zusammenarbeit und Entwicklung (GermanFederal Ministry for Cooperation and Development)
CDR	Council for Development and Reconstruction
COP	Method for groundwater vulnerability mapping
DEM	Digital elevation model
EIA	Environmental impact assessment
EIB	European Investment Bank
EPIK	Method for groundwater vulnerability mapping
FAO	Food and Agriculture Organization
GLA	Geological surveys of the German states
GITEC	German consultant implementing KfW Jeita Spring Protection Project
GW	Groundwater
JSC	Jeita spring catchment
LARI	Lebanese Agriculture Research Institute
KfW	German development bank
MENA	Middle East and North Africa
MoEW	Ministry of Energy and Water
MTBE	Methyl tertiary butyl ether
SAEFL	Swiss Agency for Environment, Forests and Landscape (=BUWAL)
SCL	Speleo Club du Liban
SRTM	Shuttle Radar Topography Mission
SW	Surface water
UNDP	United Nations Development Program
USGS	United States Geological Survey
WAJ	Water Authority Jordan
WEBML	Water Establishment Beirut and Mount Lebanon

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1	Site Selection for Wastewater Facilities in the Nahr el Kalb Catchment – General Recommendations from the Perspective of Groundwater Resources Protection	January 2011
2	Best Management Practice Guideline for Wastewater Facilities in Karstic Areas of Lebanon – with special respect to the protection of ground- and surface waters	March 2011
3	Guideline for Environmental Impact Assessments for Wastewater Facilities in Lebanon – Recommendations from the Perspective of Groundwater Resources Protection	November 2011
4	Geological Map, Tectonics and Karstification in the Groundwater Contribution Zone of Jeita Spring	September 2011
5	Hydrogeology of the Groundwater Contribution Zone of Jeita Spring	In progress
6	Water Balance for the Groundwater Contribution Zone of Jeita Spring using WEAP including Water Resources Management Options and Scenarios	March 2013
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8	Monitoring of Spring Discharge and Surface Water Runoff in the Groundwater Contribution Zone of Jeita Spring	March 2013
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10	Mapping of the Irrigation System in the Jeita Catchment	First Draft November 2011
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12	Stable Isotope Investigations in the Groundwater Contribution Zone of Jeita Spring	In Progress
13	Micropollutant Investigations in the Groundwater Contribution Zone of Jeita Spring*	May 2012
14	Environmental Risk Assessment of the Fuel Stations in the Jeita Spring Catchment - Guidelines from the Perspective of Groundwater Resources Protection	June 2012
15	Analysis of Helium/Tritium, CFC and SF6 Tracers in the Jeita Groundwater Catchment*	In Progress
16	Hazards to Groundwater and Assessment of Pollution Risk in the Jeita Spring Catchment	February 2013 (draft)
17	Artificial Tracer Tests 4C - May 2012*	April 2013
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1	Quantification of Infiltration into the Lower Aquifer (J4) in the Upper Nahr Ibrahim Valley	May 2012
1 - 1	Addendum No. 1 to Main Report [Quantification of Infiltration into the Lower Aquifer (J4) in the Upper Nahr Ibrahim Valley]	June 2012
2	Locating the Source of the Turbidity Peaks Occurring in April - June 2012 in the Dbayeh Drinking Water Treatment Plant	June 2012
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Report No.	Title	Date Completed
	Kashkoush Spring	
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2	Jeita Spring Protection Project - Feasibility Study - Rehabilitation of Transmission Channel Jeita Spring Intake – Dbaye WTP	May 2012
3	Jeita Spring Protection Project - Environmental Impact Assessment for the Proposed CDR/KfW Wastewater Scheme in the Lower Nahr el Kalb Catchment	In Progress

* prepared in cooperation with University of Goettingen

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0 Executive Summary

The Jeita spring is the most important spring of Lebanon. It provides drinking water to almost 50 % of the Lebanese population. The uncontrolled and rapid development over the past two decades has lead to a continuously high level of pollution of this most important water source of the country (MARGANE et al., in progr.). Until now, wastewater in the Jeita catchment is not collected and treated. Only through the implementation of rigorous measures this pollution load could be reduced. The implementation of a wastewater scheme, supported by the German Government, is currently underway (MARGANE, 2011; MARGANE & MAKKI, 2012; MUELLER & MARGANE, 2011). Although wastewater can be considered the main pollution source, there is a large number of other potential pollution sources which also endanger groundwater quality (RAAD et al., 2012, 2013). The implementation of groundwater protection zones, as proposed in this document, is the only effective measure that could ensure in the long-term an improvement of drinking water quality for the water supply of the Greater Beirut Area. It requires the adoption and enforcement of very strict landuse restrictions.

One of the main tasks of the German-Lebanese Technical Cooperation Project Protection of Jeita Spring is to delineate and promote the implementation of groundwater protection zones for Jeita spring and other important springs used for drinking water supply. Groundwater protection zones are established to reduce the pollution risks for drinking water sources and are commonly divided into three categories: immediate (or inner) protection zone (zone 1), intermediate protection zone (zone 2), and outer protection zone (zone 3) (MARGANE, 2003b). The groundwater contribution zone or groundwater catchment, equivalent to protection zone 3, of Jeita spring was delineated by the BGR project using about a dozen tracer tests (MARGANE et al., in progr.).

Due to the karstic nature of the Jeita catchment, any contaminant can infiltrate easily into groundwater. Groundwater flow velocities are extremely high (up to 2,000 m/h) so that pollution can be transferred almost unhindered and very fast to Jeita spring.

In karstic areas, groundwater protection zones are commonly delineated based on specific methods taking into account the groundwater flow and infiltration characteristics of a karst system. Two such methods, developed specifically for karstic areas, the EPIK method (SAEFL, 2000) and the COP method (VIAS et al., 2002, 2006) were applied in the Jeita catchment (DOUMMAR et al., 2012). The COP method was developed as part of the COST620 project of the EU and is proposed by the European geological surveys as the standard method for the protection of karst aquifers.

When the first report on groundwater vulnerability was prepared by DOUMMAR et al., the true extent of the groundwater catchment had not been known

so that the groundwater vulnerability maps did not comprise the entire catchment and the required data were not available for the now larger catchment (MARGANE, 2012a, 2012b). Moreover, due to the specific characteristics of the Jeita catchment, the COP method needed to be refined.

The resulting groundwater vulnerability maps showed that more than 70% of the groundwater catchment has a very high groundwater vulnerability. In order not to introduce unjustified restrictions on landuse, further criteria for the delineation of groundwater protection zones were introduced. The most important criteria in this context is the travel time from the land surface to the source, i.e. Jeita spring. A 10-days travel time was used to define the boundary between protection zones 2 and 3.

On the other hand, groundwater protection zone 1 was extended to the land surface, in an area close to Jeita spring where Jeita cave is only covered by 60-80 m of rocks so that rapid infiltration from the nearby residential area may lead to severe pollution and where there is a high risk of cave collapse due to construction.

The current report shows the boundaries of the groundwater protection zones that should be used during implementation by the Lebanese Government. It shows that the entire limestone plateau of the C4 is at a very high risk of pollution. It is therefore recommended to stop any further development in this area.

The report lists which specific landuse restrictions should be implemented in order to effectively reduce pollution risks in each type of protection zone. Due to the fact that many hazards to groundwater already exist in the groundwater catchment, an immediate improvement of water quality after introducing the proposed groundwater protection zones cannot be expected. Upgrading environmental requirements for critical landuse activities, such as gas stations (RAAD et al., 2012), quarries, illegal dump sites, slaughterhouses, and animal farms (all latter documented in RAAD et al., 2013) are urgently needed. In the long-term, a fund for compensation may be necessary in order to abandon landuse activities which constitute an imminent risk to water resources but are operated based on a previous license for which site and operational requirements were not based on environmental and water resources protection considerations.

Implementation of the proposed groundwater protection zones will be a great challenge, but not to do so would mean putting the population in the Greater Beirut Area at a severe health risk.

1 Introduction

In the previous assessment of the intrinsic groundwater (GW) vulnerability in the groundwater catchment of Jeita spring (DOUMMAR et al., 2012), the EPIK (SAEFL, 2000; BUWAL, 2000) and COP methods (VIAS et al., 2002, 2006) were used. Although the results obtained from both methods are similar, the COP method, compared to the EPIK method integrates more comprehensively the role of the unsaturated zone. This is why the BGR project proposes using the COP method as a standard method for groundwater protection zone delineation.

For calculation of the GW vulnerability, the COP method (VIAS et al., 2002, 2006) was introduced in the framework of the EU project COST620 in 2002 as the standard method for karst areas in Europe. COP is an index method, which uses three main factors:

- C (concentration of flow),
- O (overlying layers) and
- P (precipitation regime).

The calculation of each of these factors needs to be based on field assessments. The assessment of the COP map had to be repeated for the following reasons: first, the groundwater catchment of Jeita spring proved to be larger than originally assumed (MARGANE, 2012a, 2012b; MARGANE et al, in progr.); the GW catchment has an extent of 406 km^2 and considerably differs from the surface water catchment (251 km^2); when the GW vulnerability map was prepared by DOUMMAR et al. (2012), the GW catchment had been assumed to be only 311 km^2. Secondly, the method of GW vulnerability calculation for the COP method, as established by VIAS et al. (2002, 2006), would have overestimated the effects of swallow holes and would have resulted in a larger protection zone 2 than actually necessary. For the present COP mapping, the methodology and classification for assessment of the C Factor has therefore been modified according to the local karst characteristics (distance to swallow holes) and in order to account for the overlaying effects of swallow holes and sinking streams in some areas. The standard COP method would also have neglected the effect of surface water drainage over the aquitard and rapid infiltration into the aquifer, especially in the upper J4 aquifer. Therefore this effect had to be included.

The present document illustrates why the methodology for COP GW vulnerability mapping has been modified in the groundwater contribution zone of Jeita Spring and which effect this has.

2 Methodology

Groundwater vulnerability maps have been used for approx. 40 years in Europe and the US where they have become a standard tool for protecting groundwater resources from pollution and for the decision-making process related to landuse planning.

A review of the methods used for groundwater vulnerability mapping is given by VRBA & SAPOROZEC (1994) and MARGANE & SUNNA (2002). A related guideline prepared for specific use in the Arab region was prepared by MARGANE (2003a) in the framework of an ACSAD-BGR technical cooperation project. The commonly accepted definition of the term groundwater vulnerability was given by NATIONAL RESEARCH COUNCIL (1993) and VRBA & ZAPOROZEC (1994) as "*the tendency or likelihood for contaminants to reach (a specified position in) the groundwater system after introduction at some location above the uppermost aquifer*".

In all methods the vulnerability of an aquifer (resource) is classified according to the travel time of a drop of water from the land surface to the aquifer (percolation time). This flow is very different in porous rocks compared to hard rocks where flow preferentially follows fractures and cavities. Karst aquifers play an important role since infiltration may be highly concentrated in certain areas and travel time from the land surface to the aquifer may be extremely short. It is differentiated between specific and intrinsic vulnerability. Specific vulnerability refers to a specific contaminant, a class of contaminants or a certain prevailing human activity, while intrinsic vulnerability takes only the aquifer characteristics into consideration and not the specific behaviour of contaminants. The so-called specific vulnerability is difficult to establish, especially in areas with low data availability (as most areas of the Middle East). Thus, commonly the intrinsic vulnerability is used.

The following processes and mechanisms lead to an attenuation of the contaminant load in the rock media, through which water and contaminants pass on their way to the water table (soil, unsaturated and saturated zones) and determine the protective effectiveness or filtering effect of the rock and soil cover (MORRIS & FOSTER 2000):

- mineralogical rock composition,
- rock compactness,
- degree of jointing and fracturing,
- porosity,
- content of organic matter,
- carbonate content,
- clay content,
- metal oxides content,
- pH,
- redox potential,
- cation exchange capacity (CEC),
- thickness of rock and soil cover
- percolation rate and velocity.

An important factor that influences the vulnerability of groundwater resources is the way in which groundwater recharge takes place. In karst aquifers infiltration occurs via an interconnected network of dissolution channels, the so-called karst network. Often in the upper, near-surface part, the so-called epikarst, this karst network is more extensive than at greater depth. However, there are many factors influencing the degree of karstification, such as the (ABI RIZK & MARGANE, 2011):

- lithological composition (e.g. dolomitization processes);
- tectonics and structural development;
- climate (present-day and palaeoclimate); and the
- exposure of the rocks to biological, physical, and mechanical weathering.

During the Quaternary, large parts of the Lebanon mountain ranges (Mount Lebanon and Anti-Lebanon) were probably covered with glaciers. Esker-like structures were discovered by the project (MARGANE et al., in progr.) at very similar elevations between 800 and 1,200 m asl, predominantly around 900 m asl. The glaciation is believed to be widely responsible for the strong karstification of the limestones in the Mount Lebanon mountain range (C4 and uppermost part of J4 geological units).

Due to the topography and the deeply incised valleys in Mount Lebanon, the unsaturated zone often covers several hundred meters. Especially in areas with high vegetation cover, the air-carbon dioxide content in the unsaturated zone is high, promoting limestone dissolution. Generally, with increasing depth in the unsaturated zone, the corrosiveness decreases due to the fact that water will become increasingly saturated in calcium carbonate.

In karst areas groundwater vulnerability maps are often used to delineate groundwater protection zones. Groundwater vulnerability maps have been used extensively in Jordan under the constraint of extreme water scarcity in order to protect the few available water resources from pollution. In almost all wellfield areas, groundwater vulnerability maps have been prepared to justify landuse licensing decisions, starting in the mid-1990s until recently (MARGANE et al., 1997; MARGANE et al., 1999; SUBAH et al., 1999; MARGANE et al., 2005, 2010). Since most areas were of a mixed hydrogeological setting, the GLA method (HOELTING et al., 1994) was used in all BGR project areas for GW vulnerability mapping.

A review and comparison of groundwater vulnerability mapping methods was done by MARGANE (2003a), also discussing their advantages and disadvantages in the framework of a BGR - ACSAD technical cooperation project. It stated that the choice of the most appropriate method for groundwater vulnerability mapping to be used in a certain area depends on the data availability, spatial data distribution, the scale of mapping, the purpose of the map and the hydrogeological setting. However, as a result of the review three main methods were proposed to be used for groundwater vulnerability mapping in karst areas of the Middle East and N-Africa (MENA region):

- GLA (HOELTING et al., 1994) or the modification thereof, the PI (GOLDSCHEIDER, 2002) method;

- EPIK (SAEFL, 2000; DOERFLIGER, 1996); and
- COP (VIAS 2002, 2006).

At that time experience with the COP method had been insufficient, while the EPIK method had been used for more than 10 years in Switzerland for the delineation of groundwater protection zones.

The COP method is similar to the GLA and PI methods with the exception that the COP method integrates more comprehensively the factors precipitation and concentrated infiltration. The parameters needed for the COP method are relatively easy to acquire and the method is straightforward. However, due to the large number of calculation processes, the map compilation is time consuming and requires the use of a GIS system.

Concerning the EPIK method, GOLDSCHEIDER (2002) made the following critical remarks (excerpt):

- Some important factors are missing: The **recharge and the thickness of the unsaturated zone are not taken into account** although most authors consider these factors to be of major importance.
- **The E factor is evaluated in an unreliable way**. Epikarst can be highly developed without visible karst features.
- The **weighting system is contradictory**: the lowest weighting factor is assigned to the parameter P.
- The zero value is missing: The minimum value of each attribute is 1 even if its effect on protection is zero. Together with the different weighting factors, this may lead to inconsistent results.
- The **EPIK formula is not always applicable**: not all the factors always contribute to the protection of the system.
- EPIK is **not defined for all hydrogeological settings**: In some cases, for instance a non-karstic area that discharges into a bordering karst system by surface flow, it is impossible to define and quantify all the parameters.
- **The transformation of the vulnerability classes into source protection zones is disputable**: The EPIK vulnerability classes are directly translated into source protection zones without using any additional criteria such as travel time in the aquifer or distance to the source. However, for source protection zoning, the spring or well must be taken as the target. Thus, it is indispensable to take into account the pathway to the spring or well.

In order to be able to compare the results for both, the EPIK and the COP method in the Jeita GW catchment, both methods were used (DOUMMAR et al., 2012).

The resulting groundwater vulnerability maps are not substantially different. However, due to the above mentioned widespread critics of the EPIK method and its more universal applicability, COP was chosen as the optimal method for GW protection zone delineation in the Jeita GW catchment and should also be used elsewhere in Lebanon.

In both methods, however, the travel time is not integrated so that protection targets, as set forth commonly in protection zone 2, i.e. the die-off time of microbiological constituents, are not addressed. In Switzerland, where karst is a dominant hydro-geological setting and where the topographic features are similar to those in Lebanon, the Swiss regulations (BAFU, 2004) foresee that the travel time in protection 2 of karst aquifers needs to exceed 10 days. In other European countries, however, commonly 50 days or more groundwater travel time is used to define the boundary between GW protection zone 2 and 3. Such a protection target could not be met in Lebanon. Following the above mentioned comments, the authors propose using a combination of the COP method and a groundwater travel time of 10 days to define the extent of all groundwater protection zones in the Jeita groundwater contribution zone (Afqa, Rouaiss, Assal, Labbane and Jeita spring).

In the following chapters, both methods are described in detail.

2.1 EPIK Method

(modified after MARGANE, 2003)

2.1.1 Introduction to the EPIK Method

This method was elaborated in the framework of the COST activities of the European Commission by the University of Neuchâtel, Center of Hydrogeology, for groundwater vulnerability mapping in karst areas. It was later developed by the Swiss Agency for the Environment, Forests and Landscape into a standard tool for groundwater protection zone delineation in karst areas (SAEFL, 2000).

EPIK takes the following parameters into account:

- Development of the **E**pikarst,
- effectiveness of the **P**rotective cover,
- conditions of **I**nfiltration and
- development of the **K**arst network.

A standard classification matrix for each of these parameters is used (*Table 1*) together with standard values (*Table 2*). For each parameter a standard weighing coefficient is used (*Table 3*). The classification for each parameter and area is obtained by systematic mapping for these parameters. Guidance on how to classify the different features in the field is laid down in chapter 3.1 of the EPIK practice guide (SAEFL, 2000; compare *Annex 3*).

Table 1: Standard classification matrix for the EPIK parameters

Parameter **E**pikarst			
Karstic morphology observed (pertaining to epikarst	E_1	caves, swallow holes, dolines, karren fields, ruin-like relief, cuestas	
	E_2	Intermediate zones situated along doline alignments, uvalas, dry valleys, canyons, poljes	
	E_3	Rest of the catchment area	
parameter **P**rotective cover			
		A. Soil resting directly on limestone formations or on detrital formations with very high hydraulic conductivity[1]	B. Soil resting on > 20 cm of low hydraulic conductivity geological formations[2]
Protective cover absent	P_1	0 – 20 cm of soil	
	P_2	20 – 100 cm of soil	20 – 100 cm of soil and low hydraulic conductivity formations
	P_3	> 100 cm of soil	> 100 cm of soil and low hydraulic conductivity formations
Protective cover important	P_4		> 8 m of very low hydraulic conductivity formations or > 6 m of very low hydraulic conductivity formations with > 1 m of soil (point measurements necessary)
parameter **I**nfiltration			
Concentrated infiltration	I_1	Perennial or temporary swallow hole – banks and bed of temporary or permanent stream supplying swallow hole, infiltrating surficial flow – areas of the water catchment containing artificial drainage	
	I_2	Areas of a water catchment area which are not artificially drained and where the slope is greater than 10% for ploughed (cultivated) areas and greater than 25% for meadows and pastures	
	I_3	Areas of a water catchment area which are not artificially drained and where the slope is less than 10% for ploughed (cultivated) areas and less than 25% for meadows and pastures Outside the surface water catchment area: bases of slopes and steep slopes (greater than 10% for ploughed (cultivated) areas and greater than 25% for meadows and pastures) where runoff water infiltrates	
Diffuse infiltration	I_4	Rest of the catchment area	
parameter **K**arst network			
Well-developed karstic network	K_1	Well-developed karstic network with decimeter to meter sized conduits with little fill and well interconnected	
Poorly developed karstic network	K_2	Poorly developed karstic network with poorly interconnected or infilled drains or conduits, or conduits of less than decimeter size	
Mixed or fissured aquifer	K_3	Porous media discharge zone with a possible protective influence – fissured non-karstic aquifer	

[1] E.g.: scree, lateral glacial moraine
[2] E.g.: silt, clay

Table 2: Standard values for the EPIK parameters

E_1	E_2	E3	P_1	P_2	P_3	P_4	I_1	I_2	I_3	I_4	K_1	K_2	K_3
1	3	4	1	2	3	4	1	2	3	4	1	2	3

Table 3: Standard weighing coefficients for the EPIK parameters

Parameter	**E**pikarst	**P**rotective cover	**I**nfiltration	**K**arst network
Weighing coefficient	α	β	γ	δ
Relative weight	3	1	3	2

The overall protection index F is calculated based on the following equation:

$$F = \alpha E + \beta P + \gamma I + \delta K$$

F can obtain values between 9 and 34. The following matrix (*Table 4*) of protection indices provides the basis for the classification of the groundwater vulnerability into three classes:

- high (corresponding to Swiss protection zone S1),
- medium (corresponding to Swiss protection zone S2) and
- low (corresponding to Swiss protection zone S3).

Table 4: Protection index

$K_1=1$	$I_1=1$			$I_2=2$			$I_3=3$			$I_4=4$		
	$E_1=1$	$E_2=3$	$E_3=4$	$E_1=1$	$E_2=3$	$E_3=4$	$E_1=1$	$E_2=3$	$E_3=4$	$E_1=1$	$E_2=3$	$E_3=4$
$P_1=1$	9	15	18	12	18	21	15	21	24	18	24	27
$P_2=2$	10	16	19	13	19	22	16	22	25	19	25	28
$P_3=3$		17	20	14	20	23	17	23	26	20	26	29
$P_4=4$		18	21	15	21	24	18	24	27	21	27	30
$K_2=2$	$I_1=1$			$I_2=2$			$I_3=3$			$I_4=4$		
	$E_1=1$	$E_2=3$	$E_3=4$	$E_1=1$	$E_2=3$	$E_3=4$	$E_1=1$	$E_2=3$	$E_3=4$	$E_1=1$	$E_2=3$	$E_3=4$
$P_1=1$	11	17	20	14	20	23	17	23	26	20	26	29
$P_2=2$	12	18	21	15	21	24	18	24	27	21	27	30
$P_3=3$		19	22	16	22	25	19	25	28	22	28	31
$P_4=4$		20	23	17	23	26	20	26	29	23	29	32
$K_3=3$	$I_1=1$			$I_2=2$			$I_3=3$			$I_4=4$		
	$E_1=1$	$E_2=3$	$E_3=4$	$E_1=1$	$E_2=3$	$E_3=4$	$E_1=1$	$E_2=3$	$E_3=4$	$E_1=1$	$E_2=3$	$E_3=4$
$P_1=1$	13	19	22	16	22	25	19	25	28	22	28	31

$K_1=1$	$I_1=1$			$I_2=2$			$I_3=3$			$I_4=4$		
$P_2=2$	14	20	23	17	23	26	20	26	29	23	29	32
$P_3=3$		21	24	18	24	27	21	27	30	24	30	33
$P_4=4$		22	25	19	25	28	22	28	31	25	31	34

Non-existent situation in the field

Protection index value corresponding to high groundwater vulnerability, respectively Swiss groundwater protection zone S1

Protection index value corresponding to medium groundwater vulnerability, respectively Swiss groundwater protection zone S2

Protection index value corresponding to low groundwater vulnerability, respectively Swiss groundwater protection zone S3

Conditions applicable to the rest of the catchment area

2.1.2 Examples for Applications of the EPIK Method

The EPIK method has been applied in Switzerland (St. Imier spring: SAEFL, 2000; Blatti springs/Lenk catchment: SAEFL, 2000), Belgium (GOGU & DASSARGUES, 2000a) and Lebanon (delineation of groundwater protection zone for the Sannine spring that provides water for bottled water; pers. comm. Dr. A. Pochon, Centre Hydrogéologique de l'Université de Neuchâtel). In Jordan, within the framework of the Jordan Watershed/Water Quality Management Project between USAID and the Water Authority of Jordan (WAJ), groundwater protection zones for the springs of the Qairawan catchment (Jerash Governorate; CDM, 2005) were delineated based on EPIK.

2.1.3 Advantages and Disadvantages of the EPIK Method

The method requires a detailed evaluation of karst features, which is often difficult, costly and time consuming as they involve field studies, geophysics, isotope studies, hydrologic studies, an analysis of the hydraulic character, etc. The detection of typical karst features like swallow- and sink holes often requires the interpretation of aerial photograph or high resolution satellite images.

2.1.4 Data Requirements for the EPIK Method

Table 5 displays an overview about the data that required for the EPIK method.

Table 5: Parameters required and Source of Information for the Preparation of a Groundwater Vulnerability Map following the EPIK Method

Parameter	Description	Source
Development of the **E**pi-karst	Epikarst is defined as a highly fissured zone corresponding to the decompressed and weathered formations near the ground surface). This upper karst zone is not continuous. It can be decimeters to meters thick and can contain perched aquifers which can rapidly concentrate infiltrating water towards the karstic network. The availability of features like swallow holes, depressions, dolines, karren fields, ruin-like structures, intensely fractured outcrops, dry valleys helps to classify this parameter	Field work (including hand auger drillings, excavations, trenches) interpretation of aerial photographs and detailed topographic maps (scales between 1: 5,000 and 1: 25,000)
Effectiveness of the **P**ro-tective cover	The soil cover generally determines the possibility and character of attenuation and infiltration processes. Important parameters in this respect are: thickness, texture/structure, organic matter content, clay content, types of clay minerals, cation exchange capacity, water content and hydraulic conductivity. Since the determination of all these parameters is time consuming and costly only the thickness of the protective cover is used	Field measurements of soil thickness and lithology (hand auger drillings, excavations, trenches), interpretation of aerial photographs and detailed topographic maps (scales between 1: 5,000 and 1: 25,000)
Conditions of **I**nfiltration	It is distinguished between concentrated, intermediate and diffuse infiltration conditions. They can be identified by the surface water runoff characteristics (slope, runoff coefficient) and the presence or absence of preferential infiltration zones. The availability of the following features helps to classify this parameter: swallow holes, buried karst, exposed karst.	Field work, hydrological measurements and interpretations (such as spring discharge measurements over long enough time periods), interpretation of aerial photographs and detailed topographic maps (scales between 1: 5,000 and 1: 25,000)
Development of the **K**arst network	The size (diameter) and connectivity of conduits in a karst network determines the flow velocity in a karst system. Part of the karst network may have been created earlier but not be in use anymore.	The presence or absence of a karst network can be determined by direct identification of the components of the network, such as caves, potholes, active cave systems or by indirect methods, such as flow hydrograph analysis, tracer test and water quality variability.

2.2 COP Method

(modified after MARGANE, 2003a)

2.2.1 Introduction to the COP-Method

This method was introduced by the Research Group of Hydrogeology of the University of Malaga/Spain (GHUMA) as a standard method for groundwater vulnerability mapping in karst aquifers (VIAS et al., 2002) in the framework of the EU COST 620 program. It uses the parameters:

- C – concentration of flow,
- O – Overlying layers and
- P – Precipitation.

As outlined by DALY et al. (2002), the COP-Method may become the European approach for groundwater vulnerability mapping in karst areas, provided its application proves to be successful in the coming few years.

The COP-Index is obtained by (*Figure 1*):

COP-Index = (C score) * (O score) * (P score)

Step 1: Calculation of O Factor

The O factor takes into account the protective function of the unsaturated zone and the properties of the layers soil (O_S – soil subfactor) and unsaturated zone (O_L – lithology subfactor). Both are separately calculated and then added to obtain the O factor:

$$O = O_S + O_L$$

The parameters texture (mainly dependent on grain size) and thickness are used to evaluate the subfactor O_S, as shown in *Figure 1*. The calculation of the subfactor O_L is based on the parameters lithology and fracturation (ly), thickness of each individual layer (m) and hydraulic (confined) condition (cn). Similar to the GLA-Method and the PI-Method the “layer index” is calculated by successively adding the products of the lithology and fracturation values of each individual layer with its thickness:

$$\text{Layer index} = \Sigma\ (ly * m)$$

The corresponding value of the layer index (process IV of *Figure 1*) is then multiplied by the value of the hydraulic (confined) conditions to obtain the subfactor O_L.

The spatial distribution of the total rating for the O factor is displayed on the O map (*Figure 65*).

Step 2: Calculation of C Factor

The C factor represents the degree of concentration of the flow of water towards karstic conduits that are directly connected with the saturated zone and thus, indicate the reduction of protection capacity. It is differentiated between two distinct geological settings: the catchment area of a swallow hole (scenario 1) and the rest of the area (scenario 2). In the first case, all surface water is considered to ultimately be drained towards the swallow hole, whereas in the second case the amount of infiltration depends on the characteristics of the land surface.

For scenario 1, the factor C is calculated based on the parameters distance to the swallow hole (d_h), distance to the sinking stream (d_s) and the combined effects of slope and vegetation (sv):

$$C = d_h * d_s * sv$$

In the area where the aquifer is not recharged through a swallow hole (scenario 2), the C factor is calculated based on the parameters surface features (sf) and slope (s) and the combined effects of slope and vegetation (sv):

$$C = sf * sv$$

The surface features represent geomorphological karst features and the presence or absence of a protective layer that influences the character of the runoff/infiltration process.

The spatial distribution of the total rating for the C factor is displayed on the C map (*Figure 53*).

Step 3: Calculation of the P Factor

This factor represents the total quantity, frequency, duration of precipitation as well as the intensity of extreme events, which are considered to be the main factors influencing the quantity and rate of infiltration. The P factor is obtained by a summation of the subfactors quantity of precipitation (P_Q) and intensity of precipitation (P_I):

$$P = P_Q + P_I$$

For the evaluation of P_Q, only the mean precipitation of a wet year, i.e. precipitation exceeding 15% of the total average year, is used. An increasing precipitation is believed to decrease protection, arguing that the transport/concentration process is more important than the dilution process. This is thought to occur up to a precipitation range of 800-1,200 mm/a, the value above which the potential contaminant becomes increasingly diluted and thus, GW less vulnerable. By using precipitation data for a wet year, the methodology ensures that the impact of precipitation on groundwater vulnerability is based on a worst case scenario.

The calculation of the subfactor P_I is based on the assumption that increasing rainfall results in a more rapid concentration and in an increased recharge and thus, a reduced protection of underlying groundwater resources. The "mean annual intensity", or P_I, is calculated by:

$$P_I = \frac{\text{mean annual precipitation (mm)}}{\text{mean number of rainy days/year}}$$

It is believed that increased rainfall intensity generates increased runoff to those conduits that favor concentrated infiltration. In turn, decreasing rainfall intensity increasingly favors a more diffuse and slow infiltration due to a more important role of evaporation.

The spatial distribution of the total rating for the P factor is displayed on the P map (*Figure 70*).

DALY et al. (2002) point out that the COP-Method could also be used for source protection (protection of wells/springs). In this case, the K factor is added, describing the function of the karst network (similar to the K factor of EPIK).

Step 4 (optional): Calculation of the K Factor

For the assessment of the intrinsic vulnerability of a karstic source (well or spring), a factor taking into account the karst network of the mostly saturated aquifer is needed. The "vertical" pathway (from the soil to the groundwater) must be combined with the mostly horizontal pathway through the saturated karstic bedrock towards the respective source (compare *Figure 1*; GSI, 1999; GOLDSCHEIDER, 2002).

A classification system previously developed (COST 620, internal report 2000) for karst aquifers, has been adopted. It is based on a general description of the bedrock, giving a range of possibilities, from porous carbonate rock aquifers to highly karstified networks (*Table 6*).

Table 6: Classification system for the karst aquifers (adapted from COST 620, internal report 2000). The increasing degree of karstification and concentration of flow within the aquifer is from left to right.

Fractured and intergranular system			Solutionally-enlarged fissures			Conduit systems					
Inter-granular flow	Fractures		High matrix storage	Low matrix storage	No significant matrix storage	Slow active conduit network			Fast active conduit network		
	High matrix storage	Low matrix storage				High matrix storage	Low matrix storage	No significant matrix storage	High matrix storage	Low matrix storage	No significant matrix storage

By characterizing the different types of flow (migration mechanisms) and the matrix-storage capacity (physical attenuation), a more detailed classification of the aquifer can be derived, if required. This K factor is very similar to the K factor of the EPIK method (SAEFL, 2000).

The description “slow active conduit network” reflects conduit systems which are not extensive and not very efficient in draining the aquifer. “Fast active conduit system” implies an extensively developed karst network, which is efficient in draining the aquifer. The matrix characteristics of the bedrock are included, as the interaction between the conduits and the matrix may be sufficient to change the behavior of the aquifer and hence, the attenuation potential.

The means of assessing the karst network factor are the following: (1) geology, geomorphology; (2) cave and karst maps; (3) groundwater-tracing results; (4) pumping test results; (5) hydrochemistry, geochemistry; (6) remote sensing and geophysical prospecting; (7) borehole data and geophysical-logging results; (8) bedrock sampling and laboratory experiments; and (9) calibrated modeling results.

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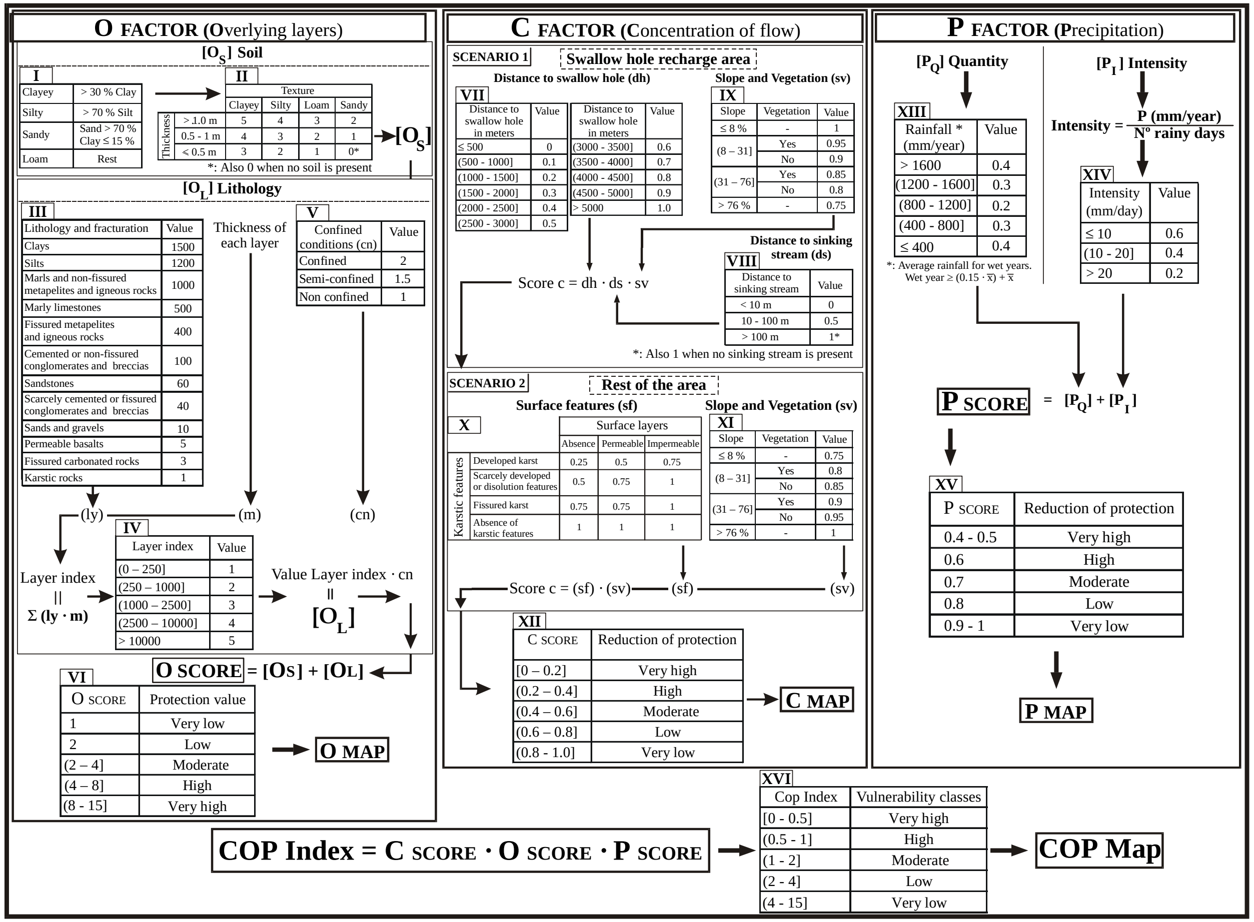

Figure 1: Flow Chart of the COP-Method (VIAS et al. 2002, 2006)

2.2.2 Examples for the Application of the COP-Method

The COP method was also applied in the Carrara area in northern Italy (BALDI et al., 2009). However, most prominently, the COP method was applied within the framework of the COST 620 program in the Sierra de Líbar and around Torremolinos, both in the Malaga province of southern Spain (VIAS et al., 2002). Both areas represent karst aquifers, which receive high amounts of rainfall. The Sierra de Líbar area is highly karstified, whereas the Torremolinos area is dominated by fissured limestone.
A more detailed description of the method is included in the final report of the COST 620 program (ZWAHLEN, 2004).

2.2.3 Advantages and Disadvantages of the COP-Method

The COP method is similar to the PI method with the exception that the COP method integrates the factor precipitation. The parameters needed for the COP method are relatively easy to acquire and the method is straightforward. However, due to the large number of calculation processes, the map compilation is time consuming and requires the use of a GIS system by which these procedures can be performed. Compared to the EPIK method, COP has the advantage of being universally applicable in any type of hydrogeological setting, while EPIK is only applicable in a purely karstic environment.

So far, there is too little experience with applications of this method to be able to judge about the suitability and applicability of the method.

2.2.4 Data Requirements for the COP Method

Table 7 on the following page lists all the required parameters for the COP mapping.

Table 7: Parameters required and Source of Information for the Preparation of a Groundwater Vulnerability Map following the COP Method

Parameter	Description	Source
C Factor	Features determining concentrated inflow: Karst features (swallow holes, sinking streams and others), slope, vegetation	Detailed karst feature mapping, mapping of vegetation cover and topography: requires intensive field work, analysis of aerial photographs and satellite images, digital elevation model.
O Factor	O_S (soil):	Soil mapping in order to determine soil texture and thickness using hand augers and soil laboratory analyses.
	O_L (lithology):	Determine thickness of each geological unit. Prepare structure contour maps based on geological mapping in order to determine top/base of geological units. Establish groundwater contour map to calculate thickness of unsaturated zone in each geological unit.
	Cn (confining conditions):	Analyze hydrogeological setting.
P Factor	Total rainfall (P_Q)	Rainfall data from meteorological stations and rainfall distribution maps for sufficiently long time period.
	Rainfall intensity (P_I)	Daily rainfall data from meteorological stations.

2.3 Source of Data

The sources of data used for groundwater vulnerability mapping is shown in *Table 8*. Topography was adopted from the Shuttle Radar Topography Mission (SRTM).

Spatial rainfall data were taken from the more reliable publication by UNDP & FAO (1973), where topography was used for interpolation while this is clearly not the case for the rainfall map accompanying the Atlas Climatique du Liban (SERVICE METEOROLOGIQUE, 1977). Climate assessment lacks fundamental preconditions regarding data collection and processing: firstly, there have never been rainfall stations at elevations > 1,800 m asl. However, 47% of the catchment is located at elevations exceeding 1,800 m asl. Secondly, until today, no station was ever equipped with a heating system so that snow had never been properly monitored. In fact, all current and former precipitation measurements are therefore invalid, as snow is an essential component of total rainfall at elevations > 1,200 m. The maximum average annual rainfall shown on the UNDP & FAO map in the Jeita GW catchment was around 1,800 mm. Due to an unrealistic rainfall distribution in the NE of the catchment, isohyetes of the UNDP & FAO map were slightly modified to better account for the snow depth observed during stable isotope sampling campaigns and other field work in the

Jeita GW catchment. Generally highest snow depth was observed near Dome du Mzaar, decreasing towards NE (*Figure 2*; MARGANE et al., in progr.).

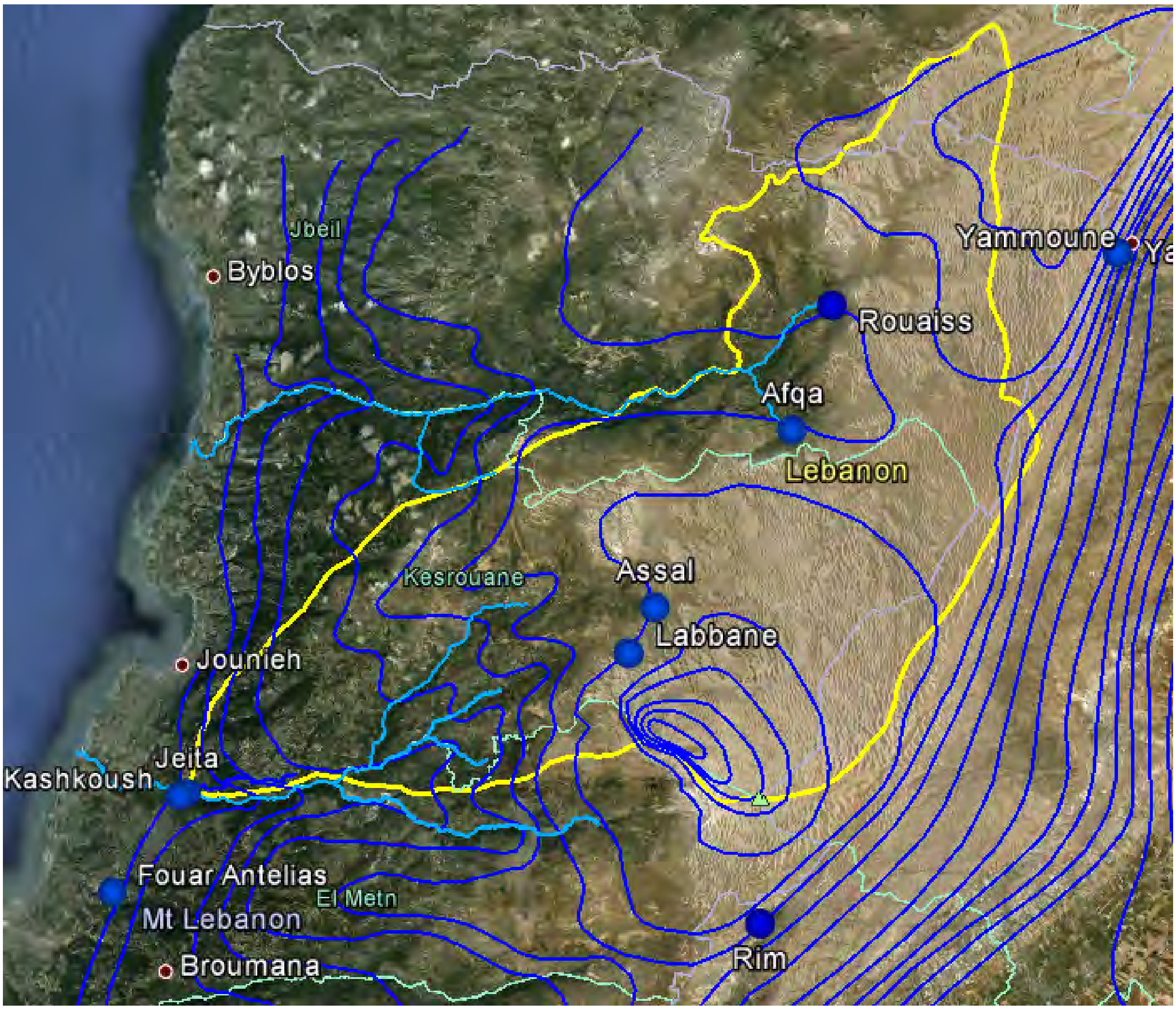

Figure 2: Modified isohyetes (blue lines) according to observed decrease of precipitation towards NE (GeoEye image 30.03.2011 from Google Earth); 100 mm intervals increasing from 900 mm/a near Jeita to 2100 mm/a near Mt. Sannine

The boundaries of the groundwater catchments were established through more than a dozen tracer tests (MARGANE et al., in progr.). Geology was mapped by HAHNE (2011) and ABI RIZK (in MARGANE et al., in progr.). The groundwater contours for the Lower aquifer (Jurassic) were estimated, based on the few available observation points and general hydrogeological considerations. A soil mapping was conducted by the Lebanese Agriculture Research Institute (LARI) for the BGR project (RAAD &

MARGANE, 2011). Surface karst features were mapped by ABI RIZK & MARGANE (2011).

Table 8: Type of data, source and specificity of data that were used for the calculation of the COP map

Type	Data	Source	Specificity
Raster	SRTM DEM (2000)	USGS, 2011	Corrected cell size 110 m; resampled to 10 m. Coverage: Lebanon
	Average monthly precipitation (1931/1960)	UNDP & FAO (1973), modified, according to MARGANE, et al. (in progr.)	Cell size: 10 m. Coverage: JEITA GW CATCHMENT
Shapefile	Boundaries of the sub-surface catchments of Afqa-, Assal-, Jeita-, Labbane- and Rouaiss spring	MARGANE et al. (in progr.)	Coverage: JSC
	Geology		
	Groundwater contour		
	Soil texture and thickness	RAAD et al. (2011)	
	Surface karst features	ABI RIZK & MARGANE (2011)	
	Landuse and landcover	SCHULER (2011)	
	Streams		
	Daily precipitation (1999-2010)	TUTIEMPO NETWORK, 2011	Beirut Airport

3 Modification of COP Method

As mentioned before, the COP method (*Figure 6*) needed to be adapted to the local conditions, with respect to the hydrogeological setting.

The COP method assesses the vertical infiltration of water between the land surface and the karst aquifer. Vulnerability is commonly assessed for the uppermost aquifer. In the uppermost part of the Jeita GW catchment this is the C4 geological unit (Upper Aquifer). In all other areas, where the C4 is not present, the J4 geological unit forms the uppermost aquifer (Lower Aquifer). A 500 - 800 m thick sequence, considered as an aquitard (J5-C3) (*Figure 3*) separates both aquifers. There is no major downward leakage through the aquitard to the Lower Aquifer. In the COP method the aquitard units are assigned a very low vulnerability due to their very low infiltration capacity. Already less than 10 m of thickness of the J5 unit (strongly weathered basalt) overlying the J4 aquifer achieve a very high O-score and the C-score is not relevant for this unit.

For the assessment of GW vulnerability, the geological and hydrogeological characteristics of the C4 and the J4 unit play the most important role. However, the COP method considers not only direct groundwater recharge but also flow concentration (surface water drainage) towards karst features with high infiltration. This flow concentration can also be generated in geological units overlying the J4 unit, namely the J5. Dolines, located in the uppermost part of the J4 and close to the outcrop of the J5, were therefore also considered in the vulnerability assessment (*Figure 4*).

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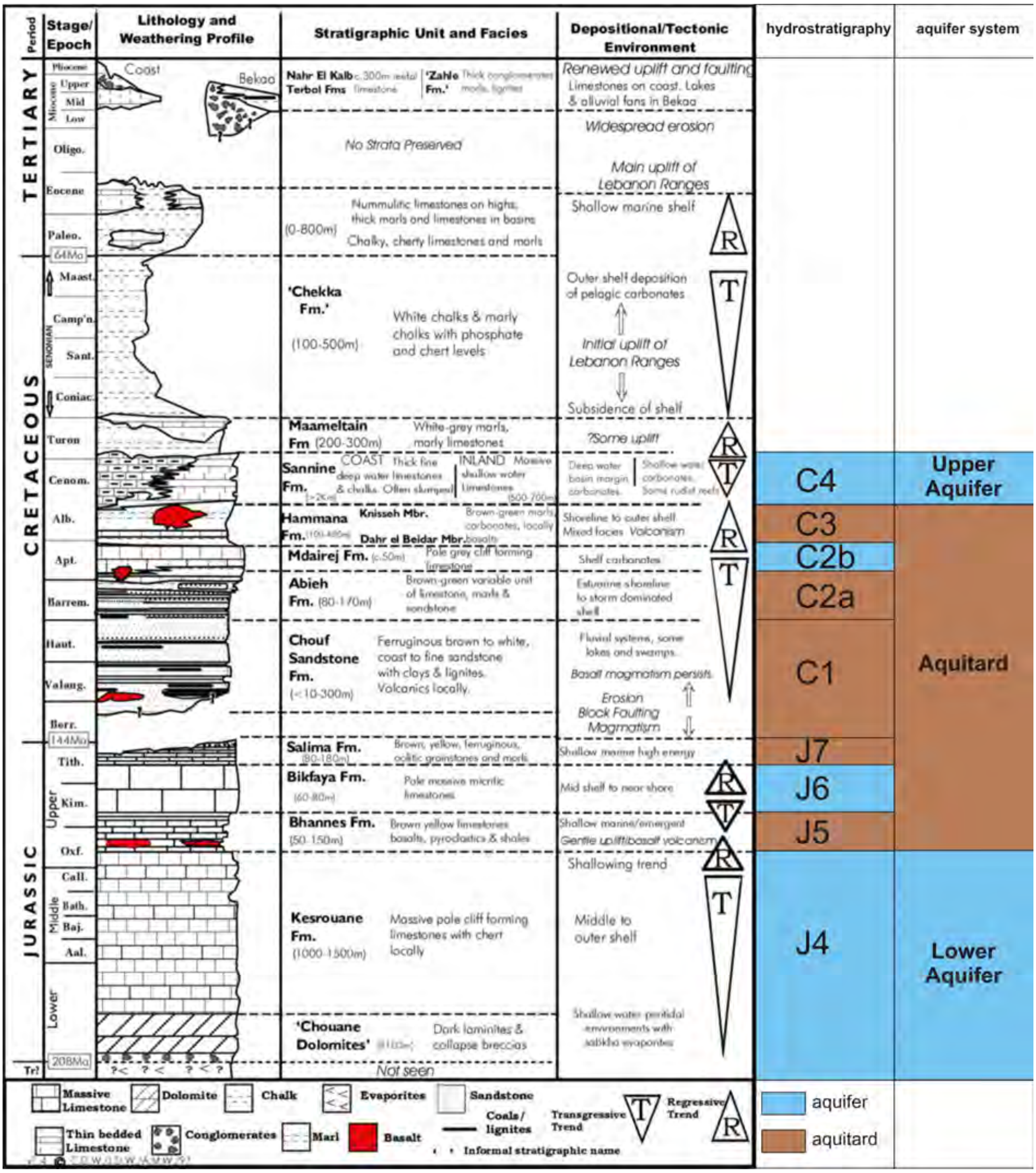

Figure 3: Hydro-lithostratigraphy, modified after WALLEY, 2001

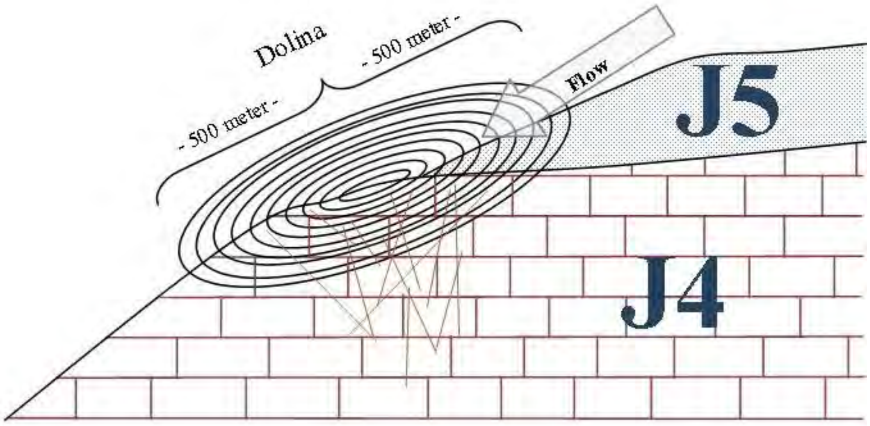

Figure 4: Concentration of surface and interflow from the J5 towards a doline in the uppermost J4

Thus, the assessment of the vulnerability of the J4 aquifer is expanded to the 500 meter buffer zone around dolines, reaching into the J5 unit (*Figure 5*).

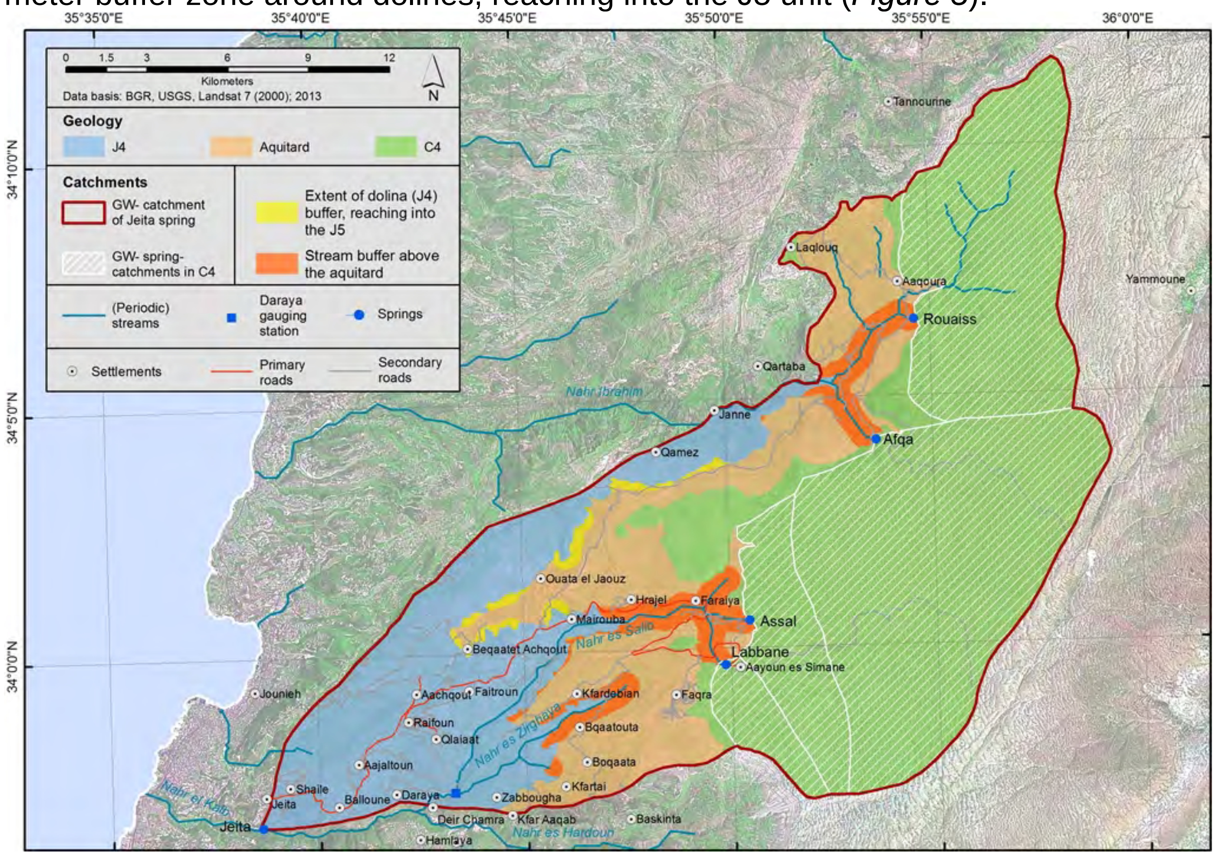

Figure 5: Impact of indirect infiltration into the J4, resulting from overlying layers

According to the original procedure, for the calculation of the C factor, there are two scenarios: one scenario for the infiltration into swallow holes and/or sinking streams and another scenario for the presence of only minor or no karst features. Swallow holes (or dolines) would have an impact to a distance of 5,000 m from their center, while sinking streams (or infiltration zones in rivers) would only have an effect until a distance of 100 m from the center of the river course. Both values were modified in order to meet the local characteristics. The influence of dolines was reduced to a maximum of 500 m, while that of sinking streams was increased to 500 m (*Figure 7*). Once more, this is true for karstified areas. However in fact, substantial amounts of contaminants may be transferred from streams into groundwater via surface water infiltration, which is very common in the uppermost J4.

Streams may pass over different hydrogeological units on their flow paths, which, in karst aquifers, may result in considerable changes in streamflow. For example, above an aquitard, a stream may be classified as “gaining stream”, whereas reaching a karstified aquifer, becoming a “losing stream”. As outlined in MARGANE (2012a, 2012 b), this is the case in the Jeita GW catchment. Besides Nahr Ibrahim, also Nahr es Salib and Nahr es Zirghaya change their character during their flow path. Between April and June 2012, near the village of Bqaatouta (located on the aquitard), the discharge of large amounts of water carrying large quantities of suspended fine materials from a quarry resulted in high turbidity in Nahr es Salib. The turbidity peak reached Jeita spring, located 13.5 km downstream, only 24 hours later (Margane 2012 c). This is why the 500 m stream buffer zone is also applied on the respective area above the aquitard (*Figure 5 and 7)*. Through introduction of the S score (*Figure* 8) the aquitard becomes partly integrated into the COP assessment. Due to the short travel time of potential contaminants within streams, this area is classified as very high vulnerable.

The presented modification of the COP method is a first attempt to integrate surface water infiltration into groundwater vulnerability mapping.

The following chapters (3.1 – 3.4) present the procedure of calculation of the C, O, P and S factor.

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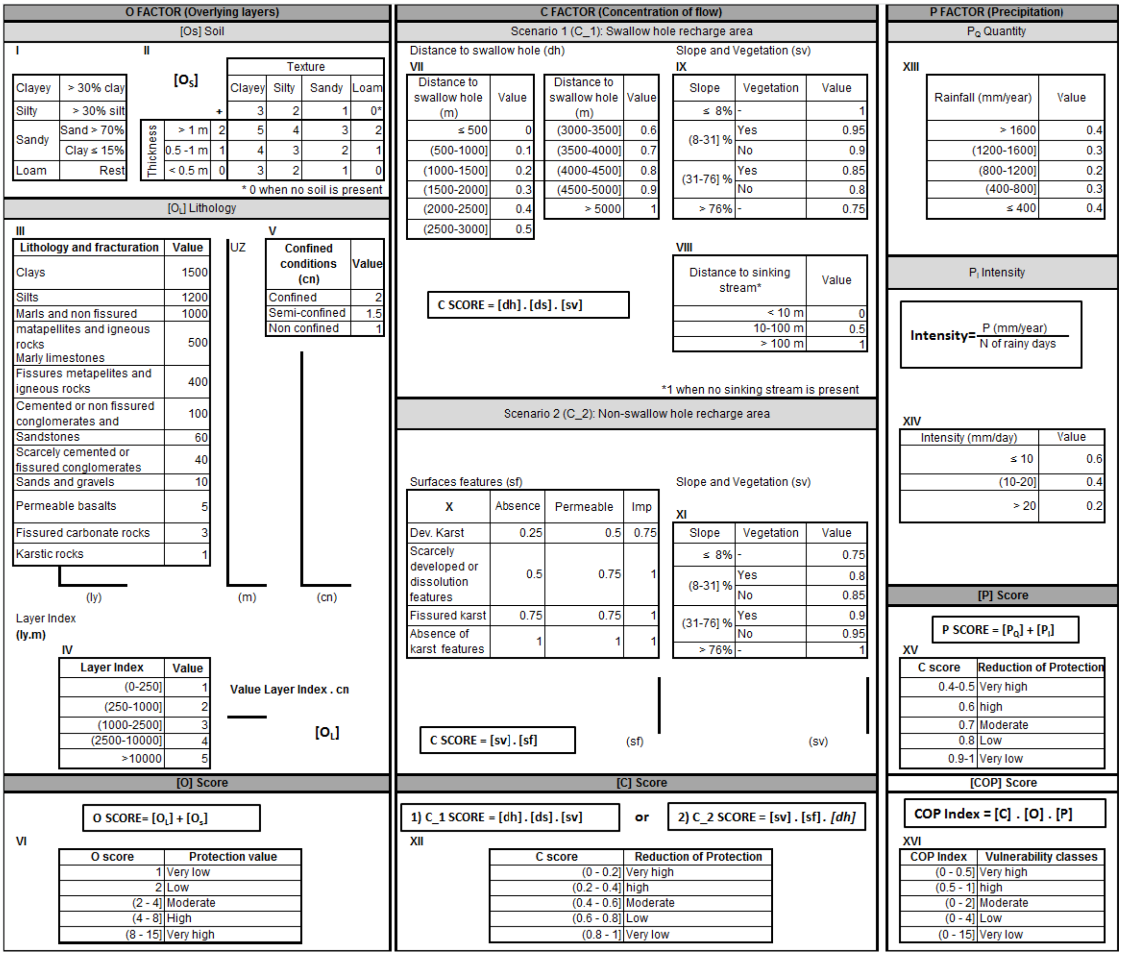

Figure 6: COP methodology according to VIAS et al. (2006)

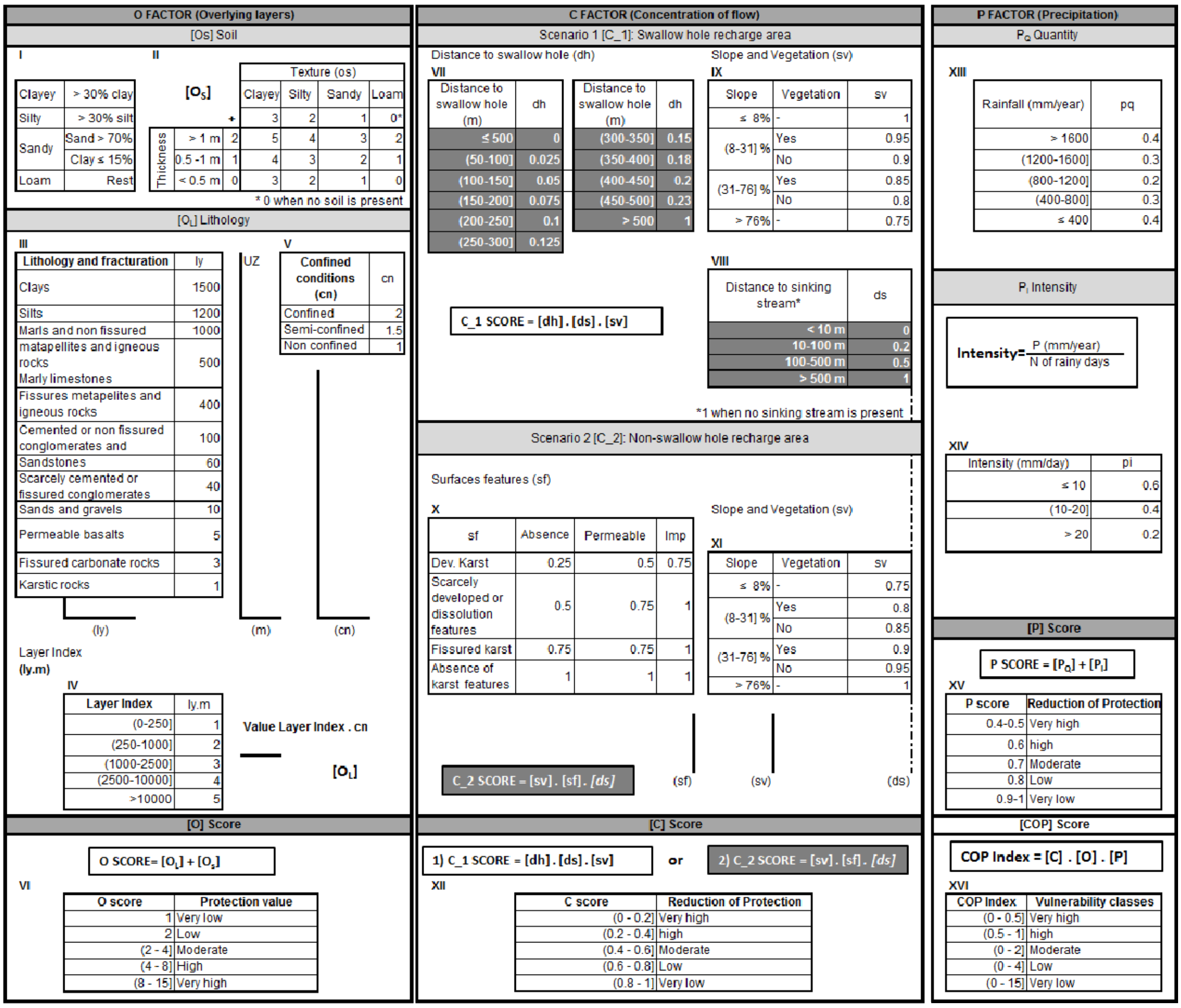

Figure 7: COP methodology modified (dark grey shading) by the project

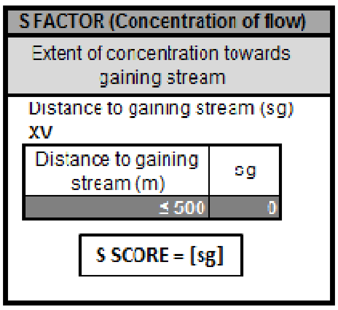

Figure 8: S Score for gaining streams above the aquitard

3.1 Procedure for Calculation of C-Factor

Two different C factors are calculated: scenario 1 (C_1) expresses the vulnerability resulting from concentrated infiltration near swallow holes (dolines), while scenario 2 (C_2) expresses the vulnerability in areas without such major features (diffuse infiltration throughout the catchment).

C_1 is calculated according to the proposed methodology of VIAS et al. (2002, 2006) by multiplication of the parameters d_h* d_s* sv. The numerical d_h value was modified according to local conditions within the Jeita GW catchment.

The methodology for the calculation of C_2 was modified as well. Surface water infiltration in rivers (sinking streams) is a major feature of infiltration in Lebanon. Sinking streams (d_s) are the main feature in scenario C_2. Here, not only sf and sv need to be taken into consideration, but also the d_s value contributing to a higher vulnerability near river courses. Infiltration along sinking streams occurs through firstly, a river section where a portion of streamflow infiltrates directly into the underlying karst network and secondly, through indirect recharge (infiltration) from surface drainage towards that stream (*Figure 9*).

Figure 9: Infiltration through sinking streams (d_s) at Mairouba

Infiltration of surface water is considered as diffuse infiltration (scenario 2), rather than concentrated infiltration (scenario 1). Accordingly, the COP method was modified in order to account for infiltration along sinking streams in scenario C_2. C_1 and C_2 are calculated by multiplication of layers VII-XI, according to *Figure 7*. Annex 1 displays the application of the described methodology in ArcGIS 10 in order to generate the respective layers.

3.1.1 Layer VII

Layer VII (d_h value) expresses the strong impact of swallow holes on GW vulnerability because they constitute a pathway for rapid infiltration into groundwater. The contribution to GW vulnerability is defined through the horizontal extent of the swallow hole. VIAS et al. (2002, 2006) group the d_h value in 10 buffer zones with a linear increment of 500 m around a swallow hole. This means that the infiltration effect is strongest in the inner circle of 0-500 m from the center of the swallow hole (d_h value = 0) and is continuously decreasing to a distance of 5,000 m from its center, where the effect becomes negligible (d_h value at > 5,000 m = 1).

Within the Jeita GW catchment, swallow holes are located mainly in the C4 and in the highly karstified areas of the uppermost J4 unit. None of the dolines has a radius larger than 500 meters. The d_h classification was therefore modified respectively; it comprises 10 classes with equal intervals of 50 m, instead of 500 m. Besides this, also the numerical vulnerability values were modified. Both geological units in which dolines occur, the C4 and the J4, are attributed by a sf value of 0.25 (*Table 11*), indicating high karstification/permeability of the rock matrix in the entire unit. Consequent application of the system proposed by VIAS et al. (2002) would lead to a high discrepancy between the resulting d_h- and sf value, as within a doline values would reach a value of 0.9 (d_h value), expressing a relative moderate vulnerability, while outside of the doline the d_h value would be 0.25, expressing a very high vulnerability (*Figure 10*). In order to reduce this unreasonable discrepancy, the total range of d_h values was modified according to *Table 9*. This modification is valid for the hydrogeological setting in all of Lebanon.

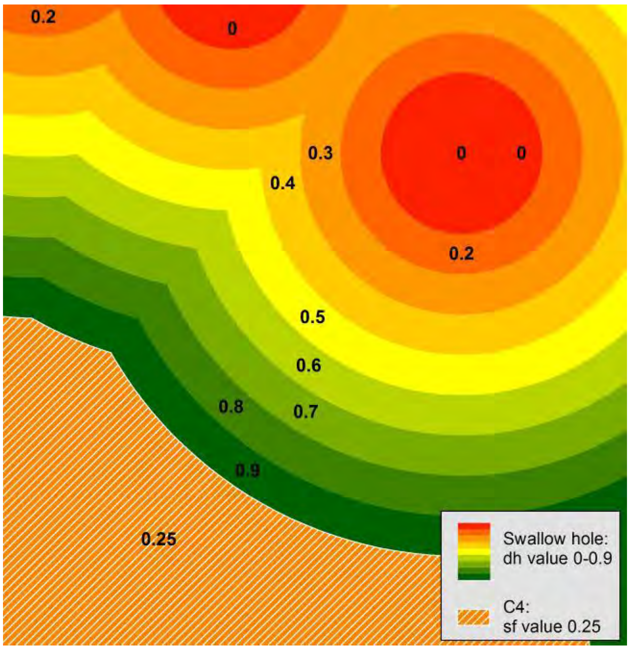

Figure 10: Discrepancy of attributed d_h- and sf values near dolines (according to classification proposed by VIAS et al. (2002)

Table 9: Modified classification for layer VII (d_h value)

Distance to swallow hole (m)	d_h value
≤ 50	0
50-100	0.025
100-150	0.05
150-200	0.075
200-250	0.1
250-300	0.125
300-350	0.15
350-400	0.175
400-450	0.2
450-500	0.225
≥ 500	1

Layer VII (d_h) has been established in ArcGIS as documented in Annex 1.1.

3.1.2 Layer VIII

Layer VIII (d_s value) takes into consideration the infiltration from streams towards the saturated zone. According to VIAS et al. (2002, 2006), the vulnerability contributed by a sinking (losing) stream is expressed by two different classes: < 10 meter = 0 and 10-100 meter = 0.5. Beyond a distance of 100 meter, all values are 1.

Within the Jeita GW catchment, locally high karstification leads to infiltration rates, reaching up to 52% (MARGANE 2012 a, 2012 b), indicating the presence of vulnerable areas in river beds. Riverbed infiltration (infiltration along sinking streams) from surface runoff clearly occurs within an extend that is larger than 100 meters (*Figure 9*), as it will also occur through infiltration of surface water drainage along the slopes during rainfall events, although to a lesser degree. Thus, the classification by VIAS et al. (2002, 2006) of infiltration along sinking streams was modified to three classes, ranging between 0 and 500 m from the center of the river course (*Table 10*).

Table 10: Modified classification for layer VIII.

Distance to sinking stream	d_S value
≤ 10	0
10-100	0.2
100-500	0.5
> 500	1

Layer VIII has been established in ArcGIS as documented in Annex 1.2.

3.1.3 Layer IX

Layer IX (sv value) takes into consideration the topography, i.e. slope in %, and land-cover, i.e. vegetation.

Layer IX is applied on areas that are covered by dolines. According to VIAS et al. (2006), within swallow hole areas, with increasing slope also the vulnerability of groundwater increases.

Layer IX has been established in ArcGIS as documented in Annex 1.3.

3.1.4 Layer X

Layer X (sf value*)* expresses the extent of karstification of the rock matrix, based on the outcropping geological unit. According to VIAS et al. (2006), values range between 0.25 and 1; the lower the value, the lower is the protective cover and the higher is the degree of karstification. *Table 11* displays the attributed sf values for the outcropping geological units (relevant sf values for the present COP mapping of the J4/C4 are displayed bold) within the Jeita GW catchment.

Table 11: Classification for layer X (relevant sf values in bold)

Geological unit	sf value
C4	**0.25**
C3	0.50
C2b	0.25
C2a	0.75
C1	1
J7	0.50
J6	0.25
J5	**1**
J4	**0.25**
Basalt	1.00

Layer X has been established in ArcGIS as documented in Annex 1.4.

3.1.5 Layer XI

Same as layer IX, layer XI (sv value) takes into consideration the topography, i.e. slope in %, and landcover, i.e. vegetation. However, layer XI is applied on areas that are not covered by dolines. According to VIAS et al. (2002, 2006), in non-doline areas, with increasing slope the GW vulnerability decreases.

Layer XI has been established in ArcGIS as documented in Annex 1.5.

3.1.6 Layer C_1

Layer C_1 is the final C layer for the areas, covered by dolines.

Layer C_1 has been established in ArcGIS as documented in Annex 1.6.

3.1.7 Layer C_2

Layer C_2 is the final C layer for the areas, not covered by dolines.

Layer C_2 has been established in ArcGIS as documented in Annex 1.7.

3.1.8 Final C Layer

The final C layer has been established in ArcGIS as documented in Annex 1.8.

The final C layer includes layer C_1 and layer C_2. It is displayed in *Figure 53*.

3.2 Procedure for Calculation of O-Factor

The O factor represents the overlying layers on top of the rock matrix: soil cover (O_S value) and bedrock lithology (O_L value).

3.2.1 Layer I & II

Layer II (O_S value) represents the soil characteristics in terms of texture and thickness. Due to constraints in availability of reliable and valid soil data, the used O_L value is based on the underlying geology, field assessments (RAAD & MARGANE, 2011) and on 3D satellite image analysis, using Google Earth. The O_S value is attributed to the geological units, according to *Table 12* (relevant O_S value for the present COP mapping are displayed bold).

Table 12: Classification of the O_S value (relevant values are displayed bold)

Geological unit	O_S value	Remark
C4	0	-
C3	2	-
C2b	0	-
C2a	2	▪ In the area of Faraiya: O_S 3
C1	4	-
J7	3	-
J6	3	▪ Between Hrajel and Faraiya: O_S 5
J5	5	-
J4	3	▪ In areas without soil cover (e.g. quarries): O_S 0; ▪ In areas of low soil thickness (Raashine, Jouret el Hachich, Ouata ej Jaouz): O_S 2; ▪ In small depressions: O_S 5
Basalt	5	-

Layer II has been established in ArcGIS as documented in Annex 2.1.

The final O layer is shown in *Figure 65*.

3.3 Procedure for Calculation of P-Factor

The P factor includes precipitation, representing climatic conditions that contribute to vulnerability within the catchment. For the calculation of P, the sum of two sub-factors is taken into account: the quantity of rainfall per year ($P_{Q)}$ and the intensity of rainfall (numbers of rainy days per year) (P_I).

3.3.1 Layer XIII

Layer XIII expresses the quantity of rainfall per year. Long-term annual rainfall distribution data was taken from UNDP & FAO (1973), which has been modified according to MARGANE, et al. (in progr.), as shown in *Figure 11*.

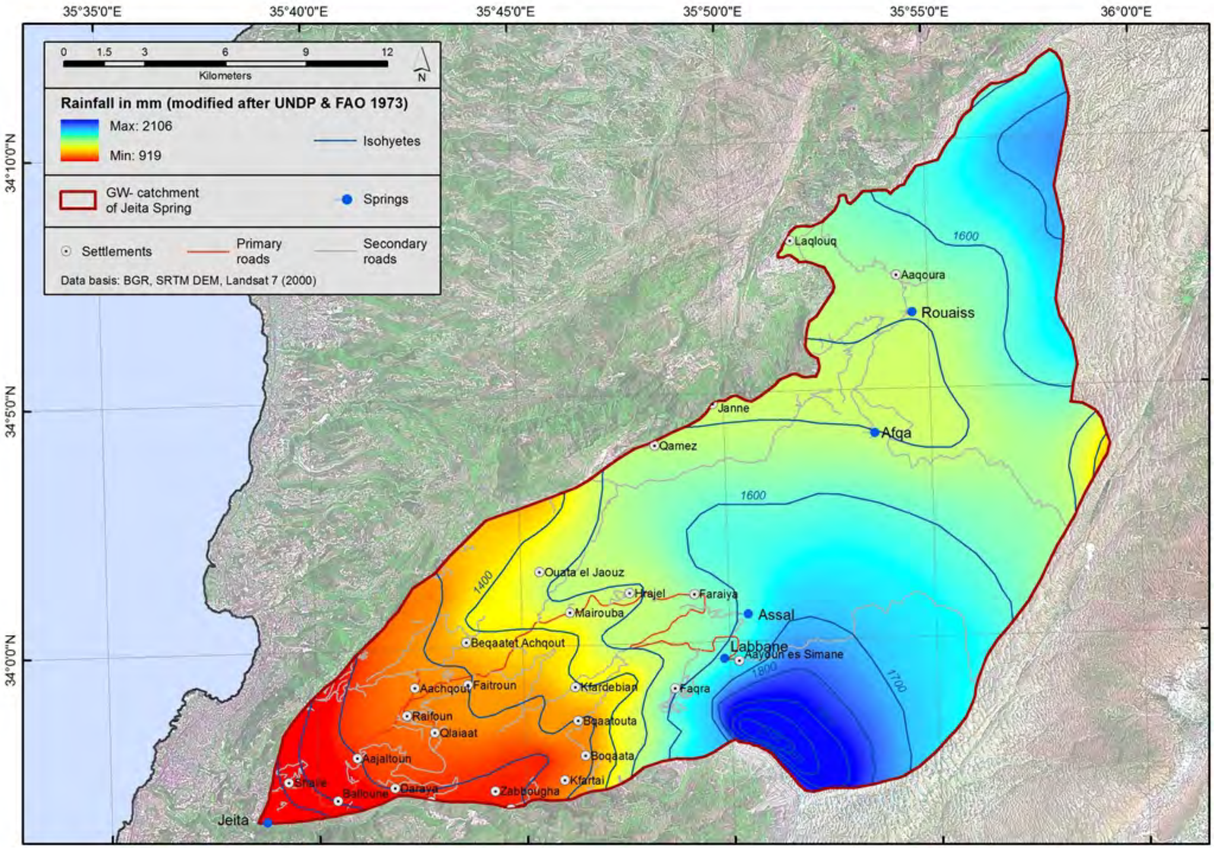

Figure 11: Mean annual rainfall distribution between 1939 and 1970, according to UNDP & FAO (1973), modified by MARGANE et al. (in progr.).

Due to data constraints, layer XIII is calculated based on the average annual rainfall records between 1939 and 1970, neglecting the requirement of using only precipitation data for wet years because those data were not available. The annual rainfall distribution is classified according to Table 13.

Table 13: Classification for layer XIII

Rainfall (mm per year)	P_Q value
> 1,600	0.4
1,200-1,600	0.3
800-1,200	0.2
400-800	0.3
≤ 400	0.4

With increasing rainfall quantity above the range of 800-1,200 mm/y, the protective impact increases; increasing quantities of rainfall increasingly dilute pollutants; this, in turn, leads to decreased resource vulnerability.

Layer XIII has been established in ArcGIS as documented in Annex 3.1.

3.3.2 Layer XIV

Layer XIV (P_I value) expresses the rainfall intensity during wet years. Rainfall intensity is the ratio of the amount of rainfall and the number of rainy days per year. The number of rainy days in Lebanon for wet years is around 80 days, according to the analysis of rainfall data at station Beirut International Airport (1999-2010) (Table 14).

Table 14: Annual rainfall and number of annual rainy days at Beirut airport between 1999 and 2010; bold: wet year (annual rainfall + 15% of average of water years 1999-2010)

Hydrological year	Total rainfall (mm/y)	Number of rainy days
1999-2000	742	70
2000-2001	618	66
2001-2002	786	86
2002-2003	**1,080**	**81**
2003-2004	526	47
2004-2005	691	57
2005-2006	742	67
2006-2007	746	62
2007-2008	436	42
2008-2009	**866**	**82**
2009-2010	**960**	**78**
Average (av)	**744.8**	**80.3**
Annual precipitation for a wet year = av + (av * 0.15) = 856 (bold) Number of rainy days = 80 (average of wet years)		

Due to data constraints and because the rainfall intensity does not necessarily correlate with increasing altitude (*see Figure 12*), the value of 80 days was adopted over the entire catchment. Concerning data availability, ATLAS CLIMATIQUE DU LIBAN (1977) states that period 1931-60 was used, even though only three stations in all of Lebanon had complete data during that period; all others were artificially generated. During 1931-1960 the average number of rainy days ranges between 73 and 79. The intensity of rainfall is classified according to *Table 15*.

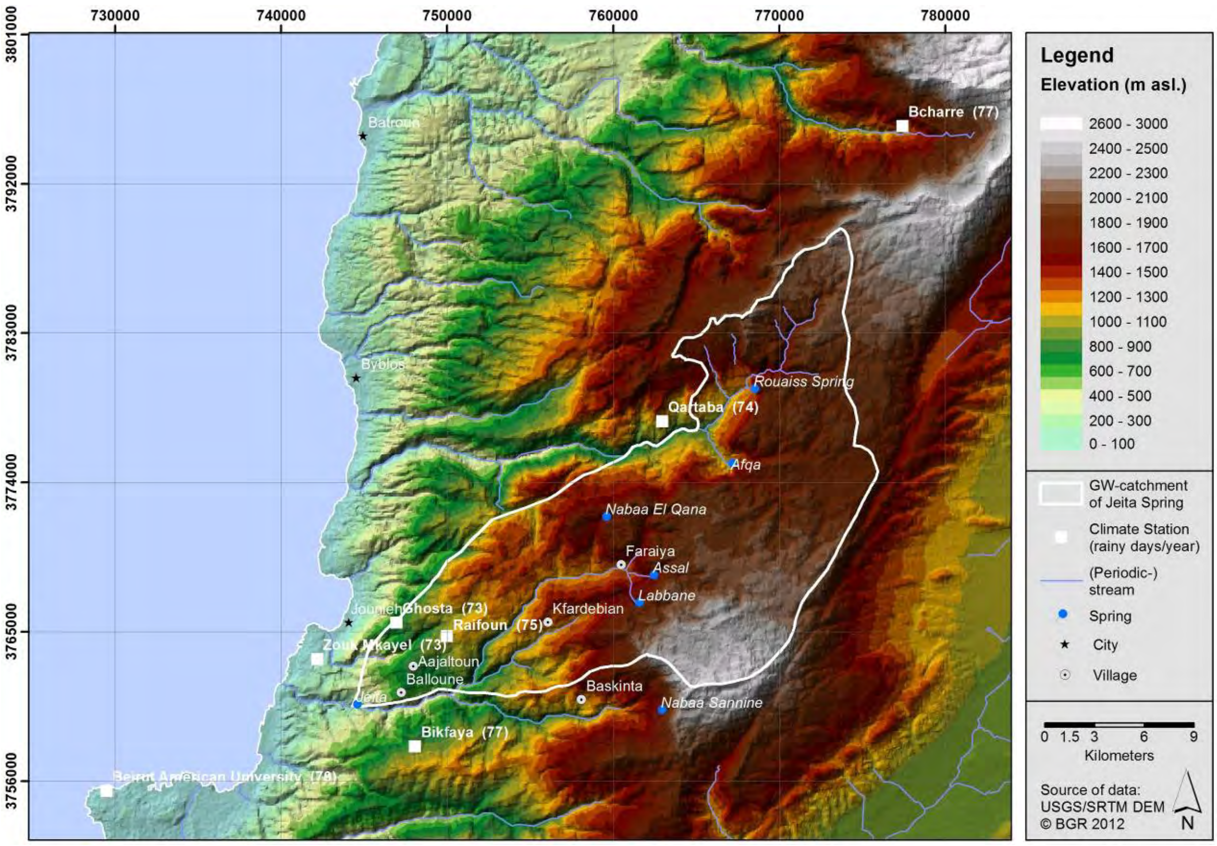

Figure 12: Quantity of average annual rainy days for selected climate stations; source of data: ATLAS CLIMATIQUE DU LIBAN (1977)

Table 15: Classification of the rainfall intensity

Rainfall intensity	P_I value
< 10	0.6
10-20	0.4
> 20	0.2

Layer XIV has been established in ArcGIS as documented in Annex 3.2.

3.3.3 Final P Layer

The final P layer is the sum of layer XIII and XIV. The final P layer has been established in ArcGIS, as documented in Annex 3.3 and it is displayed in *Figure 70*.

3.4 Procedure for Calculation of S-Factor

The S factor includes the slopes, i.e. the buffer of concentrating surface runoff of major gaining streams (Nahr es Salib, es Zirghaya and Ibrahim, above the aquitard. Due to the relative wide fluvial valleys, a buffer of 500 meters defines the area of concentrating surface runoff towards streams (*Figure 8*). Flow towards the aquifer is relatively fast and infiltration into the uppermost part of the aquifer has been proven. Therefore, the S-factor was added to the COP method to account for the local conditions.

The final S layer has been established in ArcGIS, as documented in Annex 4 and it is displayed in *Figure 71*.

4 Groundwater Vulnerability in the area overlying Jeita Cave

Jeita Spring is located at the end of a 5.4 km long cave system, coming from ENE direction. This cave is partly about 60 m wide and ends at the so-called “siphon terminale”, where it descends to an unknown depth. Beyond this point the cave system has not been explored. This part of the cave has been mapped by the Speleoclub du Liban (SCL, 1990).

In the accessible part of Jeita cave (lower 800 m) it can be observed that water enters the system from above at several places during the rainy season, although not in large quantities. It is not known how the situation is in other parts of the Jeita cave during the rainy season because cave explorations are done only during the dry season. The injection for tracer test 2B-1 (DOUMMAR et al., 2010b; conducted in August

2010, *Figure 13*) is located approx. 250 m from the center line of Jeita cave. The depth to groundwater (saturated zone) reaches up to 550 m under the village of Balloune. A horizontal movement of infiltrating water in a karst network of 250 m in this area is assumed to be justified. Tracer injected also in August at site 2A-2 was not measured in Jeita spring, probably due to the fact that tracer infiltration was very slow; in this case, dilution would have been too high, decreasing the tracer concentration at Jeita to an undetectable level. From tracer test 2A-2 it can thus not be concluded that there is no connection to Jeita cave.

Figure 13: Buffer zone of 250 m from the center line of Jeita cave, defining groundwater protection zone 2A according to very high risk of infiltration

Within a radius of 250 meters, groundwater vulnerability is classified as very high because of the very high risk of infiltration. This part of groundwater will need special protection because this area carries the highest pollution risk. At the same time, it is the most extensively built-up area with numerous potential pollution sources. The vulnerability at the land surface over Jeita cave has been established according to Annex 5.

5 Description of the Final Groundwater Vulnerability Map

The final groundwater vulnerability map is displayed in Annex 5, *Figure 74*, ranging between very high and very low (*Table 16*).

Table 16: Absolute and relative coverage of the COP vulnerability classes within the Jeita catchment

Vulnerability	Vulnerability index	Area in km^2	Share in %
very high	0-0.5	288	70.9
high	0.5-1	39	9.5
moderate	1-2	3	0.7
low	2-4	1	0.2
very low	4-10	76	18.8

5.1 Very high vulnerability

Groundwater is very high vulnerable above the whole C4 unit and partly above the J4 (*Table 17*), as well as within the stream buffers above the aquitard.

Table 17: Absolute and relative coverage of relevant very high vulnerable areas

Geological unit	Vulnerable area in km^2	Share of total very high vulnerable area in %
Aquitard	19.2	6.7
J4	49.2	17.1
C4	219.6	76.3

From the total J4 coverage of 87 km^2, 56.5% (49.2 km^2) is accounted for very high vulnerable GW. Existence of very highly vulnerable areas above the J4 is mainly influenced by four factors:

I. Jeita cave (buffer),
II. Existence of dolines,
III. Existence of sinking streams and
IV. Absence of soil cover.

The respective very high vulnerable areas include the villages of Balloune (2.6 km from Jeita), the area between Deir Chamra (6.5 km) - Faitroun (9.2 km) - Mairouba (13.6 km), Qamez (20 km) and the area between Jour el Bawashek (7.2 km) - Raashine (10 km) - SW of Mchati. Also, all upper springs (Afqa, Assal, Labbane and Rouaiss) directly drain at the very high vulnerable C4. Labbane spring, for example, the only source for Chabrouh dam, is located 400 meters away (downstream) from the village of Aayoun es Simane.

5.2 *High vulnerability*

Groundwater is highly vulnerable almost exclusively above the J4 unit (*Table 18*). 43.5% of the J4 is mapped as high vulnerable.

Table 18: Absolute and relative coverage of relevant high vulnerable areas

Geological unit	Vulnerable area in km^2	Share of total high vulnerable area in %
J5	0.5	1.3
J4	37.8	98.6

Existence of high vulnerable areas above the J4 is mainly related to four factors:

I. Low sf value,
II. Absence of sinking streams,
III. Absence of dolines and
IV. Absence of soil cover.

Besides the J4, groundwater may be highly vulnerable above the aquitard, within the buffer area of sinking streams.

The respective high vulnerable areas include the SW part of the Jeita GW catchment between Shaile (1.5 km from Jeita) - Daraya (5.6 km) - Aajaltoun (4.3 km) - Bzoum-mar (5.7 km) - Raifoun (7 km) - Qlaiaat (7.2 km) - Aachqout (7.6 km), west of Faitroun (9.2 km), Hiyata (11.3 km), Zabbougha (8.7 km), Raashine (7.3 km) and slightly Hrajel (15.4 km) and Faraiya (18.3 km).

5.3 *Moderate vulnerability*

Moderate groundwater vulnerability occurs almost exclusively above the aquitard (*Table 19*).

Table 19: Absolute and relative coverage of relevant moderate vulnerable areas

Geological unit	Vulnerable area in km^2	Share of total high vulnerable area in %
J4	0.1	4.1
Aquitard	2.6	95.9

Patches of areas that are moderate vulnerable include the area north of Jouret ed Dardour (10 km distance to Jeita), east of Faqra (17.5 km), west of Qanat Bakich (15.7 km), below Chabrouh dam (19.2 km) and around Afqa (26.3 km).

5.4 Low vulnerability

Low groundwater vulnerability occurs almost exclusively above the aquitard (*Table 20*).

Table 20: Absolute and relative coverage of relevant low vulnerable areas

Geological unit	Vulnerable area in km^2	Share of total moderate vulnerable area in %
Aquitard	0.8	98.5

The existence of low vulnerable areas is mainly related to:

I. Moderate sf value,
II. Absence of sinking streams and
III. Presence of soil cover.

Groundwater is low vulnerable in the areas north and south of Aqoura, above the C3, west of Afqa above the C3, south of Faqra and partly along Nahr es Zirghaya, beyond the 500 meter buffer zone.

5.5 Very low vulnerability

79.4% of the aquitard is classified as very vulnerable (*Table 21*).

Table 21: Absolute and relative coverage of very low vulnerable areas

Geological unit	Vulnerable area in km^2	Share of total high vulnerable area in %
Aquitard	75.6	99.4

Very low groundwater vulnerability is related to:

I. A very high sf value and
II. A very high O_S value.

Groundwater is very low vulnerable in the entire center of the catchment, in Kfartai, Boqaata, Bqaatouta, west of Kfardebian, Lassa, Seraaita, SE of Ouata el Jaouz and west of Aqoura.

6 Groundwater Pollution Risks

This chapter presents a quantitative analysis between the spatial distribution of GW hazards with respect to the underlying GW vulnerability. The respective map is displayed in Annex 6, *Figure 75*. A qualitative analysis is out of scope here; it can be found in Special Report No. 16 (RAAD et al., 2013).

6.1 Agriculture

Agriculture covers an area of 31.4 km^2 within the Jeita GW catchment. *Table 22* presents the agricultural areas, located on a specific vulnerability class.

Table 22: Total area (km^2) and share (%) of agriculture per vulnerability class

Vulnerability index	Vulnerability	Area in km^2	Share in %
0-0.5	very high	8.8	28.0
0.5-1	high	2.4	7.6
1-2	moderate	0.9	3.0
2-4	low	0.2	0.8
4-10	very low	19.0	60.7

With decreasing GW vulnerability index, the total share of covering agriculture increases. 28.0% of agricultural activity takes place above very high vulnerable GW (mainly within the 500 meter buffer zone of streams above the aquitard), whereas 60.7 % above very low vulnerable GW.

As it is the aquitard, which offers favorable conditions for agriculture, 87.4% of the whole activity takes place above this unit. *Figure 14* shows agricultural activity above the aquitard (moderate-very low vulnerable), clearly separated from the J4 (very high-high vulnerable).

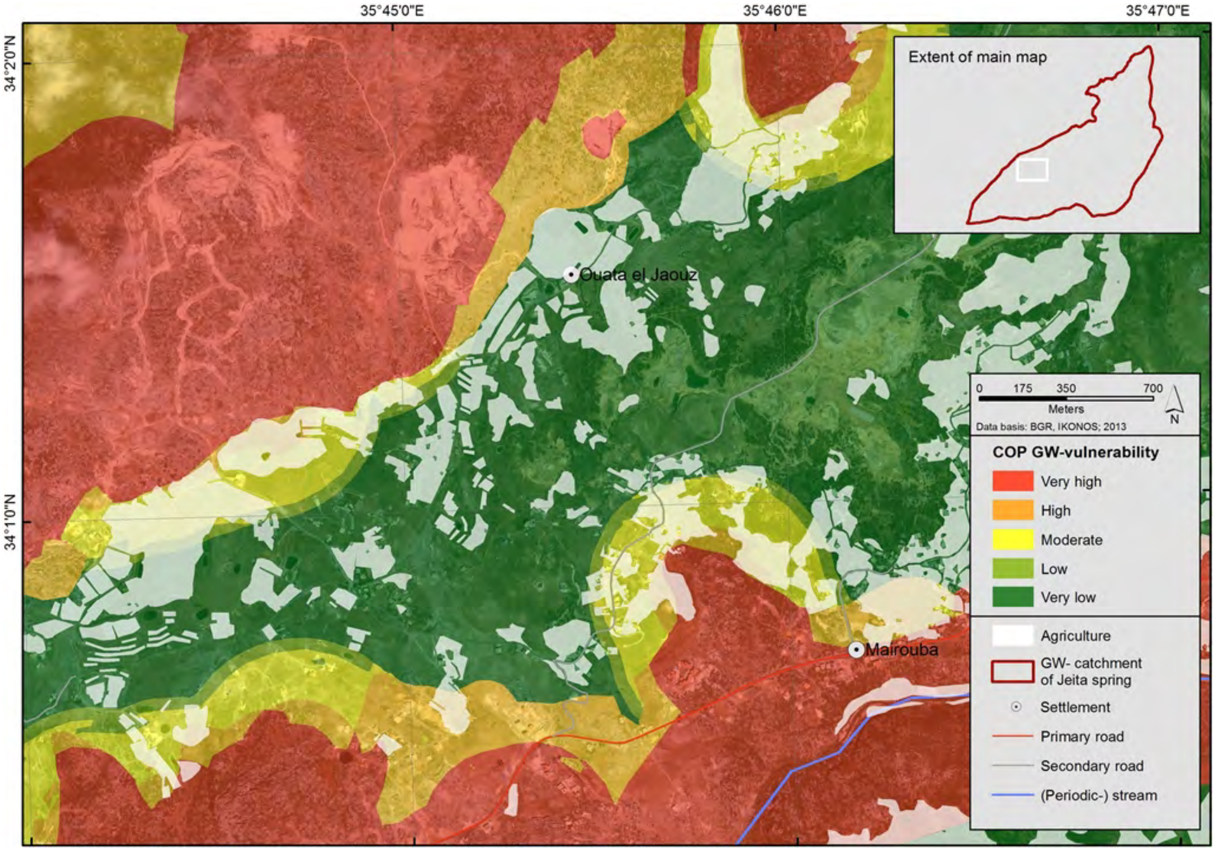

Figure 14: Agriculture above very low to moderate vulnerable groundwater

6.2 Dumpsites

Currently, 47 illegal dumpsites are mapped within the catchment. *Table 23* presents the quantity of dumpsites, located on a specific vulnerability class.

Table 23: Total quantity and share of dumpsites per vulnerability class

Vulnerability index	Vulnerability	Area in km^2	Share in %
0-0.5	very high	34	70.8
0.5-1	high	10	20.8
4-10.0	very low	3	6.3

Three dumpsites are located south of Ouata el Jaouz, above very low vulnerable GW above the J5/C1.

More importantly, ten dumpsites are located above high vulnerable GW; one below Aayoun es Simane, on top of the C3 and nine others on top of the J4, close to the Keserwan highway. However, 34 dumpsites are located above very high vulnerable GW; 29 of them above the J4, showing a high concentration of illegal dumpsites in the area of Boqaata Achqout (*Figure 15*).

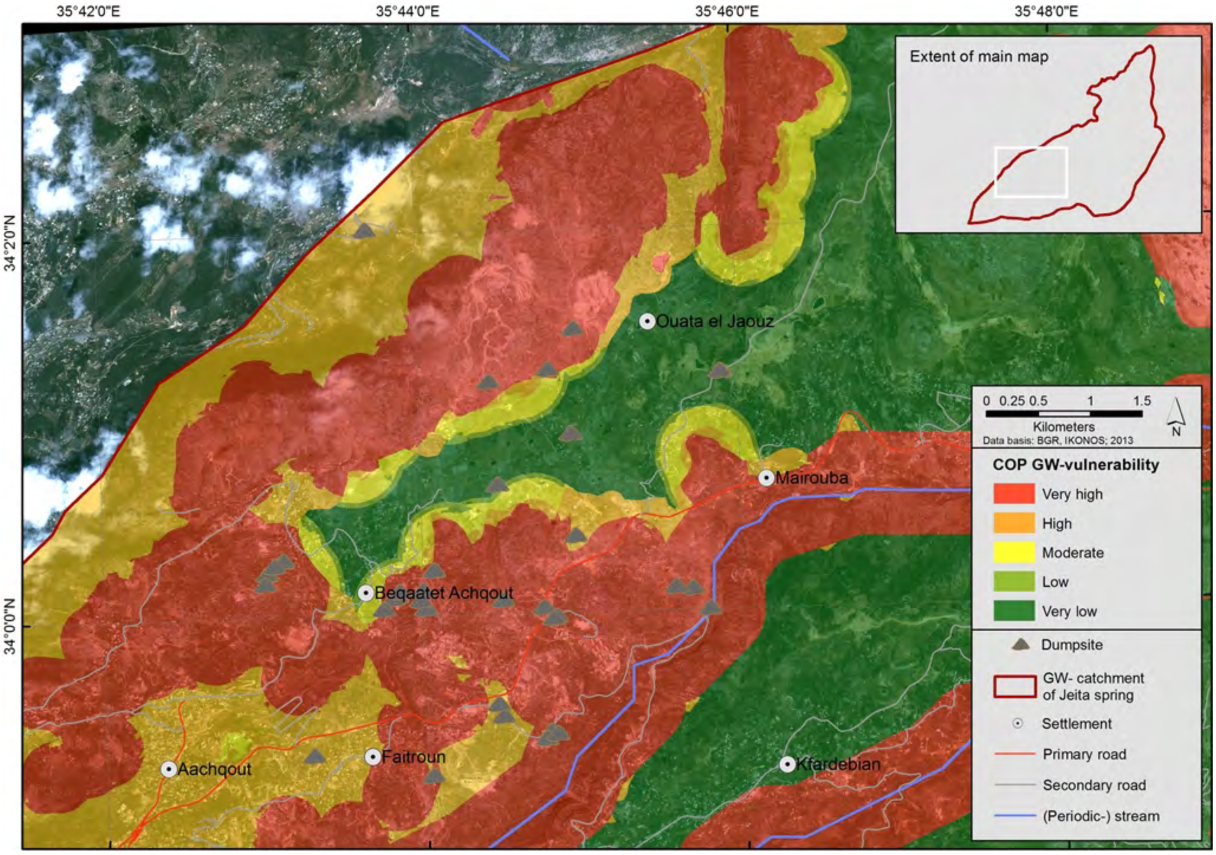

Figure 15: High concentration of dumpsites above very high GW vulnerability

6.3 Gas stations

Currently, 58 gas stations are operated within the catchment. *Table 24* presents the number of gas stations, located on a specific vulnerability class.

Table 24: Total quantity and share of gas stations per vulnerability class

Vulnerability index	Vulnerability	Area in km^2	Share in %
0-0.5	very high	20	34.5
0.5-1	high	25	43.1
1-2	moderate	1	1.7
4-10.0	very low	12	20.7

No gas station is located on the C4 geological unit. In principle they are well distributed within the center and SW of the catchment, with a concentration in the western part, above the J4 unit. A total of 45 gas stations are operated on high and very high vulnerable GW and three of them are located right above Jeita cave (*Figure 16*).

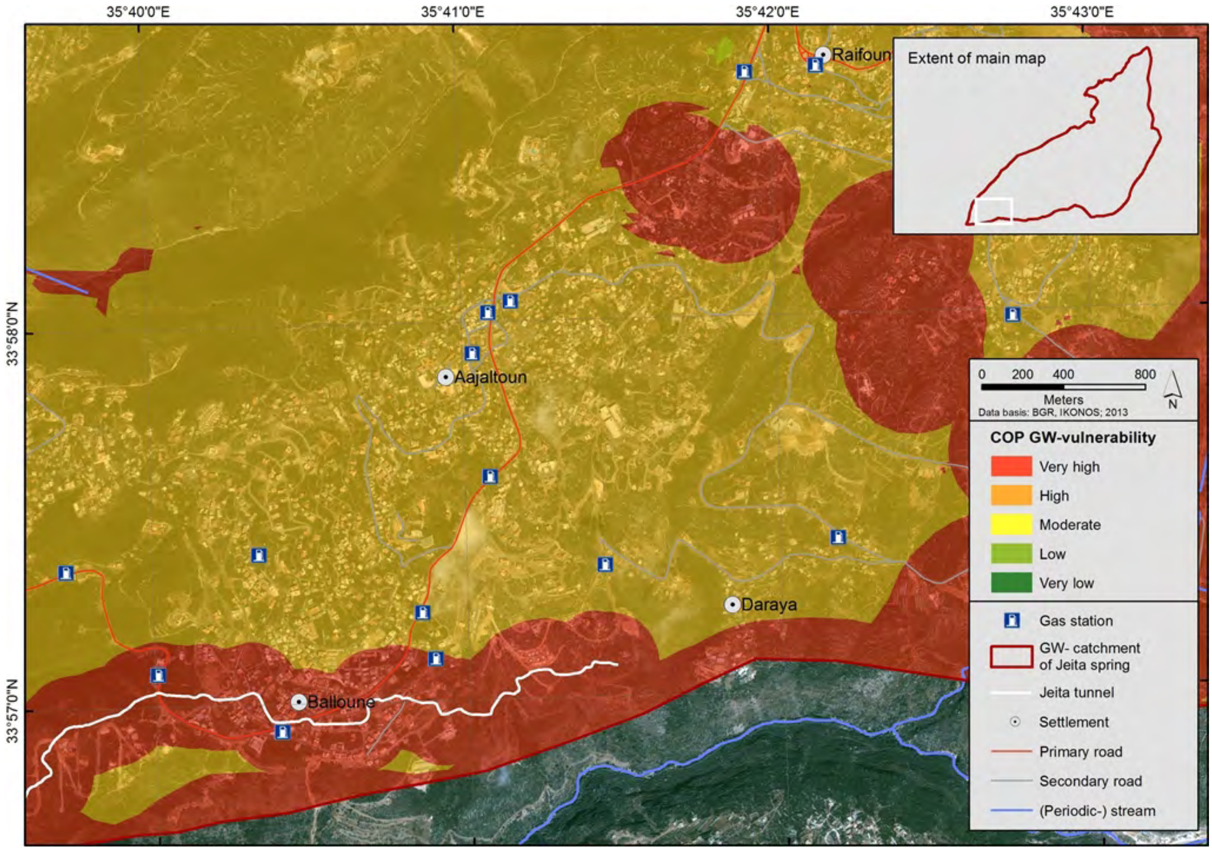

Figure 16: High concentration of gas stations above (very-) high vulnerable GW, in the SW of the catchment

6.4 Livestock

Currently, 31 animal farms are operated within the catchment. *Table 25* presents the number of livestock farms, located on a specific vulnerability class.

Table 25: Total quantity and share of livestock farms per vulnerability class

Vulnerability index	Vulnerability	Area in km^2	Share in %
0-0.5	very high	8	25.8
0.5-1	high	7	22.6
4-10.0	very low	16	51.6

16 farms are located above very low vulnerable GW resources, for example in the area of Bqaatouta and north of Hrajel. In turn, 15 are currently managed above (very) high vulnerable GW, distributed above the J4 aquifer. GW is not only threatened directly by infiltration of pollutants of farms but also indirectly through infiltration via surface water courses. *Figure 17* displays the location of a farm that is in close proximity to Nahr es Salib.

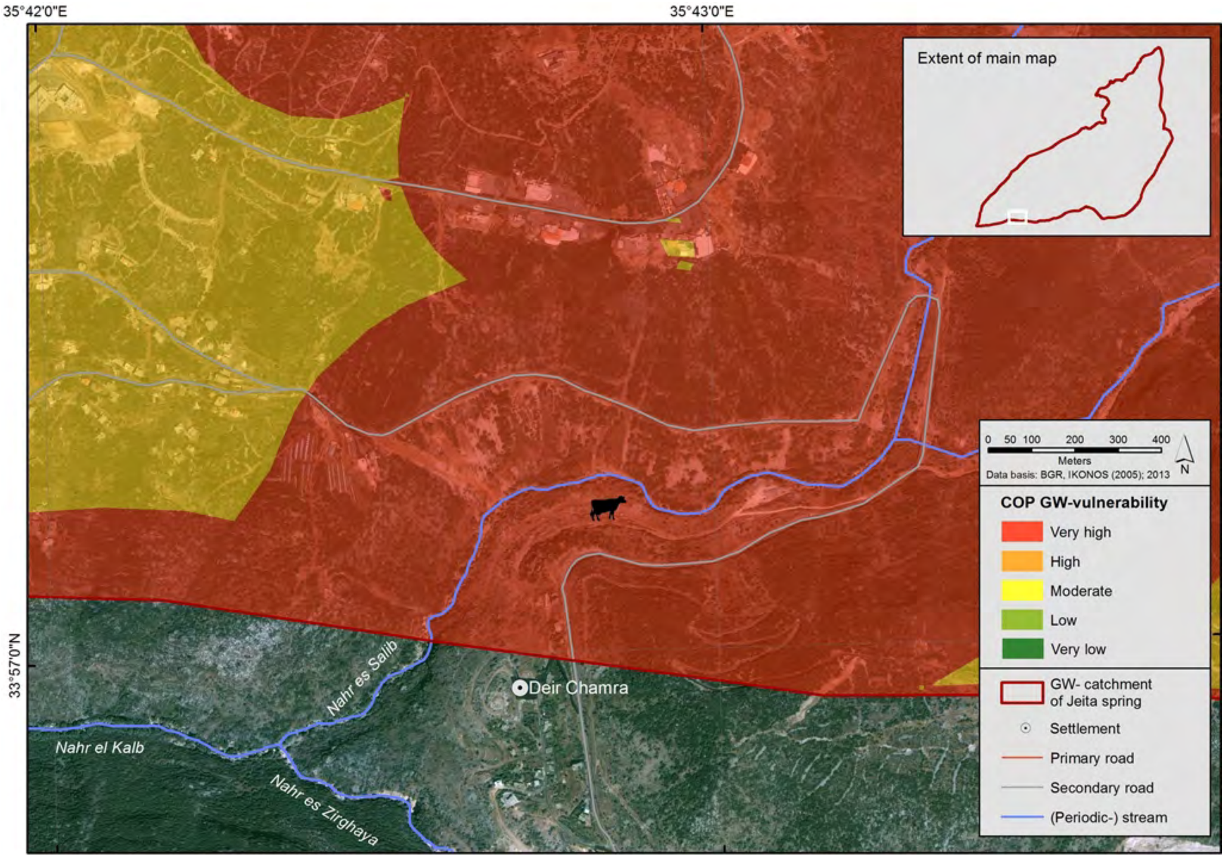

Figure 17: Livestock farming in <50 meter distance to Nahr es Salib

6.5 Quarries

Currently, eight quarries are operated within the catchment. *Table 26* presents the number of quarries, located on a specific vulnerability class.

Table 26: Total number and share of quarries per vulnerability class

Vulnerability index	Vulnerability	Area in km^2	Share in %
0-0.5	very high	1	12.5
4-10	Very low	7	87.5

One quarry is operated in a very high vulnerable area, NW of Ouata el Jaouz. Further south and east, four quarries are operated on top of a very low vulnerable are above the J5/C1. Three quarries are located east of Bqaatouta, on top of a very low vulnerable area of the C1. In spite of a very low GW vulnerability below, quarries may have indirectly an impact on groundwater, namely via surface water courses (MARGANE 2012 a, 2012 b). These quarries are displayed in *Figure 18*, showing their location south of Nahr es Zirghaya.

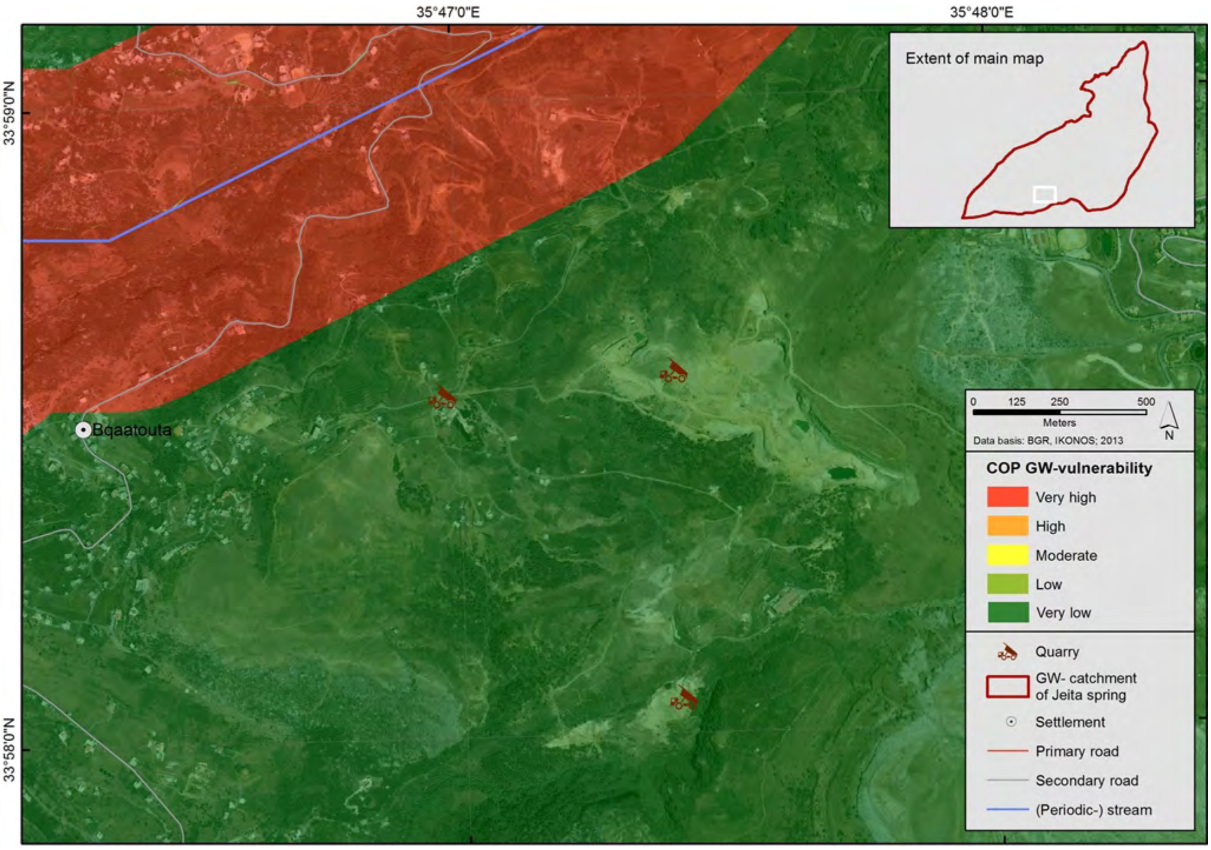

Figure 18: Quarries above very low vulnerable GW may have an impact on surface water

7 Recommended Groundwater Protection Zones

The comparison of international regulations concerning groundwater protection zones (MARGANE, 2003b) shows that the zoning schemes and travel times used for defining the boundaries between zones are quite different and often depend on the local hydrogeological setting and the possibility of legal implementation of landuse restrictions. In the regional context, Jordan has played a leading role in implementing water resources protection regulations because pollution had put the scarce water resources increasingly at risk since the early 1990s. In July 2006 the government of Jordan adopted the Guidelines for Drinking Water Resources Protection, previously proposed by MARGANE & SUNNA (2002). In the meantime, protection zones for around 34% of the Jordanian drinking water resources have been delineated and implemented, mostly facilitated by German development aid projects, implemented by BGR (MARGANE et al., 2008; SUBAH & MARGANE, 2011). The experience gained in Jordan, where the boundaries of protection zones 1 and 2 were marked by sign-posts (*Figure 19 and 20*) and implementation of landuse restrictions was followed up by the Water Authority of Jordan (WAJ) and the Environmental Rangers, a police task force, shows that water resources protection efforts have been quite successful.

When people notice that protection rules are being broken, they can report it to a WAJ call center. The integration of water resources protection requirements was achieved also with the support of German development aid projects, implemented by BGR.

Similar efforts were undertaken by BGR in Syria (protection zone of Figeh spring; MARGANE et al., 2011) and Yemen (MARGANE et al., 2007a; MARGANE & BORGSTEDT, 2007; MARGANE et al., 2007b).

Figure 19: Signpost marking the Boundary of Groundwater Protection zone 1 in Jordan

Figure 20: Signpost marking the Boundary of Groundwater Protection zone 2 in Jordan

Concerning the groundwater catchment of Jeita spring, a division in the following zoning scheme is proposed:

- zone 1 (50 m upstream, 15 m to each side, 10 m downstream of the spring and 10 m to each side of related water infrastructure, e.g. conveyor line, reservoir, etc. until entry into the actual water supply infrastructure); Zone 1 includes the area over the cave and underground river with a rock cover of less than 100 m;
- zone 2A (groundwater travel time < 10 days, very high groundwater vulnerability, possible direct rapid infiltration into underlying Jeita cave: buffer zone 250 m from projected course);
- zone 2B (groundwater travel time < 10 days, high groundwater vulnerability);
- zone 3A (groundwater travel time > 10 days, very high groundwater vulnerability) and
- zone 3B (all other parts of the groundwater catchment).

7.1 Groundwater Protection Zones for Jeita Spring

The protection zones of Jeita spring (2A – 3B) are displayed in Annex 7, *Figure 76*.

7.1.1 Protection Zone 1

Protection zone 1 should cover all parts of water resources, which are directly accessible, until reaching the drinking water treatment plant. This comprises:

- the entire Jeita cave (approx. 5.8 km long), i.e. the touristic part of Jeita grotto: both parts, the upper gallery and lower grotto (because there is a direct connection between them) and that part of the cave, which can be reached on foot, either from the touristic entrance or from the so-called Daraya tunnel;
- the water conveyor (canal and tunnel) from Jeita spring to the Dbayeh drinking water treatment plant.

Protection zone 1 should also encompass the area over Jeita cave where the overlying rock thickness is less than 100 m or where faults can lead to a rapid infiltration. Construction in the area with reduced rock cover over the cave may lead to cave collapse.

Distances

As outlined above, the extent of protection zone 1 for Jeita spring comprises a larger area than explained in chapter 7. The protection zone 1 should cover a distance of 10 m from the water source (underground river, canal, tunnel) to all sides, including all areas that could directly drain to the water).

Principally, access to protection zone 1 should only be granted to authorized staff of the water utility (Water Establishment Beirut and Mount Lebanon). However, this will not be possible e.g. for the underground river, currently accessible by electric boat.

Areas to be protected

Jeita cave: For the touristic part of Jeita cave the objective of restricted access cannot be met. Here, all persons accessing the touristic part must be instructed by the Jeita grotto (Mapas) staff and further, must be obliged to leave their belongings at the entrance in order to prevent possible contamination. Also, operation and maintenance by Mapas needs to consider not using any potential hazardous substances, which could reach the water in Jeita grotto. Batteries needed for the operation of the boats in Jeita grotto must be encapsulated so that leakage cannot occur. Constructions in Jeita grotto must be discussed with and agreed by the Water Establishment Beirut and Mount Lebanon.

A substantial part of the upper level of Jeita cave is located under a deeply incised valley and does not have a sufficient rock overburden. Between the pools and the touristic endpoint, the overlying rock thickness is only between 60-80 m (*Figure 21 and 23*). There is a high risk of cave collapse due to construction using heavy machinery. Excavations for buildings commonly reduces the overburden by up to 15 m. In the critical zone shown in *Figure 21*, an immediate construction stop is advised. Groundwater protection zone 1 should cover those areas that could drain into the underground river (*Figure 22*).

Jeita-Dbayeh water conveyor: Access to the canal from Jeita to Dbayeh should be restricted by establishing a fence at a distance of 10 m. Houses near the conveyor, such as those currently at Kashkoush spring and Mokhada should be removed. If this is not feasible, the wastewater cesspits of these houses have to be replaced with closed systems (septic tanks) and the collected wastewater has to be taken out regularly and transported to a designated location. There are some small commercial businesses very close to the canal in Mokhada. These will need to be removed.

Landuse restrictions in Zone 1

Any landuse by the water utility within zone 1 must consider the following:

- Oil, grease, lubricants, pesticides, fungicides, batteries and any substances that are potentially hazardous to water should not be stored or used in zone 1.
- Constructions, other than required for the operation and maintenance of the water conveyance system, are not allowed.

A construction ban is required to protect Jeita cave from collapses in the area directly overlying the cave and where only an insufficient rock overburden exists (critical zone in *Figure 21*).

Modifications required in Protection Zone 1

- A fence must be erected along the canal at 10 m distance from the canal.
- Houses and commercial businesses at the canal must be removed (10 m distance).
- Construction ban in the critical zone (risk of cave collapse)

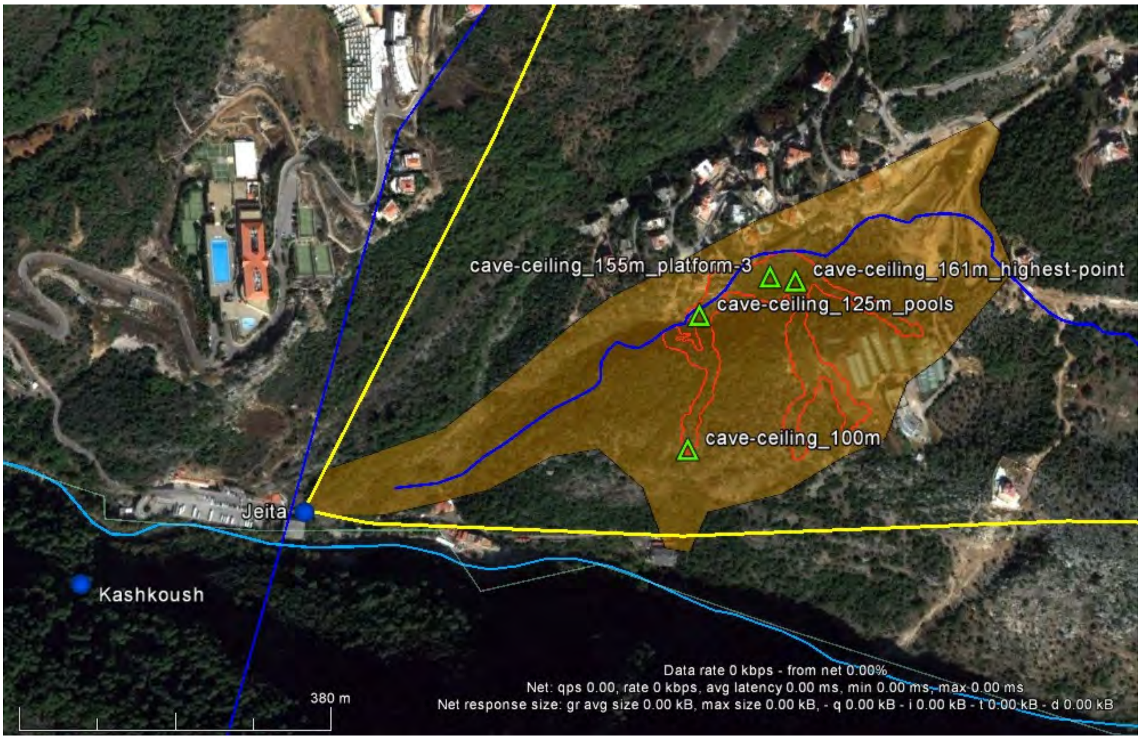

Figure 21: Critical zone (brown marked area) where an immediate construction stop is advised

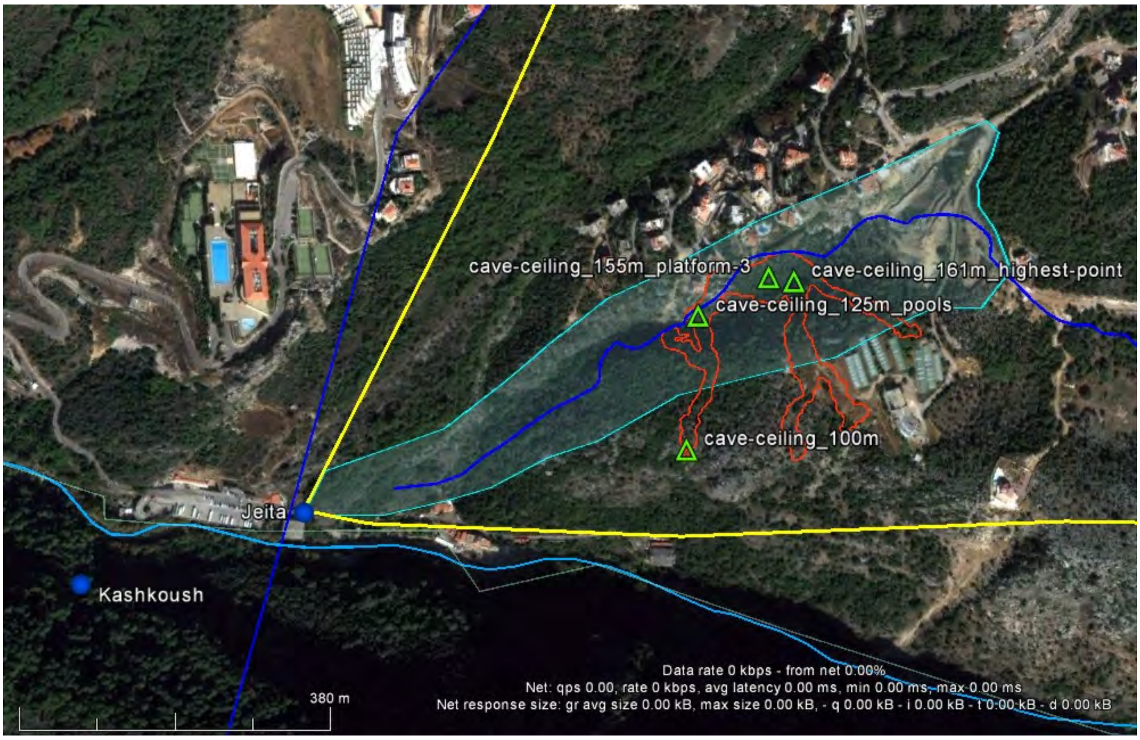

Figure 22: Groundwater protection zone 1 in the area over Jeita cave

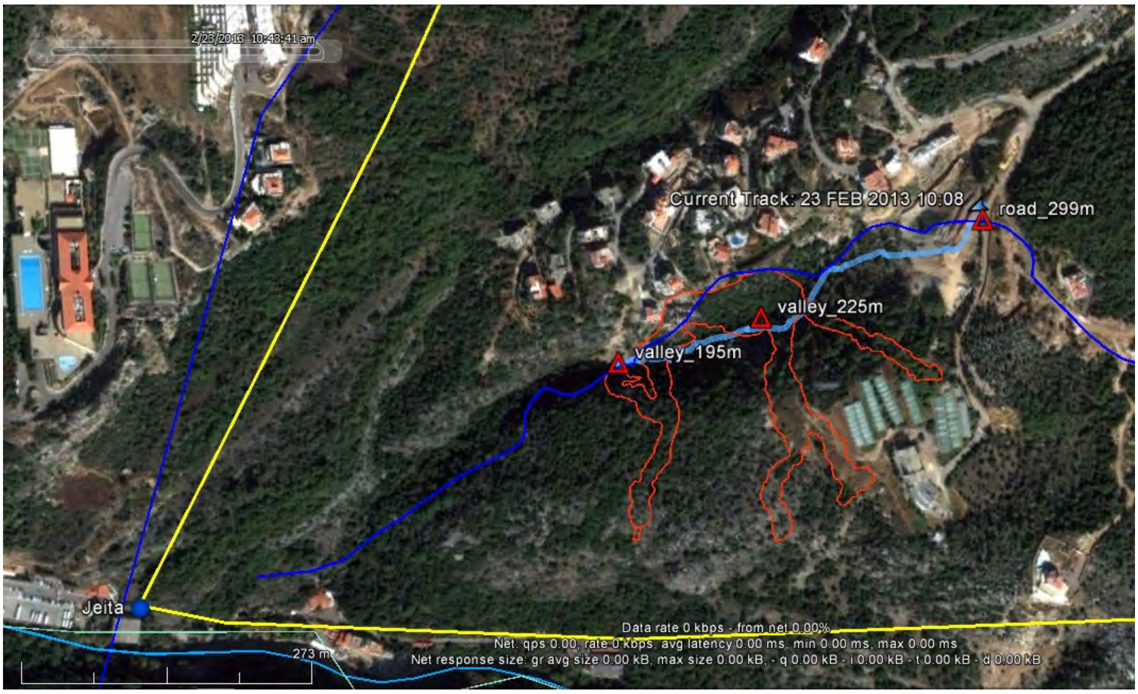

Figure 23: Elevation in valley over upper level cave

7.1.2 Protection Zone 2

Protection zone 2 contains all high- and very high vulnerable areas from where groundwater needs less than 10 days to reach Jeita spring. Due to the generally high vulnerability of GW within the J4 unit and to due to the extraordinary risk of contamination within the buffer zone in the area overlying Jeita cave, it is distinguished between zone 2A and 2B.Landuse restrictions in zone 2A need to be more strict than in zone 2B.

The 10-days limit was adopted from the Swiss regulations (BAFU, 2004). Switzerland is a mountainous country with more than 50% karst terrain. The Swiss authorities use EPIK (SAEFL, 2000) for the delineation of groundwater protection zones in karst. Also Croatia, a country with a predominantly karstic hydrogeological setting, is using a 10-days travel time to define the outer boundary of zone 2.

More strict regulations (compare MARGANE, 2003b), like in place in Germany (50 days in all hydrogeological settings, also in karst; DVGW, 2006), Great Britain (400 days) or France (50 days) could not be met in Lebanon.

In the Jeita catchment it is recommended to divide protection zone 2 into zones 2A and zone 2B, where zone 2A protects against pollution via a fast flow component. Rapid infiltration and groundwater flow especially occurs in the area overlying Jeita cave but also where surface water infiltrates into a karst network underlying the river courses. This subdivision is similar to protection objectives followed in Croatia.

Area to be protected

As previously mentioned, zone 2A covers all very high vulnerable areas, as well as the area within a distance of 250 m to both sides of Jeita cave, projected to the land surface. The latter mentioned area is shown in *Figure 24*.

All areas classified in the GW vulnerability map as high- and very high vulnerable should be designated as groundwater protection zone 2B up to a point where travel time in groundwater reaches 10 days. The dominant travel time, used in Switzerland for tracer tests, observed in tracer test 5C (DOUMMAR et al, 2012), for the injection at the Mchati well on 16 September 2011 was 253 h (mean flow velocity 67 m/h). Taking into account the fact that during the high flow period flow velocity would be higher, the boundary of protection zone 2 should extend beyond the Mchati well.

The tracer test conducted on 6 November 1913 in Hrajel (Nabeh al Maghara; KARKABI, 2009; MARGANE, 2011), showed a travel time of 6 days. A similar tracer injection at Hrajel, conducted on 3 September 1923, arrived on 10 September 1923. The tests show a slight variation in flow velocity.

The turbidity showing up at Dbayeh during 2010-2012, resulting from injections from sludge ponds of the HAJJ sandstone quarries in Bqaatouta, were monitored by BGR (MARGANE 2012 a, 2012 b) and can also be used for delineation of the groundwater protection zones. Travel time to Jeita spring was around 24 h (April-June 2012). For the above reasons the entire J4 outcrop area in Nahr es Salib and Nahr es Zirghaya is included in protection zone 2.

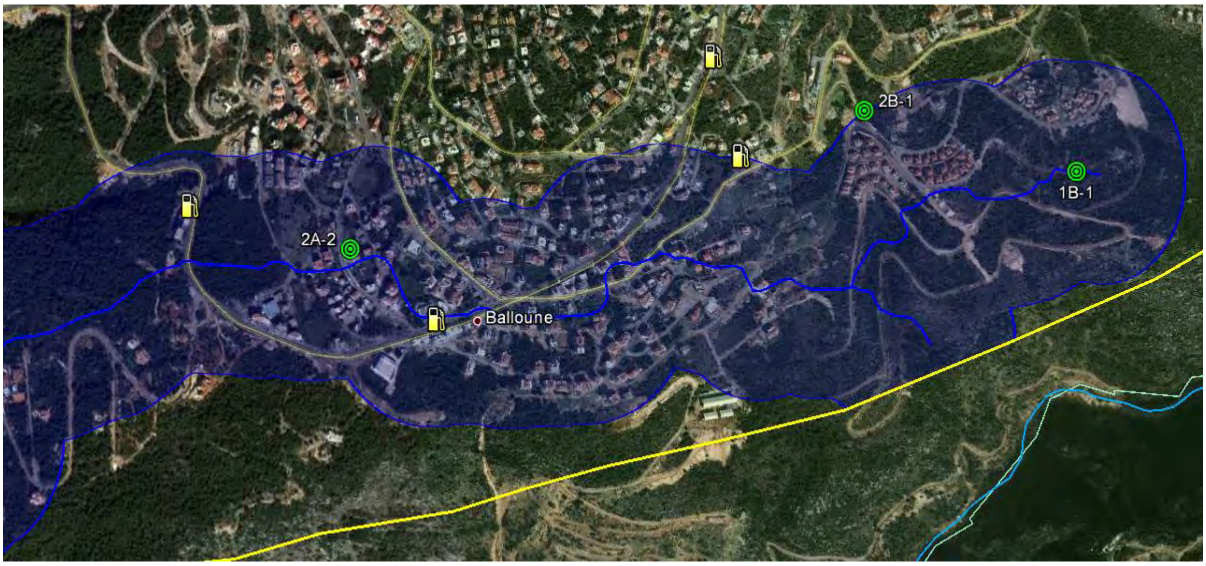

Figure 24: Extent of the 250 m buffer above the Jeita cave and location of existing gas stations

Landuse restrictions in Zone 2A

Wastewater collection in zone 2A must be of highest priority. No new commercial businesses should be allowed to be established. Infiltration of fuel and oil from gas stations and car repair workshops poses a high risk. Relocation of existing gas stations should be considered. If this is not feasible, at least adequate environmental standards must be enforced, i.e. all gas stations must be equipped with double-layer tanks, drainage collection of water from car wash facilities, etc. (RAAD et al., 2012).

This pertains to the following gas stations and should be of high priority:

- MEDCO, Balloune
- Total, Balloune
- United, Balloune (on Balloune - Daraya road)

However, in fact all other gas stations that are located within GW protection zone 2A (*Figure 25*) must also follow the implementation of guidelines.

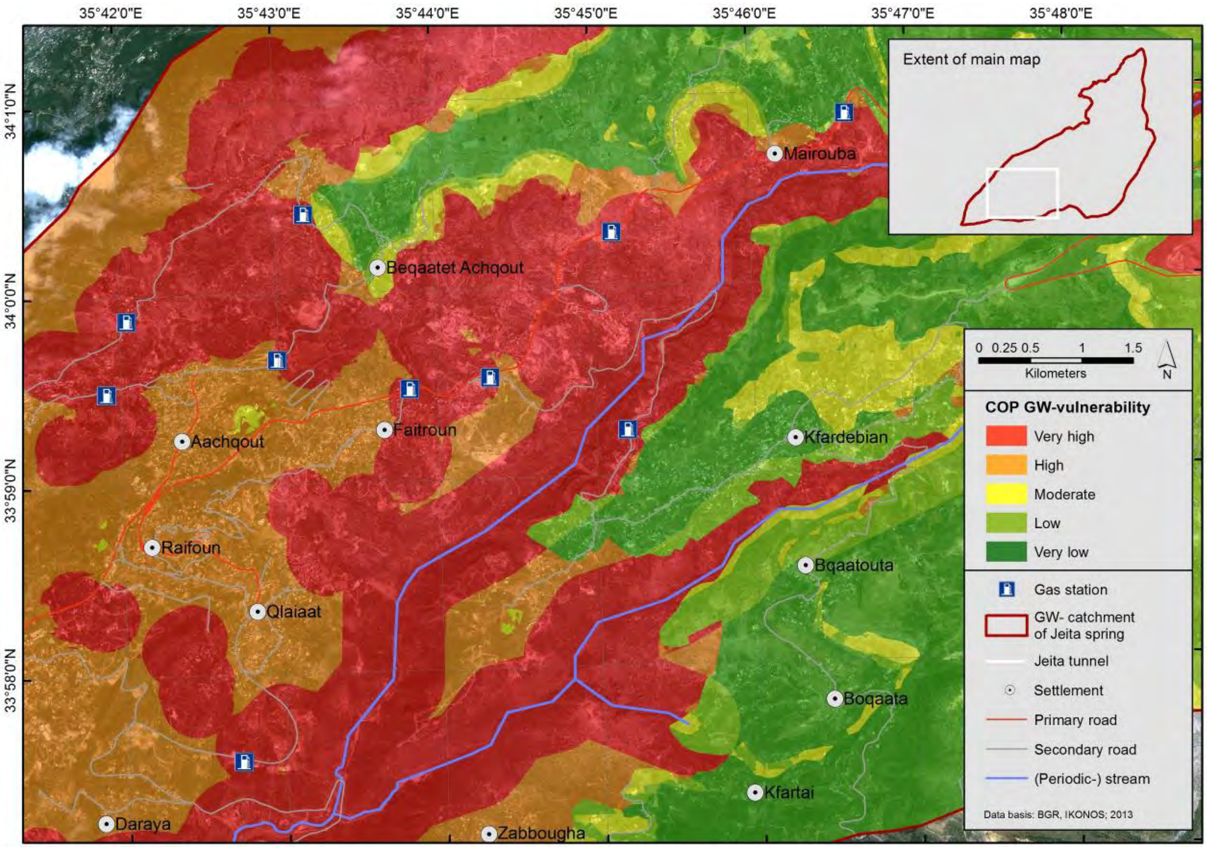

Figure 25: Gas stations in groundwater protection zone 2A (very high vulnerable)

New residential buildings should not be allowed to be built downgradient of the new wastewater collector line (escarpment collector).

The stormwater drainage along the main road (Jeita - Faraiya highway) should be enlarged to ensure that all stormwater can be drained to a location outside protection zone 2A.

The following activities shall **not be allowed in zones 2A and 2B**:

- Gas stations,
- Industrial sites,
- Commercial businesses,
- Quarries, rock cutting facilities, brick factories,
- Dumping of waste,
- Animal farms,
- Slaughterhouses,
- Application of pesticides and chemical fertilizers.

Agricultural farms shall not be allowed in protection zone 2A.

Modifications required in Protection Zone 2A

<u>Wastewater</u>:

The most imminent pollution risk in protection zone 2 is uncollected wastewater. Even if the proposed collection system will be built as planned (GITEC, 2011), some houses in this area may not be connected to the network or house owners may refuse to pump wastewater to the designated place. In all houses the existing drainage must be diverted to the new collection system and the existing cesspits must be closed. In coordination with the Water Establishment of Beirut and Mount Lebanon, the municipalities will have to enforce connection to the new wastewater network and ensure that wastewater is actually flowing to it. In many cases, especially where houses are located downgradient of the wastewater network, wastewater will have to be pumped upgradient. As this will cost money, many house owners will refuse to do so.

The new network in protection zone 2A must be constructed in such a way that leakage of wastewater into groundwater is not possible. The main collector lines should be built as line-in-line system. The connection between manholes and collector line must be tightly sealed. Manholes must be regularly inspected and cleaned.

Landuse restrictions in Zone 2B

<u>Wastewater</u>: A wastewater collection network should be established in all of protection zone 2. Untreated wastewater should be brought to a location outside the Jeita GW catchment for treatment so that no infiltration of untreated or insufficiently treated wastewater could endanger the water resources of Jeita spring. The wastewater scheme, currently implemented by CDR in cooperation with KfW and BGR, covers the built-up area shown in *Figure 26*.

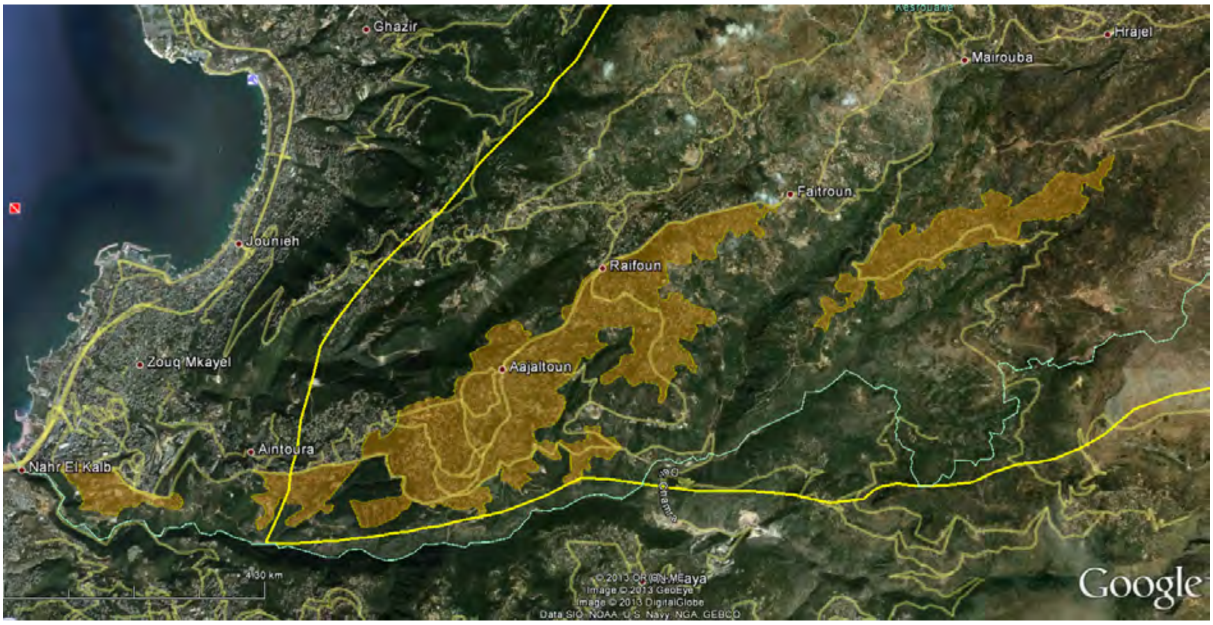

Figure 26: Area served by the KfW/CDR project (orange shaded)

The originally proposed location in Nahr es Salib was relocated based on the proposal by BGR (MARGANE, 2011) because a tracer test conducted at this location showed that treated effluent would have reached Jeita spring in less than 3 days. The following villages (*Table 27*) are not included in the CDR/KfW wastewater scheme:

Table 27: Municipalities that will not be served by the FC project Protection of Jeita Spring but by other projects (EIB hatched; Italian Protocol grey shaded)

Jeita (north of highway)	Boqaata Aachqout (Qarkouf)
Shaile (north of highway)	Raashine
Daraoun	Ouata el Jaouz
Bzoummar	Ain ed Delbe
Ghosta	Mairouba
Mchati	Hrajel
Aachqout	Faraiya
Raifoun	Aayoun es Simane
Faitroun	Faqra Club

The last three villages (grey marked) are supposed to be included in a wastewater scheme to be erected by the Italian Protocol at Mairouba, while some of the aforementioned villages are included in a wastewater project to be financed by the European Investment Bank (EIB) (hatched marked). However, little progress has been made on these two projects over the past 15 years.

All wastewater collector lines in protection zone 2B must be constructed in such a way that leakage of untreated wastewater into groundwater does not take place.

Also, gas stations in protection zone 2B should be forced to install double-layer tanks.

Modifications required in Protection Zone 2B

<u>Waste dumps</u>: all existing illegal waste dumps should be removed. Deposition of construction waste should not be allowed in protection zones 2A and 2B, but only at designated locations in zone 3. The construction waste must not contain any other substances than rocks, cement and bricks. Any other substances, such as paint, metal, plastics, solvents, oil, etc. shall be brought to designated collection places for this type of waste. Those locations must be controlled at all times. The amount and provenience of deposited construction waste must be registered at the entrance to the site. The underground of the designated construction waste dump must be sealed and compacted.

The slaughterhouses located in zone 2, in Aajaltoun (Murr) and Ghosta should be closed.

[The animal farms in the Beit Chebab, Mar Boutros, Safilee and Hemlaya area pose a high risk to Kashkoush spring (MARGANE & CHRABIEH, 2013). Water from Kashkoush spring is fed into the Jeita-Dbayeh water conveyor some 500 m downstream of Jeita spring. The capture of and conveyance system from Kashkoush spring has been upgraded by CDR in 2003. However, due to high pollution loads, the water from Kashkoush spring can most of the time not be used.]

7.1.3 Protection Zone 3

Groundwater protection zone 3 of Jeita spring comprises the entire groundwater catchment (or groundwater contribution zone). This area has been delineated using more than a dozen tracer tests (MARGANE et al., in progr.).

A large part of the groundwater discharged from the Upper (C4) Aquifer at Afqa, Assal, Labbane and Rouaiss springs may infiltrate indirectly into the Lower (J4) Aquifer and thus, contribute considerably to the discharge of Jeita spring. Protection zone 3 of Jeita spring therefore covers not only the area of direct groundwater recharge (GWR) in the Lower Aquifer but also the groundwater (C4) and surface water catchments that feed Jeita spring (through indirect groundwater recharge in the Upper Nahr Ibrahim, Nahr es Salib and Nahr es Zirghaya valleys). For this reason the groundwater catchment of Jeita spring also comprises the entire groundwater catchments of the Afqa, Assal, Labbane and Rouaiss springs. This mechanism of indirect

GWR from the Upper Aquifer to the Lower Aquifer was proven through differential discharge measurements in the Upper Nahr Ibrahim (MARGANE, 2012a, 2012b) and stable isotope analyses (KOENIGER & MARGANE, 2013).

Area to be protected

The extent of protection zone 3 of Jeita spring complies with the whole GW catchment of Jeita spring (*Figure 27*) and is shown in *Figure 76*. Groundwater travel time in groundwater protection zone 3 exceeds 10 days. Helium/Tritium analyses show (GEYER, 2013) that the mean groundwater residence time, including both, fast and slow flow components, in the catchment is around 2 years. Meeting the objective of protection against non- or hardly degradable water constituents in zone 3 is therefore fairly impossible. However, through implementation and enforcement of strict landuse bans contamination by such substances can be avoided.

Figure 27: Groundwater Contribution Zone of Jeita Spring (yellow line) and GW catchments of the C4 springs Afqa, Assal, Labbane and Rouaiss

Landuse restrictions in Zone 3

Landuse restrictions imposed on the catchments of Afqa, Assal, Labbane and Rouaiss springs are superior to those imposed on Jeita spring. Due to the extremely high groundwater vulnerability, these catchments are divided in protection zones 1 and 2, only. As long as no independent decrees on groundwater protection are available for Afqa, Assal, Labbane and Rouaiss springs, the landuse restrictions mentioned here must be implemented because the aforementioned springs are part of the Jeita groundwater catchment.

Protection zone 3 should provide protection against contamination affecting water over long distances such as chemicals which are not or not easily degraded.

The following landuse activities shall **not be allowed in protection zone 3**:

- Waste disposals,
- Industrial sites of any type,
- Commercial businesses involving the use and/or storage of heavy metals, toxic or hazardous substances (e.g. pesticides),
- The establishment of new gas stations.

Modifications required in Protection Zone 3

7.2 Groundwater Protection Zones for Assal Spring

Water from Assal spring enters the distribution system without any treatment. Chlorination only takes place at Chabrouh dam for the water coming from Labbane spring. At times when water is stored at and distributed from Chabrouh dam, water is mixed with Assal water when entering the Assal reservoir. However, when no water is distributed from Chabrouh dam, and only Assal water is used, there is no chlorination. **It is urgently recommended to add a chlorination facility at Assal reservoir.**

The protection zone of Assal spring (zone 2) is displayed in Annex 7, *Figure 76*.

7.2.1 Protection Zone 1

It is strongly recommended to extend the fence around the spring, the water distribution system, the reservoir and the conveyor from the spring to the reservoir, and ensure that only authorized staff of WEBML can enter the water supply infrastructure. Currently the perimeter is too small to meet the requirements (50 m upstream, 15 m to its sides) and the site is commonly open because the lock is not working.

Surface water drainage shall neither enter the spring, the water distribution system, the conveyors between spring and reservoir or the reservoir. This must be ensured by physical means.

Area to be protected

The area to be protected is shown in *Figure 28*.

Assal spring: At least the perimeter 50 m upstream, 15 m to both sides and 10 m downstream of the spring must be protected.

Conveyor from spring to distribution system: A buffer zone of 10 m to each side from the conveyor must be established.

Water distribution system: A buffer zone of 10 m to each side from the distribution system must be established.

Conveyor from the water distribution system to the reservoir: A buffer zone of 10 m to each side from the conveyor must be established. The conveyor must be protected against potential inflows from surface water. Access of unauthorized persons must be blocked by suitable physical means. The fence must be extended to this part.

Reservoir: A buffer zone of 10 m to each side from the reservoir must be established.

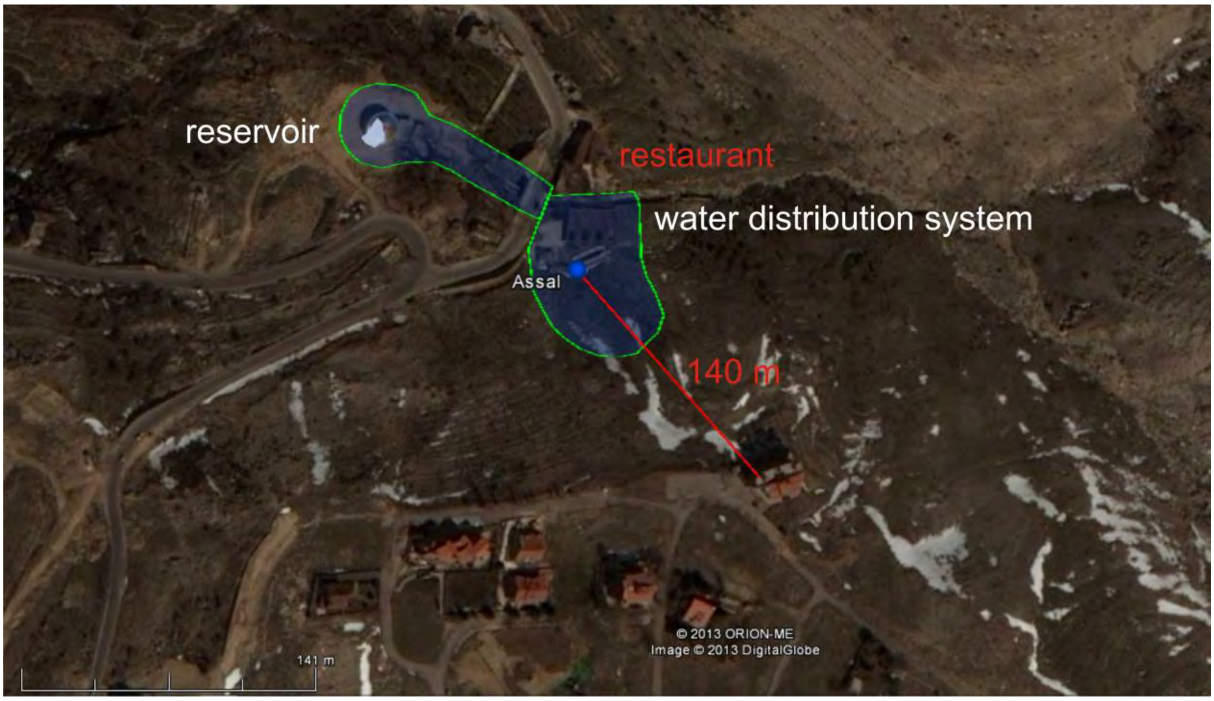

Figure 28: Protection Zone 1 of Assal Spring and its water infrastructure components

Existing Pollution Risks

A restaurant is located very close to the spring and water distribution system. The restaurant must be inspected to ensure that no pollution risk emanates from it.

It must be ensured that no surface water can drain from the area upstream towards the spring, especially from the buildings and the road south of it (distance only 140 m).

Landuse restrictions in Zone 1

No construction of any kind shall be allowed in zone 1, unless absolutely necessary for water resources operation purposes. Even then such constructions must be in compliance with water safety requirements: no toilets, washing facilities, septic tanks or cesspits shall be erected within protection zone 1.

Modifications required in Protection Zone 1

The fence needs to be extended, covering the area upstream of the spring and the area between spring and reservoir.

The stormwater drainage system at the road must be improved, ensuring that no stormwater can enter the water supply system.

7.2.2 Protection Zone 2

Area to be protected

According to the groundwater vulnerability map, the entire catchment of Assal spring is classified as very highly vulnerable. Therefore, the entire groundwater catchment of Assal spring must be designated as groundwater protection zone 2.

Existing Pollution Risks

The following pollution risks must be addressed:

- Wastewater: No wastewater collection or treatment system yet exists. Most houses presumably have cesspits open at the bottom so that wastewater from the houses infiltrates quickly into the underground and reaches groundwater.
- Hotels and resorts: There are a number of hotels and resorts within protection zone 2. Risks: infiltration of wastewater and heating oil from storage tanks.
- Ski lift stations: There are two main stations in the Assal catchment: Wardeh (also called Domaine Wardeh) and Aayoun es Simane (also called Domaine Jonction). At the Aayoun es Simane ski station there is a gas station and repair workshop for the machinery required for skiing and lift operations. The Aayoun es Simane ski lift station located on the boundary between the Labbane and Assal GW catchments, both in protection zones 2, while the Wardeh

lift station is located in protection zone 2 of Assal spring. Risks: infiltration of wastewater (from toilets and restaurants), fuel from storage tanks and oil from the repair workshops.

- Skidoo and quad bike rentals: In Aayoun es Simane and along the road to the Wardeh parking, there are several skidoo and quad bike rentals. Another skidoo rental is located on the road passing close to Labbane spring. Most of them have their own repair workshop on site. There is a high risk of infiltration of fuel from storage tanks and oil from the repair workshops. Rentals must be informed about the risk and regular inspections are necessary to avoid contaminations.

The residential buildings close to the spring (*Figure 29*) pose an imminent pollution risk. Most of these houses are believed to be equipped with open cesspits only, facilitating rapid infiltration of untreated wastewater. The establishment of a wastewater collection network is therefore of highest priority in this area.

According to our knowledge there is no fuel storage at the Wardeh ski lift station, but there is an oil storage for heating. Also, there is a repair workshop at Aayoun es Simane for all machinery used for ski lift operations, as well as several skidoo and quad bike rentals, partly with workshops and probably with unlicensed fuel storage. There is a gas station located at the Aayoun es Simane ski lift station, storing an unknown amount of fuel.

Infiltration of fuel and oil into groundwater from these points is therefore considered a high pollution risk.

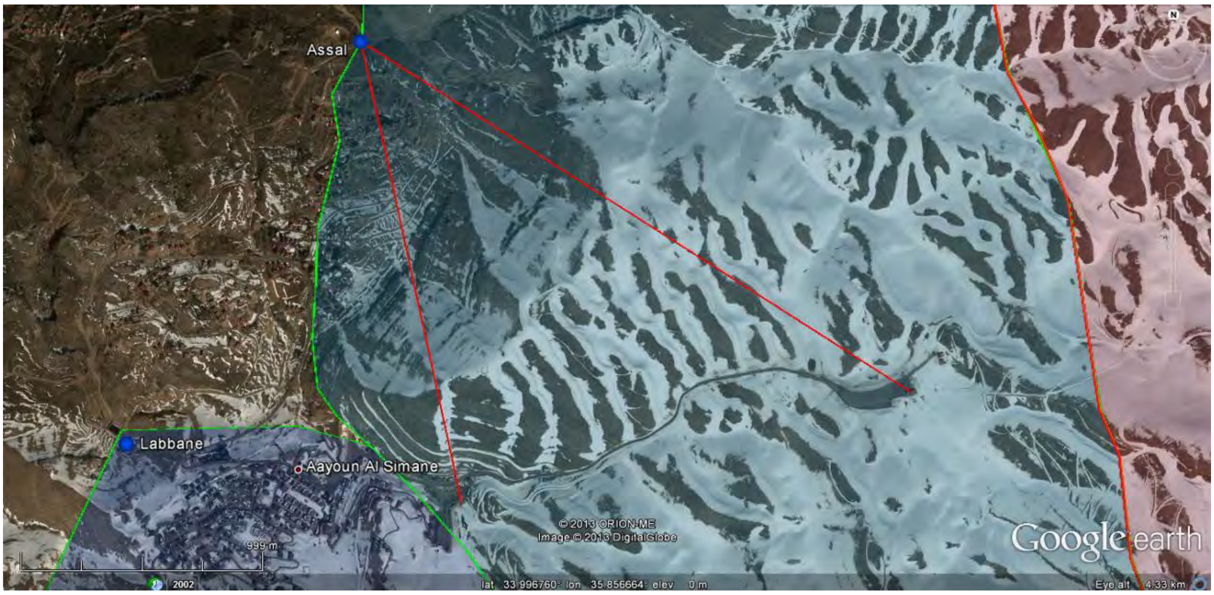

Figure 29: High Pollution Risk of Assal Spring from Operation of Ski Lift Stations

Landuse restrictions in Zone 2

The following landuse activities shall **not be allowed in protection zone 2**:

- Gas stations,
- Industrial sites,
- Commercial businesses (e.g. repair shops) using or storing hazardous substances,
- Storage of hazardous substances,
- Quarries, rock cutting facilities, brick factories,
- Dumping of waste,
- Animal farms,
- Agricultural farms,
- Slaughterhouses,
- Application of pesticides and chemical fertilizers.

Hotels: It is highly recommended not to allow building of new or extensions of exiting hotels with more than 20 rooms in zone 2. They should be built only downstream of the GW catchments of Assal and Labbane, i.e. in protection zone 3 of Jeita spring.

Restaurants: new restaurants should not be allowed unless they are connected to the new wastewater collection system. A wastewater collection system must be installed for all existing restaurants using closed septic tanks. These septic tanks must have a sufficiently large holding capacity to accommodate all wastewater occurring during winter and be regularly emptied after the winter season. The untreated wastewater must be brought to a designated location by an authorized company.

Ski lift stations: It is also recommended not to allow building new or extensions of exiting ski lift stations unless environmental impact assessments (EIAs) have been prepared proving that negative impacts on water resources (groundwater and surface water) cannot occur. An EIA should be undertaken for the existing ski lift stations; these stations should be upgraded implementing constructional changes so that negative impacts on water resources (groundwater and surface water) cannot occur.

Skidoo and quad bike rentals: No new or extensions of existing skidoo and quad bike rentals should be allowed. The existing skidoo and quad bike rentals should not be allowed to store fuel or undertake repairs on their premises. Repairs should be done outside protection zones 2 of Afqa, Assal, Labbane and Rouaiss spring catchments.

Army: The army check point at Wardeh has to consider environmental-friendly operation. Fuel should not be stored here.

Modifications required in Protection Zone 2

The gas station at the Aayoun es Simane ski station (Domaine Jonction) must be relocated outside the GW catchments of Assal and Labbane, i.e. to protection zone 3 of Jeita spring and upgraded to modern technology, i.e. double-layer tanks with leakage sensors should also be installed. All other fuel storages and repair shops, e.g. those of skidoo and quad bike rentals, must be removed. The repair workshop at the Aayoun es Simane ski station (Domaine Jonction) must be equipped with a drainage collection system. Any used oil must be collected and brought to a designated location outside this protection zone.

Restaurants: new restaurants should not be allowed unless they are connected to the new wastewater collection system. A wastewater collection system must be installed for all existing restaurants using closed septic tanks. These septic tanks must have a sufficiently large holding capacity to accommodate all wastewater occurring during winter and be regularly emptied after the winter season. The untreated wastewater must be brought to a designated location by an authorized company.

Ski lift operations: It should be controlled that ski lift operations operate in full compliance with water resources protection requirements as set out in the related EIA. The potential negative impacts on water resources (groundwater and surface water) must be negligible.

Skidoo and quad bike rentals: It must be controlled that Skidoo and quad bike rentals comply with the set regulations not to store fuel or undertake repairs on their premises.

Skidoo users: Clear signs at the skidoo rentals and at several places inside the catchment must instruct skidoo users about the risk of groundwater contamination by fuel and oil leakages. Related signposts must be erected by the skidoo and quad bike rentals. Skidoos might also enter from the Afqa, Labbane or Rouaiss catchment to the Assal catchment. Therefore, the information must be provided in the entire area of groundwater protection zones 2 for the Afqa, Assal, Labbane and Rouaiss springs.

7.3 Groundwater Protection Zones for Labbane Spring

Water from Labbane spring is conveyed to Chabrouh dam, where it is treated (aeration, rapid sand bed filtration and chlorination) before distribution.

The protection zone of Labbane spring (zone 2) is displayed in Annex 7, *Figure 76*.

7.3.1 Protection Zone 1

It is strongly recommended to erect a fence around the spring, the reservoir and the conveyor from the spring to the reservoir, so that only authorized staff of WEBML can enter the water supply infrastructure. The use of skidoos, a common winter activity in the area, must be clearly prohibited in protection zone 1. A skidoo was found in the Labbane reservoir in winter 2011/2012 (*Figure 30*). During that winter there was about 5 m of snow near Labbane spring and the fence around the reservoir was badly damaged. The fence still needs to be repaired.

Figure 30: Skidoo found in Labbane reservoir (21 FEB 2012)

No surface water drainage shall enter either the spring, the conveyor to the reservoir or the reservoir. The surface runoff channel passing close to Labbane spring (*Figure 31*) must be deviated to pass to the north of the reservoir. This drainage system must be built in such a way that no underflow or overflow could occur. A large part of surface water running off in this channel is draining stormwater from the Faraiya – Aayoun es Simane road. The stormwater drainage along this road must be upgraded so that no stormwater runs off from the road towards Labbane spring. All stormwater must be drained along the road.

Figure 31: Protection Zone 1 of Labbane Spring with proposed fence and surface drainage systems

Area to be protected

Labbane spring: At least the perimeter comprising the following distances must be protected: 50 m upstream, 15 m to both sides and 10 m downstream of the spring.

Reservoir: A buffer zone of 10 m to each side from the reservoir must be established.

Conveyor from spring to reservoir: A buffer zone of 10 m to each side from the reservoir must be established.

Conveyor from reservoir to Chabrouh dam: The conveyor must be protected against potential inflows from surface water. Access of unauthorized persons must be blocked by suitable physical means.

Landuse restrictions in Zone 1

No construction of any kind shall be allowed in zone 1, unless absolutely necessary for water resources operation purposes. Even then, such constructions must be in compliance with water safety requirements: no toilets, washing facilities, septic tanks or cesspits shall be erected within a distance of 10 m from protection zone 1.

Modifications required in Protection Zone 1

A fence shall be erected encompassing all parts of zone 1, i.e. the spring, the conveyor and the reservoir at the minimum distances stated above.

A surface water drainage must be established near Labbane spring (*Figure 31*) collecting and deviating all surface water currently running off towards Labbane spring as stated above.

The passage of skidoos near protection zone 1 of Labbane spring and reservoir must be prohibited. The skidoo rental near the restaurant on the road near Labbane spring must be informed accordingly.

7.3.2 Protection Zone 2

Area to be protected

According to the groundwater vulnerability map, the entire catchment of Labbane spring is classified as very highly vulnerable. Therefore, the entire groundwater catchment of Labbane spring must be declared as groundwater protection zone 2.

Existing Pollution Risks

The following pollution risks must be addressed:

- <u>Wastewater</u>: No wastewater collection or treatment system yet exists. Most houses presumably have cesspits open at the bottom so that wastewater from the houses infiltrates quickly into the underground and reaches groundwater.
- <u>Hotels and resorts</u>: a large number exists within protection zone 2. The most extensive is the InterContinental Mzaar Resort and Spa with around 250 rooms. Risks: infiltration of wastewater and heating oil from storage tanks.
- <u>Ski lift stations</u>: There are three main stations: Wardeh (also called Domaine Wardeh; distance: 3,250 m), InterContinental (also called Domaine Refuge or Mzaar 2000; distance: 900 m) and Aayoun es Simane (also called Domaine Jonction; distance: 1,400 m). At the Aayoun es Simane ski station there is a gas station and repair workshop for the machinery required for the skiing and lift operations. The Aayoun es Simane ski lift station located on the boundary between the Labbane and Assal catchments, both in protection zones 2, while the Wardeh lift station is located in protection zone 2 of Assal spring. Risks: infiltration of wastewater (from toilets and restaurants), fuel from storage tanks and oil from the repair workshops.
- <u>Skidoo and quad bike rentals</u>: In Aayoun es Simane and along the road to the Wardeh parking there are several skidoo and quad bike rentals. Another skidoo rental is located on the road passing close to Labbane spring. Most of

them have their own repair workshop on site. There is a high risk of infiltration of fuel from storage tanks and oil from the repair workshops. Rentals must be informed about the risk and regular inspections are necessary to avoid contaminations.

Landuse restrictions in Zone 2

The following landuse activities shall **not be allowed in protection zone 2**:

- Gas stations,
- Industrial sites,
- Commercial businesses (e.g. repair shops) using or storing hazardous substances,
- Storage of hazardous substances,
- Quarries, rock cutting facilities, brick factories,
- Dumping of waste,
- Animal farms,
- Agricultural farms,
- Slaughterhouses,
- Application of pesticides and chemical fertilizers.

Hotels: It is highly recommended not to allow building of new or extensions of existing hotels with more than 20 rooms in zone 2. They should be built only downstream of the GW catchments of Assal and Labbane, i.e. in protection zone 3 of Jeita spring.

Restaurants: new restaurants should not be allowed unless they are connected to the new wastewater collection system. A wastewater collection system must be installed for all existing restaurants using closed septic tanks. These septic tanks must have a sufficiently large holding capacity to accommodate all wastewater occurring during winter and be regularly emptied after the winter season. The untreated wastewater must be brought to a designated location by an authorized company.

Ski lift stations: It is also recommended not to allow building new or extensions of exiting ski lift stations unless environmental impact assessments (EIAs) have been prepared proving that negative impacts on water resources (groundwater and surface water) cannot occur. An EIA should be undertaken for the existing ski lift stations; these stations should be upgraded implementing constructional changes so that negative impacts on water resources (groundwater and surface water) cannot occur.

Skidoo and quad bike rentals: No new or extensions of existing skidoo and quad bike rentals should be allowed. The existing skidoo and quad bike rentals should not be allowed to store fuel or undertake repairs on their premises. Repairs should be done outside protection zones 2 of Afqa, Assal, Labbane and Rouaiss spring catchments.

Modifications required in Protection Zone 2

Wastewater: The collection of wastewater at Aayoun es Simane must have highest priority. The nearest buildings are located only around 300 m distant from Labbane spring. Therefore the pollution risk by infiltrating wastewater is very high.

Figure 32: High pollution risk of Labbane Spring resulting from wastewater infiltration

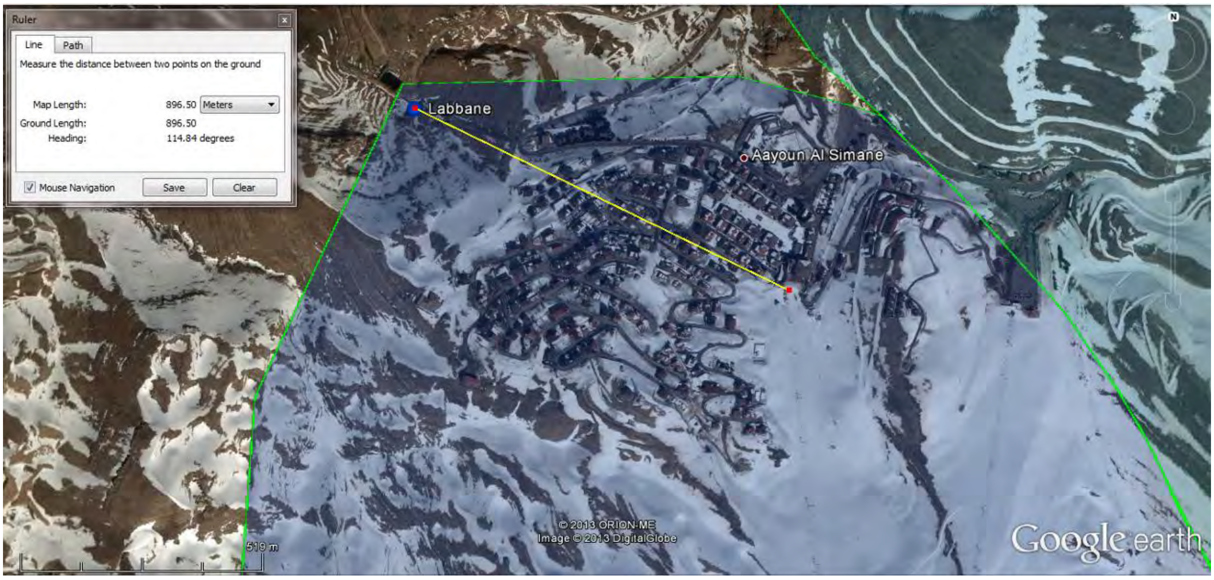

Figure 33: High pollution risk of Labbane Spring resulting from the operation of ski lift stations

Hotels and resorts: Hotels and resorts should only be allowed to be built under the condition that EIAs are prepared and that as a result of these the impact on water resources is negligible. For all existing hotels and resorts with more than 20 rooms, an environmental assessment with the focus on potential negative impacts on water resources (groundwater and surface water) should be prepared. Until a wastewater collection system is installed, all hotels and resorts must install closed septic tanks. These septic tanks must be regularly emptied and the untreated wastewater must be brought to a designated location by an authorized company.

Restaurants: Until a wastewater collection system is installed all restaurants must install closed septic tanks. For restaurants where the collected untreated wastewater cannot be evacuated during winter, the holding capacity of the septic tanks must be large enough to accommodate all wastewater occurring during the winter season. These septic tanks must be regularly emptied and the untreated wastewater must be brought to a designated location by an authorized company.

Ski lift operations: It should be controlled that ski lift operations operate in full compliance with water resources protection requirements as set out in the related EIA. The potential negative impacts on water resources (groundwater and surface water) must be negligible.

Skidoo and quad bike rentals: It must be controlled that Skidoo and quad bike rentals comply with the set regulations not to store fuel or undertake repairs on their premises.

Skidoo users: Clear signs at the skidoo rentals and at several places inside the catchment must instruct skidoo users about the risk of groundwater contamination by fuel and oil leakages. Related signposts must be erected by the skidoo and quad bike rentals. Skidoos might also enter from the Afqa, Assal or Rouaiss catchment to the Labbane catchment. Therefore, the information must be provided in the entire area of groundwater protection zones 2 for the Afqa, Assal, Labbane and Rouaiss springs.

7.4 Groundwater Protection Zones for Afqa Spring

The water supply installations at Afqa spring are in a poor condition and should be upgraded. Afqa spring has a long-term average discharge of 123 MCM/a. This water could be used much more efficiently. The spring capture should be established in a professional way. Currently, water use is completely uncontrolled (*Figure 34*).

The discharge of Afqa spring should be monitored. The current monitoring is unsuitable (MARGANE 2012 a, 2012 b).

Figure 34: Uncontrolled exploitation of Afqa Spring

The protection zone of Afqa spring (zone 2) is displayed in Annex 7, *Figure 77*.

7.4.1 Protection Zone 1

Area to be protected

At least the perimeter 50 m upstream, 15 m to both sides and 10 m downstream of the spring must be protected.

Landuse restrictions in Zone 1

No construction of any kind shall be allowed in zone 1, unless absolutely necessary for water resources operation purposes. Even then, such constructions must be in compliance with water safety requirements: no toilets, washing facilities, septic tanks or cesspits shall be erected within a distance of 10 m from protection zone 1.

Modifications required in Protection Zone 1

The site is uncontrolled and freely accessible. A fence needs to be erected comprising at least the entire protection zone 1. There is no water infrastructure worth mentioning and the entire spring capture urgently needs to be constructed in a professional way.

There is a dilapidated restaurant near outlet 2 of the spring. Wastewater from this restaurant must be collected in a septic tank, which must be regularly emptied.

7.4.2 Protection Zone 2

Area to be protected

According to the groundwater vulnerability map, the entire GW catchment of Afqa spring is classified as very highly vulnerable. Therefore, the entire groundwater catchment of Afqa spring must be designated as groundwater protection zone 2.

Existing Pollution Risks

Grazing is undertaken between June and November but only a few Bedouin shepherds live within the Afqa catchment. The overall number of cattle should remain low.

Skidoos are used in the catchment during winter. There are a number of skidoo and quad bike rentals along the road from Aayoun es Simane to the Wardeh parking. Most of them have their own repair workshops and some of them must be assumed having fuel storage tanks on their premises. The rental and use of skidoos and quad bikes constitutes a high risk of groundwater contamination by fuel and oil leakages.

Landuse restrictions in Zone 2

Afqa spring is the spring in the Upper (C4) Aquifer with the highest yield and has a very high exploitation potential. I**t is highly recommended not to allow any residential development in the Afqa catchment** in order to preserve groundwater quality in a good status.

The following landuse activities shall **not be allowed in protection zone 2**:

- Gas stations,
- Industrial sites,
- Commercial businesses (e.g. repair shops) using or storing hazardous substances,
- Storage of hazardous substances,
- Quarries, rock cutting facilities, brick factories,

- Dumping of waste,
- Animal farms,
- Agricultural farms,
- Slaughterhouses,
- Application of pesticides and chemical fertilizers.

Hotels: It is highly recommended not to allow building of new or extensions of existing hotels with more than 20 rooms in zone 2. They should be built only downstream of the GW catchments of Assal and Labbane, i.e. in protection zone 3 of Jeita spring.

Restaurants: new restaurants should not be allowed unless they are connected to the new wastewater collection system. A wastewater collection system must be installed for all existing restaurants using closed septic tanks. These septic tanks must have a sufficiently large holding capacity to accommodate all wastewater occurring during winter and be regularly emptied after the winter season. The untreated wastewater must be brought to a designated location by an authorized company.

Ski lift stations: It is also recommended not to allow building of new or extensions of exiting ski lift stations unless environmental impact assessments (EIAs) have been prepared proving that negative impacts on water resources (groundwater and surface water) cannot occur. An EIA should be undertaken for the existing ski lift stations in the Wardeh (Domaine Wardeh) and Aayoun es Simane (Domaine Jonction) area; these stations should be upgraded implementing constructional changes so that negative impacts on water resources (groundwater and surface water) cannot occur.

Skidoo and quad bike rentals: No new or extensions of existing skidoo and quad bike rentals should be allowed. The existing skidoo and quad bike rentals should not be allowed to store fuel or undertake repairs on their premises. Repairs should be done outside protection zones 2 of Afqa, Assal, Labbane and Rouaiss spring catchments.

Skidoo users: Clear signs at the skidoo rentals and at several places inside the catchment must instruct skidoo users about the risk of groundwater contamination by fuel and oil leakages. Related signposts must be erected by the skidoo and quad bike rentals. Skidoos might also enter from the Assal, Labbane or Rouaiss catchment to the Afqa catchment. Therefore, the information must be provided in the entire area of groundwater protection zones 2 for the Afqa, Assal, Labbane and Rouaiss springs.

Grazing of sheep shall be allowed if the overall number of cattle in the entire catchment is low (< 1,000). However, no residential buildings or fixed installations shall be allowed for Bedouins.

Modifications required in Protection Zone 2

Wastewater: The pollution risk by infiltrating wastewater is very high. A wastewater collection system must be installed at Wardeh and La Cabane using closed septic tanks. The wastewater from these septic tanks must be regularly emptied and be brought to a designated treatment facility.

Hotels and resorts: Hotels and resorts should only be allowed to be built under the condition that EIAs are prepared and that as a result of these the impact on water resources is negligible. For all existing hotels and resorts with more than 20 rooms, an environmental assessment with the focus on potential negative impacts on water resources (groundwater and surface water) should be prepared. Until a wastewater collection system is installed, all hotels and resorts must install closed septic tanks. These septic tanks must be regularly emptied and the untreated wastewater must be brought to a designated location by an authorized company.

Restaurants: Until a wastewater collection system is installed all restaurants must install closed septic tanks. These septic tanks must be regularly emptied and the untreated wastewater must be brought to a designated location by an authorized company.

Ski lift operations: It should be controlled that ski lift operations operate in full compliance with water resources protection requirements as set out in the related EIA. The potential negative impacts on water resources (groundwater and surface water) must be negligible.

Skidoo and quad bike rentals: It must be controlled that Skidoo and quad bike rentals comply with the set regulations not to store fuel or undertake repairs on their premises.

Skidoo users: It must be controlled that the skidoo rentals erected signs at their premises instructing skidoo users about the risk of groundwater contamination by fuel and oil leakages.

7.5 Groundwater Protection Zones for Rouaiss Spring

The water supply installations at Rouaiss spring are in a poor shape and should be upgraded. The long-term average discharge is unknown but fairly high, probably around 96 MCM/a. This water could be used much more efficiently. The spring capture should be established in a professional way. Currently, water use is completely uncontrolled.

The discharge of Rouaiss spring should be monitored directly at the spring. The current monitoring is unsuitable (MARGANE 2012 a, 2012 b) and is located approx. 1.6 km downstream of the spring, after surface water from another catchment has entered the stream.

The protection zone of Rouaiss spring (zone 2) is displayed in Annex 7, *Figure 77*.

7.5.1 Protection Zone 1

Area to be protected

No construction of any kind shall be allowed in zone 1, unless absolutely necessary for water resources operation purposes. Even then, such constructions must be in compliance with water safety requirements: no toilets, washing facilities, septic tanks or cesspits shall be erected within a distance of 10 m from protection zone 1.

Landuse restrictions in Zone 1

The site is uncontrolled and freely accessible. A fence needs to be erected, comprising at least the entire protection zone 1.

Modifications required in Protection Zone 1

The site is uncontrolled and freely accessible. A fence needs to be erected comprising at least the entire protection zone 1. There is no water infrastructure worth mentioning and the entire spring capture urgently needs to be constructed in a professional way.

There is a dilapidated restaurant near outlet 2 of the spring. Wastewater from this restaurant must be collected in a septic tank, which must be regularly emptied.

7.5.2 Protection Zone 2

Area to be protected

According to the groundwater vulnerability map, the entire GW catchment of Rouaiss spring is classified as very highly vulnerable. Therefore, the entire groundwater catchment of Rouaiss spring must be designated as groundwater protection zone 2.

Landuse restrictions in Zone 2

The following landuse activities shall **not be allowed in protection zone 2**:

- Gas stations,
- Industrial sites,
- Commercial businesses (e.g. repair shops) using or storing hazardous substances,
- Storage of hazardous substances,
- Quarries, rock cutting facilities, brick factories,

- Dumping of waste,
- Animal farms,
- Agricultural farms,
- Slaughterhouses,
- Application of pesticides and chemical fertilizers.

Hotels: It is highly recommended not to allow building of hotels in zone 2. They should be built only downstream of the GW catchments of Rouaiss and Afqa, i.e. in protection zone 3 of Jeita spring, e.g. in Akoura.

Restaurants: Restaurants should not be allowed.

Ski lift stations: It is also recommended not to allow building of ski lift stations unless environmental impact assessments (EIAs) have been prepared proving that negative impacts on water resources (groundwater and surface water) cannot occur.

Skidoo and quad bike rentals: No skidoo and quad bike rentals should be allowed.

Skidoo users: Clear signs at the skidoo rentals and at several places inside the catchment must instruct skidoo users about the risk of groundwater contamination by fuel and oil leakages. Related signposts must be erected by the skidoo and quad bike rentals. Skidoos might also enter from the Afqa, Assal or Labbane catchment to the Rouaiss catchment. Therefore the information must be provided in the entire area of groundwater protection zones 2 for the Afqa, Assal, Labbane and Rouaiss springs.

Grazing of sheep shall be allowed if the overall number of cattle in the entire catchment is low (< 1,000). However, no residential buildings or fixed installations shall be allowed for Bedouins.

Modifications required in Protection Zone 2

Skidoo users: It must be controlled that the skidoo rentals erected signs at their premises instructing skidoo users about the risk of groundwater contamination by fuel and oil leakages.

8 Proposed Landuse Restrictions

The groundwater protection zone decree has to define landuse restrictions and allowances for all activities, which could possibly have a negative impact on groundwater quality. These restrictions and allowances have to be formulated as clear as possible so that there remains no doubt about what is allowed and what is not allowed.

The restrictions and allowances listed in the matrixes below (*Table 28-43*) are compiled from the respective German, Swiss and Australian regulations and are meant as recommendations. The final decision depends on the local situation and should be made by the local authorities in accordance with both, water resources protection requirements and local acceptance and ability of implementation. Such decrees, and specifically the imposed landuse restrictions, however, must be uniformly applied in all protection zones; using different landuse restrictions in the same legal context in other areas would be unjustified.

It is also highly recommended using the proposed methodology and classification scheme in all of Lebanon. Groundwater protection depends on the vulnerability and travel time in groundwater, i.e. characteristics of the groundwater system. These characteristics, i.e. the hydrogeological settings, are similar for major karst springs in all of Lebanon and therefore, the method used for Jeita spring can easily be applied in all other areas of Lebanon.

The proposed landuse restrictions are divided, according to present landuse activities; some of them may not occur in the protected area in the future. It is, however, important to include all potential landuse activities in a decree for groundwater protection zones.

The project recommends divide protection zone 2 into zone 2a and zone 2b because of the high pollution risk and the fast travel time in certain areas. This subdivision may not be necessary in other GW catchments.

The decree should state which institution is responsible for the related follow-up and enforcement of landuse restrictions.

Commercial Land Uses

Table 28: (In-) compatibility of commercial activities within protection zone 1, 2, 3a and 3b

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
Construction or extension of facilities or plants for the production, treatment, use, processing, and storage of substances which may possibly contaminate groundwater and are non- or hardly degradable and radioactive substances, such as substances from refineries, iron, and steel mills, non-ferrous metal works, chemical plants Facilities for the storage of chemicals and nuclear facilities (excepting facilities for medical applications as well as equipment for metering, testing and control)	incompatible	incompatible	incompatible	incompatible
Handling of substances contaminating water	incompatible	incompatible	incompatible[4]	incompatible[4]
Use of materials from which contaminants may be washed or leached, such as	incompatible	incompatible	incompatible	incompatible

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
use of rubble, residues from incinerators, slag and mining residue for the construction of road, waterway, railroad and air transportation systems and facilities or structures built for noise control				
Aircraft servicing	incompatible	incompatible	incompatible	incompatible
Airports or landing grounds for aircrafts (including helicopters)	incompatible	incompatible	incompatible	incompatible
Amusement centers	incompatible	incompatible	incompatible[6]	compatible
Automotive businesses	incompatible	incompatible	compatible	compatible
Boat servicing	incompatible	incompatible	incompatible	compatible
Dry cleaning premises	incompatible	incompatible	incompatible	compatible
Farm supply centers	incompatible	incompatible	incompatible[6]	compatible
Garden centers	incompatible	incompatible	Incompatible[6]	compatible
Laboratories (analytical, photographic)	incompatible	incompatible	incompatible[6]	compatible
Market halls	incompatible	incompatible	incompatible[6]	compatible
Mechanical servicing	incompatible	incompatible	incompatible[6]	compatible
Pesticide operator depots	incompatible	incompatible	incompatible	compatible
Restaurants and taverns	incompatible	incompatible	incompatible[6]	compatible
Shops and shopping centers	incompatible	incompatible	Incompatible[6]	compatible
Transport & municipal works depots	incompatible	incompatible	incompatible[6]	compatible
Vehicle wrecking and machinery	incompatible	incompatible	incompatible	compatible
Used tire storage / processing / disposal facilities	incompatible	incompatible	incompatible	incompatible
Warehouses	incompatible	incompatible	incompatible[6]	compatible

Responsible agency for follow-up and enforcement of landuse restrictions:

Industrial Land Uses

Table 29: (In-) compatibility of industrial activities within protection zone 1, 2, 3a and 3b

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
Heavy Industry	incompatible	incompatible	incompatible	incompatible
Light or general Industry	incompatible	incompatible	incompatible	incompatible
Petroleum refineries	incompatible	incompatible	incompatible	incompatible
Chemical manufacture / formulation	incompatible	incompatible	incompatible	incompatible
Dye works and tanneries	incompatible	incompatible	incompatible	incompatible
Metal production /finishing	incompatible	incompatible	incompatible	incompatible
Concrete / Cement production	incompatible	incompatible	incompatible	compatible

Urban Land Uses

Table 30: (In-) compatibility of urban activities within protection zone 1, 2, 3a and 3b

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
Buildings	incompatible	incompatible	Incompatible[6]	compatible
Development zones	incompatible	incompatible	incompatible[6]	compatible
Development and extensions of cemeteries for earth sepul-ture	incompatible	incompatible	incompatible	compatible
Development and extensions of cemeteries for urn sepul-ture	incompatible	incompatible	compatible	compatible
Hospitals, health centers	incompatible	incompatible	incompatible[6]	compatible
Veterinary, dental centers	incompatible	incompatible	incompatible[6]	compatible
Prisons	incompatible	incompatible	incompatible[6]	compatible
Drinking water treatment plants	incompatible	compatible	compatible	compatible
Markets, trade fairs, festivals and other similar gatherings outside appropriate facilities	incompatible	incompatible	incompatible[6]	compatible

Energy Generation and Electricity Conveyance Systems

Table 31: (In-) compatibility of energy and electric conveyance systems within protection zone 1, 2, 3a and 3b

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
Power plants	Incompatible	incompatible	incompatible	incompatible[7]
Transformers and electricity lines holding cooling or insulating fluids possibly contaminating water	incompatible	incompatible	incompatible[5]	incompatible[8]

Land Uses related to Exploration, Mining and Mineral Processing

Table 32: (In-) compatibility of mining activities within protection zone 1, 2, 3a and 3b

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
Extractive industries (sand, clay, peat and rock) with excavations above groundwater table	incompatible	incompatible	incompatible	compatible
Extractive industries (sand, clay, peat and rock) with excavations below groundwater table	incompatible	incompatible	incompatible	incompatible
Mineral and energy source exploration	incompatible	incompatible	incompatible	incompatible[8]
Mineral and energy source exploitation	incompatible	incompatible	incompatible	incompatible
Mineral processing	incompatible	incompatible	incompatible	incompatible
Oil or gas extraction / decontamination for transport	incompatible	incompatible	incompatible	incompatible
Quarries, if groundwater cover is reduced substantially and above all, if groundwater is uncovered permanently or high groundwater level periods or cleaning strata are uncovered and groundwater cannot be protected adequately	incompatible	incompatible	incompatible	incompatible

Agricultural Land Uses - Animals

Table 33: (In-) compatibility of livestock activities within protection zone 1, 2, 3a and 3b

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
Animal breeding if the number of animals implies a risk to the quality of groundwater because of the limited area on which they are kept and/or the limited area available for the disposal of manure	incompatible	incompatible	incompatible	compatible
Installation and extension of liquid manure containers, solid manure sites or silos	incompatible	incompatible	incompatible	compatible
Animal sale yards and stockyard	incompatible	incompatible	incompatible	compatible
Aquaculture	incompatible	incompatible	incompatible	compatible
Dairy sheds	incompatible	incompatible	incompatible	compatible
Livestock grazing, feedlots	incompatible	incompatible	compatible	compatible
Piggeries	incompatible	incompatible	incompatible	compatible
Poultry farming (housed)	incompatible	incompatible	incompatible	compatible
Stables	incompatible	incompatible	incompatible	compatible

Agricultural Land Uses - Plants

Table 34: (In-) compatibility of farming activities within protection zone 1, 2, 3a and 3b

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
Application of fertilizers	incompatible	incompatible	incompatible[2]	compatible
Application of pesticides	incompatible	incompatible	incompatible[2]	compatible
Application of pesticides employing air-borne distribution methods	incompatible	incompatible	incompatible	compatible
Application of liquid or solid manure or silage seepage on waste land	incompatible	incompatible	incompatible	compatible
Application of liquid or solid manure or silage	incompatible	incompatible	incompatible	compatible
Storage of liquid or solid manure or soluble fertilizer outside permanently sealed sites and silage production outside permanent silos	incompatible	incompatible	incompatible	compatible
Deforestation, plowing of legume-grass meadows and fallow	incompatible	incompatible	incompatible	compatible
Spray irrigation in excess of field capacity	incompatible	incompatible	incompatible	compatible

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
Broad land cropping i.e. non-irrigated	incompatible	incompatible	compatible	compatible
Orchards	incompatible	incompatible	compatible	compatible
Horticulture	incompatible	incompatible	compatible	compatible
Floriculture	incompatible	incompatible	incompatible	compatible
Nurseries (potted plants)	incompatible	incompatible	incompatible	compatible
Silviculture (tree farming)	incompatible	incompatible	incompatible	compatible
Soil amendment (clean sand, loam, clay, peat)	incompatible	incompatible	compatible	compatible
Soil amendment (industry byproducts & biosolids)	incompatible	incompatible	incompatible	compatible
Viticulture (wine & table grapes)	incompatible	incompatible	incompatible	compatible

Agricultural Land Uses – Processing Facilities

Table 35: (In-) compatibility of agricultural processing activities within protection zone 1, 2, 3a and 3b

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
Animal product rendering works	incompatible	incompatible	incompatible	compatible
Abattoirs	incompatible	incompatible	incompatible	incompatible[6]
Dairy product factories	incompatible	incompatible	incompatible	compatible
Manure stockpiling / processing facilities	incompatible	incompatible	incompatible	compatible
Tanneries	incompatible	incompatible	incompatible	incompatible
Wool-scourers	incompatible	incompatible	incompatible	compatible
Vegetable / food processing	incompatible	incompatible	incompatible	incompatible[6]
Breweries	incompatible	incompatible	incompatible	incompatible
Composting / soil blending commercial	incompatible	incompatible	incompatible	compatible
Forestry product processing-pulp & paper, timber reservation, or wood fiber works	incompatible	incompatible	incompatible	compatible
Wineries	incompatible	incompatible	incompatible	compatible

Wastewater Facilities

Table 36: (In-) compatibility of wastewater facilities within protection zone 1, 2, 3a and 3b

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
Sewers (gravity)	incompatible	incompatible[1]	incompatible[1]	compatible
Sewers (pressure mains)	incompatible	incompatible[1]	incompatible[1]	compatible
Sewage pump stations	incompatible	incompatible[1]	incompatible[1]	compatible
Wastewater treatment plants	incompatible	incompatible	incompatible	incompatible[1]
Wastewater application to	incompatible	incompatible	incompatible	incompatible[2]

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
land				
Transportation of sewage or wastewater	incompatible	incompatible[9]	compatible	compatible
Installation or extension of sewage, wastewater or stormwater drains	incompatible	incompatible	incompatible[1]	incompatible[1]
Discharge of untreated wastewater (other than treated precipitation) into surface water, flowing into Zone II			incompatible	incompatible
Release of wastewater to the ground inclusive of sewage distribution fields other than: drainage of uncontaminated precipitation and wastewater from wastewater treatment plants serving individual homes	incompatible	incompatible	incompatible	incompatible
Release of stormwater (other than uncontaminated water from roofs) to the ground	incompatible	incompatible	compatible	compatible

Responsible agency for follow-up and enforcement of landuse restrictions:

Infiltration Facilities (of Unpolluted Waters)

Table 37: (In-) compatibility of infiltration/MAR activities within protection zone 1, 2, 3a and 3b

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
Infiltration of natural waters (with chemical composition uninfluenced by human activities) and facilities thereof	incompatible	incompatible	compatible	compatible
Infiltration of treated wastewaters (with chemical composition influenced by human activities) and facilities thereof	incompatible	incompatible	incompatible	incompatible

Waste Disposals, Storage Facilities, Temporary Storage Facilities and Pipelines

Table 38: (In-) compatibility of waste disposal, storage and pipelines within protection zone 1, 2, 3a and 3b

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
Injection of liquid wastes into groundwater	incompatible	incompatible	incompatible	incompatible
Plants for the treatment and disposal of solid waste (other than plants for the handling and storage of such wastes)	incompatible	incompatible	incompatible	incompatible
Plants for handling and temporary storage of solid waste (e.g. destined for waste recycling)	incompatible	incompatible	incompatible[8]	compatible
Sites for the storage of residue from thermal power stations and incinerators, blast-furnace slag and foundry sand	incompatible	incompatible	incompatible	incompatible
Sites for the disposal of contaminated and uncontaminated loose and solid rocks (such as tailings) if decomposition and leaching may affect groundwater	incompatible	incompatible	incompatible	incompatible
Sites for the disposal of uncontaminated loose and solid rocks where no leaching of hazardous substances may take place	incompatible	incompatible	compatible	compatible
Disposal of sludge from sewage treatment plants or cesspools and disposal of compost	incompatible	incompatible	incompatible	incompatible
Temporary storage of sludge from sewage treatment plants or cesspools and disposal of compost	incompatible	incompatible	incompatible[1]	compatible
Storage of chemical fertilizers or pesticides	incompatible	incompatible	incompatible[9]	compatible
Storage or stockpiling of mining residue	incompatible	incompatible	incompatible	incompatible
Recycling facilities	incompatible	incompatible	incompatible[8]	compatible
Recycling depots	incompatible	incompatible	incompatible[8]	compatible
Fuel depots	incompatible	incompatible	incompatible	incompatible[9]
Depots of liquid gas	incompatible	incompatible	compatible	compatible
Above ground storage of toxic / hazardous substances	incompatible	incompatible	incompatible	incompatible[9]
Underground storage tanks for toxic / hazardous substances	incompatible	incompatible	incompatible	incompatible

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
Storage of fuel oil and diesel fuel	incompatible	incompatible	incompatible[9]	incompatible[9]
Storage of liquid gas	incompatible	incompatible	compatible	compatible
Pipelines carrying fluids which may contaminate water	incompatible	incompatible	incompatible	incompatible

Facilities related to Transportation by Automobiles (e.g. Tunnels, Petrol Stations, Car Parks, etc.)

Table 39: (In-) compatibility of automobile infrastructure within protection zone 1, 2, 3a and 3b

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
Roads and other similar facilities for transportation (except for trails)	incompatible	incompatible[13]	compatible	compatible
Changes of facilities for transportation, unless made to improve the protection of groundwater	incompatible	incompatible[13]	compatible	compatible
Release of stormwater from roads or other transportation systems to the ground	incompatible	incompatible	incompatible[12]	incompatible[12]
Transportation of substances possibly contaminating groundwater	incompatible	incompatible	incompatible[9]	compatible
Transportation of radioactive substances	incompatible	incompatible	incompatible[9]	compatible
Use of pesticides for vegetation control on transportation systems	incompatible	incompatible	incompatible[2]	compatible
Transportation systems	incompatible	incompatible	incompatible[8, 9, 10]	compatible
Gasoline stations	incompatible	incompatible	incompatible[9]	compatible
Service stations	incompatible	incompatible	incompatible[8, 9, 10]	compatible
Vehicle parking (commercial)	incompatible	incompatible	incompatible[6]	compatible
Roads in tunnels	incompatible	incompatible	incompatible[6]	compatible
Unpaved roads or tracks for agricultural use only	incompatible	compatible	compatible	compatible
Unpaved roads or tracks for forestry only	incompatible	compatible	compatible	compatible

Construction Sites, Constructions of Buildings and Facilities above the Land Surface and Construction Changes thereof

Table 40: (In-) compatibility of construction activities within protection zone 1, 2, 3a and 3b

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
Construction and extension of buildings such as for commercial and agricultural use and changes in the use of buildings and structures	incompatible	incompatible	incompatible[6]	Compatible
Sites for the storage of building materials which may contaminate groundwater	incompatible	incompatible	incompatible	incompatible[9, 10]
Temporary construction works	incompatible	incompatible	compatible	compatible
Construction /Mining camps	incompatible	incompatible	incompatible	compatible
Penetration of strata overlying groundwater, other than laying of buried utility lines and civil engineering excavations	incompatible	incompatible	incompatible	compatible
Laying of buried utility lines and civil engineering excavations	incompatible	incompatible[11]	incompatible[11]	compatible
Drilling operations	incompatible	incompatible	incompatible[14]	compatible
Development and extension of artificial bodies of water	incompatible	incompatible	incompatible[14]	compatible

Activities related to Geothermal Energy (such as Drillings, Injection Facilities, etc.)

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
Production of geothermal energy	incompatible	incompatible	incompatible	incompatible
Drilling of geothermal boreholes	incompatible	incompatible	incompatible	incompatible
Groundwater use for heating or cooling purposes (with abstraction and injection facilities)	incompatible	incompatible	incompatible	incompatible

Underground Constructions

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
Development of underground facilities for storage of substances contaminating water	incompatible	incompatible	incompatible	incompatible

Recreational and Sports Facilities, Tourism Facilities

Table 41: (In-) compatibility of recreational and sports facilities within protection zone 1, 2, 3a and 3b

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
Equestrian centers	incompatible	incompatible	incompatible	compatible
Golf courses	incompatible	incompatible	incompatible	compatible
Permanent motor racing facilities	incompatible	incompatible	incompatible	compatible
Motor racing	incompatible	incompatible	incompatible	compatible
Swimming pools	incompatible	incompatible	compatible	compatible
Recreational parks -irrigated	incompatible	incompatible	compatible	compatible
Ski lifts	incompatible	incompatible	incompatible[8]	compatible
Rifle ranges	incompatible	incompatible	compatible	compatible
Caravan parks	incompatible	incompatible	compatible	compatible
Motels, hotels, lodging houses, hostels, resorts	incompatible	incompatible	incompatible[6]	compatible
Clubs-sporting or recreation	incompatible	incompatible	compatible	compatible

Educational and Research Land Uses

Table 42: (In-) compatibility of educational and research activities within protection zone 1, 2, 3a and 3b

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
Community education centers	incompatible	incompatible	incompatible[6]	compatible
Primary / secondary schools	incompatible	incompatible	incompatible[6]	compatible
Scientific research institutes	incompatible	incompatible	incompatible[6]	compatible
Tertiary education facilities	incompatible	incompatible	incompatible[6]	compatible

Military Sites and Shooting Ranges

Table 43: (In-) compatibility of military and shooting activities within protection zone 1, 2, 3a and 3b

Land use/Activity	Zone I	Zone II	Zone IIIA	Zone IIIB
Military training camps and casernes	incompatible	incompatible	incompatible[6]	compatible
Military hospitals	incompatible	incompatible	incompatible[6]	compatible
Military airfields	incompatible	incompatible	incompatible	incompatible
Military helicopter landing pads	incompatible	incompatible	compatible	compatible
Military storage facilities of substances hazardous to groundwater	incompatible	incompatible	incompatible[6, 8, 9]	incompatible[6, 8, 9]
Military shooting ranges	incompatible	incompatible	compatible	compatible

Notes:

[1] unless checked for defects at regular intervals and no release of untreated wastewater possible
[2] unless in keeping with good agricultural practices as regards timing and quantities and meeting technical standards and best practice guidelines
[3] excepting silage-making under plastic sheeting on tight base plates surrounded by retention basins
[4] except for minor quantities for residential use, storage of fuel oil for residential use and storage of diesel fuel for farming operations
[5] except for above ground lines or installations
[6] unless sewage and wastewater other than uncontaminated precipitation are completely and safely piped outside
[7] unless gas-fired
[8] unless substances used are not hazardous to groundwater or technical loss of substances cannot occur
[9] unless technical loss of substances is proven not to occur (checks on regular basis; technical system must prevent leakage and infiltration of hazardous substances, e.g. using double-layer tanks with leakage detection)
[10] unless sewage and wastewater other than uncontaminated precipitation are completely and safely piped outside
[11] unless no substances hazardous to groundwater are used and precautions are being taken against the infiltration of such substances into the ground
[12] except for embankment drainage and large distribution systems in ground with vegetation
[13] unless stormwater is completely and safely piped outside
[14] unless by water utility for water supply

9 Implementation of Groundwater Protection Zones

The proposed groundwater protection zones for the Jeita, Afqa, Assal, Labbane and Rouaiss springs will be the first in Lebanon. The implementation of each of them the will require the preparation of a related decree. However, implementation will also require substantial efforts concerning **enforcement of the proposed landuse restrictions and follow up on environmental sound practices for existing landuse activities**. As the assessment of hazards to groundwater have shown (RAAD et al., 2012, 2013), a **modification and harmonization of landuse licensing procedures** is urgently required. **Landuse planning in Lebanon needs to be modernized and take water resources protection aspects and environmental requirements into consideration**.

A **monitoring program of water quality** should be implemented and continuously maintained by WEBML in order to determine the effectiveness of enforcement and to single out remaining pollution problems. The capacity and instrumentation of the existing water laboratory of WEBML is not suited for this task. Currently heavy metals and a wide range of organic constituents cannot be analyzed by the Dbayeh lab. A new laboratory that is able to monitor all potentially hazardous water constituents is urgently needed since many years.

Even if groundwater protection zones are implemented as proposed, there will still be a high pollution risk, due to the extremely high flow velocities in groundwater. An additional pollution risk is that the existing water supply infrastructure is very old. It urgently needs to be replaced by a modern infrastructure. To avoid interruption of water supply in case of accidental or intentional contamination or damage of the water supply infrastructure, a **contingency plan** must be prepared by WEBML. The BGR project has proposed to improve the capture of Jeita spring and conveyance to Dbayeh because currently only a fraction of the usable amount can be used and approx. 30% of conveyed water is lost through the leaky system (GITEC & BGR, 2011). At the same time, it was proposed to establish an alternative conveyance system between Jeita and Dbayeh so that if one conveyor line was damaged the other could still be used. In the current configuration, the Greater Beirut Area would be out of water for a long time if the conveyor was damaged, e.g. by a rockfall or a landslide.

The declaration of the Afqa and Rouaiss groundwater catchments as Nature Protection Zones should be considered. Examples from Austria show, how the healthy environment in a protective area can attract tourism for recreation to the protected areas (VNÖ 2010).

The spring captures of all major springs are in a poor condition. Currently, at none of them accurate spring discharge measurements and water quality monitoring are undertaken by the Lebanese authorities. Therefore, neither the available amount nor the quality was known before the start of the BGR project. The continuous measurements undertaken by the BGR project at Jeita, Kashkoush, Assal and Labbane springs are the first attempt to come to real and continuous quality and quantity assessments. The same is valid for surface water monitoring and the monitoring of meteorological data. Due to massive gaps in historical and present data records, until now, reliable water resources assessments have not been possible. Imprecise or false assessments will lead to wrong water infrastructure planning.

It is urgently recommended to improve the monitoring of all components of the water balance. As springs are the main source of water supply, we urge the implementation of discharge monitoring for all springs yielding more than 10 MCM/a.

10 Proposed Monitoring of Impact from Existing Groundwater Hazards

Individual water quality parameters were collected by the BGR project since August 2010 using multiparameter probes. However, due to limited funds and insufficient locally available laboratory capacity, the project could not conduct a comprehensive water quality monitoring program for Jeita and other springs in the catchment, using weekly hydrochemical analyses. Currently the Dbayeh laboratory analyzes selected bacteriological constituents in raw water only every 4 days and other parameters only every 1-6 months. Heavy metals and organic constituents, such as e.g. pesticides are not analyzed at all. It is recommended that WEBML undertakes, separate from its standard monitoring program, a monitoring program to regularly assess the impact from a number of existing hazards to groundwater:

Jeita spring
<u>Gas stations</u>: Monitoring of MTBE and fuel components (once a month)
<u>Heating oil tanks and generators</u>: Monitoring of diesel fuel components (once a month)
<u>Agricultural farms</u>: Monitoring of all pesticides used in the catchment (once a month)

Labbane spring
<u>Gas station at ski station Aayoun es Simane</u>: Monitoring of MTBE and fuel components (once a month)
<u>Heating oil tanks and generators (hotels and resorts)</u>: Monitoring of diesel fuel components (once a month)

Because the existing laboratory is not capably to conduct such analyses, this will require the establishment of a new modern laboratory.

11 General Recommendations

The future delineation of groundwater protection zones for other springs and wellfields in Lebanon will require extensive hydrogeological groundwork. So far, only few tracer tests to determine groundwater flow velocities and groundwater catchments were used in other catchments. In order to have sufficient certainty about the distribution of groundwater flow velocities and the boundaries of a groundwater catchment, the application of such hydrogeological methods is indispensable. We highly recommend using the same approach for future protection zone delineations as used in this report.

The groundwater investigations carried out in the Jeita GW catchment in the framework of the German-Lebanese Technical Cooperation project Protection of Jeita Spring thoroughly destroyed the myth, widely prevalent in Lebanon, that groundwater catchments must somehow be similar in extent to surface water catchments. Understanding this fact is the basis for water resources planning, especially in a karst-dominated country as Lebanon. To come to a better understanding of the groundwater systems in Lebanon, which is currently virtually unknown, groundwater investigations, such as conducted by the BGR project, need to be executed all over the country. This requires qualified human resources, equipment and local governmental institutions, which are willing and capable to undertake such studies. Currently, however, there is not even a geological survey existent in Lebanon and the current institutions are not able to carry out a water resources assessment or water resources monitoring program, as it has been done by the BGR project. The Water Strategy presented in 2012 by the Ministry of Energy and Water contains only one page presenting the available water resources. The numbers provided in this 'assessment' are, however, not based on measurements but on speculative assumptions. This is probably why the source of information was not mentioned. Such wrong and misleading assessments will only lead to wrong planning and failed investments in the water sector. How should water resources be properly managed in Lebanon without having neither the information about available water resources, nor the required institutional capacity?

It is highly recommended to establish a Water Resources Institute, subordinate to but independent of the Ministry of Energy and Water, that would be responsible for all tasks related to water resources monitoring (quality and quantity), water resources assessments and water resources management, i.e. allocation to the different sectors based on measured values. As the Water Establishments are the main users and beneficiaries of the information to be provided by this proposed institution, they should have an interest to contribute to such an institute.

Groundwater protection zone delineation should follow a standard guideline document. This needs to be developed by the Ministry of Energy and Water. The Water Law (code de l'eau) must provide an article related to the declaration of groundwater protection zones so that they can be legally implemented through a related decree.

Groundwater protection zone delineation studies do not need to be undertaken exclusively by consultants, which would be very expensive. They could also be undertaken by qualified universities. Geology, and more specifically hydrogeology, which is the main qualification needed for this task, is currently, however, taught only at one university, AUB. The human resources capacity in this field must significantly be increased to deal with the challenges of the future.

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ANNEX GIS

For the preparation of all GIS layers, the desired *Workspace (Environment Settings, Geoprocessing)* is defined, as well as the *Mask* (*Raster Analysis*) to the referring Raster Dataset (e.g. DEM) and the *Cell Size (Raster Analysis)* is set on 10m.

ANNEX 1: Documentation of C layers in ArcGIS

1.1 Layer VII

To create areas with a defined radius around point features (i.e. dolines), the *Multiple Ring Buffer (Analysis)* is used (*Figure 35*). *Buffer unit* is set on *meters*, *Field name* is labeled as *dh (note: depending on the quantity of single point locations, ArcGIS may take several minutes to an hour, to calculate this command)*.

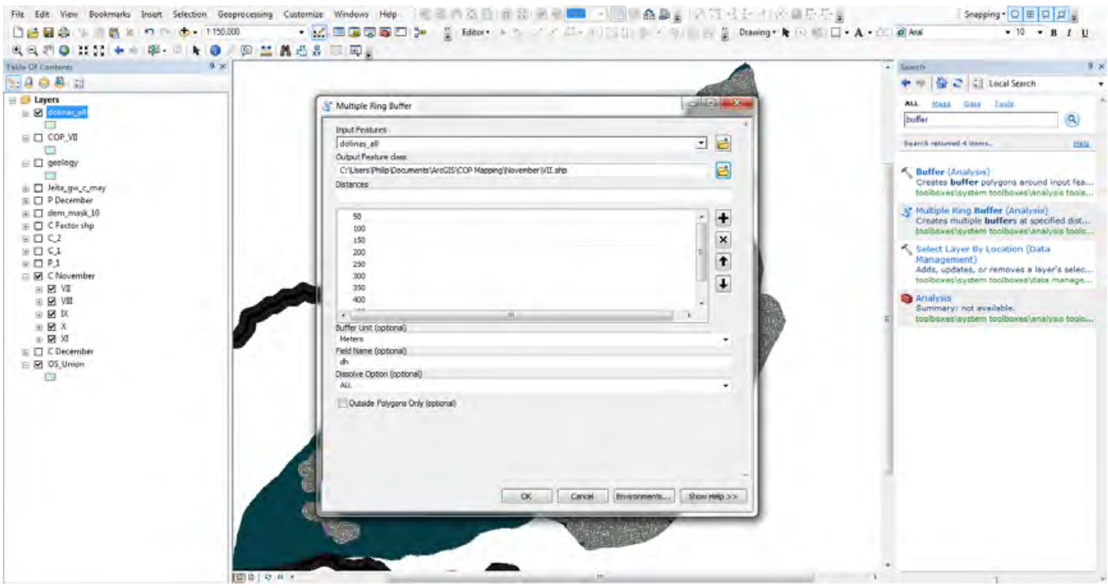

Figure 35: Multiple Buffer Analysis in ArcGIS

The created output of concentric rings does of course not take geological boarders into account; dolines, located on top of the lower elevated part of the C4, close to the border of the lower C3, may extend into the C3 and dolines, located on top of the J4 at the boarder to the higher J5 may expand into the J5. In the latter case, there is no problem; surface runoff may concentrate topographically from the higher J5 to the lower J4 (*Figure 4*).

However, in case of the C4, the extent of the doline buffers that reach into the lower located C3 can be neglected (opposed effect than in case of the J4/J5). Thus, the created multiple ring buffer of the C4 dolines is erased by the geology layer by using *Erase (Analysis)* (*Figure 36*) (*select* the geological units below the C4).

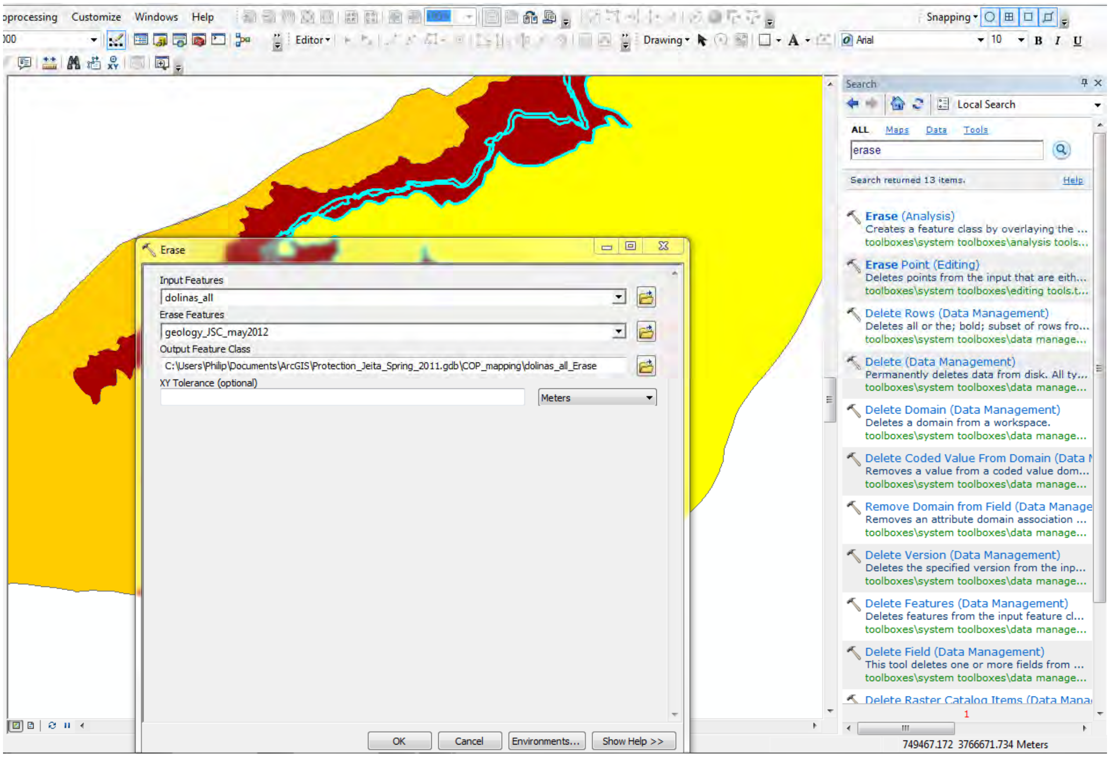

Figure 36: Erase Analysis in ArcGIS

Afterwards, *Add Field, Field Type Float, Label dh* is done and classified, according to *Table 9*. The output is converted into a raster file by using *Feature to Raster (Conversion)* (*Figure 37*) while selecting *Field,* according to the respective field that includes the d_h value. The respective layer is clipped according to the extent of the COP area (J4, partly J5, and C4) by using the *Clip (Analysis)* tool. The final layer is displayed in *Figure 38*.

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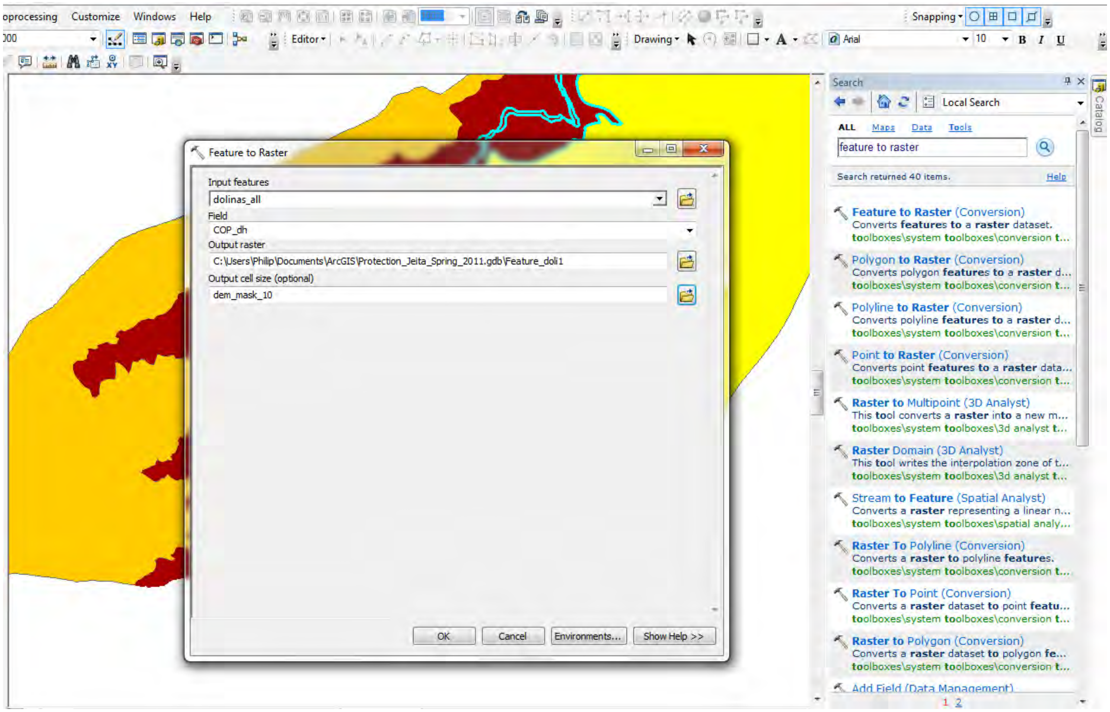

Figure 37: Feature to Raster Conversion in ArcGIS

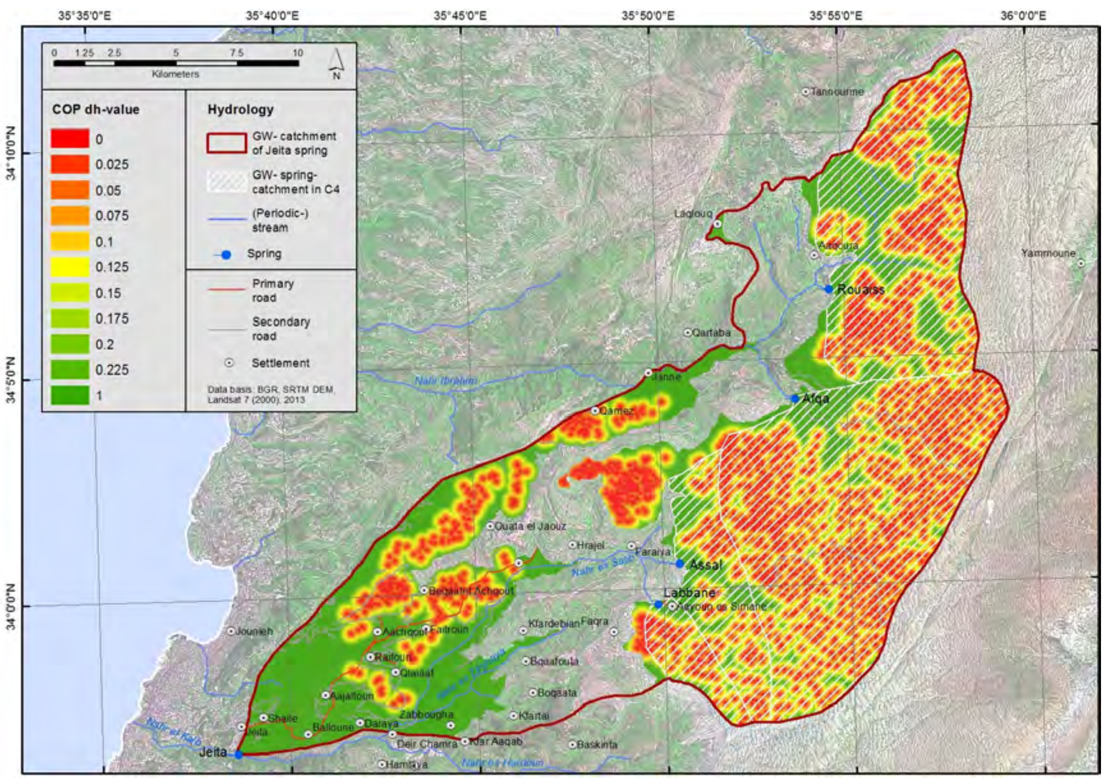

Figure 38: Layer VII

1.2 Layer VIII

Distance to sinking streams (VIII) is created with the same tool as used for Layer VII (*Multiple Ring Buffer (Analysis))*, applied on all major (periodic-) streams within the catchment. The output is converted into a raster file by using *Feature to Raster (Conversion)* while selecting *Field* according to the respective field that includes the ds value. The respective layer is clipped according to the extent of the COP area (J4, partly J5, and C4) by using the *Clip (Analysis)* tool.

Figure 39 displays the extent of the ds value.

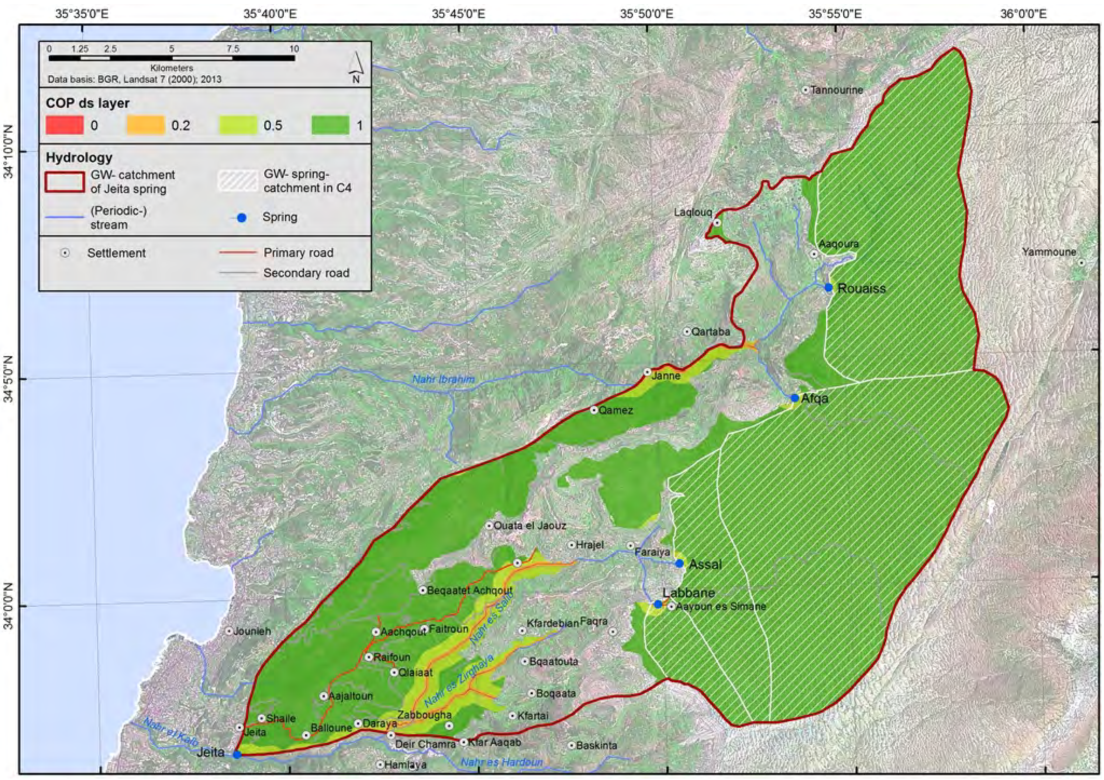

Figure 39: Layer VIII

1.3 Layer IX

To calculate the spatial distribution of slope, the *Slope (Spatial Analyst)* (*Figure 40*) is used, with the SRTM DEM as input file. The output raster file is further reclassified by using *Reclassify (3D Analyst) (Figure 41)*, according to VIAS et al. (2006). This raster file is then processed to a vector file by using *Feature to Raster (Conversion)* to generate the feature *Slope_Reclass*.

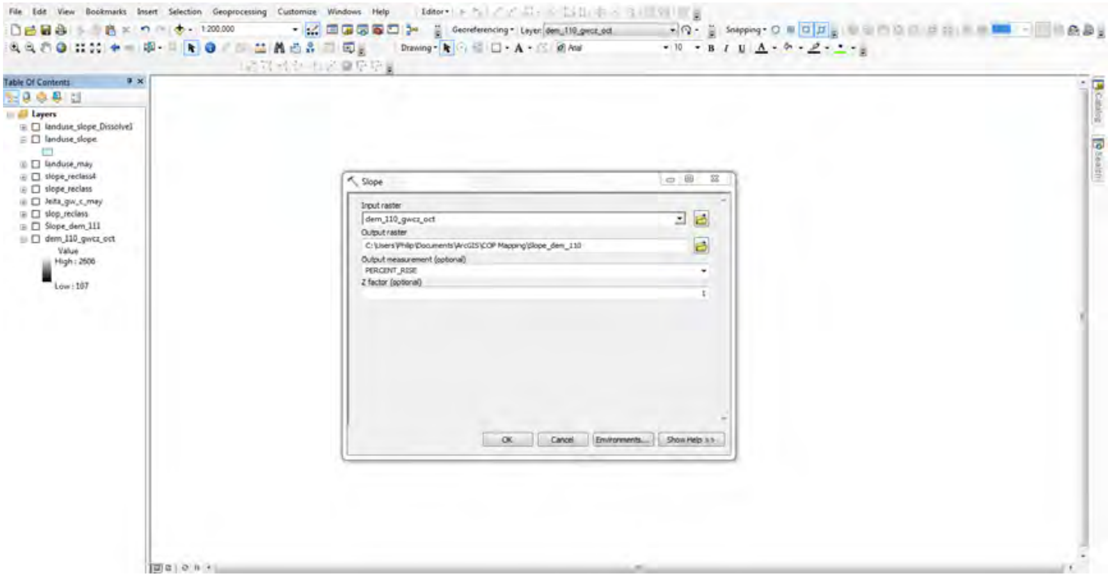

Figure 40: Slope Spatial Analyst in ArcGIS

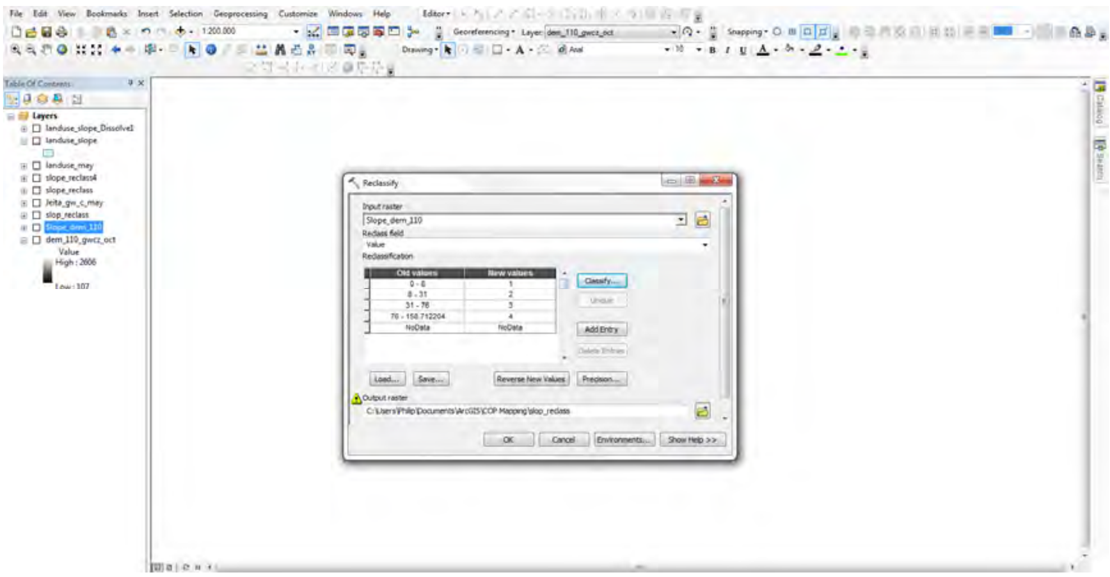

Figure 41: Reclassify 3D Analyst in ArcGIS

After completion of the slope shapefile, the landcover shapefile needs to be prepared. Open the landcover.shp file and *Add field* (Label: *vegetation*) in the *Attribute Table,* choose *Field type* as *short integer*. Start the *Editor* and edit the column *vegetation*: attribute 1 for vegetation and 0 for No vegetation and stop editing.

After preparation of both shapefiles, they are intersected by using *Intersect (Analysis)* (*Figure 42*) to generate the output *landuse_slope.*

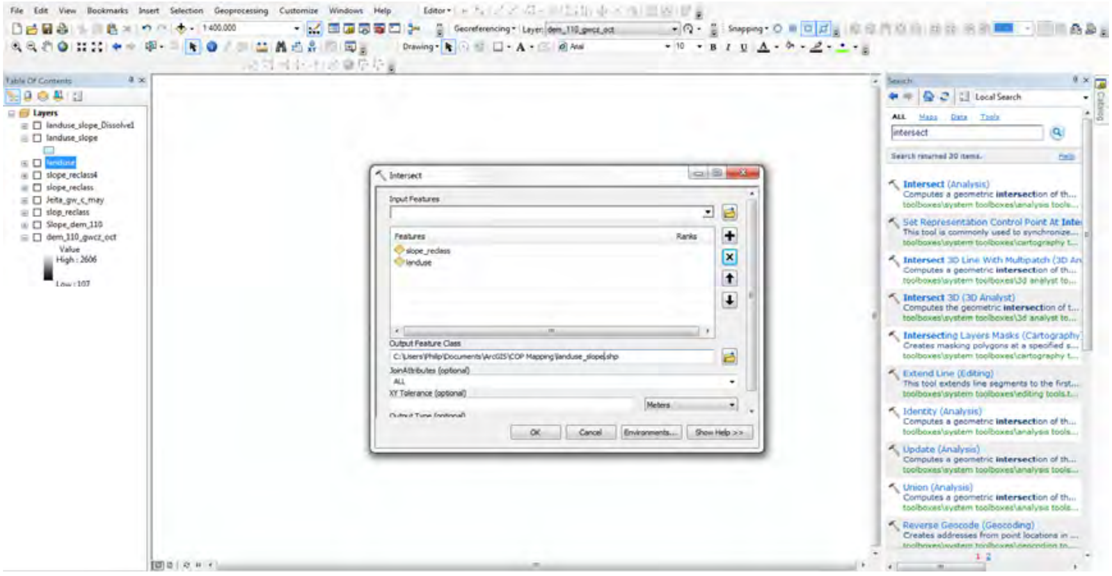

Figure 42: Intersect Analysis in ArcGIS

In a next step, *landuse_slope is dissolved* by using *Dissolve (Data Management)* (*Figure 43*) to aggregate the field *vegetation* and gridcode (slope).

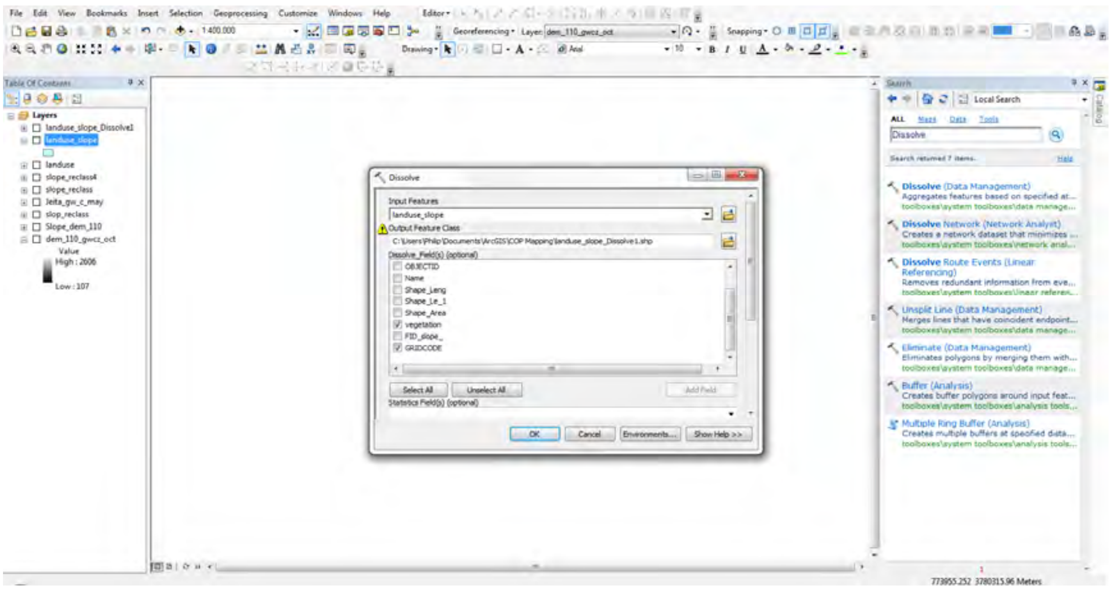

Figure 43: Dissolve Data Management in ArcGIS

The dissolved *landuse_slope* file is attributed according to VIAS et al. (2006) by *Add Field, Field type Float* and editing of the column (*Figure 44*).

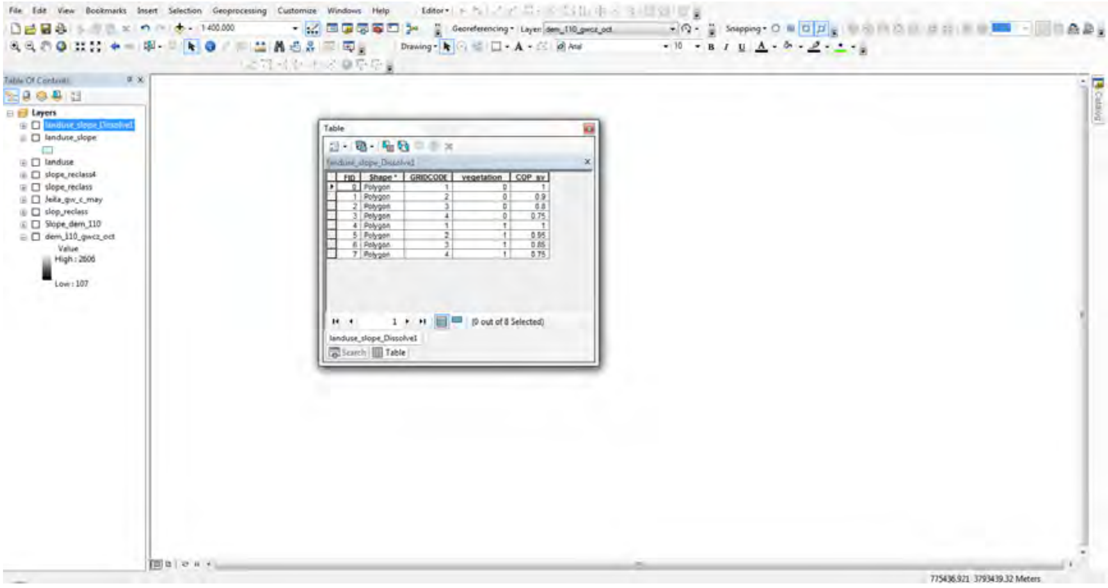

Figure 44: Properties table of layer IX

The created slope/vegetation shapefile is clipped according to the coverage of dolines of layer VII by using the *Clip (Analysis)* tool (all areas of the covering dolines are *selected*).

The output is converted into a raster file by using the *Feature to Raster (Conversion)* tool while selecting *Field* according to the respective field that includes the sv value. The respective layer is clipped according to the extent of the COP area (J4, partly J5, and C4) by using the *Clip (Analysis)* tool.

The extent of the sv value is displayed in *Figure 45*.

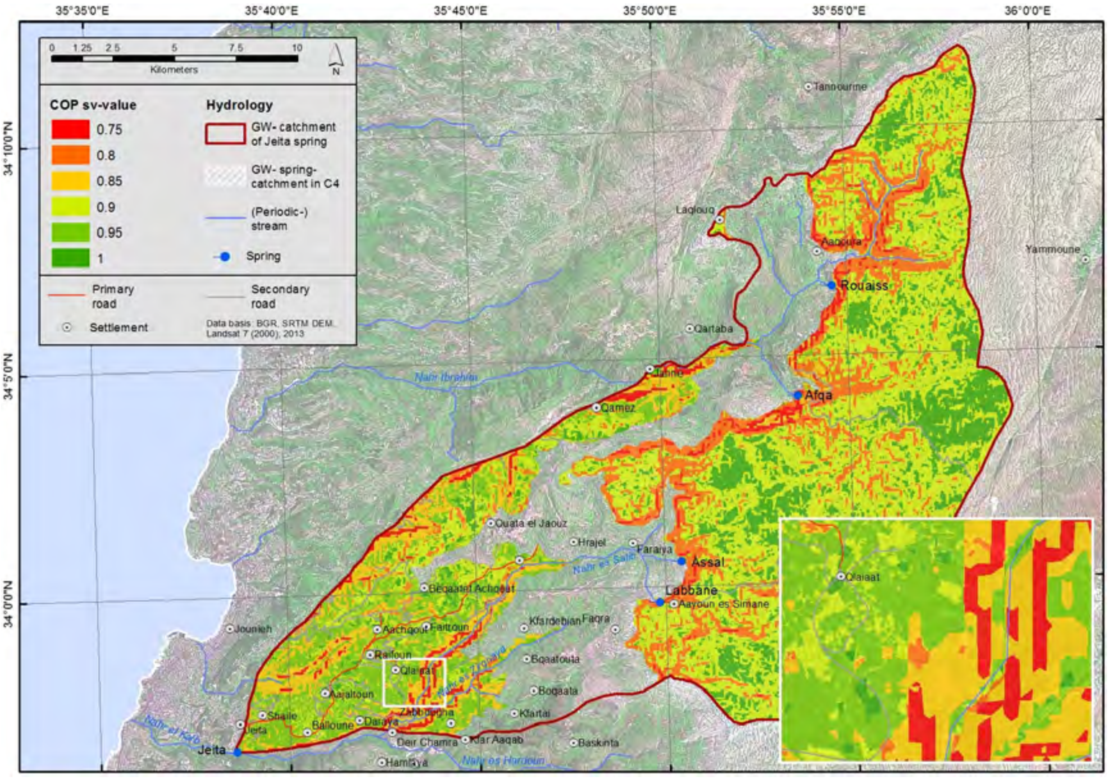

Figure 45: Layer IX

1.4 Layer X

Layer X is established by using the geology layer (.shp) to which a field is added (*Add Field, Field type Float*); its numbers are entered by *start editing* and entering the respective numbers, according to *Table 11*.

The created shapefile is clipped according to the absence of dolines of layer VII by using the *Clip (Analysis)* tool (all non-covering areas of the dolines are *selected*).

The output is converted into a raster file by using *Feature to Raster (Conversion)* while selecting *Field* according to the respective field that includes the sf value. The respective layer is clipped according to the extent of the COP area (J4, partly J5, and C4) by using the *Clip (Analysis)* tool. The extent of the sf value is displayed in *Figure 46*.

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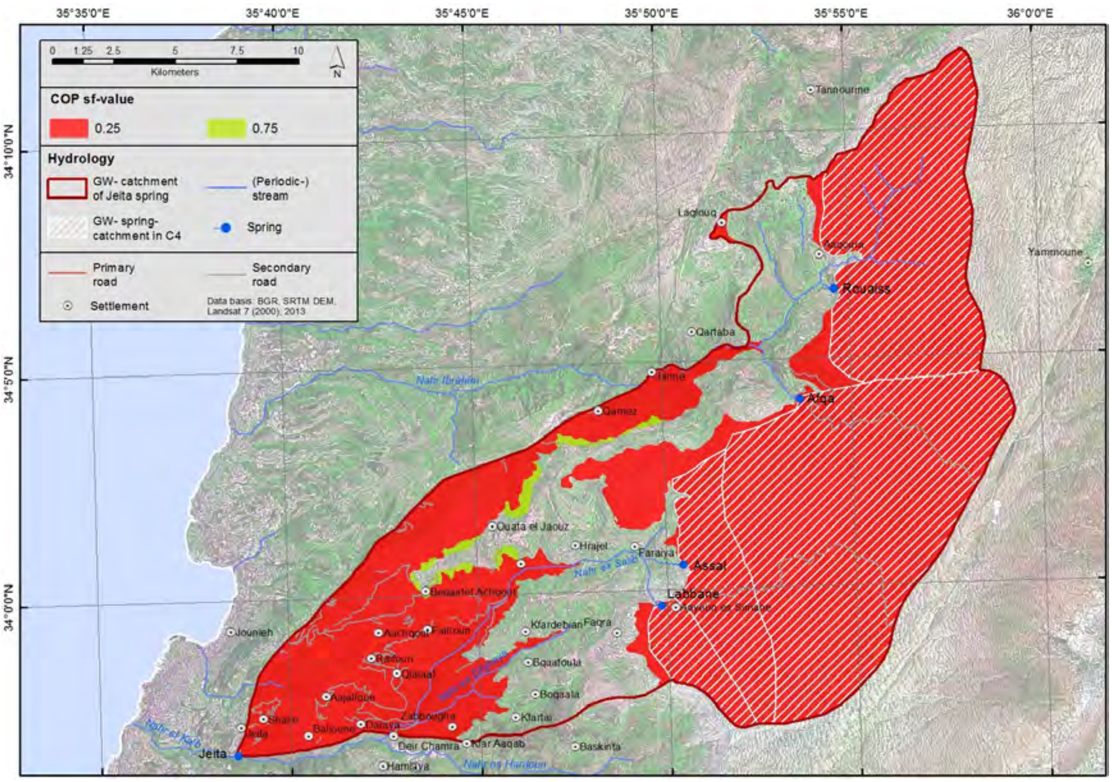

Figure 46: Layer X

1.5 Layer XI

Layer XI is established by using layer IX (.shp), *Add Field sv* and entering of the data, opposed to the existing sv value (*Figure 7*).

The created shapefile is clipped according to the absence of dolines of layer VII by using the *Clip (Analysis)* tool (all non-covering areas of the dolines are *selected*).

The output is converted into a raster file by using *Feature to Raster (Conversion)* and while selecting *Field* according to the respective field that includes the sv value. The respective layer is clipped according to the extent of the COP area (J4, partly J5, and C4) by using the *Clip (Analysis)* tool.

Figure 47 displays the extent of the sv value for Layer XI.

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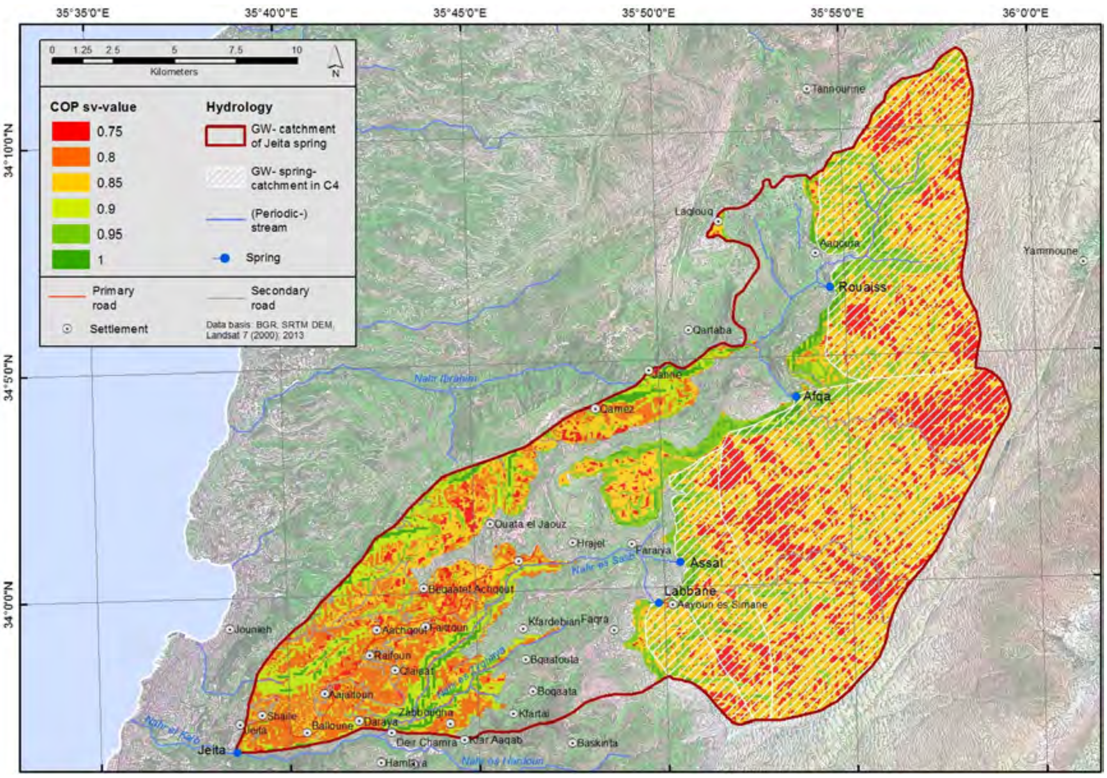

Figure 47: Layer XI

1.6 Layer C_1

Layer C_1 is calculated by multiplication of the final raster layer VII, VIII and IX by using the *Raster Calculator (Spatial Analyst)* tool (*Figure 48*).

The final C_1 layer is displayed in *Figure 49*.

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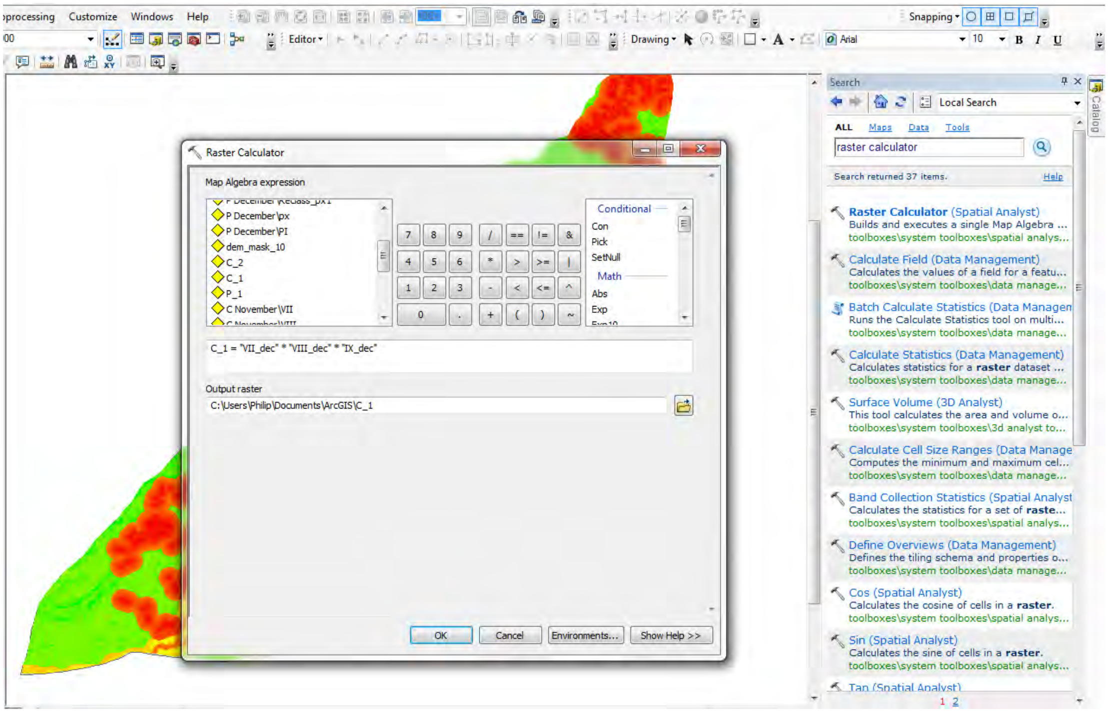

Figure 48: C_1: Multiplication of layer VII, VIII and IX in the Raster Calculator tool in ArcGIS

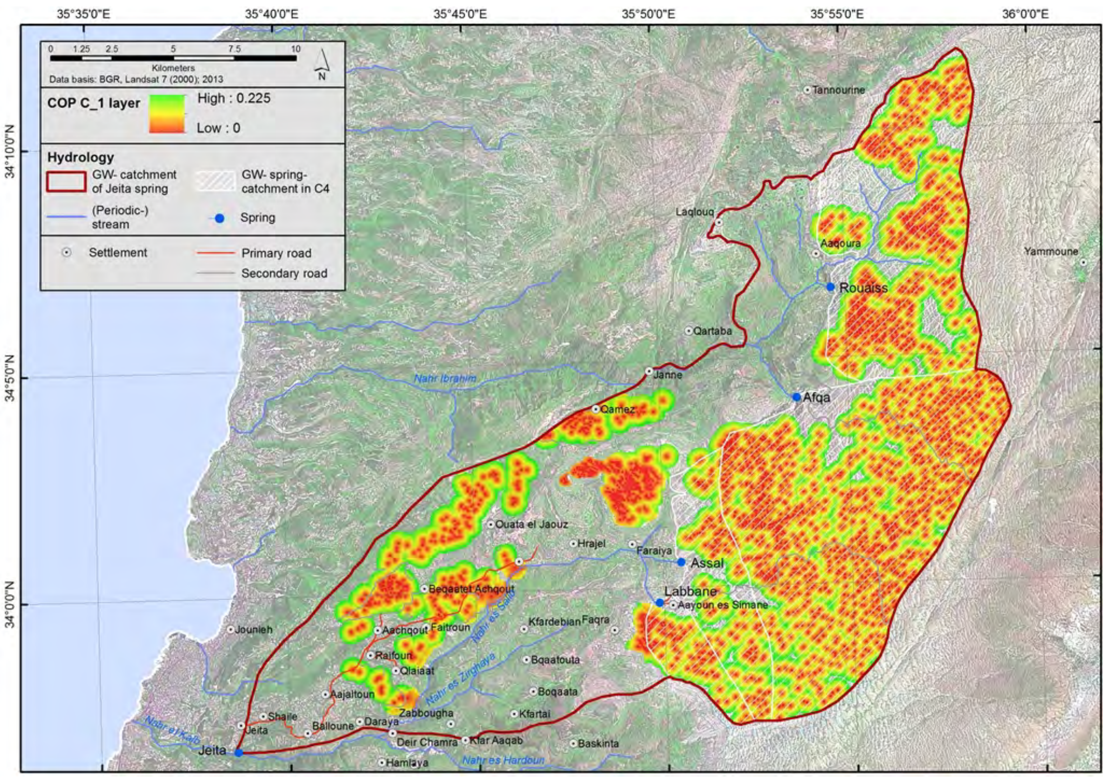

Figure 49: Final C_1 layer

1.7 *Layer C_2*

Layer C_2 is calculated by multiplication of the final raster layer VII, VIII and IX by using the *Raster Calculator (Spatial Analyst)* tool (*Figure 50*).

The final C_2 layer is displayed in *Figure 51*.

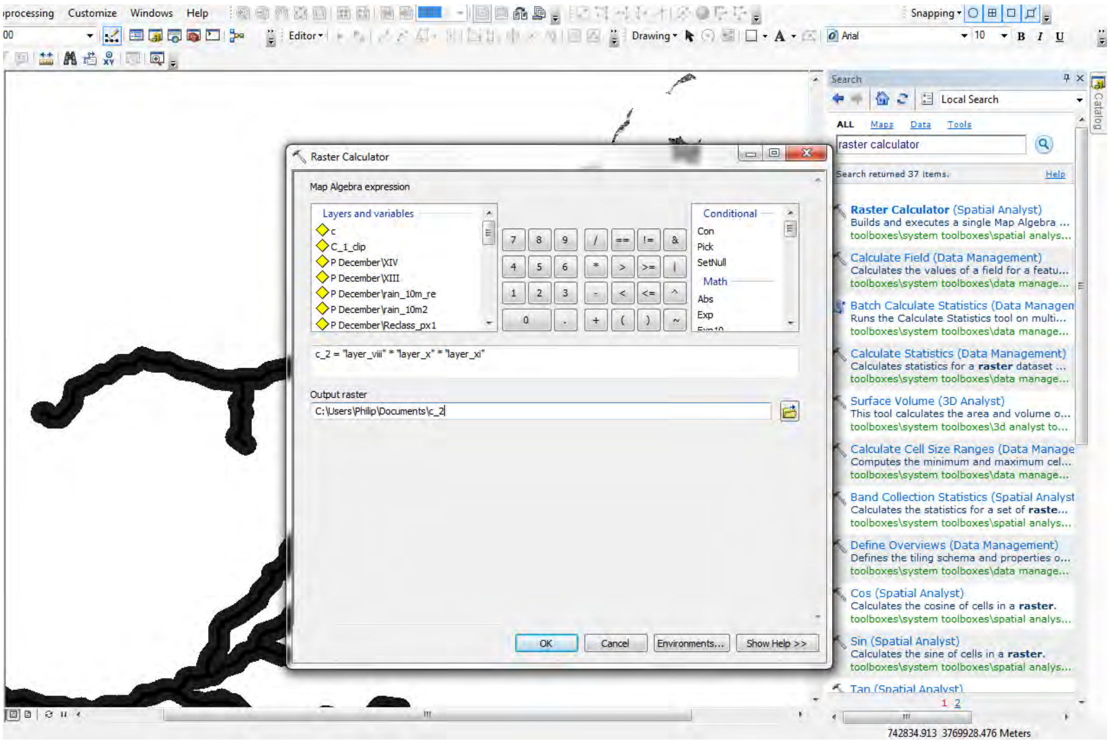

Figure 50: C_2: Multiplication of layer VIII, X and XI in the Raster Calculator tool in ArcGIS

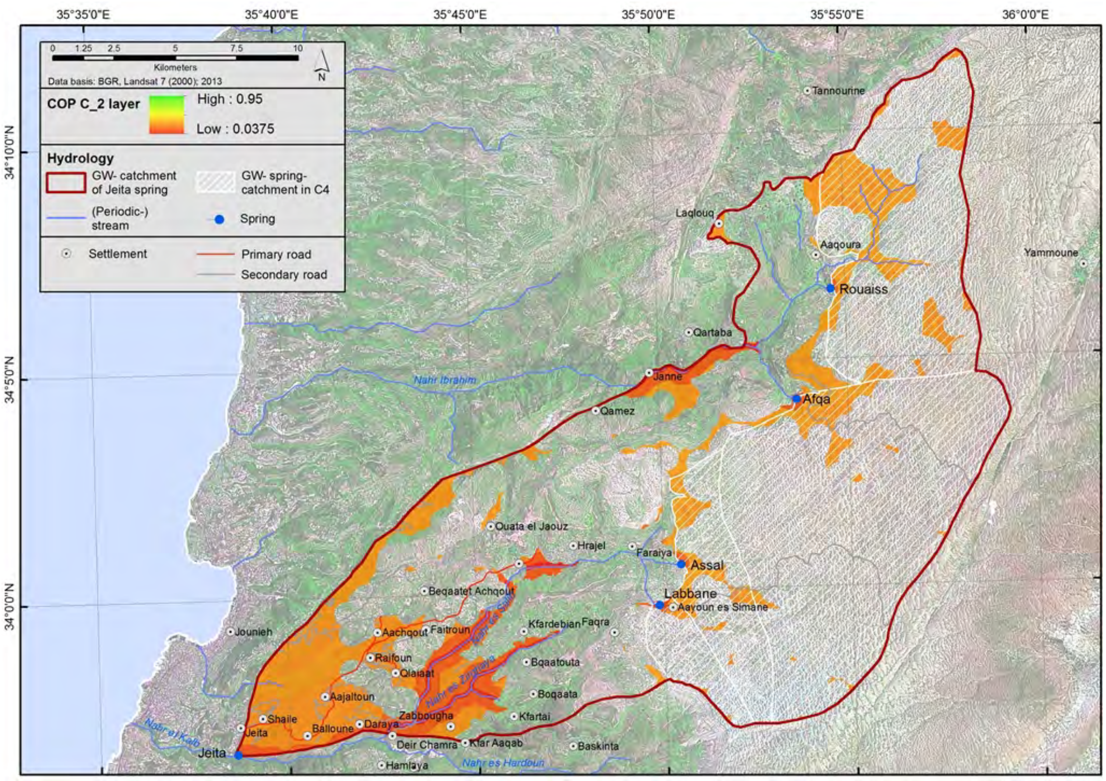

Figure 51: Final C_2 layer

1.8 Final C Layer

The final C layer is established by merging the final rater datasets of C_1 and C_2 by using the *Mosaic To New Raster (Data Management)* tool (*Figure 52 and 53*).

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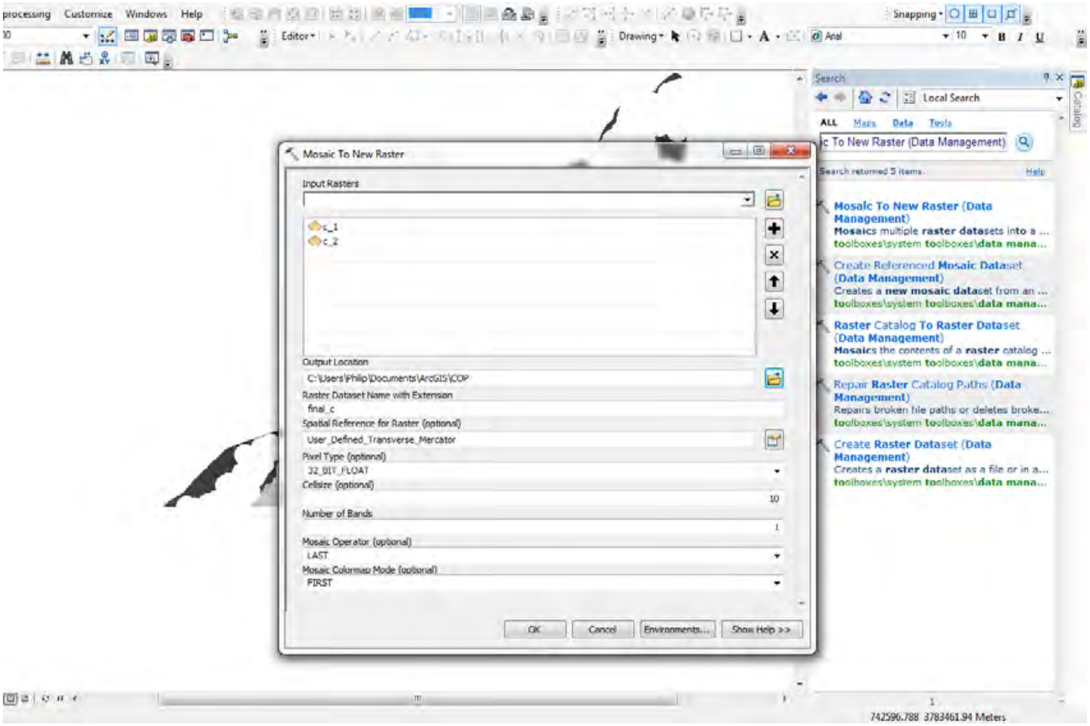

Figure 52: Merging C_1 and C_2 by using the *Mosaic To New Raster Data Management* tool in ArcGIS

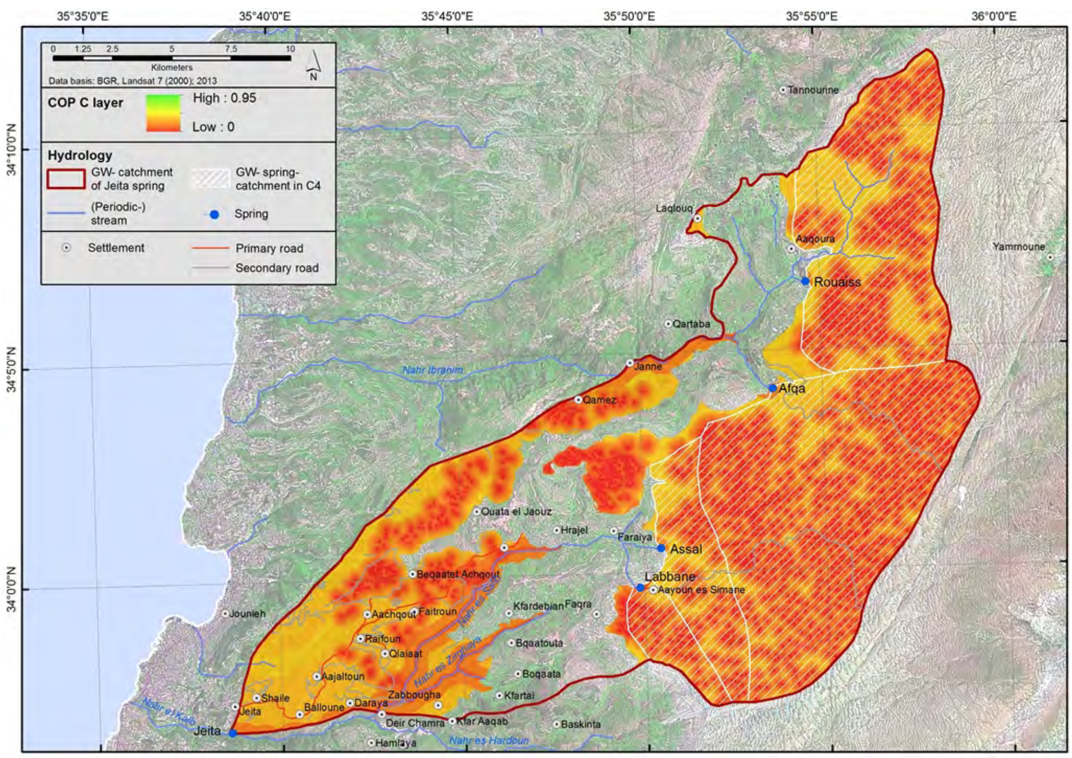

Figure 53: Final C layer

ANNEX 2: Documentation of O layers in ArcGIS

2.1 Layer II

Layer II is based on the geology, which is processed in Google earth in order to identify local exceptions of the general attributed O_S value. The geology shapefile is converted into a kml file by using the *Layer to KML (Conversion)* tool. The kml output is then imported into Google earth to digitalize local exceptions of the general O_S value (*Figure 54*).

Figure 54: Mapping of the O_S value in Google Earth.

All digitalized polygons are then converted into a shapefile by using the *KML To Layer (Conversion)* tool. To integrate this layer into the existing *O_S* shapefile (geology layer with *Field* O_S value), the geology layer is erased by the established *local O_S shapefile* (*Figure 55*).

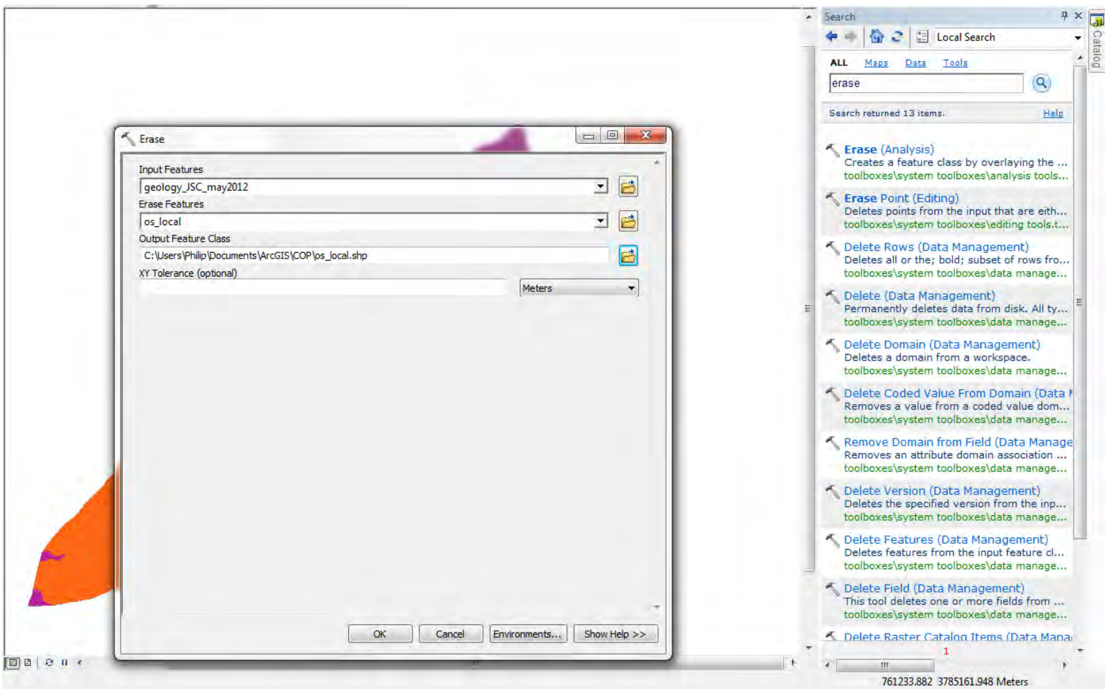

Figure 55: Erase Analysis in ArcGIS

In a next step, the *local* O_S *shapefile* is loaded into the previously established (erased) geology layer by using the ArcCatalog (*note: the target shapefile must be within a geodatabase*). The respective layer is clipped according to the extent of the COP area (J4, partly J5, and C4) by using the *Clip (Analysis)* tool.

The final O_S layer is displayed in *Figure 56*.

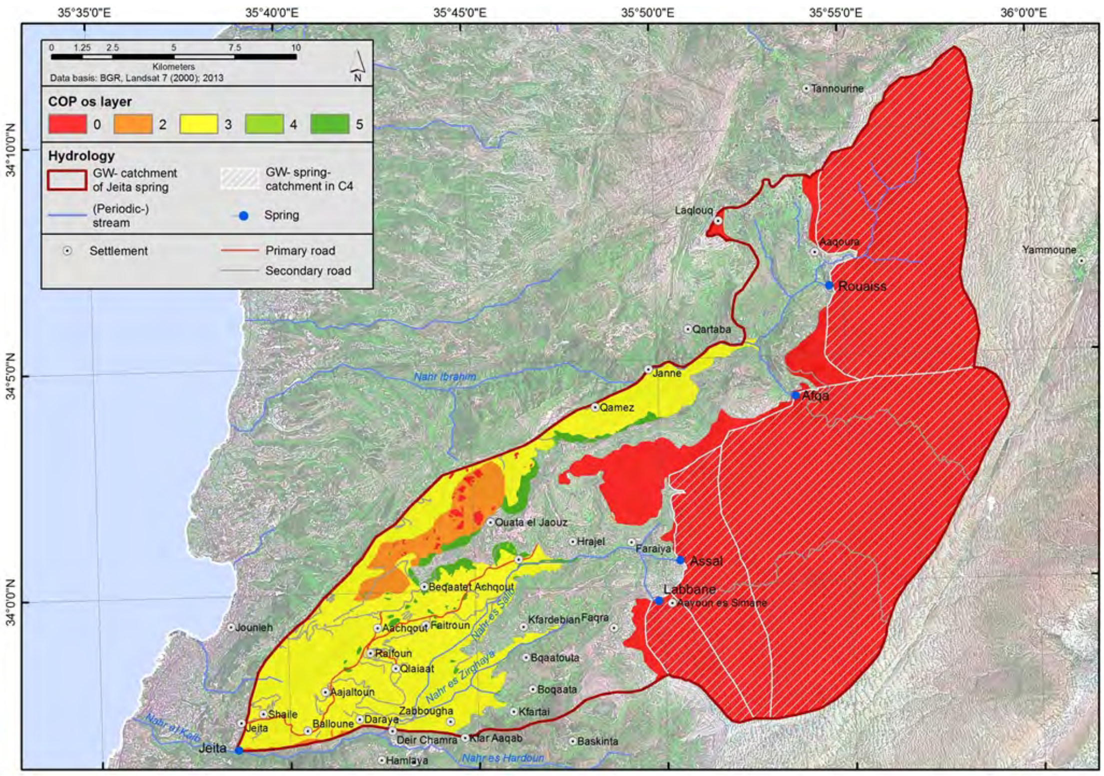

Figure 56: Layer II

2.2 Layer III

The O_L value for the Aquitard (J5-C3) and the C4 raster datasets are established by using the *Feature to Raster (Conversion) tool*, based on the geology vector file and its attributed O_L values.

The O_L value for the J4 is more specific. First, the extent of the groundwater contour (*Figure 57*) raster dataset is cropped according to the extent of the J4 by using the *Extract by Mask (Spatial Analyst)* tool.

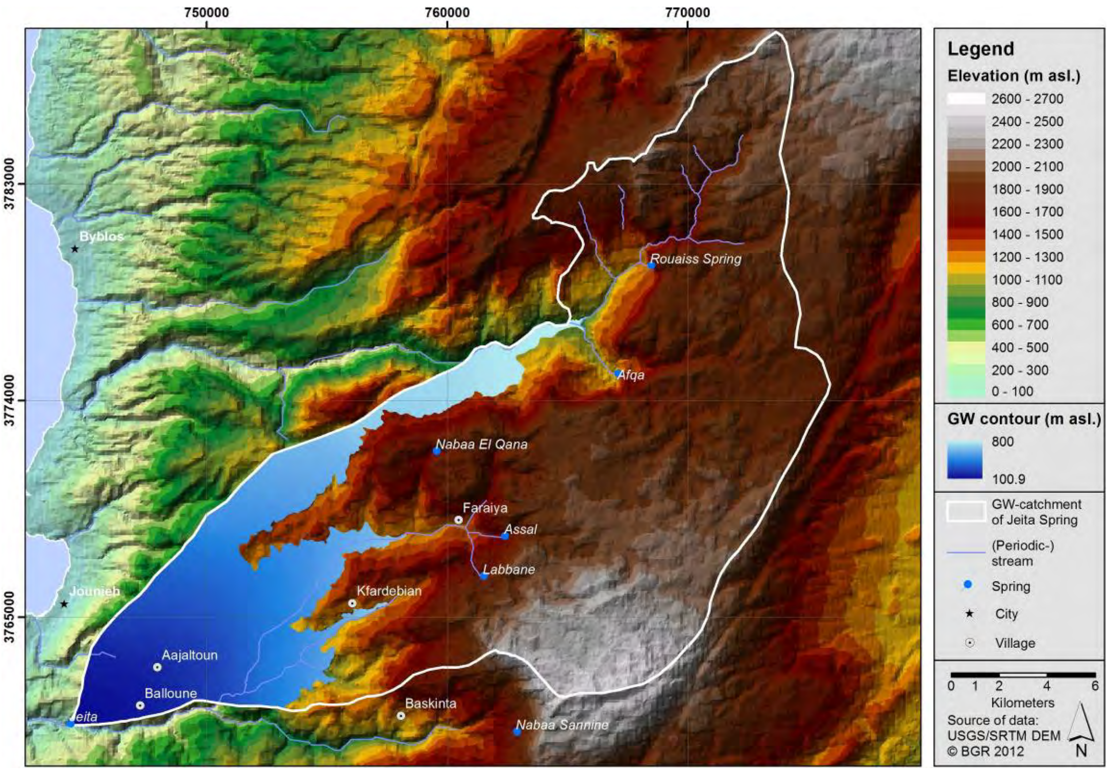

Figure 57: Topography and groundwater level in m asl

To derive the thickness of the unsaturated zone (*Figure 59*), i.e. the distance between the land surface and the groundwater level, the groundwater contour raster of the J4, is subtracted from the DEM by using the *Raster Calculator (Spatial Analyst)* tool (*Figure 58*).

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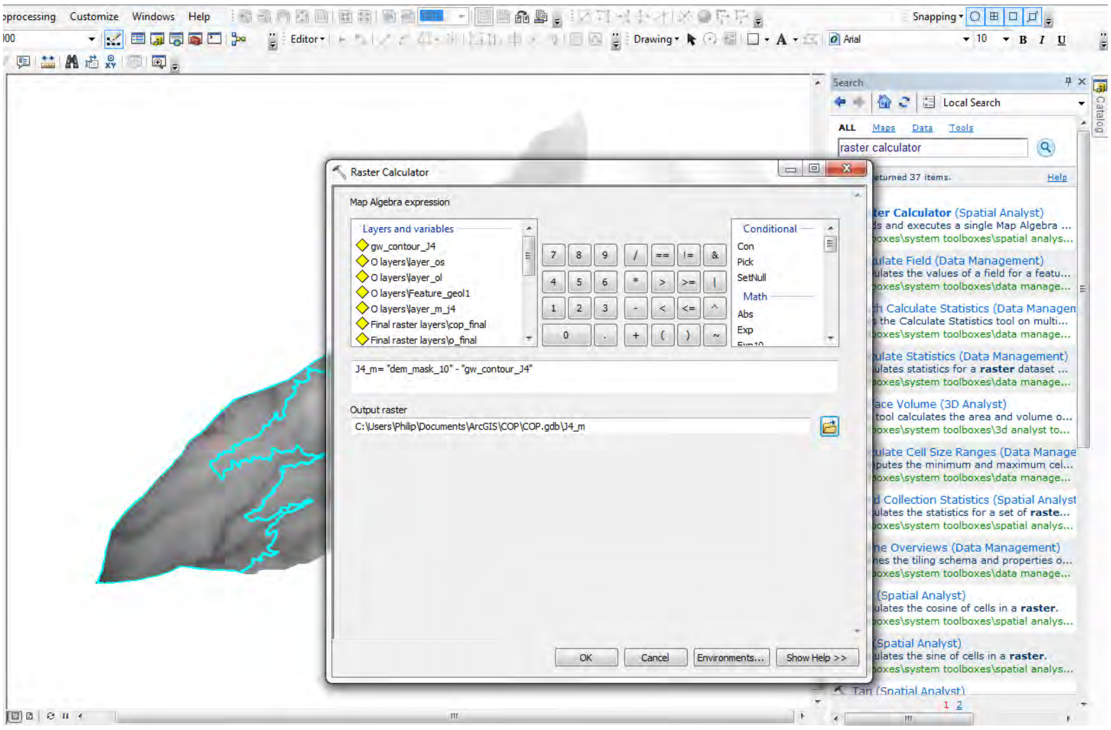

Figure 58: Calculation of the thickness of the unsaturated zone by using the Raster Calculator tool in ArcGIS

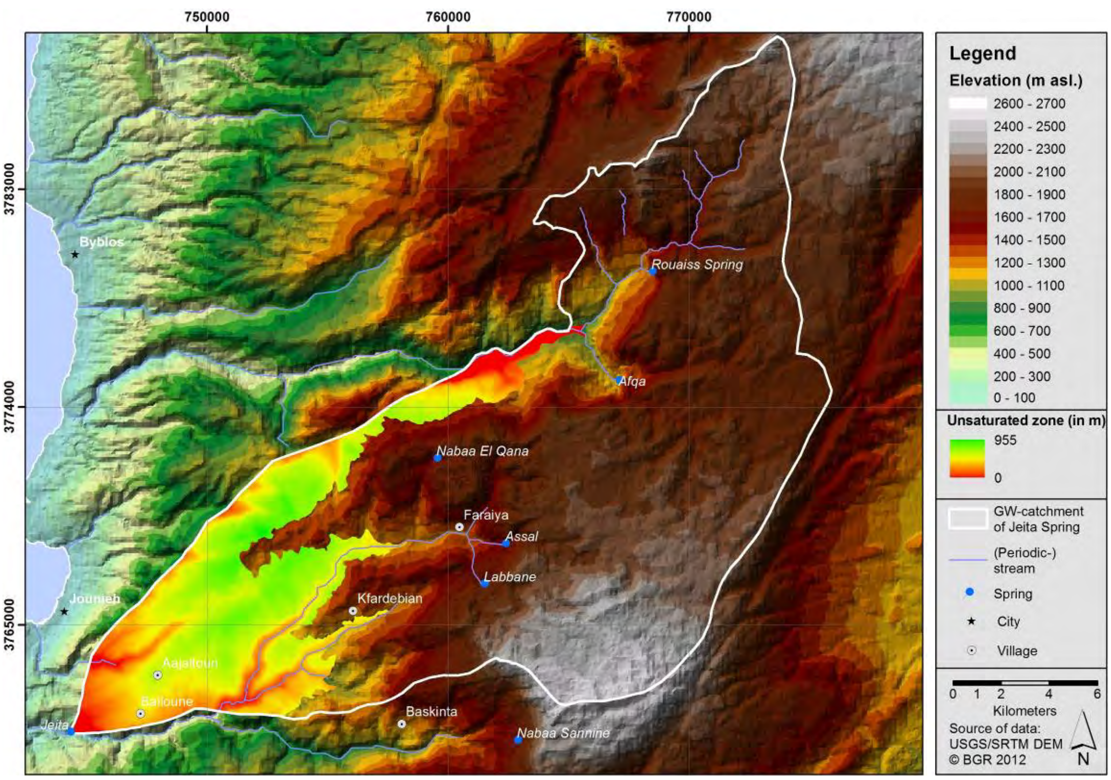

Figure 59: Thickness of the unsaturated zone of the J4 in m

This raster, expressing the distance between surface and GW level, is reclassified, according to *Figure 7* (layer IV), by using the *Reclassify (3D Analyst)* tool (*Figure 60 and 61*) (*in the present case, the maximum thickness is 955; therefore, classification of two classes is enough*).

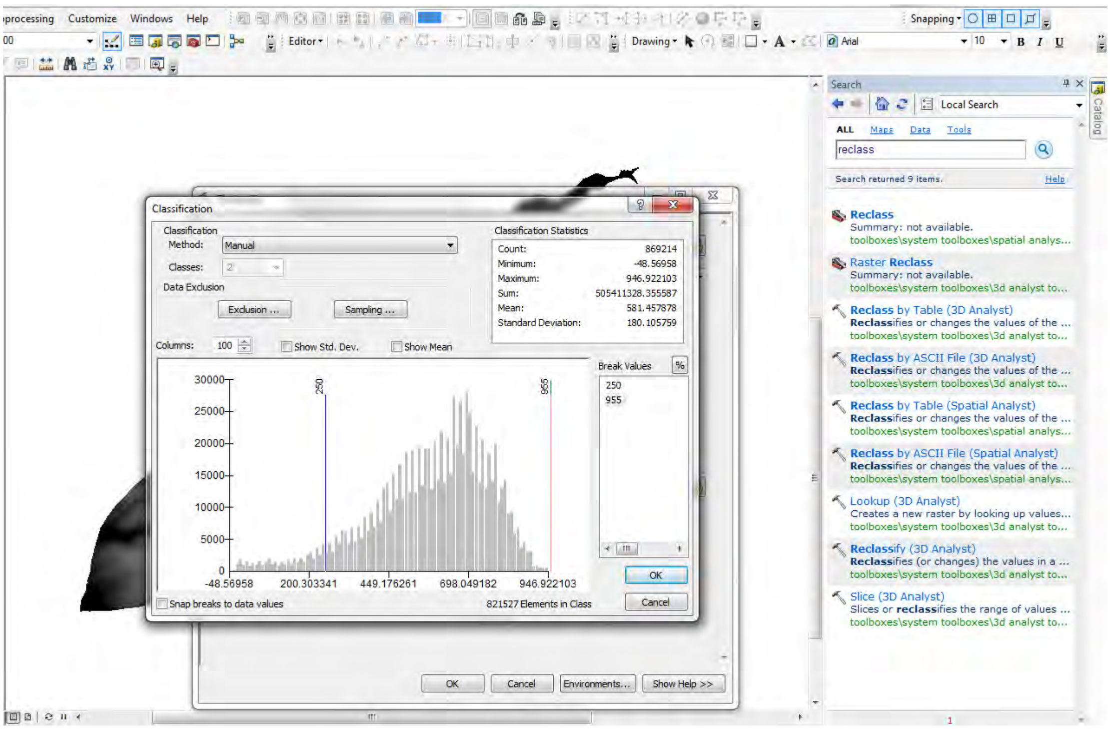

Figure 60: Reclassification of layer IV in ArcGIS

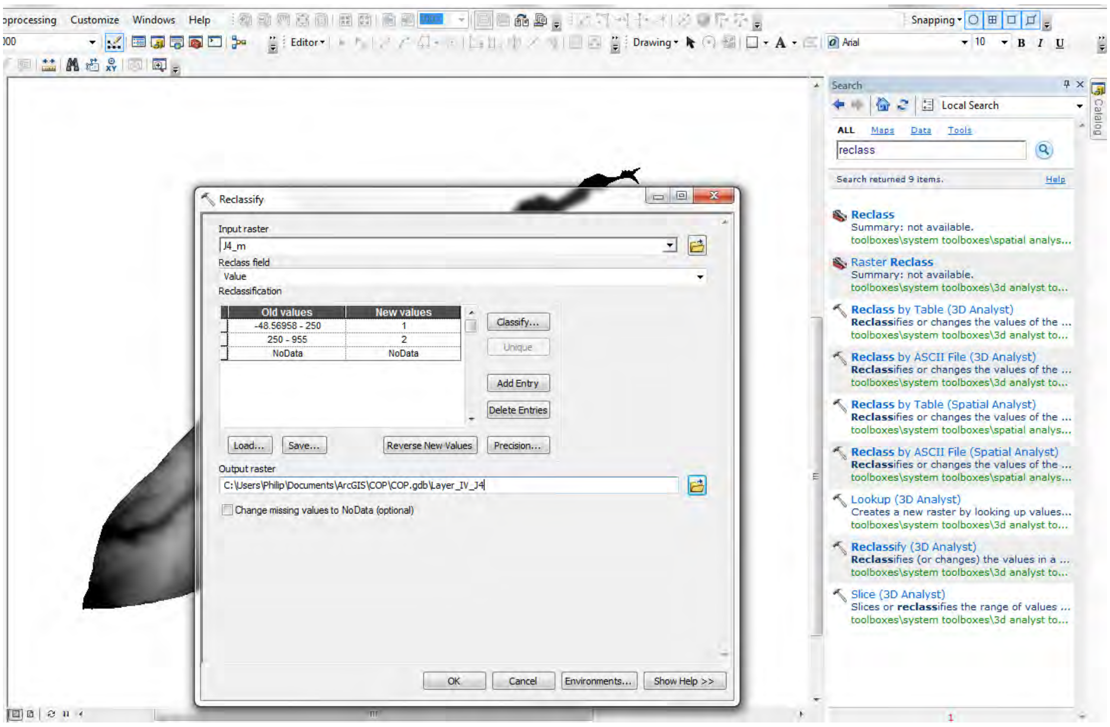

Figure 61: Reclassification of layer IV in ArcGIS

Since cn and ly are both 1 for the J4, the previously created raster dataset just needs to be merged with the O_L raster dataset of the Aquitard/C4, which is done by the *Mosaic To New Raster (Data Management)* tool (*Figure 62*).

The respective layer is clipped according to the extent of the COP area (J4, partly J5, and C4) by using the *Clip (Analysis)* tool.

The final O_L layer is displayed in *Figure 63*.

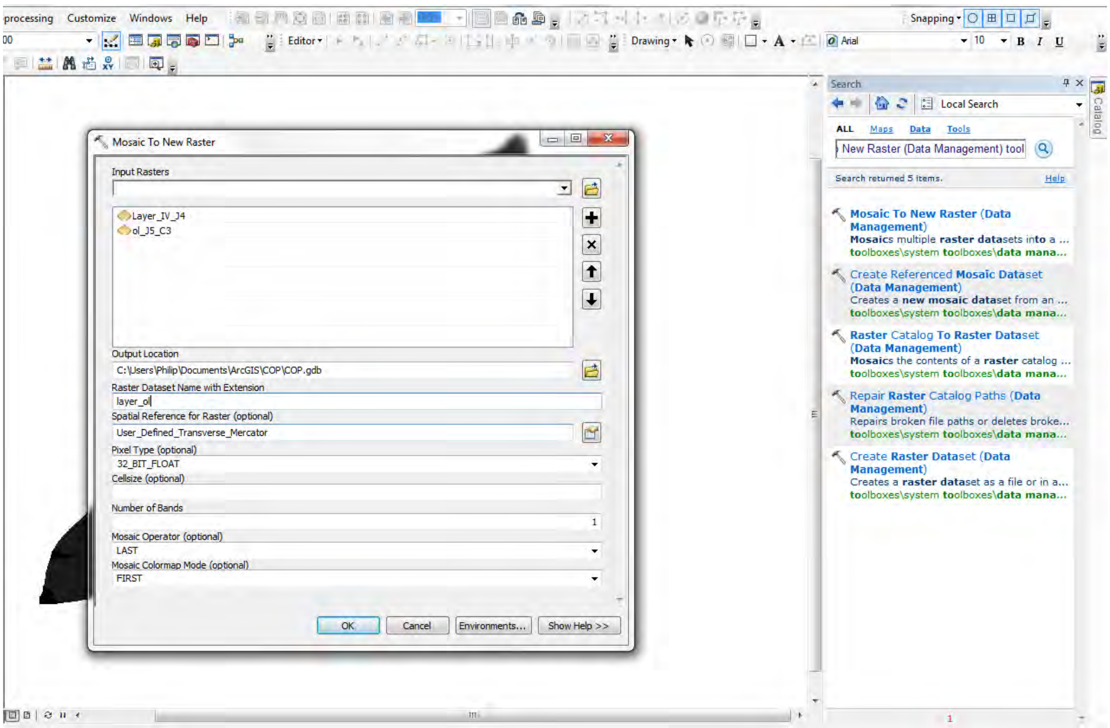

Figure 62: *Mosaic To New Raster Data Management* in ArcGIS

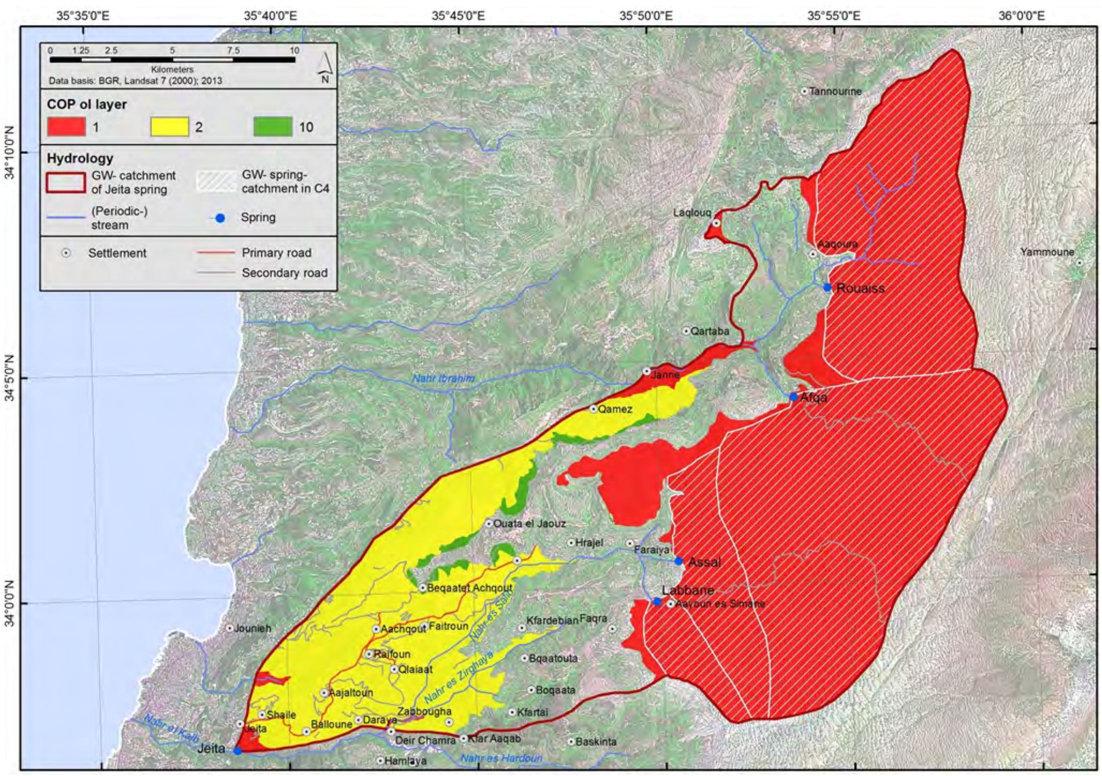

Figure 63: Final O_L layer

2.3 Final O Layer

The final O layer is established by adding layer II to layer III by using the *Raster Calculator (Spatial Analyst)* tool (*Figure 64 and 65*).

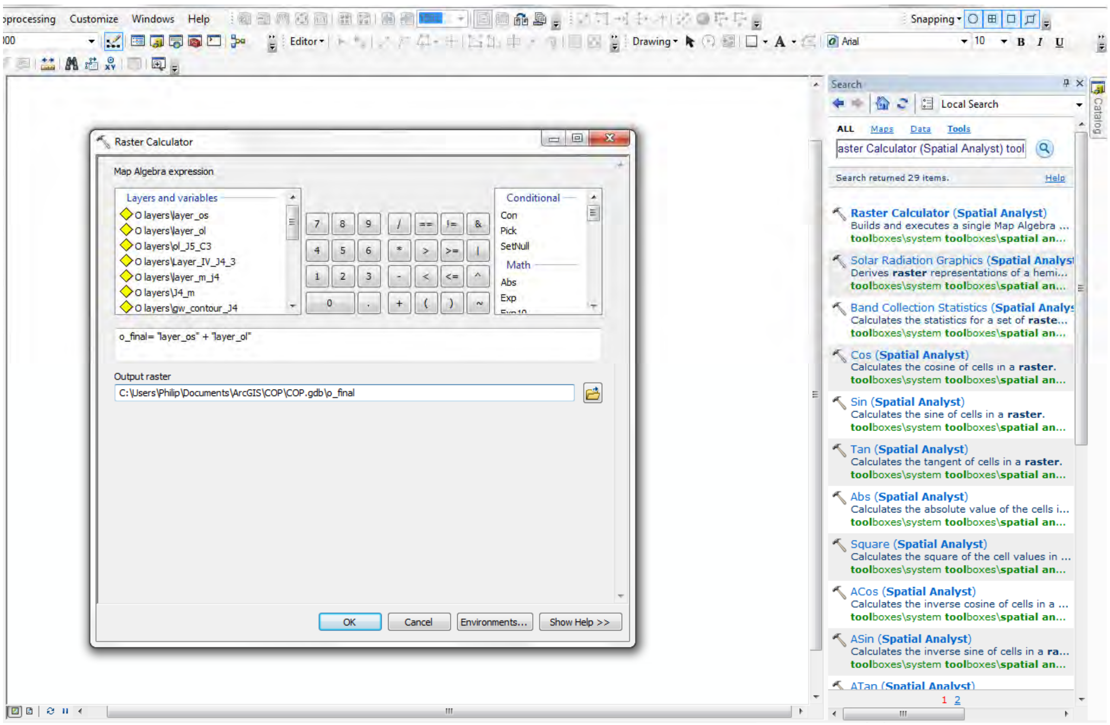

Figure 64: Calculation of the final O layer by using the Raster Calculator in ArcGIS

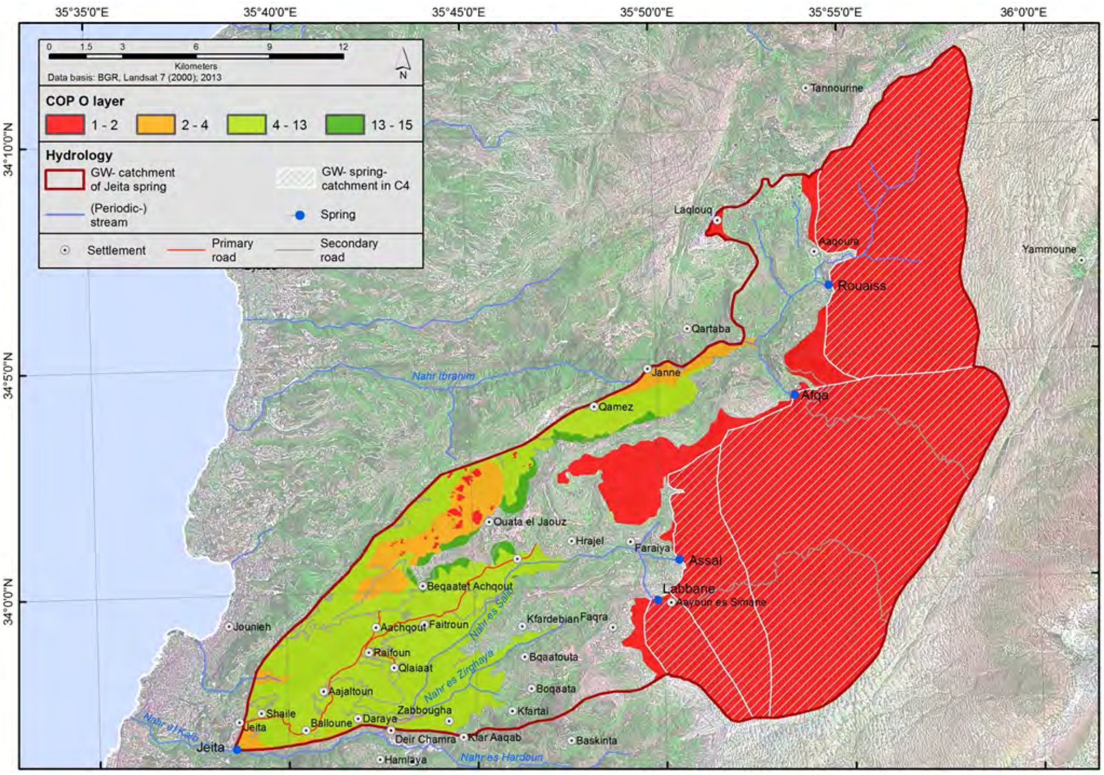

Figure 65: Final O layer

ANNEX 3: Documentation of P layers in ArcGIS

3.1 Layer XIII

Layer XIII is established by using *Reclassify (3D Analyst)* and by adding the reclassification data according to *Table 13*.

The reclassified raster file is converted into a vector file by using *Feature to Raster (Conversion)*, selecting *Field*, which includes the P_Q value. The respective layer is clipped according to the extent of the COP area (J4, partly J5, and C4) by using the *Clip (Analysis)* tool.

The final P_Q layer is displayed in *Figure 66*.

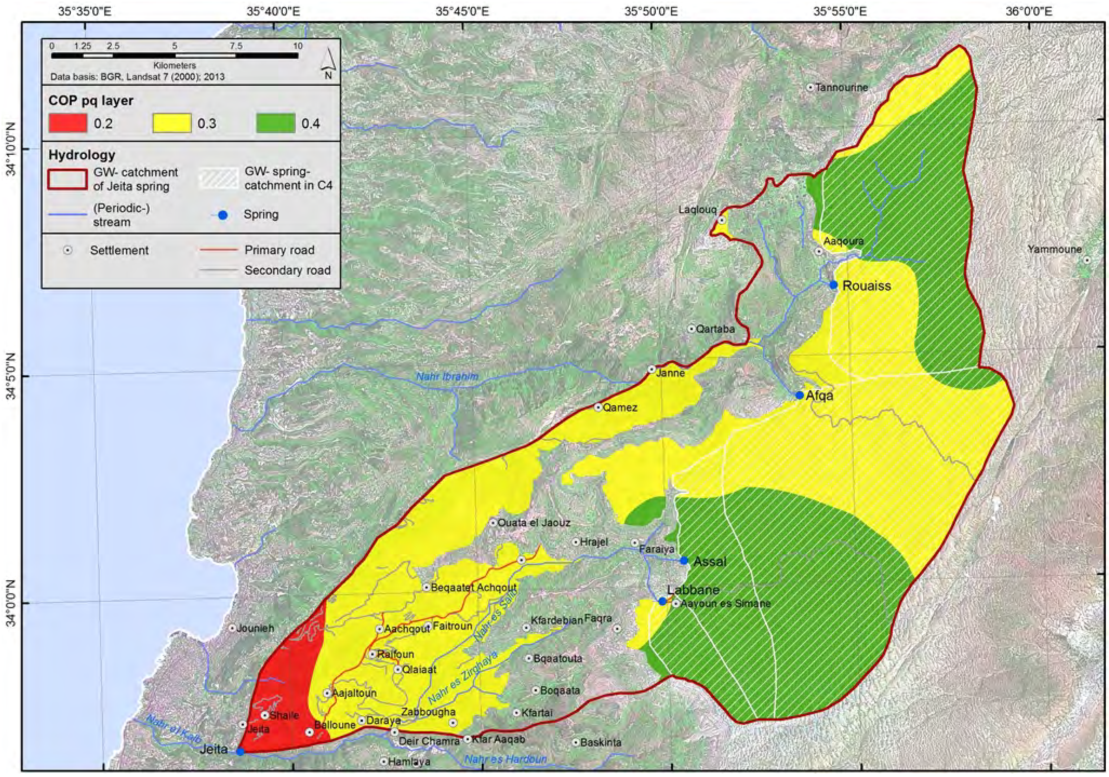

Figure 66: Layer XIII

3.2 Layer XIV

Layer XIV expresses the rainfall intensity, which is established by dividing the rainfall distribution raster dataset by the value *80* (*Table 14*) (*Raster Calculator (Spatial Analyst)*) (*Figure 67*).

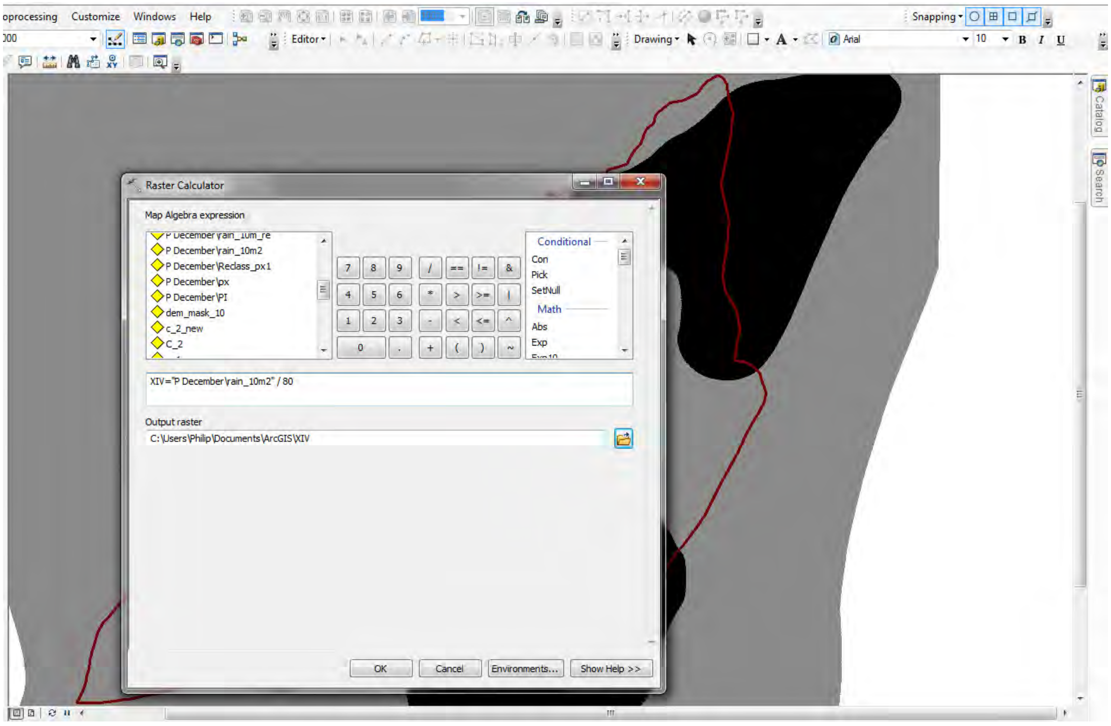

Figure 67: Raster Calculator Spatial Analyst in ArcGIS

By using the *Reclassify (3D Analyst)* tool, the rainfall intensity raster dataset is classified according to *Table 15*. The respective layer is clipped according to the extent of the COP area (J4, partly J5, and C4) by using the *Clip (Analysis)* tool.

The generated output indicates existence of classes 0.4 and 0.2 (*Figure 68*).

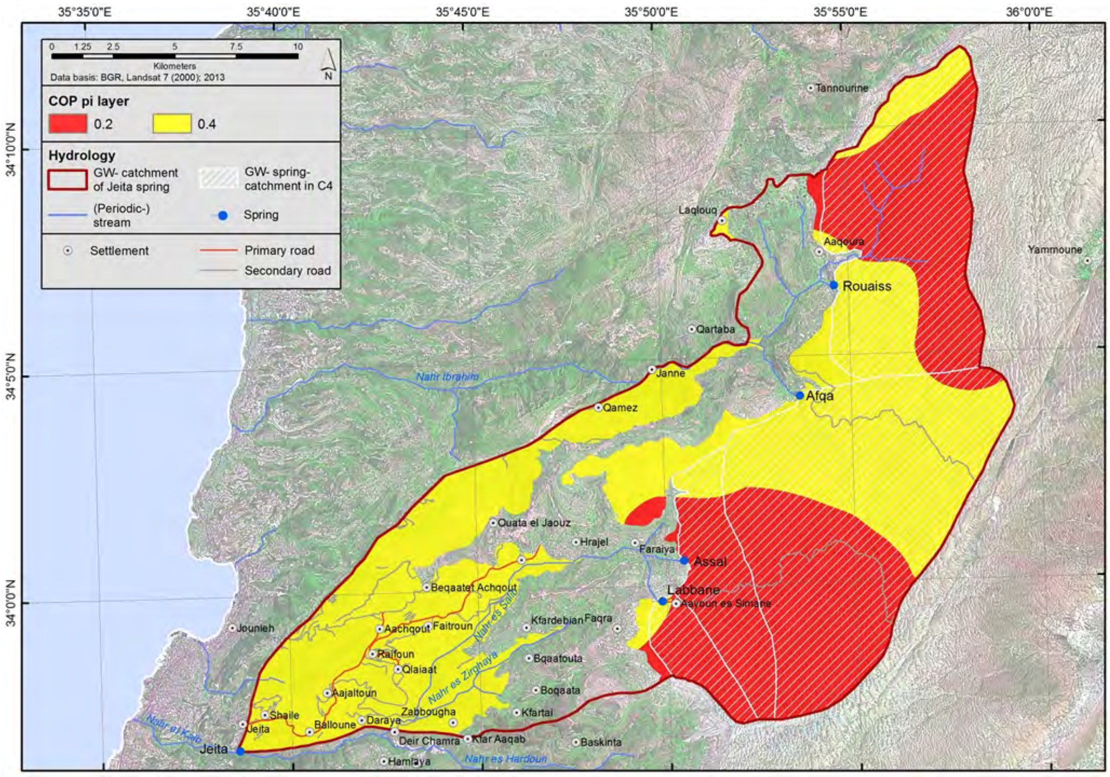

Figure 68: Layer XIV

3.3 Final P Layer

The final P layer is the sum of layer XIII and XIV, established by using the *Raster Calculator (Spatial Analyst*) tool (*Figure 69*).

The final P layer is displayed in *Figure 70*.

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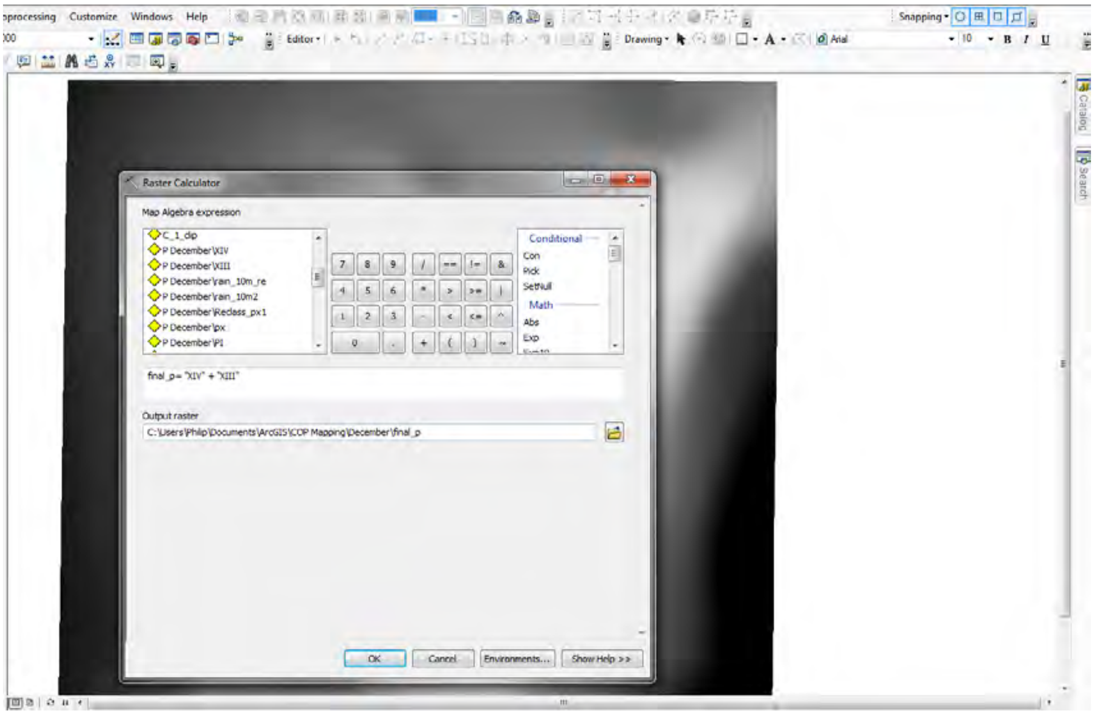

Figure 69: Summation of layer XIII and XIV by using the Raster Calculator in ArcGIS

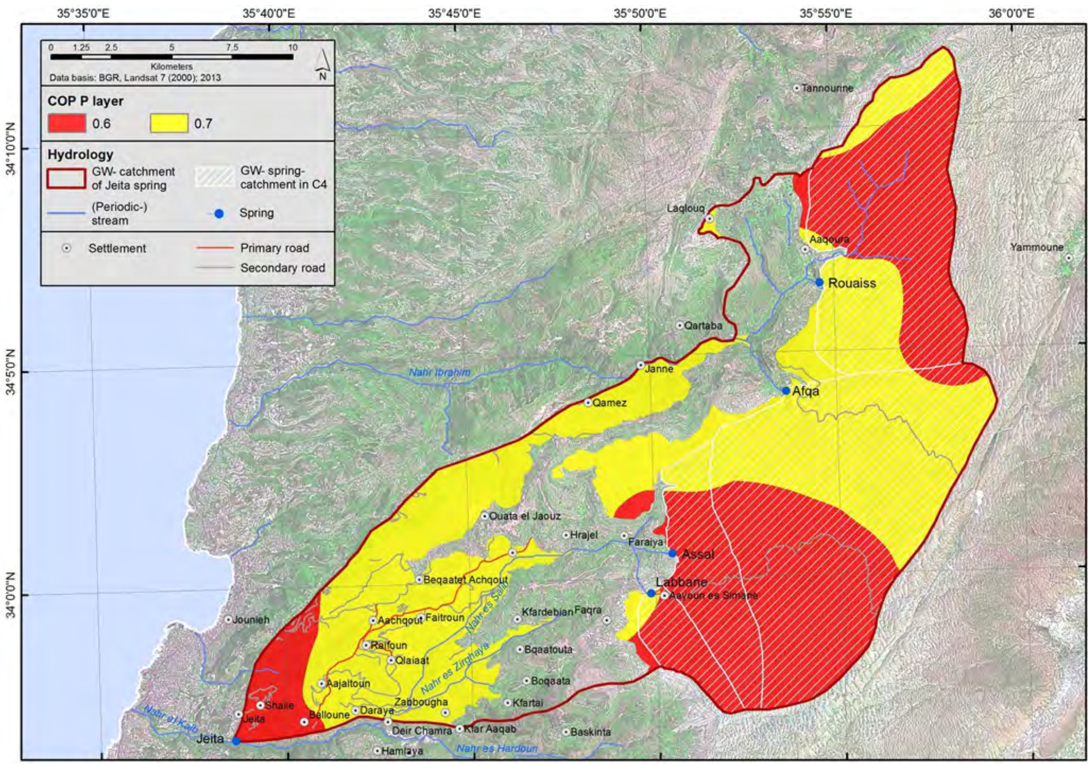

Figure 70: Final P layer

ANNEX 4: Documentation of S layers in ArcGIS

4.1 Layer IV

The stream buffer of 500 meters is clipped according to the extent of the aquitard by using the *Clip (Analysis)* tool in ArcGIS. A new *field is added*, using *long integer*, edited by a value of 0.

The output is converted into a raster file by using *Feature to Raster (Conversion)* while selecting *Field,* according to the sg value.

The final sg layer is displayed in *Figure 71*.

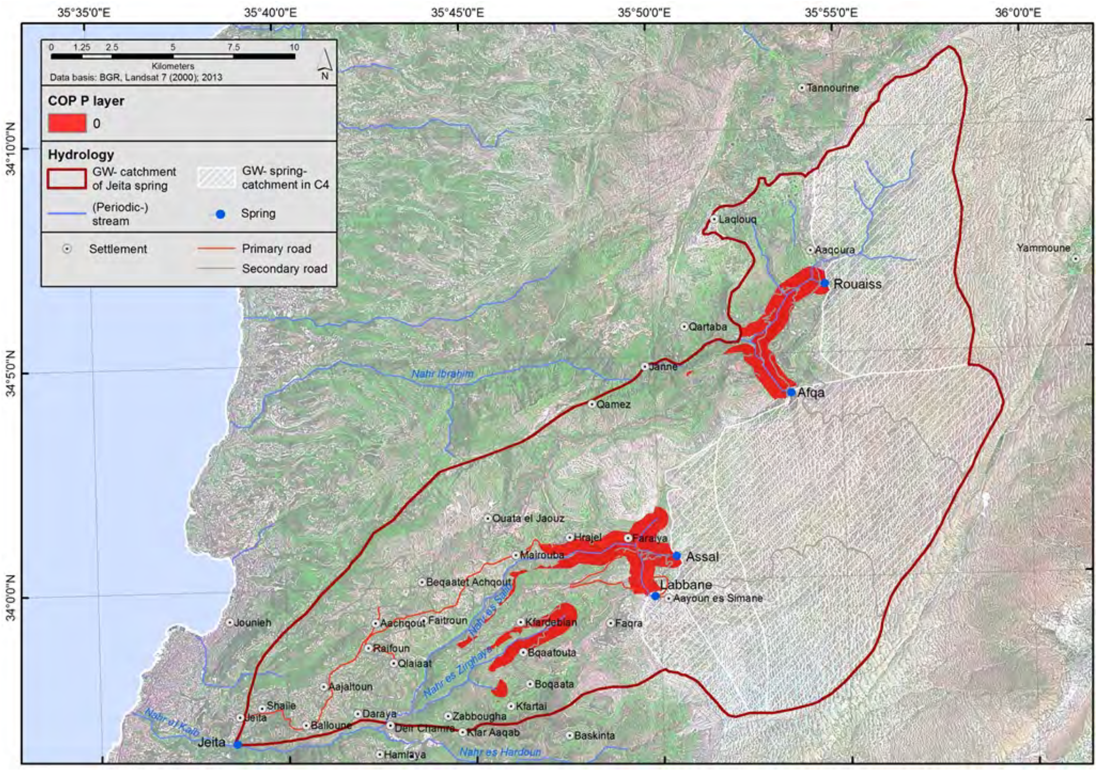

Figure 71: Final S layer

ANNEX 5: Documentation of COP layer in ArcGIS

The final COP map is calculated by multiplication of the final C-, O- and P layer by using the *Raster Calculator (Spatial Analyst)* tool (*Figure 72*).

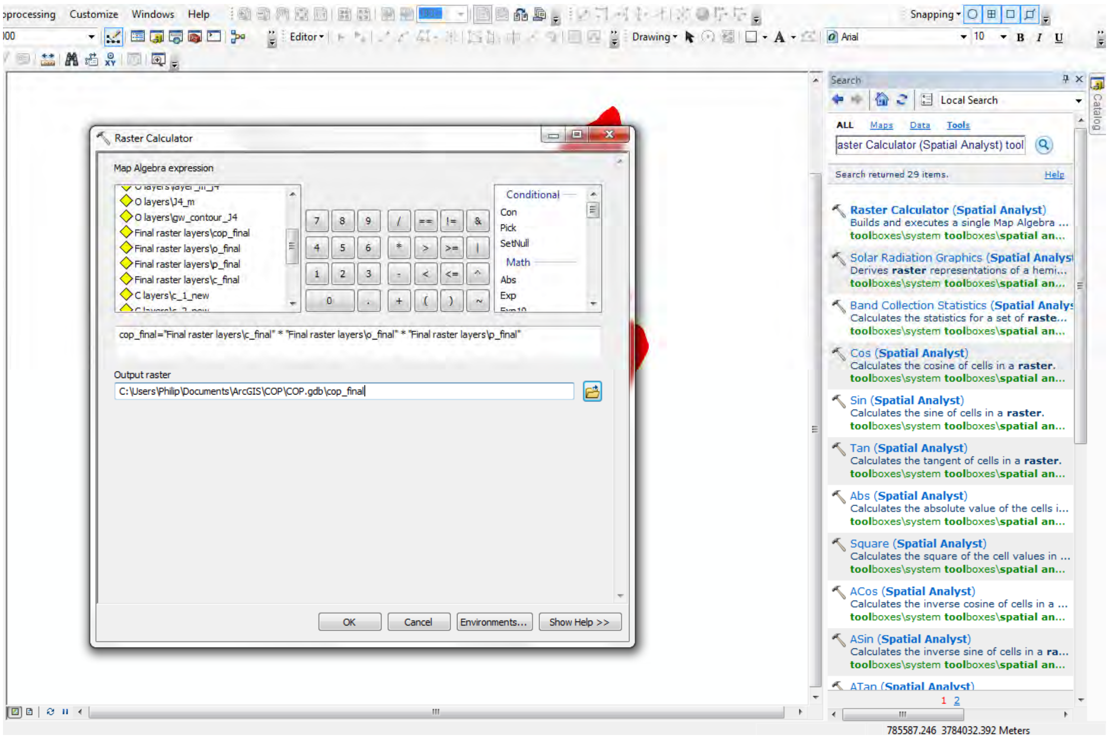

Figure 72: Multiplication of layer C, O and P by using the Raster Calculator in ArcGIS

The raster output is reclassified according to VIAS et al., 2006 by using the *Reclassify (3D Analyst)* tool. Further, the S layer is integrated by using the *Mosaic To New Raster Data Management* tool in ArcGIS and transformed into a vector file by using the Raster to Polygon (Conversion) tool.

As stated in chapter 4, the vulnerability of the Jeita cave is included in the final vulnerability map. This is done by using the *Buffer (Analysis)* tool (250 meter) to calculate the vulnerable area of the tunnel system. This shapefile is used to cut the respective extent of the cop-shapefile by using the *Erase (Analysis)* tool. Finally, the buffer-tunnel shapefile is loaded into the erased cop-shapefile and merged with the object class of the highest vulnerability.

Figure 73 displays the respective extent of the tunnel.

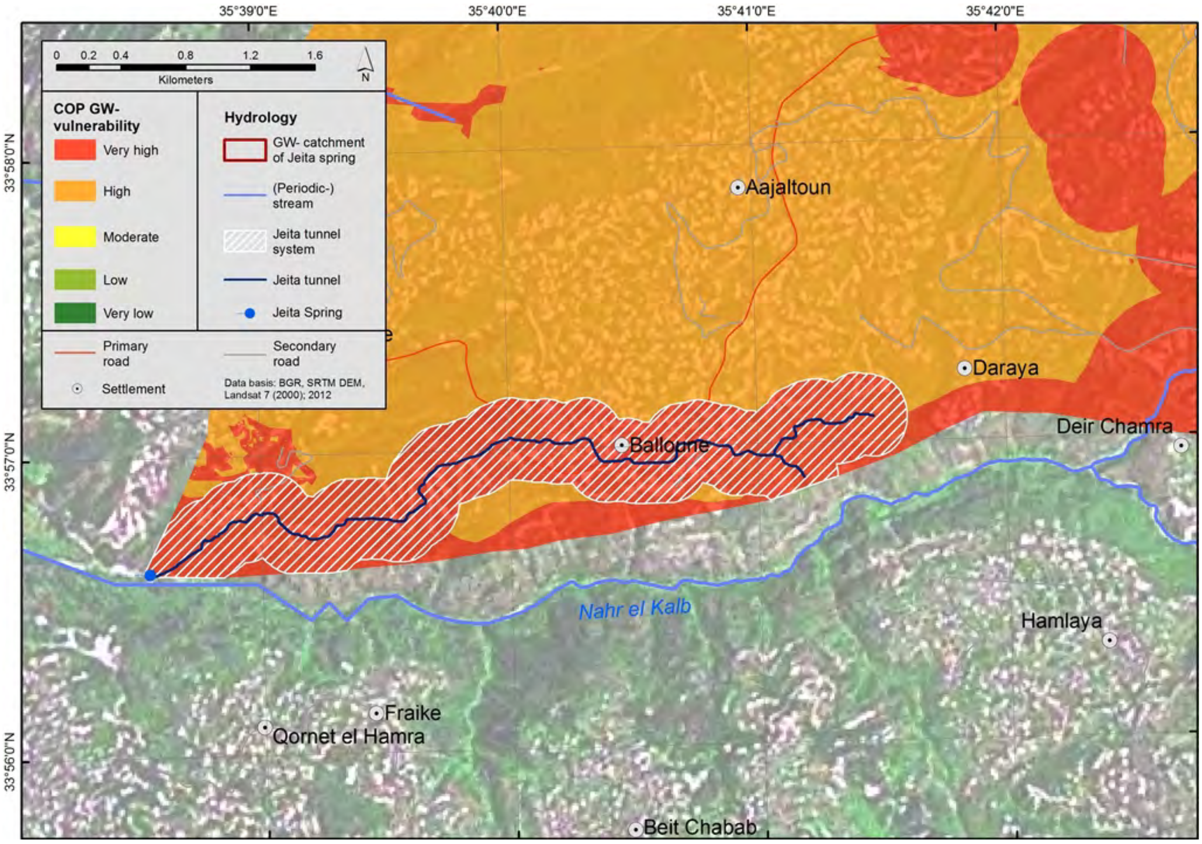

Figure 73: Extent of the Jeita cave system and its vulnerability

The final COP map is displayed in *Figure 74.*

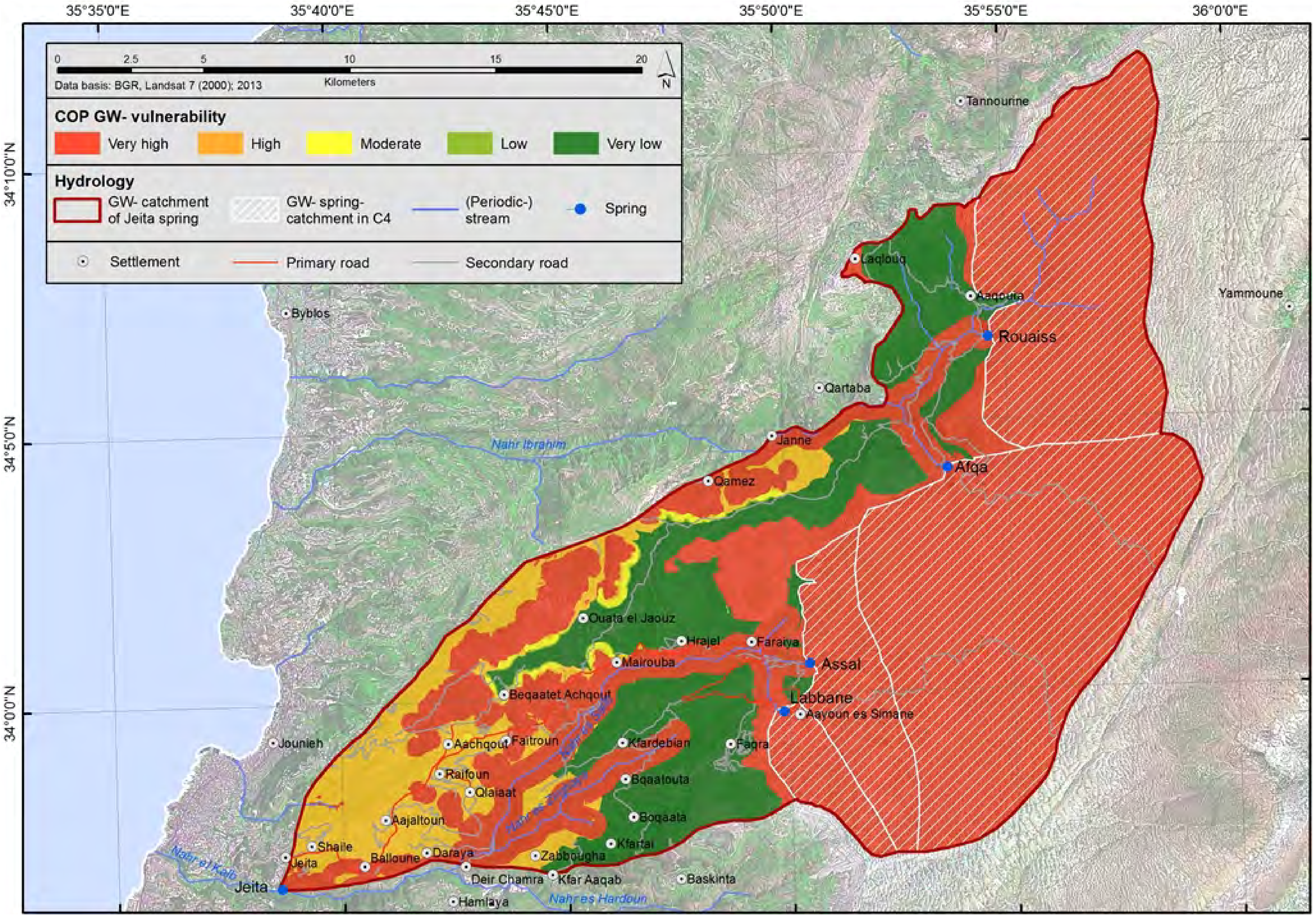

Figure 74: Final COP groundwater vulnerability map

ANNEX 6: COP GW vulnerability and GW hazards

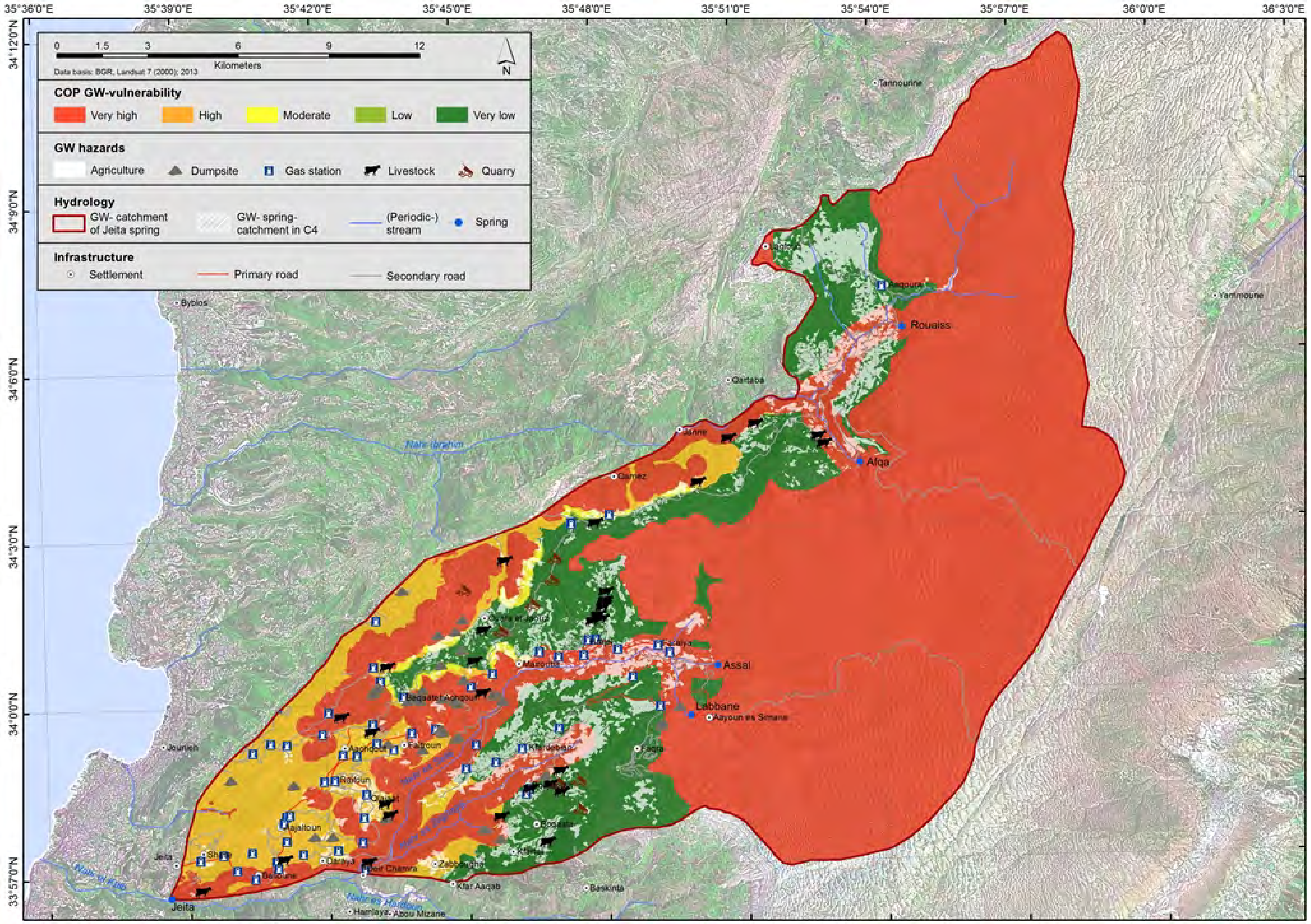

Figure 75: COP GW vulnerability and point- and nonpoint GW hazards

ANNEX 7: GW Protection zones

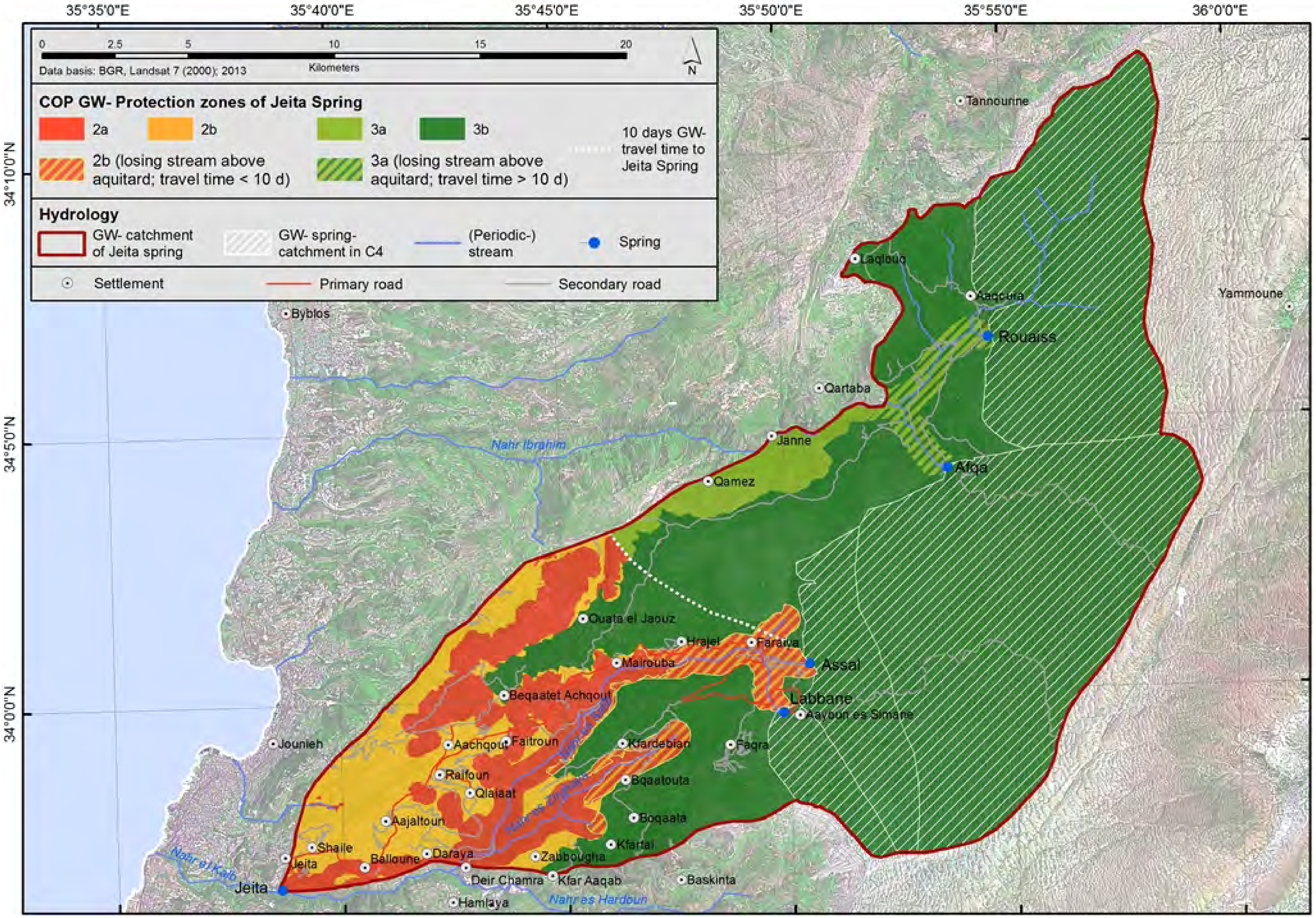

Figure 76: Protection zones 2a, 2b, 3a and 3b for Jeita spring

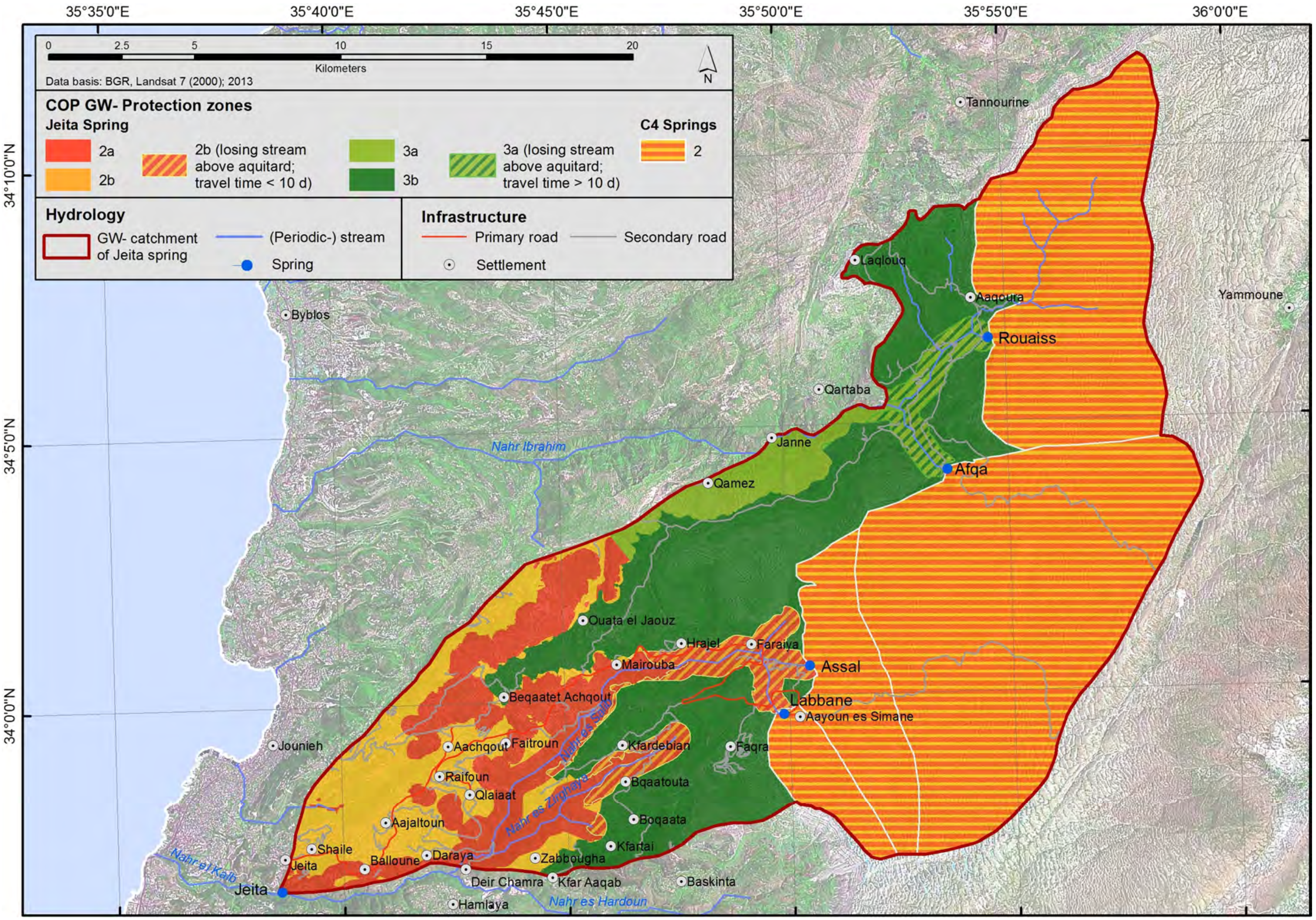

Figure 77: Protection zones 2, 2a, 2b, 3a and 3b for Jeita, Afqa, Assal, Labbane and Rouaiss spring