MOBILISATION DES EAUX SOUTERRAINES POUR L'ALIMENTATION EN EAU POTABLE A ZAHLÉ – LIBAN

AIDE À LA DÉCISION

COOPERATION ENTRE

- LA MÉTROPOLE MONTPELLIER MÉDITERRANÉE
- LE DÉPARTEMENT DE L'HÉRAULT
- LA RÉGION OCCITANIE
- L'AGENCE DE L'EAU RHÔNE MÉDITERRANÉE CORSE ET
- L'ÉTABLISSEMENT DES EAUX DE LA BÉKAA

Assessment of Soil vulnerability and potential for rain water management in Zahle area

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1. Introduction

Zahle is the center of Mouhafazat Bekaa and consists of 17 main cadastral units (Annex 1-Figure 1). Zahle area is distinguished by its dynamic development both horizontally and vertically. The population growth and commercial/industrial activities implies altitudinal and horizontal expansion towards traditional agricultural lands located in the northwest and zones witnessing risk of land slide and soil erosion in the southwest part. All these risks are added to the potential damage from the industrial zone located in the eastern part of the city stretching from foot slope towards the fertile plain. Land use map from the new satellite image (2018) showed city expansion and the presence of several polluting activities like poultry and livestock husbandry, hospitals, and other point sources of contamination, which can be added to the diffuse sources like energy and transport as well as the agricultural activities. Previous studies showed fast movement of soluble pollutants from the soil surface to the groundwater for less than 3 years (Müller and Darwish, 2004; Darwish et al., 2000). Some areas of the plain, like Fayda, show higher vulnerability due to water stagnation during winter, shallow water table during the dry season with a residence time less than one year, for the percolation rate and soluble pollutants transfer towards the groundwater.

The geomorphological features of the Berdaouni Watershed represent a variety of low to medium permeability lithological formations, covered by quaternary substratum and semi permeable, fine gravely, sediments forming the soil cover. The soil types have different textures from clay to loam, which can multiply the risks of pollutants transfer towards the groundwater (Figure 2). An additional factor is added to this picture, which is the shallow depth of water table in the footslopes/Bekaa plain areas (Figure 3).

Several studies assessed the vulnerability of the agricultural soil-groundwater system in Central Bekaa to pollution with heavy metals. The oldest was undertaken in late nineties (Darwish et al., 2000) showed increased level of heavy metals and nitrates in the shallow water table, while the deep groundwater (75-150 m), usually used for irrigation witnessed good protection from heavy metals. The soil permeability, however, provide a weak protection from soluble pollutants like nitrates which are soluble and move with wetting front indicating excess nitrogen fertilizer application and over irrigation raising the need for water accounting in the plain (Figure 4). A recent study confirmed the hazards of heavy metal contamination and fragility of the mountain ecosystem and Bekaa plain (Darwish et al., 2008, 2008a; Darwish, 2018) and analyzed the threats to ecosystem functions and services caused by biotic and abiotic factors (Abdallah et al., 2018).

The project supported by BGR (1997-2002) in cooperation with ACSAD and CNRS-Lebanon, focusing on Central Bekaa area, mapped the groundwater table depth and followed the fate of soluble chemicals in the soil-groundwater continuum (Darwish et al., 2004). Using the K-tracer technique, these field works showed relatively high speed of soluble pollutants leaching through agricultural soils and consequent accumulation in the groundwater (Möller et al., 2002; Darwish et al., 2011). The mentioned studies emphasized the vulnerability to contamination of the soil-groundwater system in the Central Bekaa Plain. In this study, we prospected the hazards related to soil pollution from different sources of contamination and assessed the potential transfer of pollutants towards the groundwater using the soil saturated hydraulic conductivity.

2. This study, its objectives and scope of work

This study is contracted in order to bring knowledge and understandings, about soil risks and opportunities regarding water and groundwater management, to urban planners and city council representatives in charge of the "Zahle Development Plan".
The aim of this study is thus to assess the state of soil resources:

- Their abilities in term of local rain water harvesting that might allow ecosystem restoration and/or green public areas
- Their vulnerability to landslides, erosion and pollution that might undermine the quantity and quality of surface water and groundwater resources. Soil erosion can reduce the capacity of the soil to intercept rainfall and flowing water. Reduced recharge and sediment deposition alter water resources. Natural recharge can dilute the concentration of soluble pollutants found in the groundwater. Sediments can bring chemicals and pesticides downslope into lowlands and open channels and contaminate the soil and water.

The scope of work of the study includes:

- Evaluate soil permeability for qualitative and quantitative water protection and potential transfer of soluble pollutants to groundwater.
- Assess potential rainwater immediate capture and filtration (harvesting within the soil) in relation to soil quality; in order to alleviate non-point or diffuse pollutions downstream.
- Assess the environmental hazards like soil erosion, landslide and soil vulnerability to pollution.

This study covers Zahle municipal territory but also focuses on the three particular areas that are more prone to urbanization in the near future. These areas are the hills of Bhoucha (N1), Dhour Zahle (N2) and the Industrial area neighborhood tagged with N3 (Figure 5). Hence, comments on maps and recommendations dedicated to these areas would be given through the document and in its conclusions.

This study is expected as a tool and toward a more integrated water management, preparing an evolution toward a systemic or holistic approach; to be undertaken within a consideration of ground and surface water as related -or unique- resource(s).

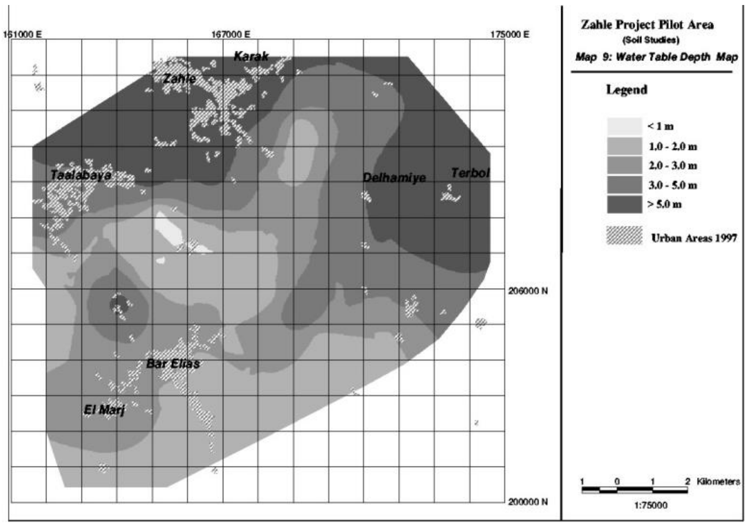


Figure 3. Water table depth in Central Bekaa
Source: 2002 BGR-ACSAD-CNRS Project

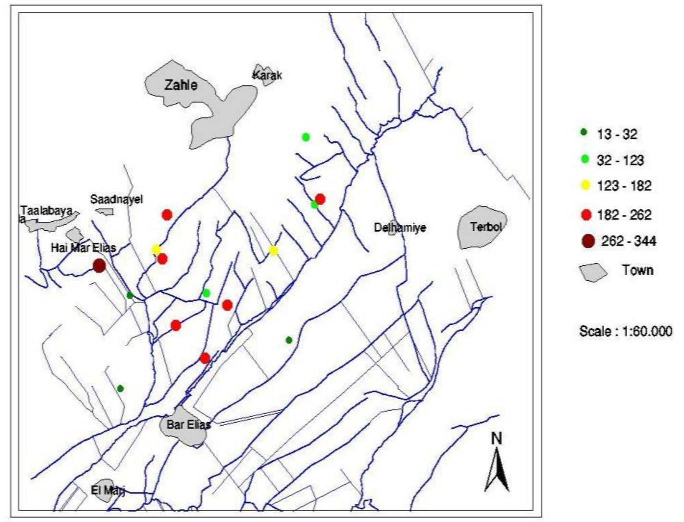


Figure 4. Nitrate concentration (mg/l) in the shallow water table of the central Bekaa Valley (Source: 2002BGR-ACSAD-CNRS Project)

3. Methodology

The work is based on the measurements and calculation of soil permeability in the City of Zahle. Mapping of soil permeability and assessment of permeability and water retention capacity of the soil-geological system is necessary to evaluate the potential risk of transfer of pollutants towards the groundwater. Soil permeability was be based on extensive field measurement for different soil types in 2019. A field minidisc infiltrometer was used to measure saturated hydraulic conductivity of the surface soil layer in the field (Figure 6). The results were used to calibrate the USDA approved methodology of measuring soil hydraulic conductivity using a model software (SPAW), which incorporates soil texture, gravel content, organic matter content and compactness (bulk density) to estimate soil permeability. Soil data from the soil map of Lebanon at 1:50,000 scale (Darwish et al., 2006) was used as background information to calibrate with field measurements and assess the saturated hydraulic conductivity of the subsoil layers.

According to USDA, the soil permeability mapping is classified into three main class categories: A. High permeability with high sand or gravel content and saturated hydraulic conductivity above 4.5 mm/hour; B. Moderate permeability soil (suggested) with a clay content below 20% and sand content above 50% and saturated hydraulic conductivity ranging between 2.1 and 4.5 mm/hour; and C. Weak permeability soils with clay content above 40% and sand content below 50% and saturated hydraulic conductivity below 2mm/hour. The latter class might accelerate surface runoff and bring flooding risks. The second permeability class is proposed in this study to cover the terraced red soil developed on permeable hard limestone. This soil is characterized by clay and clay loam texture promoting water retention and moderate permeability promoted by agricultural practices or soil morphology that allows retaining water in the soil for better conservation - either by feeding irrigation or by percolating slowly towards natural ground reservoirs. High permeability class has good potential for water recharge but it can transfer soluble pollutants towards the saturated soil layers and groundwater.

The integration between slope, soil typology and the structure and nature of soil layers (texture, gravel content, organic matter content), and infiltration based on measurements of top soil layer and calibration of the USDA methodology (USDA, 2007) for the estimation of soil infiltration rate based on pedo-transfer function, flow direction, sources, contaminants type, groundwater vulnerability and flood risks. Based on texture and gravel content, the USDA methodology classifies the soils into four groups (A-High, B-Moderate, C-low and D-very Low). Referring to our field measurements and the calibration made with the USDA approach and because we included also the organic matter content and rock type, and to gain more spatial details and accuracy we subdivided the soils into five hydrological classes: Very low (<2 mm/hour), Low (2-3.5 mm/hour), moderate (3.5-4.5 mm/hour), high (4.5-5.5 mm/hour) and very high (>5.5 mm/hour).

Soil erosion was assessed based on the Universal Soil Loss Equation adapted to the Lebanese and more specifically to the Zahle conditions. Parameters like topography and slop gradient, soil texture, soil depth, organic matter content, land cover and land use were considered in the adapted models (Annex 2)Each parameter was divided into five classes (rate) and given a weight according to its significance in soil protection from erosion. Soil vulnerability to pollution was assessed based on the proximity and pressure exerted by different land use classes.
Other environmental hazards like vulnerability to landslides were mapped using the geo-hydrological approach implemented in the Center for Remote Sensing CNRS to map natural risks. Lanslide map was done using the value bi univariate statistical method. They consider land stability in relation to surface geology, stratification, land cover and land use as well as rainfall pattern.

In the overall assessment done for Zahle pilot area, the following elements were used: Dubertret geology map and updated geology map (Figure 7 and 8), soil map produced by CNRS, new land cover and land use map, topographic map, Digital Elevation Model, Land use map update from URBI, water canalization (including irrigation) map from the municipality's updated cadastral map, Zahle water infrastructure plan map from BTD, Naji Kehdi's Zahle maps from the annexes of his book, documents on public wells from BWE, etc.

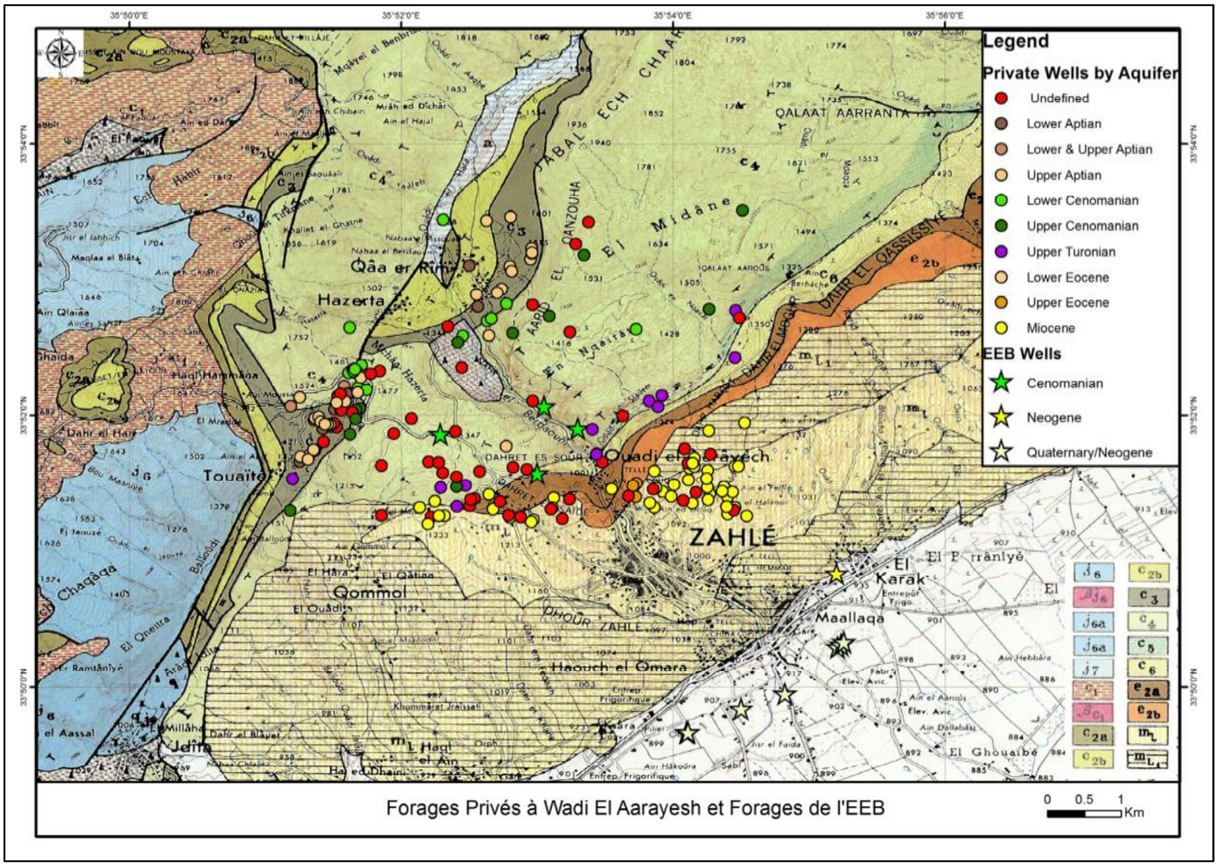


Figure 7. Distribution of private wells and EEB wells on the geology map of Dubertret (Source: BWE - APIEU 2018)

4. Results

A. Groundwater pollution Risks assessment:

A.1. Mapping of groundwater vulnerability

The well location was integrated with the sources of contamination to delineate a protection zone based on integrated assessment of the soil-groundwater pollution risks to cover all sources of pollution including human activities and agriculture.

A.2. Mapping of the sources of pollution.

The sources of contamination in the city of Zahle are the industry (including pollutant artisanal activities), the settlement and refugees' areas, chicken and livestock farming, hospitals, fuel stations, WWTP, solid waste treatment facility and landfill and agriculture. Based on the recent land cover map of Lebanon (CNRS), the dominant land use in the Zahle area is agriculture, which exceed 50% of the area of study (Figure 9).

The urban zone is 61.4% of the artificial area. Human pressure is associated with traffic, energy consumption, solid and liquid waste disposal and management. The relative proportion of different land use categories confirms the dominance of human and industrial infrastructure (Figure 10). Based on the recent land cover map of Lebanon (CNRS), the industrial and commercial land use exceeds 19.7% of the area with oil, trace metal and organic waste disposal and emission.

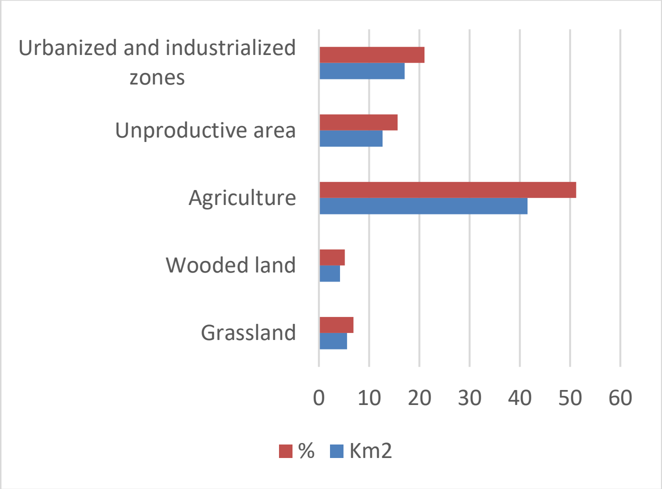


Figure 9. Relative land use areas and proportion of major sources of contamination within the City of Zahle

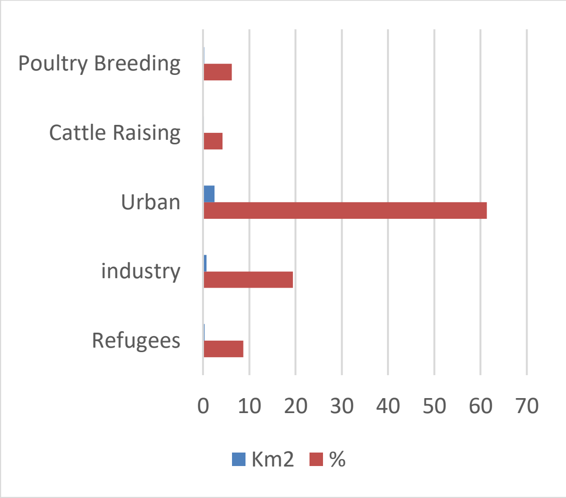


Figure 10. Land use - land cover in Zahle area (Source: Land cover map of Lebanon, CNRS)

The sources of contamination are spread all over the city area, notably urban expansion with a bulk in the area surrounding the Berdawni River. The area of focus N 1 is subject to natural hazards like terrain instability and erosion beside increased appearance of gas stations and poultry farms. Focus area N2 is more subject to expanding urban and farming activities. Zone N 3 is closer to the industrial area and includes part of the plain with arable soils subject also to pressure from refugees' camps, cattle raising and potential flood, thus is subject to increased human pressure. Camps of refugees and animal production are spread also on other arable lands (Figures 5 and 8).

A.3. Mapping of soil permeability and assessment of the permeability and water retention capacity of the soil-geological system.

A.3.1. Upper soil horizon

The upper soil horizon varies in depth between few centimeters on the eroded slopes and 30 cm in the plain where farmers apply recurrent plowing. This superficial soil layer is enriched with organic matter, usually not compact and loose structure, notably if the soil is cultivated and amended with organic fertilizers. The classification of the hydraulic conductivity of the plow layer showed large area with low hydraulic conductivity notably in the eroded hills surrounding Zahle from the North and West and in the plain with compacted surface soil layer to the eastern border of the area (Figure 11). However, the central part of Zahle, especially near the lower borders of the main city and whole industrial zone is characterized by moderately low and moderately high infiltration. This area receives the pressure from legal and illegal settlements and the animal production sector.

A.3.2. The middle soil horizon

In the second layer with depth reaching 60 cm, the most permeable area is enlarged and spread toward the plain to reach the water treatment plant and encompass larger input from polluting sources, city with higher impact towards the speed of contaminants transfer (Figure 12).

A.3.3. Lower soil horizon

The lower sol horizon between 60 cm and 100 cm shows larder area of low hydraulic conductivity that can halt the speed of pollutants transfer. However, the northern and southern parts of the area of study show moderate hydraulic conductivity with contamination risk from the industrial zone, massive poultry breeding and illegal settlements (Figure 13).

A.4. Analysis of soil exposure to contamination and transfer of pollution to the public wells of the Bekaa Water Establishment (BWE) in Zahle

Mapping of the overall exposure of the soils of Zahle area to the transfer of contaminants from different sources of contamination like farming, industry, hospitals, sewage water was done. The model was based on the integration of the saturated hydraulic conductivity of the 3 studied soil layers, type of lithology and its permeability, topography and surface flow direction from outside the perimeter of study (Figure 14). The analysis of the surface flow direction pattern in the upper Zahle sub watershed showed a dense and short complex drainage lines which end up in the Berdawni River with an outlet point at the north western border of the area of study.

This area with the surrounding low hydraulic conductivity is suitable for clean water collection infrastructure. The areas with very low and low hydraulic conductivity marked on the map in dark green and green colors in the upper watershed are suitable for water storage for reuse in irrigation while areas with moderate and high transfer rate marked in yellow and orange are more suitable for groundwater recharge (Figure 15). The suitable areas for water harvesting were circled in dark circles (Figure 14). However, additional field investigations and inspections must be done to check the slope, land use and economic feasibility. Three of the BWE well are located in the high permeability zone (Wells 1, 2 and 3), and four wells are located in the moderate soil permeability zone (Wells 4, 5, 6 and 14). Thus additional precautions must be exerted to protect and prevent polluting activities in the immediate surrounding of the wells, whose depth varies between 125m and 200m and are excavated on quaternary/Neogene geological formation, with adequate consideration of protection zones.

The lower part of the area of study, notably Fayda witness shallow water table, thus land use in the area must be controlled to avoid urban and industrial expansion and reduce the input of chemicals and prevent the soil-groundwater from contamination with nitrates, heavy metals and pesticides. This can be done through the shift to integrated agricultural production and gradual introduction of organic farming.

Results revealed a significant area of the Zahle City with high and moderate vulnerability to pollution with surface flow from natural (soil erosion, landslide) and manmade hazards. The central part of the area of study is the zone the most exposed and most vulnerable to the input of contaminants from hospitals, sewage water, gas stations, refugees and animal husbandry (Figure 16)***.***

The lower eastern part of the Zahle area is most affected by industrial activities. The soil vulnerability to contamination based on the soil vicinity to different land uses (urban, industry, animal husbandry) and sources of contamination was produced to highlight the zones with potential soil contamination **hazards** by pollutants coming from emissions and effluents. To be transferred towards groundwater, pollutants must reach first the soil **surface**, which is the main element of landscape and the leading factor of agricultural production, beside its role as filter protecting water quality. Mapping of groundwater vulnerability to contamination showed 41% and 30% of the area of study to have **high and moderate hydraulic conductivity** (Figure 17). Focus areas 1 and 2 are located mainly on very low and low hydraulic conductivity, which suggests lower risk of soluble pollutants transfer to groundwater. However, this is associated with higher exposure to erosion and landslides. The management of this area must consider the improvement of drainage conditions and slope stability for landscape conservation. Water harvesting suggest the formation of earth reservoirs with advantage of low permeability resulting in lower infiltration losses (Figure 14). Focus area 3 is mostly spread over moderate and high hydraulic conductivity which suggest controlled land use due to higher sensitivity to pollutant transfer to the subsoil and contamination of aquifer.

Indeed, the statistical analysis showed more than half of the territory to be exposed to contamination risk caused by exposure to sources and remarkable percolation rate of soluble pollutants towards the water table and deep groundwater, notably is focus zone 3 (Figure 17).

A.5. Mapping of existing wells and contamination risks

The majority of the BWE wells, spread in the upper Zahle area, are located within the very low and low soil exposure to pollutant transfer (Figure 15. However, six wells in the central part of the study area are located within the area with high hazard of contaminants transfer. This requires special measures to prevent pollution like establishing a well-defined protection zone with strong rules of land use and practices that do not undermine the quality of recharged water.

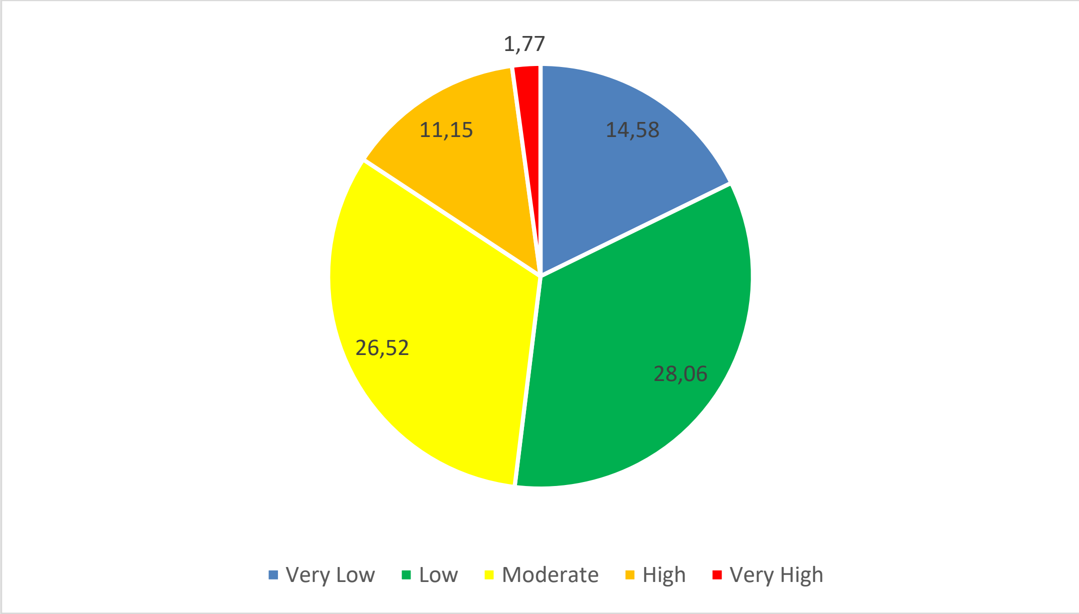


Figure 17. Exposure of land use categories of Zahle city to contamination

Land use in the surrounding of the targeted 15 public wells consists in dominance of urban and industry beside the highway in the lower wells versus the dominance of natural land cover in the wells located in the upper hills of city (Figure 18).

The surface area of each land use category was calculated to figure out the areas which will be subject to controlled management depending on the risk imposed by the corresponding land use. The dominance of industrial sources of contamination are identified in the vicinity to wells 4, 5 and 6 (Figure 19). This land use might reject trace elements in the air and in the open channels. Wells 1 and 2 show prevalence of medium and low density urban fabric around them, which represent the main source of solid and liquid wastes. Field crops prevail near well 1, representing a source of agro chemicals (nitrates, pesticides, herbicides).

Wells number 7 and 8 reveal the dominance of grassland and field crops, which facilitate the protection from potential sources of contamination in case the future land use will remain unchanged or controlled. Wells number 10-13 represent fruit trees land use while wells 9 and 14 show dominance of bare rocks. Well N 15 represents a special case due to the dominance of quarrying activities beside its location. Due to the potential use of explosives in the process of mineral extraction.

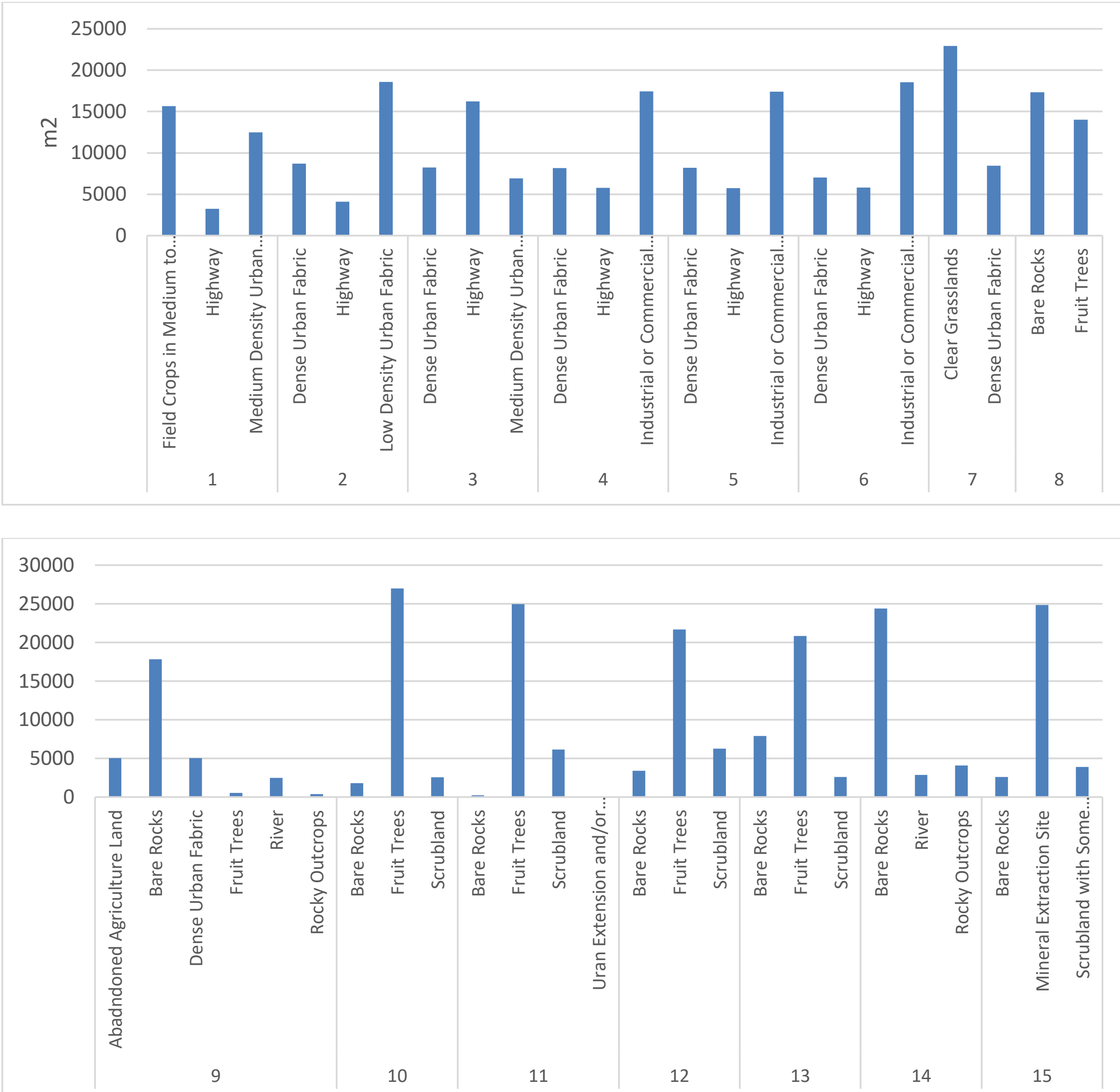


Figure 19. Land use in the surrounding of BWE wells in Zahle city

B. Natural and manmade hazards

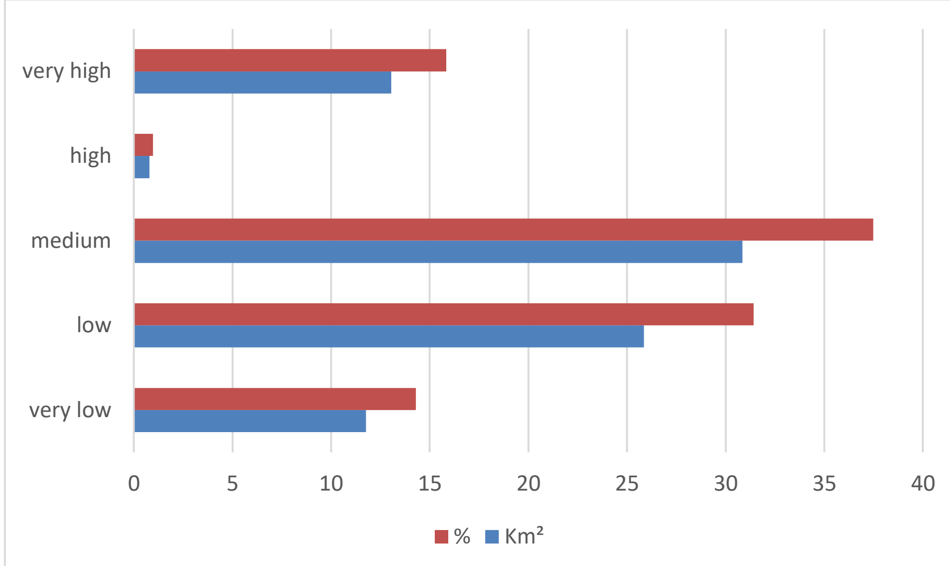
B.1. Flood Hazards

Building on the CNRS study on flood risk assessment (Abdallah et al., 2013), as well as updating the Land Use\Cover map (LUC) of 2017 (CNRS, 2017) showed a significant part of the area of interest N 3 to be prone to flood in the southern part of the study area, partly reaching the lower limits of the industrial zone (Figure 20). The flood can bring different quality water into the plain which can contaminate the surrounding soils by non-treated waters, farming and industrial effluents dumped into the Litani River. Unless the river is cleaned from different source of organic and chemical pollution, the contamination risks of the soil and groundwater in the area of interest N 3 will remain unsolved.

B.2. Soil Erosion

Mapping of water related erosion hazards was done considering the topography, slope gradient, lithology type and permeability, soil depth, soil texture, soil permeability, and in relation to running water paths and rain-related water accumulation levels, especially within the upper and lower parts of Berdaouni river bed.

The erosion map showed a dominance of low and very low erosion hazard area (38 km^2), located in the foot slopes and level plain (Figure 21). This area is the most prone to accumulation of sediments carried by runoff water from the upper locations carrying pollutants from different industrial and oil related sources.

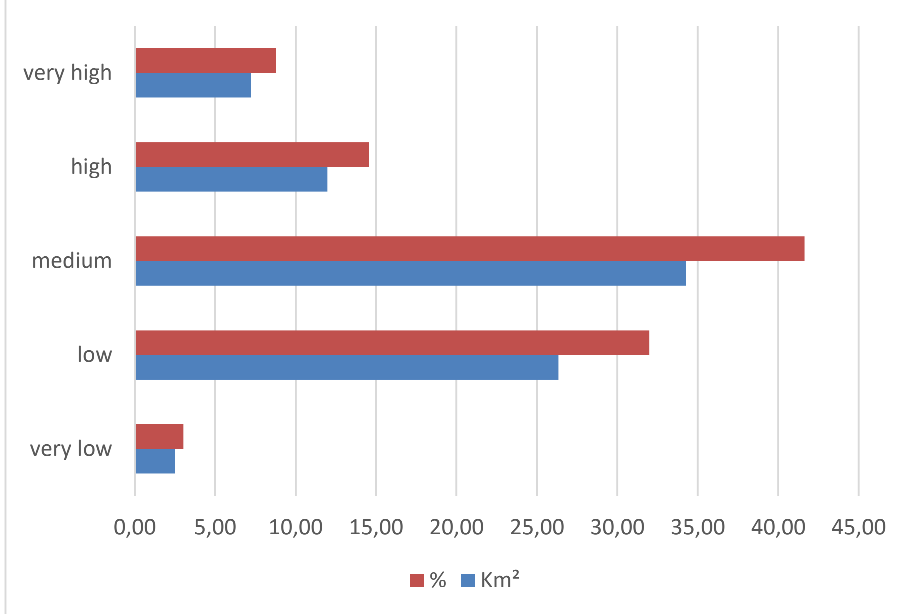


The area of medium erosion hazard is 31 km^2 while the high and very high erosion hazard is limited to 1 and 13 km^2 respectively.

The major part of the upper two areas of interest are located within the very high and medium erosion hazards which bring about the risks related to accelerated runoff as a results of changed landuse from natural into artificial structures associated with chaotic urban expansion. Erosion is associated with transport of eroded material and its sedimentation in the low areas, which can multiply the risk of pollutants transfer.

B.3. Landslides

Landslides hazard was mapped considering the type of lithology and topography which characterize the permeability and infiltration rate and predefines the consolidation rate of soil material under different land cover and land use. The area of study is distinguished by the dominance of medium and low landslide hazard.

The areas of interest 2 and 3 are completely located within a low-very low susceptible to land slide area (Figure 22). The most upper parts of the study area shows high and very high landslide hazard that implies additional measures to prevent risks to human setlement, arable land and infrastructure, notably in zone 1.	

6. Conclusion

This study brought an assessment of the state of soil resources which can be summarized as followed:

- Areas where soils should be protected as much as possible, notably in focus zone 1 and 2, which are the most suitable for water harvesting. These two zones must be however protected from soil erosion and landslides (focus zone 1) and agricultural activities with potential use of pesticides (zone 1 and 2).
- Focus zone 3, which is located at the lower basin representing mainly the agricultural land use receives the impact of all land uses in the upper watershed, thus make it very exposed to pressure from all human and natural factors. This zone is especially sensitive to industrial effluents and to the potential transfer, in relatively short time, of soluble pollutants to groundwater.
- The terraced mountainous areas with fruit tree production must be conserved as anthropic soil formation with high ability for water recharge and velocity reduction that can alleviate the hazards related with intensive runoff.
- Rocky lands with absence of soils or poor soil characteristics make them less important for agriculture but very suitable for wildlife and recreation activities.

Based on these consideration it is recommneded to:

1. Undertake prevention measures to control land use and notably agricultural practices in the upper watershed to protect the soil and water quality and limit their impact on lower watershed. The zone of interest 1 is located within very high and moderate erosion hazards. Mismanaged agricultural activities and building new areas can be associated with enhanced erosion and sedimentation of soil particles carrying polutants to lower land

and soil with high exposure to pollutant transfer towards the food chain and groundwater-surface water.

2. Control the emission and effluents from industry and other sources and permanently monitor their compliance with the environmental laws and regulations. Notably in area of interest 3 where water table is shallow and the soil is used for agricultural production. Farmer practice in this area was described as excessive use of nitrogen fertilizers that reflected on the level of nitrates in the water table which is sufficient for two-three cropping seasons with sole reliance on soila nd groundwater pools. Pesticide application in this area is extremely dangerous because pesticides are soluble in water and can be transferred to food chain and reach the Berdawni and Litani Rivers and threaten public health and ecosystem functions.
3. Set a land use control in the upper part and in the immediate perimeter of the Bekaa Water Establishment wells to prevent farther expansion of urban and industry and additional effluents and emissions that can end up in the recharge water. Runoff water can be collected in green areas to be constituted as soil reservoirs along the high and middle watershed in sites surrounding the drainage lines on soils with low exposure to contaminats transfer.
4. Public wells N 1 and 2 are subject to urban influence while well N 3 is close to highway. These three wells are the most affected by human activities. Wells N 4, 5 and 6 are mostly affected by industrial activities and can be prone to large chemical and organic contamination. Wells 10-13 are located in the viccinity to agricultural areas, notably fruit trees, which usually undergo treatments with pesticides and application of fertilizers. These prcatices must be controlled trough increased farmer's awareness on the fact that you cannot hide a pollution when it starts in the soil or water. Pollutants will eventually reach the lower lands, sources of drinking water and irrigation water. It is kind of a closed circle. Public well N 15 is potentially affected by quarries that can increase the risks of contamination with heavy metals. Wells N 9 and notably 14 are relatively the most protected and thus they must be protected from any sources of contamination.

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Annexes 1:

Figure 1. Location of the Zahle area of study in central Bekaa, Lebanon

Figure 2. Soil textural classes in the area of study (Source: CNRS)

Figure 5. Location map of the three focus areas of study in the city of Zahle

Figure 6. Points of field measurements of soil permeability within the Zahle area.

Figure 8. Detailed geology map of the Zahle area of study (Source: CNRS)

Figure 11. Saturated hydraulic conductivity of the upper, most exposed soil layer, in Zahle area

Figure 12. Saturated hydraulic conductivity in the middle soil horizon

Figure 13. Hydraulic conductivity of the subsoil in the City of Zahle

Figure 14. Surface flow from the upper watershed of Zahle city and suitability for water harvesting drawn over the soil hydraulic conductivity from the combination of all soil layers

Figure 16. Soil vulnerability to contamination in Zahle area based on different sources of contamination

Figure 15. Overall soil hydraulic conductivity with digital distribution of BWE wells in Zahle City

Figure 18. Land cover land use surrounding the BWE wells

Figure 17. Flood prone area in the surrounding of Litani River in the vicinity of Zahle city (Source: CNRS).

Figure 21. Erosion hazards of Zahle area (Source: CNRS)

Figure 22. Landslide hazards in Zahle area

Annex 2. ***Soil-Water Erosion risk in Lebanon***
Parameters and related layers used to assess soil-water erosion risk in Lebanon at a scale of 1/200 000 (Darwish, 2002).