Geographical Information Systems (GIS)

Assessing Vulnerability in Amman - Zarqa Groundwater Basin, Jordan

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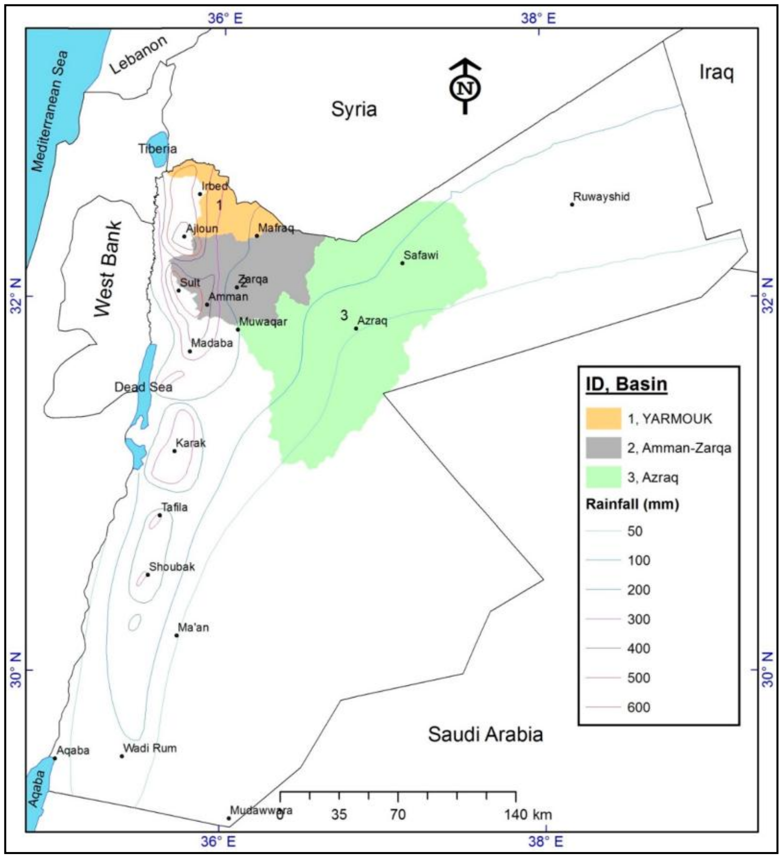
Abstract: *In this era, more pollution is extremely showing up due to various industrial and human related activities, which harmfully affect the main sources for our living, more specifically water which is the most valuable resource for humans and that is mainly obtained from groundwater in Jordan. In this study, different natural factors were addressed and discussed using the "DRASTIC" method including the chemical properties, soil properties and site conditions, to identify the areas with high vulnerability to pollution. However, these diverse factors were fundamentally represented by seven layers including Depth to groundwater, Net Recharge, Aquifer media, Soil media, Topography, Impact of vodaze Zone, and lastly the Hydraulic Conductivity. Using the "DRASTIC" method for the sake of assessing vulnerability in groundwater basins, all these seven layers were assigned with weights and ratings that inclusively calculate the effect of each factor, and manipulate the result by identifying the most vulnerable spots in these basins. Eventually, by addressing the different human-related factors that might threaten the groundwater healthiness in these areas, it was found that one of the spots with very high vulnerability to contamination was having a landfill in almost the middle of the area, and that absolutely show that the basin's groundwater quality is under big threat.*

Introduction

Groundwater in Jordan is considered to be the major source for different uses, either for industrial, agricultural or domestic use. furthermore, the decay in groundwater quality might lead to unpleasant results and may cause serious problems. In the last few years, many countries had the initiatives to apply certain measures of developing land use strategies for protecting groundwater from pollution.



In Jordan, there are three main basins the country depends on for its water requirements, and the most basin that needs more attention because of the high population, and the different industrial and urban activities that are happening around is the Amman-Zarqa Basin, which resides in the northern part of Jordan.

This basin has almost more than 60% of the countries' population, and this indicates the huge responsibility the country has to take, in order to mitigate the pollution in this area in different approaches, for further maintaining and preserving the different natural resources of the country, including mainly the basin's groundwater.

Within the study, there will be a subdivision of the study area into several hydro-geological units with different levels of vulnerability, to further assess the vulnerability of groundwater to contamination taking into consideration the different pollution factors and the human related toxic sources which might ruin these resources.

Problem Statement

Groundwater contamination is on the rise mostly from human-related activities, regarding setting factories and their wastes, pipelines, landfills, residential places and other reasons that may cause pollution and contamination, "DRASTIC" method is used to address and identifies areas where groundwater is susceptible to pollution, and thus finding out which places need more attention due to their high vulnerability, and as a result may lead to more appropriate plans for land development and resources protection, this utilized method is highly flexible and many parameters can be included or excluded to further obtain more accurate and precise results.

Background

Groundwater is the source of water for wells and springs, and it basically fill spaces between particles of soil or between cracks in bedrock. However, the water which are coming from either rainfall or surface waters infiltrate down to recharge the groundwater, and the last destination may be unconfined aquifers or confined aquifers which collect the water in a saturated zone within which water is preserved and do no more infiltration due to the closed surrounded area. As groundwater source is mainly from the ground surface, consequently many aspects might cause contamination to the underground water, by reaching the water table or by getting to the groundwater aquifers.

Different factors cause contamination to the groundwater, some of them are related to the chemical properties of the elements, of which the latter, chemicals may dissolve with the surface water and thus infiltrate down into the ground, other factors are related to the soil formation and properties that eventually have an influence on the amount of water being hold in the soil, and the ability of keeping or moving of percolating water. Different chemical properties levels of solubility, adsorption, degradation or volatility for a toxic element or pesticides may lead to a more contamination possibility of groundwater.

Soil's properties are of an important factor in either leading to a more contamination by allowing more infiltration of dissolved chemicals, or forming a block from letting water infiltrate into the ground, and thus less possibility of groundwater contamination. Soil texture, organic matter content in soil and soil permeability are indicating of how much the soil is able to hold water within its structure or releasing the water and let it infiltrate and percolate down to the groundwater.

Site conditions of how much rainfall rate in this area, formation and structured materials of the underground layers, in addition to the deepness between the surface and aquifer. As areas with higher water tables are more susceptible to contamination and the materials that form the layers differ in their permeability, and thus their ability to inhibit the movement of water and chemicals.

To summarize, a great vulnerability of groundwater can be characterized by the following variables briefed by this short statement:

Pesticides or toxic materials with high solubility along with low adsorption persistence, and a sandy soil with low organic matter, and a site with shallow depth to groundwater, more permeable layers between the land surface and water table, all previous statements with a heavy rain will lead to a more vulnerability of groundwater to pollution.

Methodology

Through the "DRASTIC" method, seven Major layers that have been used in this study including (Depth to Water, Net Recharge, Aquifer Media, Soil Media, Topography, Impact of Vadoze Zone, Hydraulic Conductivity) have been either digitized, brought from various sources or even derived from other layers by different calculations.

One of the layers that has been mainly used in different parts of the research is the elevation, it has been clipped by using the "Data management tools", and as a raster it has been clipped to be compatible with the basin's area through the category of "raster processing" tools. However for using the elevation, Slope layer had to be derived from the elevation layer by the "Surface" tools which resides in the "Spatial analyst" tools. Eventually the layer had to be reclassified to show more appropriate data through the "Reclass" tools which resides again in the "Spatial analyst" tools.

Since most of the layers were not available as layers but as images, therefore, they have been digitized by "ArcGis" by creating different shapes that illustrates those images, and thus been merged into one shape by the "Merge" tool, and to further reclassify these shapes of these layers, new fields were added to the attribute table to re-categorized the different polygons to their different types, and thus filling these tables with suitable values from other trusted researches. Layers that have been totally digitized are (Depth to Groundwater, Soil Media, Impact of Vadose Zone, Hydraulic conductivity).

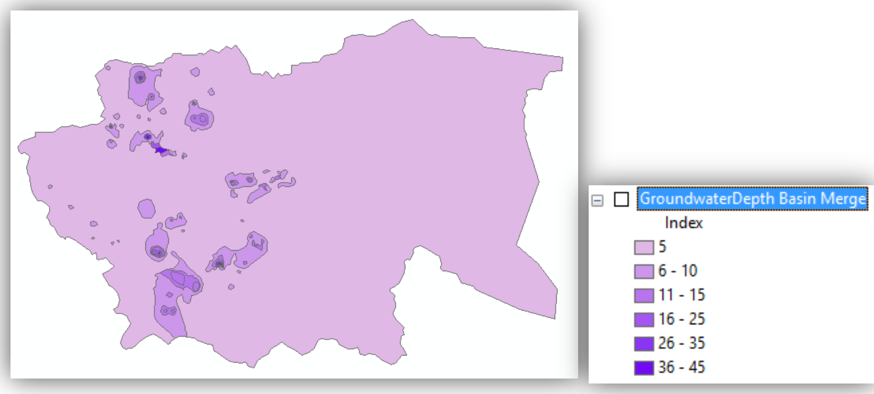
On the other hand, there were some layers that have been derived from some other layers which were originally digitized. "Net Recharge" layer depends mainly on Slope, Rainfall, and Soil permeability, the latter two layers were digitized whereas the slope had been derived as was before-mentioned, combining these 3 layers will result a new layer which is basically the "Net Recharge" using the raster calculator.

when all the layers got in place, a raster calculator was used to manipulate the effect of each layer which was having different weight, and within these layers different ratings were set to each level according to its severity, weights were 1 to 5 for the layers according to their value of effect, and each factor was generally divided into 5 different levels which incurred assigning 5 different ratings to each severity level.

Maps Results

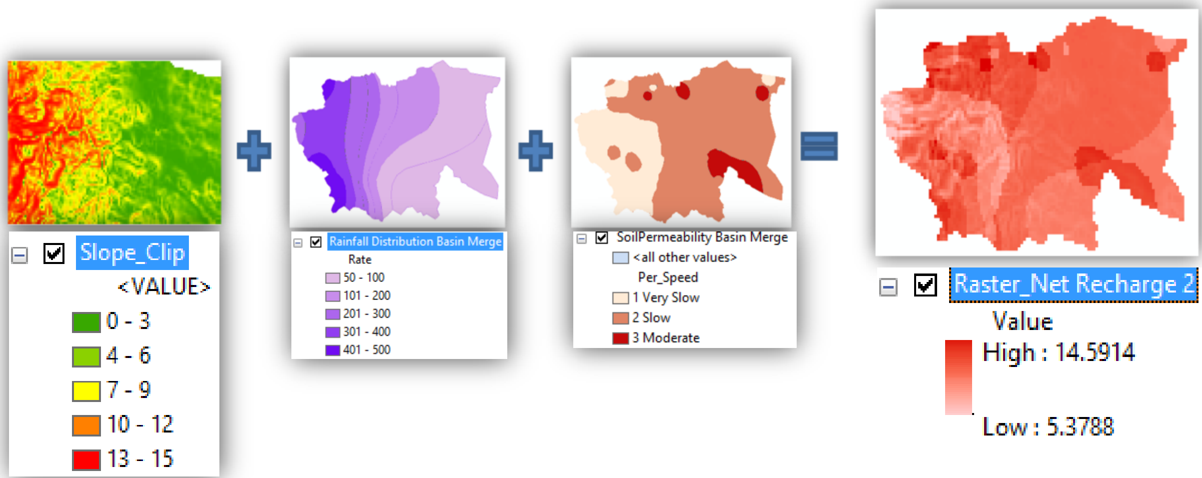
As before-mentioned, "DRASTIC" method had been used in this study which included the seven factors that affect the groundwater vulnerability to pollution, and the following images demonstrate these different factors represented by layers either been digitized or derived from other layers. The following layers are the seven layers which together form a vulnerability assessment for the Groundwater in the Amman-Zarqa Basin:

1 - **D**epth to Groundwater [weight.5]: Deep water tables is considered to be more safe with regards to pollutants and contamination than shallow water tables.

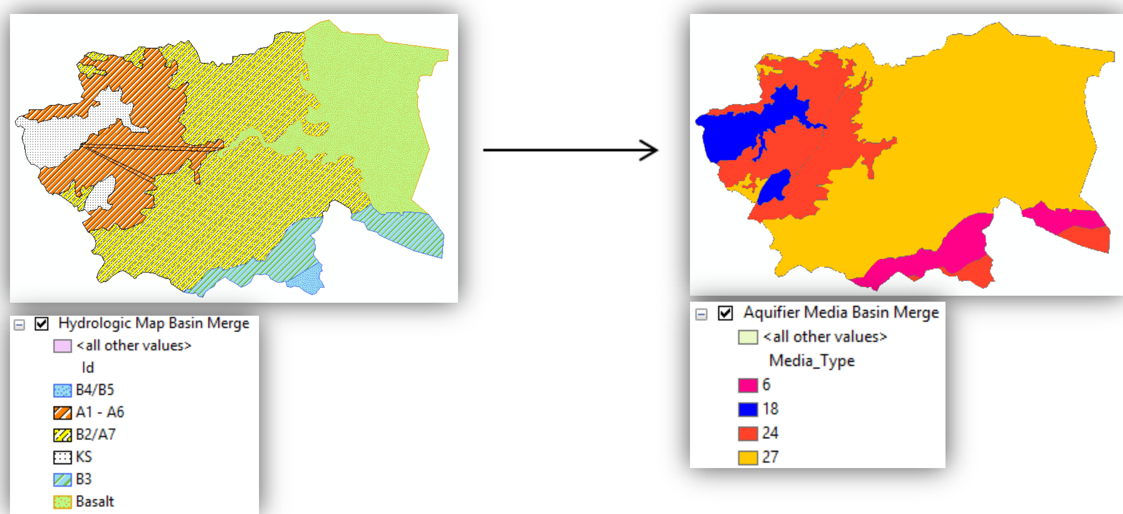


2- Net **R**echarge [weight.4]: High recharge rate indicates more infiltration into the ground which might accompany contaminants and pollutants, and is calculated mainly by three variables: Slopes which form more steeps and thus the water will not be settle in the area, but will steeps down to other areas, whereas the more precipitation and the more soil permeability the higher the recharge rate, because of the big amount of water, and the ease of water infiltration into the ground, which eventually means more vulnerability to contamination.

The following equation was used to manipulate the "Net Recharge" out of the three layers: ("Raster_Rainfall" / 100) + ("R_Soil Permeability"*2) + (6-("Slope_bil1_C1" / 3))



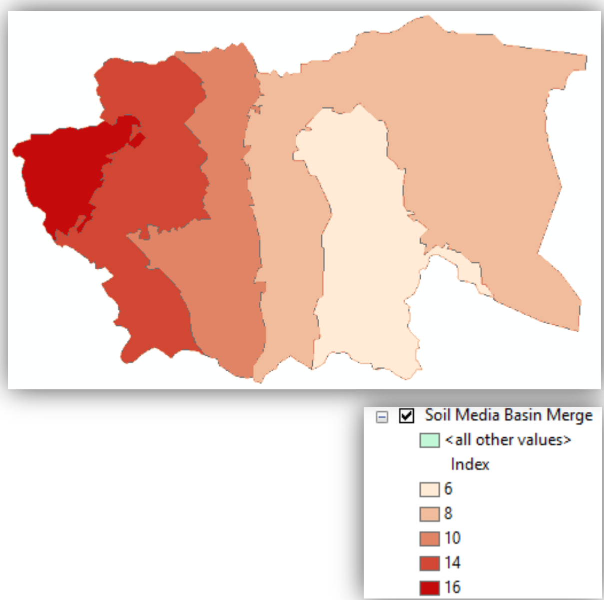
3- **A**quifer Media [weight.3]: Aquifer media differs in term of the material formation, and thus determine chances resistance against the transportation of the pollutants towards the underground water. The major aquifer system in the area is the Amman/Wadi Sir (B2/A7), these aquifers are well jointed and fissured, and on a local scale exhibit solution channels and karstic features. It is considered that the two aquifers are hydraulically connected and that in some locations they are separated by an aquiclude *(i.e.,* Ghudran Formation, Bl), which consists of chalk, marl and marly limestone. The Amman formation (B2), which acts as an aquifer, consists mainly of chert and limestone with phosphate beds. The Wadi Sir Aquifer lies below the Amman Formation and consists mainly of highly–fractured limestone, dolomitic limestone and some chert concretions (El–Naqa A., Hammouri N., Kuisi M., 2006).



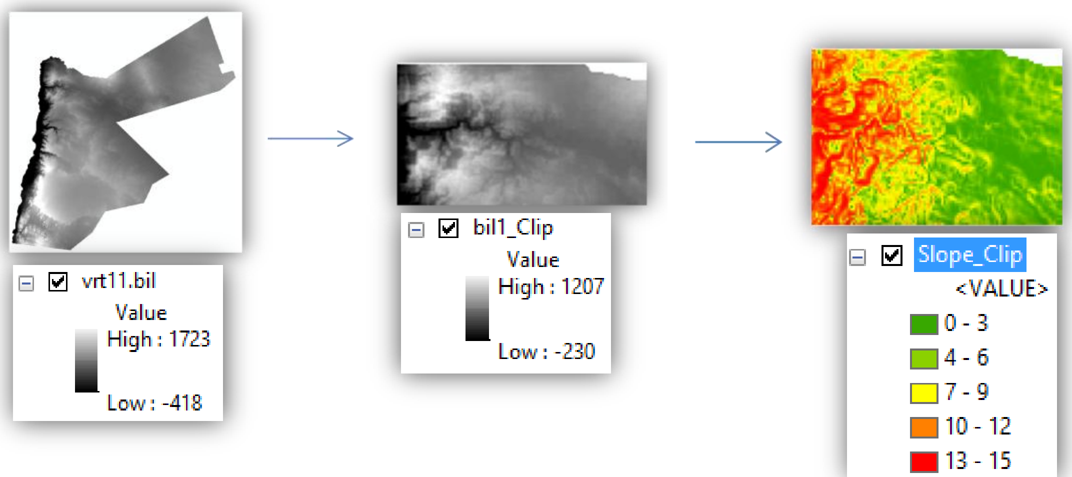
4- **S**oil Media [weight.2]: the soil media exposes pollutants moving time from surface to water table, according to the figure below it is shown that the basin is divided into 5 areas in term of soil media, Table.1 illustrates the different soil media in each area.

Soil Media	Rating	Final Rating - Index
Clay Loam	**3**	**6**
Silty Loam	**4**	**8**
Loam	**5**	**10**
Shrinking	**7**	**14**
Sand	**8**	**16**

Table.1 (Reference. Al-Rawabdeh A., Al-Ansari N., Al-Taani A., Knutsson S., May 2013)



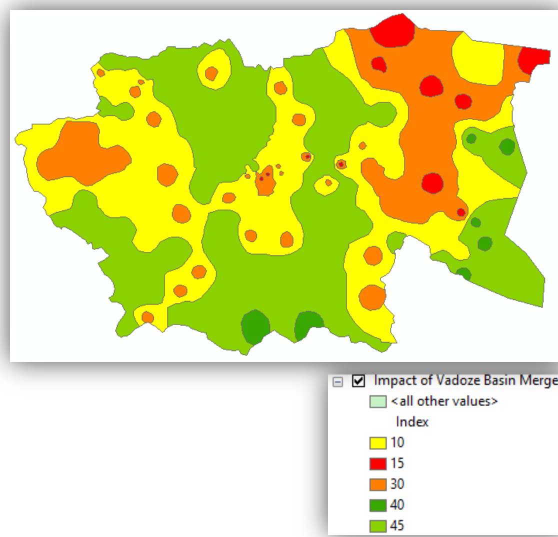
5- **T**opography [weight.1]: a high slope results in rapid runoff, which indicates less chance to infiltrate contamination into ground.



6- **I**mpact of Vodaze Zone [weight.5]: the vadoze zone thickness and matrix are affect contamination intensity and transport timing, Table.2 shows the different Vodaze Zone formations and layers.

Vodaze Zone	Rating	Final Rating - Index
Silt/clay	**2**	**10**
Shale, Limestone	**3**	**15**
Sandstone, Bedded limestone, Sand and gravel with silt	**6**	**30**
Sand and gravel	**8**	**40**
Basalt	**9**	**45**

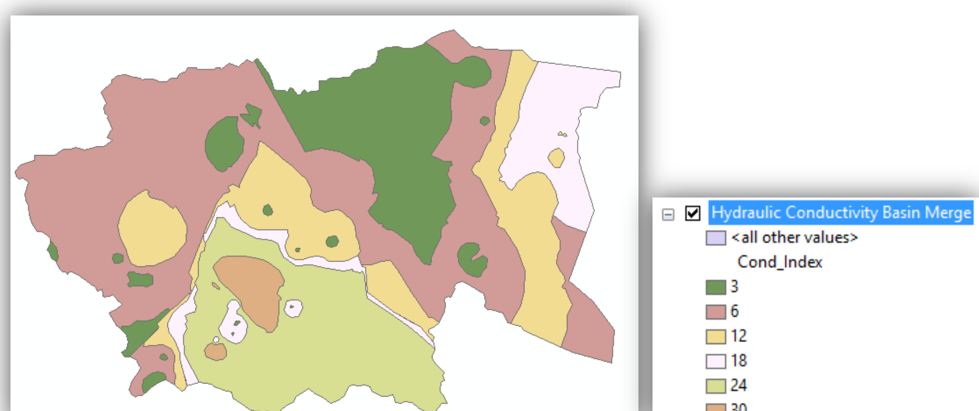
Table.2 (Reference. Al-Rawabdeh A., Al-Ansari N., Al-Taani A., Knutsson S., May 2013)



7- Hydraulic **C**onductivity [weight.3]: the hydraulic conductivity of the aquifer indicates the quantity of water percolating through the aquifer, Table.3 Shows the different levels of Hydraulic Conductivity in this area.

Hydraulic Conductivity	Rating	Final Rating - Index
4.716*10 - 7 - 4.716*10 - 5	**1**	**3**
4.716*10 - 5 - 1.41*10 - 4	**2**	**6**
1.41*10 - 4 - 3.3*10 - 4	**4**	**12**
3.3*10 - 4 - 4.716*10 - 4	**6**	**18**
4.716*10 - 4 - 9.43*10 - 4	**8**	**24**
>9.43*10 - 4	**9**	**30**

Table.2 (Reference. Al-Rawabdeh A., Al-Ansari N., Al-Taani A., Knutsson S., May 2013)

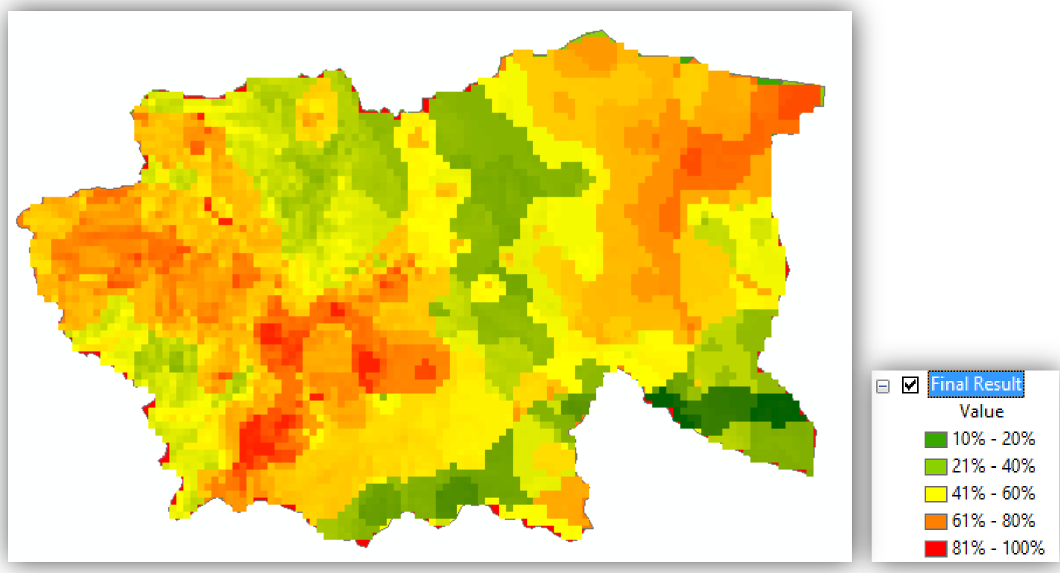


In accordance with the previous layers, it was shown that every layer had its own unique output values that illustrate the variety of its effect on different areas. However, with regards to "DRASTIC" method equation of including all factors into one equation using the raster calculator to manipulate these different variables and obtain the final result.

The output values of every layer were re-adjusted in the equation to deliver a range of about 1-5, so that all of these factors will end up used balanced in the equation and in the same range, the following equation was used in the raster calculator:

*((Depth-to-Groundwater-weight * Depth-to-Groundwater/10)* +
*(Net-Recharge-weight * Net-Recharge-rating/3)* +
*(Aquifer-Media-weight * Aquifer-Media-rating/5)* +
*(Soil Media-weight * Soil Media-rating/3)* +
*(Slope-weight * Slope-rating/3)* +
*(Impact-of-Vodaze-Zone-weight * Impact-of-Vodaze-Zone-rating/10)* +
*(Hydraulic-Conductivity-weight * Hydraulic-Conductivity-rating/6))*

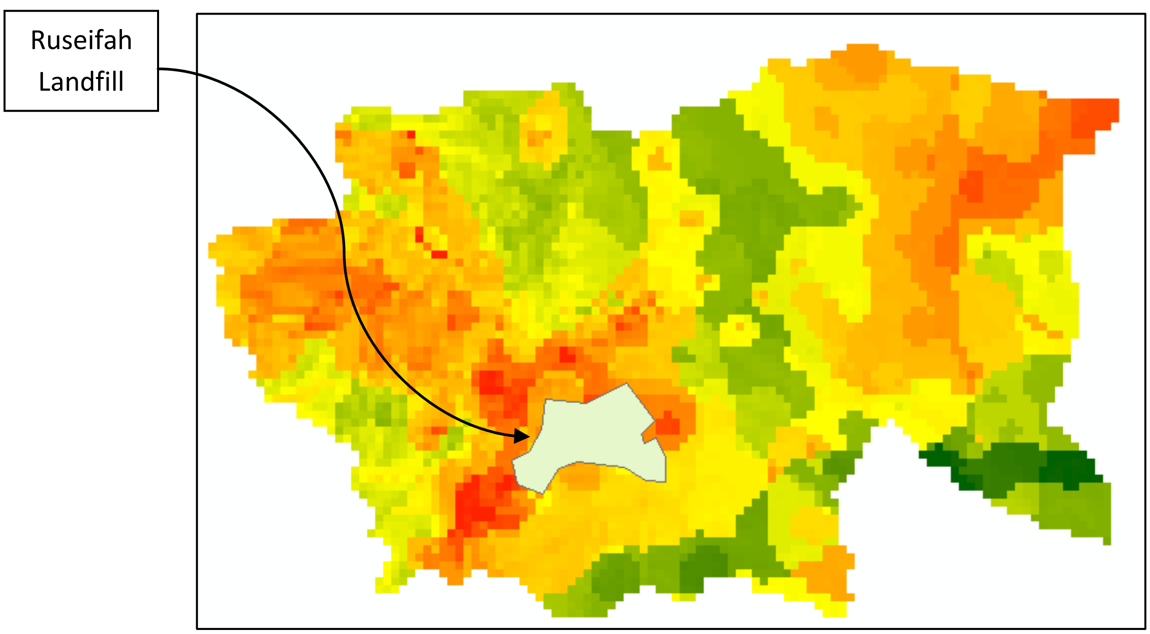
After making the math, an image had been emerged showing different values of groundwater vulnerability, and thus had to be reclassified to show a more percentage-like results which is shown in the following image.



Discussion

As was clarified throughout the study, the Amman-Zarqa is highly vulnerable to pollution in many areas including the Amman-Zarqa Dumpsite or as called "Ruseifah Dumpsite", this dumpsite may cause disastrous contamination to groundwater, which as a result may threaten the water sources in Jordan, especially for drinking purposes.

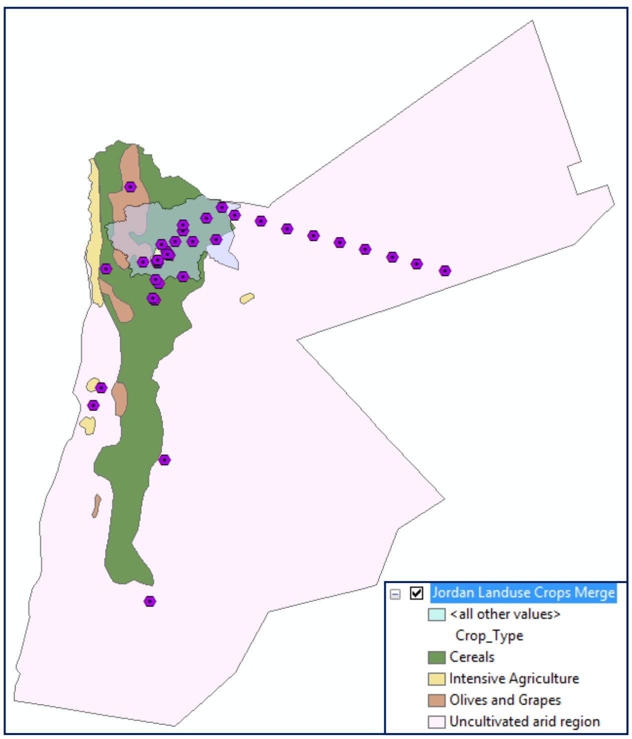
Regarding the diversity of groundwater pollution factors, and as this study basically dealt with the natural factors that define the groundwater vulnerable areas, more studies can be conducted for what kind of threats may be of a big concern, and investigating of the different actions the government has to activate for elimination or at least mitigating the negative impacts of such threats on groundwater, either by applying industrial regulation, changing plans of land development, or even discussing different possible solutions for the "Ruseifah Dumpsite", for example by creating "biogas" plant investment or any other projects that can mitigate the pollution being caused in this area.

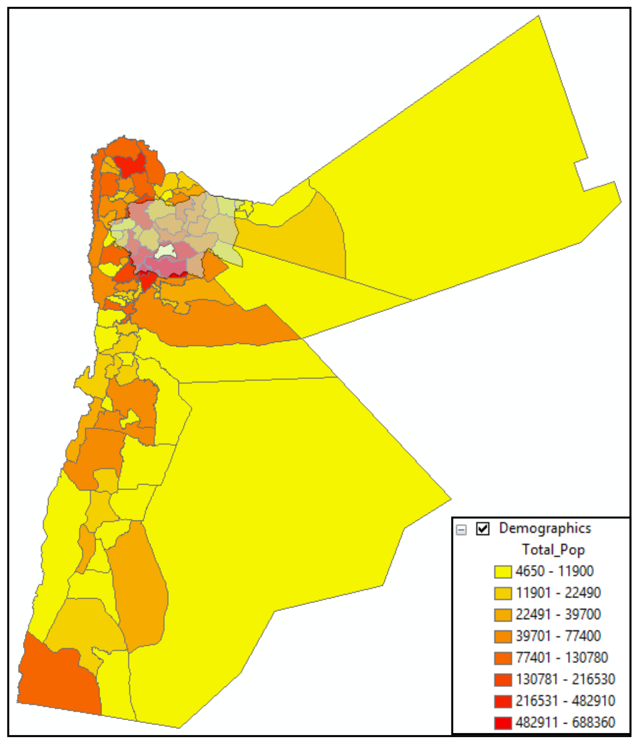


after conducting spatial analysis for the population in Jordan, it is clearly shown the high concentration of people in this basin especially in the area where the landfill resides. In addition, after researching on the different distribution of factories and other industrial-related facilities, it was found that this area is congested with factories, and as a result, there is a high possibility of contamination from these factories and facilities.

Digging deep into the history of Jordan, regarding importing the oil and natural gas from Saudi Arabia, Iraq and Egypt, it was found as well there are pipelines used for importing oil shale and natural gas which partially resides in the basin, and those are of a high risk if there will be plans to re-use them again in the future.

This study has many aspects to be studied carefully, and be researched by geologists, urban planners and government representatives, altogether to further evaluate the current situation and planning for better strategies that can mitigate the risks anticipated and seeking for better solutions to further secure the countries' water resources.





Finally, this study was based mainly on other research articles and many layers were digitized based on previous sampled results, as with more studies to be conducted in this field, more accurate measurements should be taken for each factor and up-to-date data should be acquired to create a more trust-worthy research, which eventually might lead to a better understanding of the current hazardous threats and their repercussions on water resources in Jordan.

References

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