Groundwater Resources, the DRASTIC Method and Applications in Jordan

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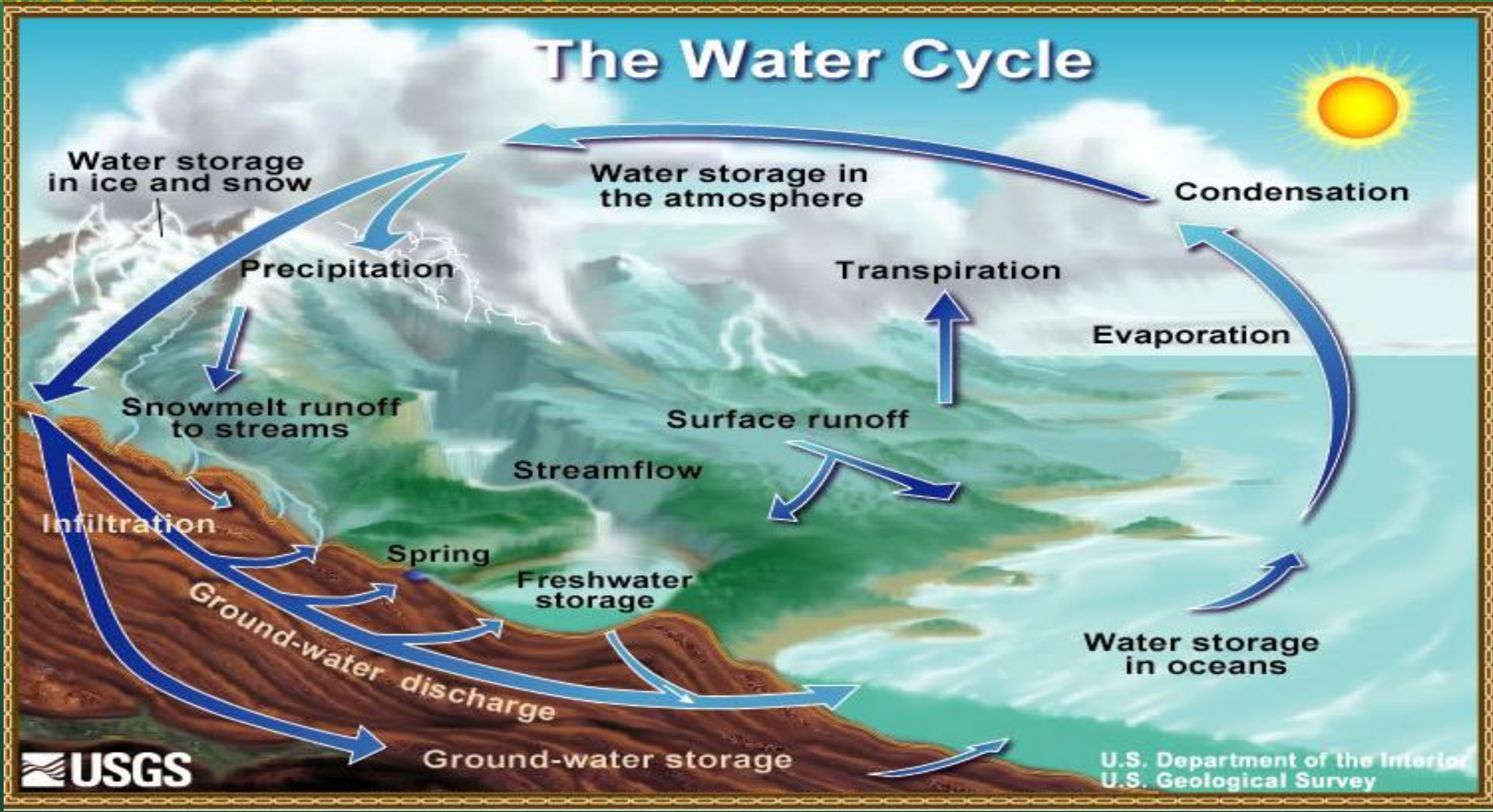
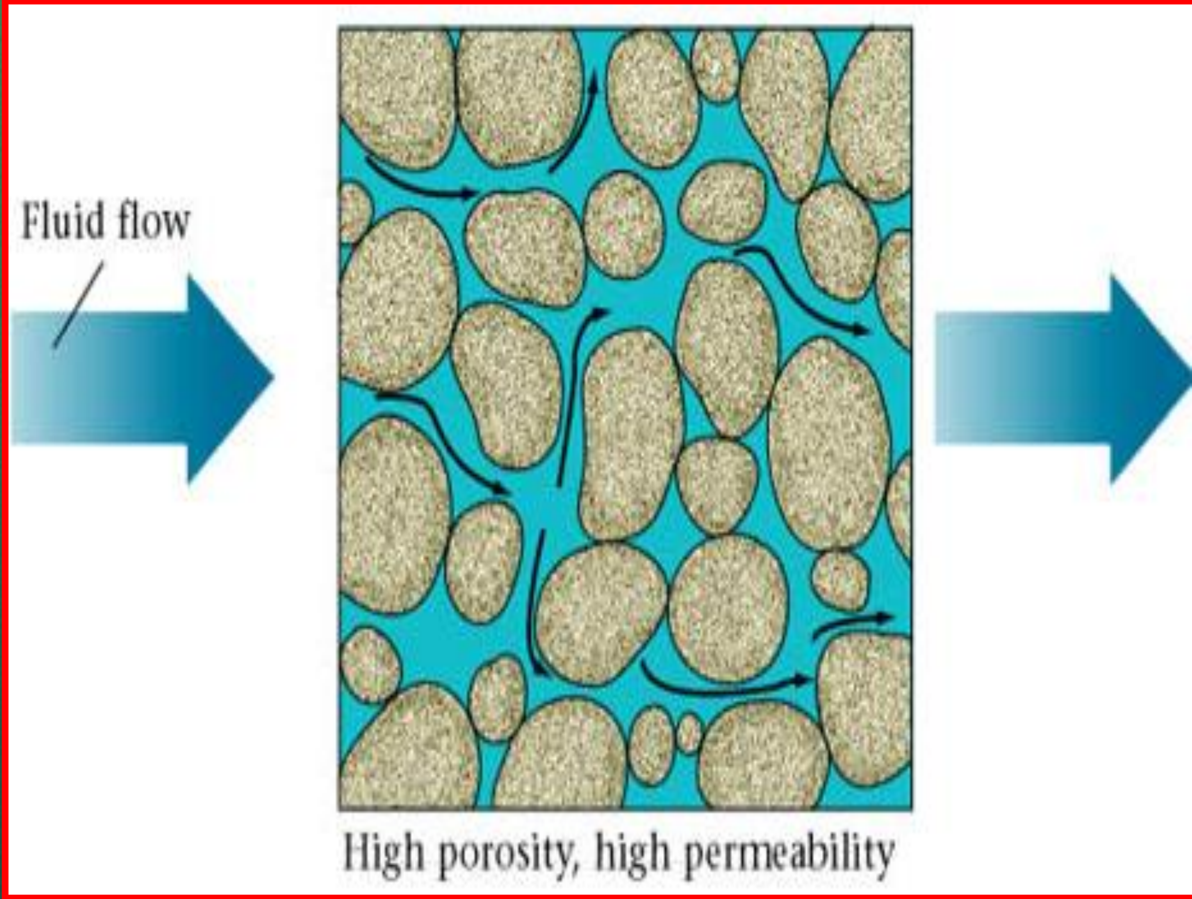
The source of Groundwater



http://ga.water.usgs.gov/edu/watercyclegraphichi.html

Basics of Groundwater Flow

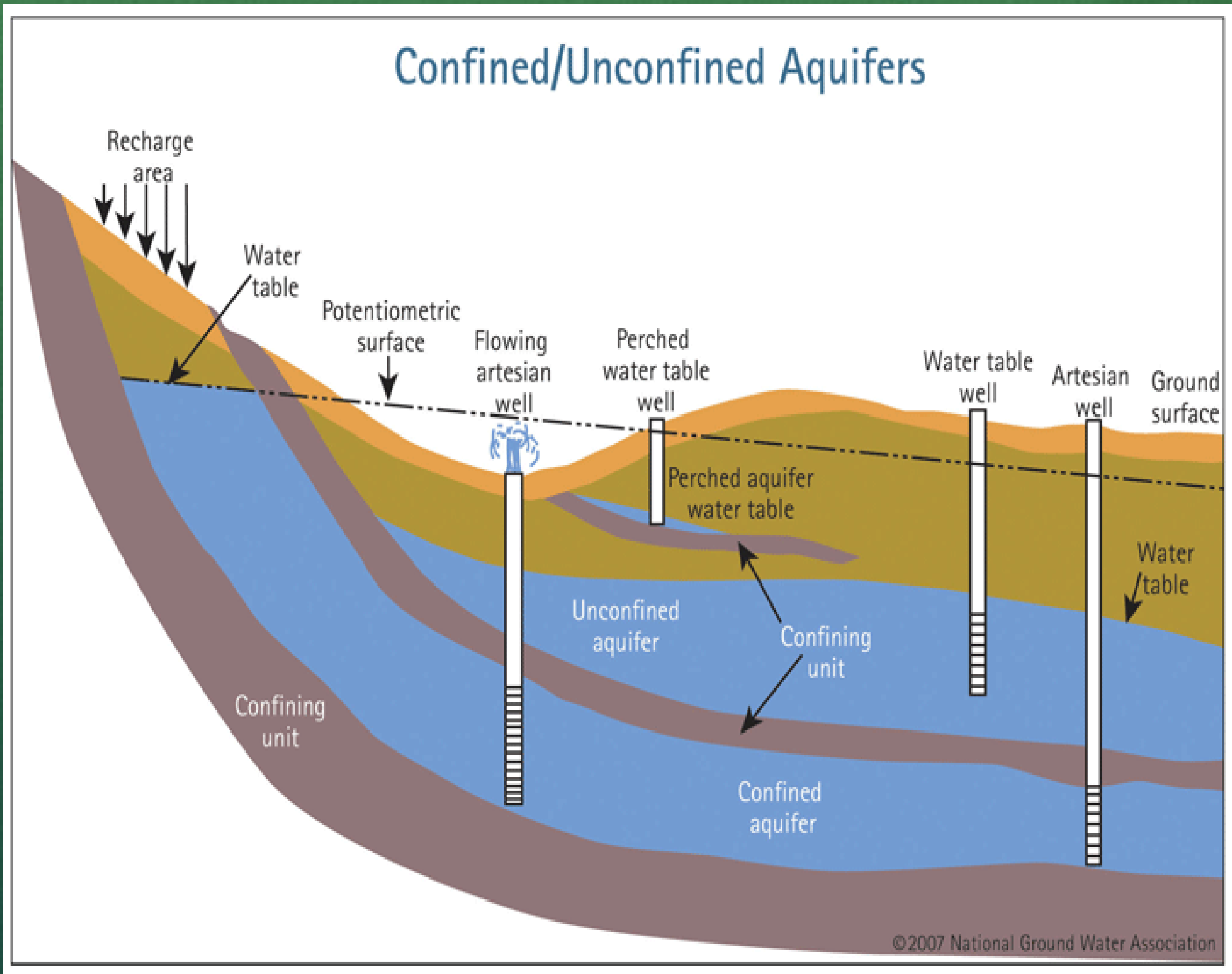
Groundwater is water located beneath the earth's surface in soil pore spaces and in the fractures of rock formations



Groundwater formations (Aquifers)

Aquifer types:

- Confined aquifer
- Unconfined aquifer



Groundwater Discharge

The discharge of groundwater (Q) in m^3/day is evaluated by Darcy's Law:

$$Q = AV$$
$$= A. K I$$

The discharge of groundwater per 1m width of water-bearing layer (q) in m^3/day is:

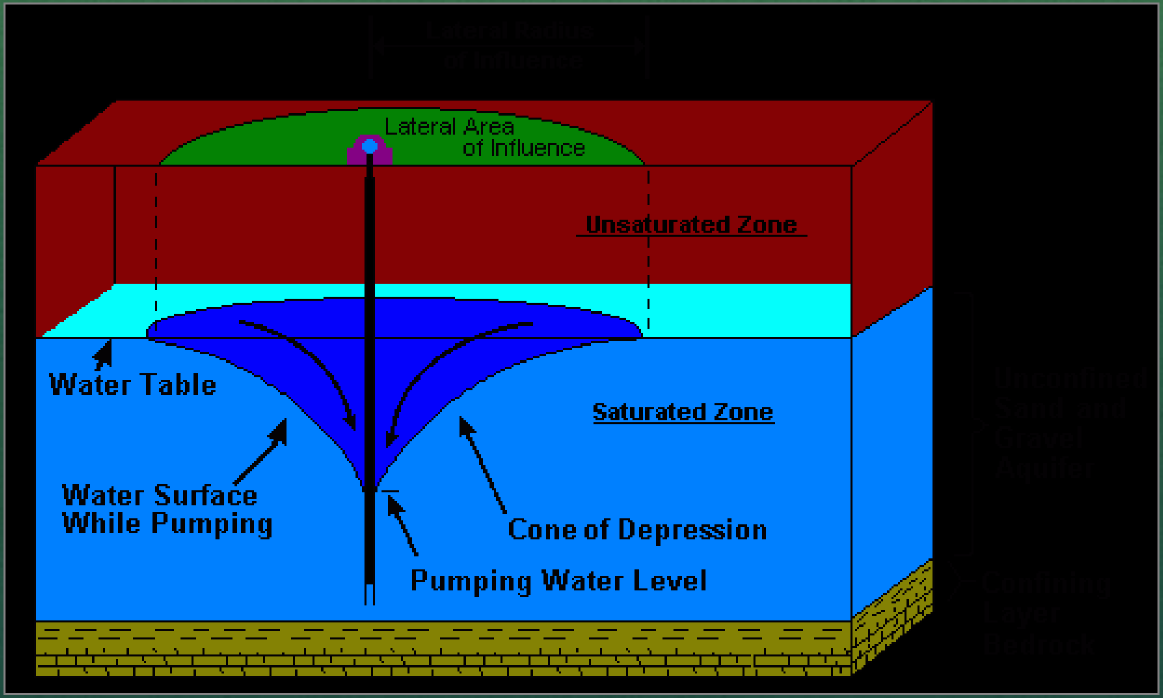
$$A = h*1m = h$$
$$q = K h I = K*h*-\Delta H/\Delta L$$

K: permeabiltiy coefficient (m/day)
h: thickness of water-bearing layer (m)
I: groundwater surface gradient

Groundwater Discharge

The discharge from unconfined aquifer:

$$Q = A*K*I = 2 \prod r*h*(K)*\Delta h/\Delta r$$



Groundwater Basics

►Infiltration: movement of water into soil from matric and gravity forces

►Percolation: movement due to gravity alone

►Porosity: total void space in rock or soil as volume

$$\text{Porosity} = 100*V_v/V_t$$

- 10% for glacial till
- 20-50% for sands and gravels
- 33-60% for clays

►Permeability: the ability of water to flow through a soil

Assessing Groundwater Vulnerability

There are three traditional methods for assessing groundwater vulnerability to pollution:

- Process-based: Involves numerical modeling and is useful at the local level but not the regional level
- Statistical: Involves correlating actual water quality data to spatial variables and requires a large amount of site specific data
- Overlay and Index: Involves obtaining and combining maps of the parameters that affect the transport of contaminants from the surface to groundwater, then assigning an index value to those parameters; the results are a spatially oriented vulnerability index

The DRASTIC Method: An Overlay and Index Method

- Developed by US EPA
- Provides a basis for evaluating the vulnerability to pollution of groundwater resources based on hydrogeologic parameters.
- Provides an approach to evaluate an area based on known conditions without the need for extensive, site specific pollution data.
- Provides an inexpensive method to identify areas that need more investigation.

Key Assumptions Made

1) Contamination occurs at the ground surface.
2) The contaminant enters the water table when rain falls on the surface and percolates into the saturated zone.
3) The contaminant travels with water, at the same rate as water.
4) The method will be applied to no greater than 100 acres.
5) The aquifer is unconfined (the method can be modified for a confined aquifer).
6) The dominant pollutants are not pesticides (the method can be modified to include pesticides).

The Drastic Method: Parameters Used in the Index

- **D:** Depth to Groundwater
  The depth from the ground surface to the water table in unconfined aquifer and to the bottom of the confining layer in confined aquifer
- **R:** Net Recharge
  The total quantity of water which is applied to the ground surface and infiltrates to reach the aquifer
- **A:** Aquifer Media
  Consolidated or unconsolidated rock which serves as an aquifer (such as sand, gravel, and limestone)
- **S:** Soil Media
  The uppermost portion of the vadose zone characterized by significant biological activity
- **T:** General Topography or Slope
  The slope and slope variability of the land surface
- **I:** Vadose Zone
  The zone above the water table which is unsaturated or discontinuously saturated
- **C:** Hydraulic Conductivity of the Aquifer:
  The ability of the aquifer materials to transmit water

Governing Equation

Each parameter is assigned a rate and a weight.

$$\text{DRASTIC Index} = D_r \times D_w + R_r \times R_w + A_r \times A_w + S_r \times S_w + T_r \times T_w + I_r \times I_w + C_r \times C_w$$

r = the rating for the parameter
w = an assigned weight for the parameter

Assigning a Rate

Each of the parameters in the model is grouped into ranges of values or broad categories that are assigned a rate from 1-10.

Topography (Percent Slope)	
Range	**Rating**
0-2	10
2-6	9
6-12	5
12-18	3
18+	1

Highly Varied Topography at Wadi Rum

Assigning a Rate

Impact of the Vadose Zone Media	
Media Type	**Rating**
Confining Layer	1
Silt/Clay	3
Shale	3
Limestone	6
Sandstone	6
Bedded Limestone/Sandstone/Shale	6
Sand & Gravel with Clay/Silt	6
Metamorphic/Igneous	4
Sand and Gravel	8
Basalt	9
Karst Limestone	10

Karst Limestone
at Ajloun Forest Reserve

Assigning a Weight

Weights are fixed in the methodology.

Parameter	**Weight**
Depth to Water	5
Net Recharge	4
Aquifer Media	3
Soil Media	2
Topography	1
Impact of the Vadose Zone Media	5
Hydraulic Conductivity of the Aquifer	3

So the governing equation becomes:

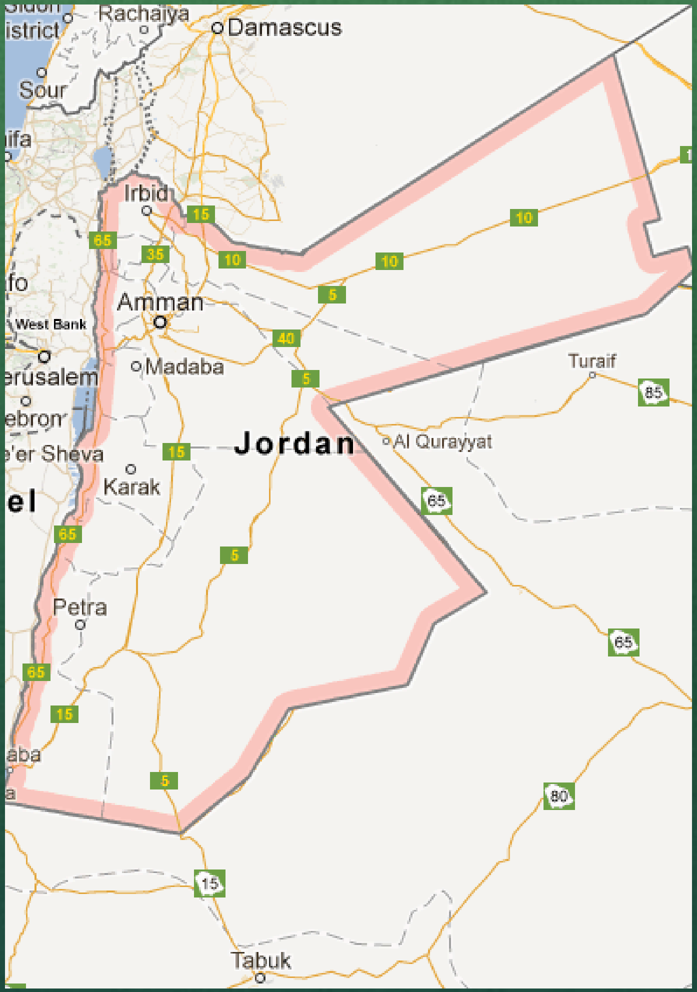
$$\text{DRASTIC Index} = 5D_r + 4R_r + 3A_r + 2S_r + T_r + 5I_r + 3C_r$$

Geographic information system (GIS)

- GIS is a system of hardware and software used for storage, retrieval, mapping, and analysis of geographic data.
- Spatial features are stored in a coordinate system (latitude/longitude, state plane, UTM, etc.), which references a particular place on the earth.
- Descriptive attributes in tabular form are associated with spatial features. Spatial data and associated attributes in the same coordinate system can then be layered together for mapping and analysis.
- GIS can be used for scientific investigations, resource management, and development planning.

GIS Models

- Most GIS use one of two basic spatial data models to represent the real world, namely the Vector model and the Raster model.
- In the vector model, objects or conditions in the real world are represented by the **points** and **lines** that define their boundaries.



GIS Models

- Raster data models represent geographical space by dividing it in a series of units, each of which is limited and defined by an equal amount of earth's surface. The matrix of cells, organized into rows and columns is called a grid

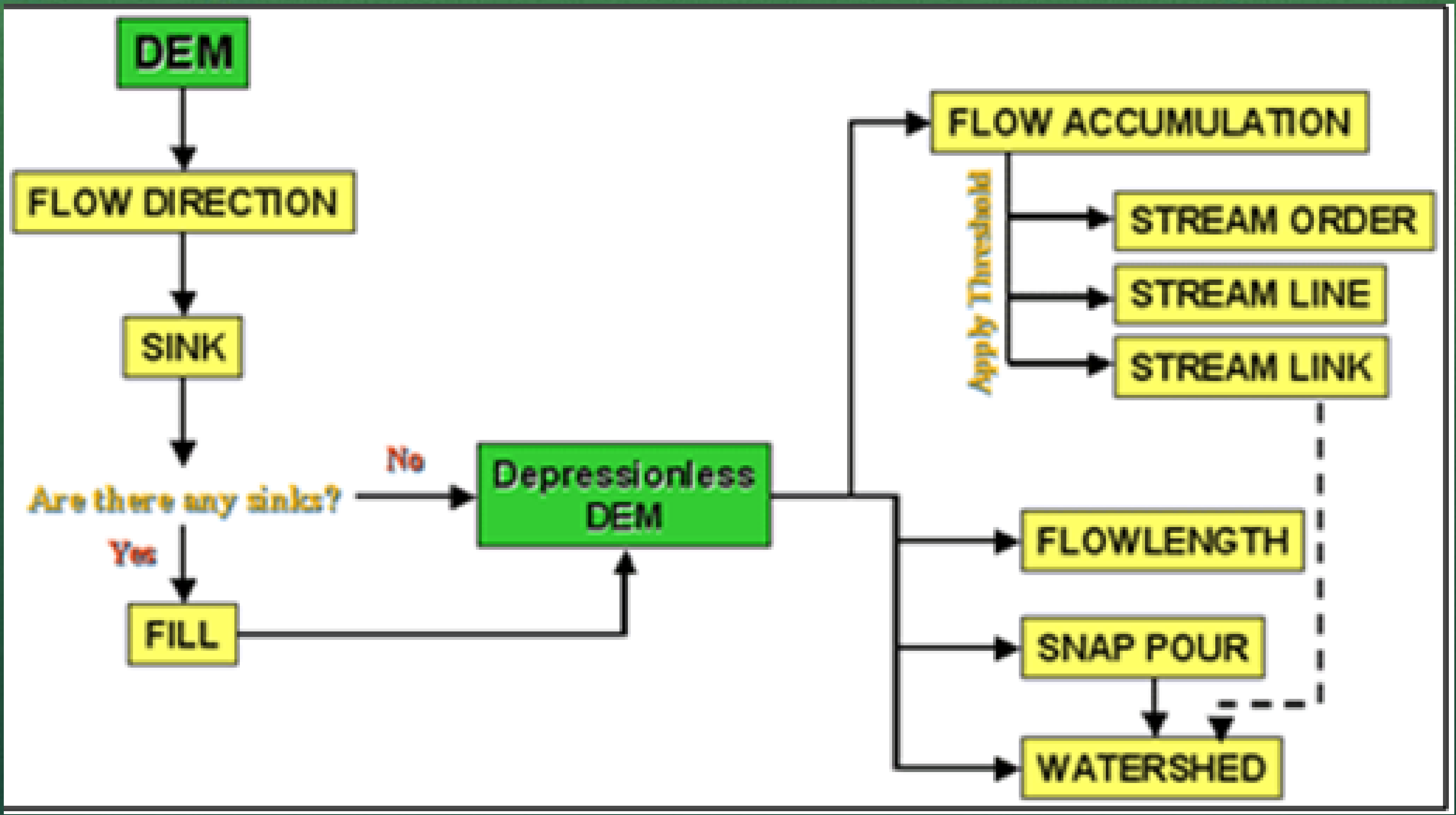
Applications of GIS

- Delineation of Watershed.

  Watersheds is: "The region draining into a river, river system, or body of water." Watersheds are always physically delineated by the area upstream from a given outlet point.

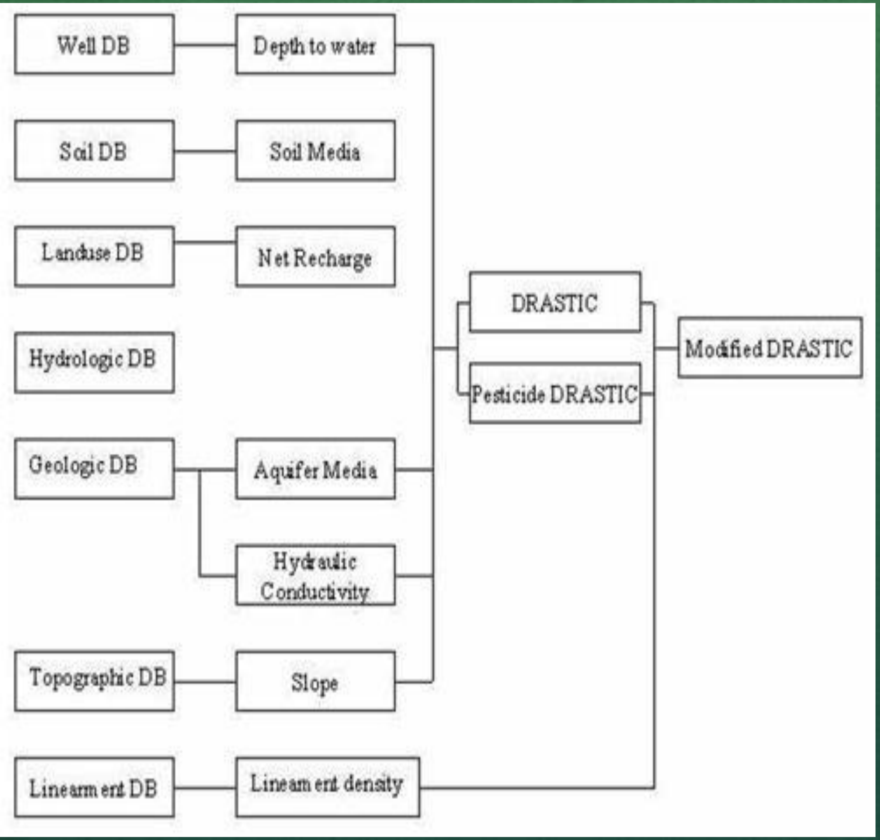
  You must start with a surface, digital elevation model (DEM), that has no sinks.

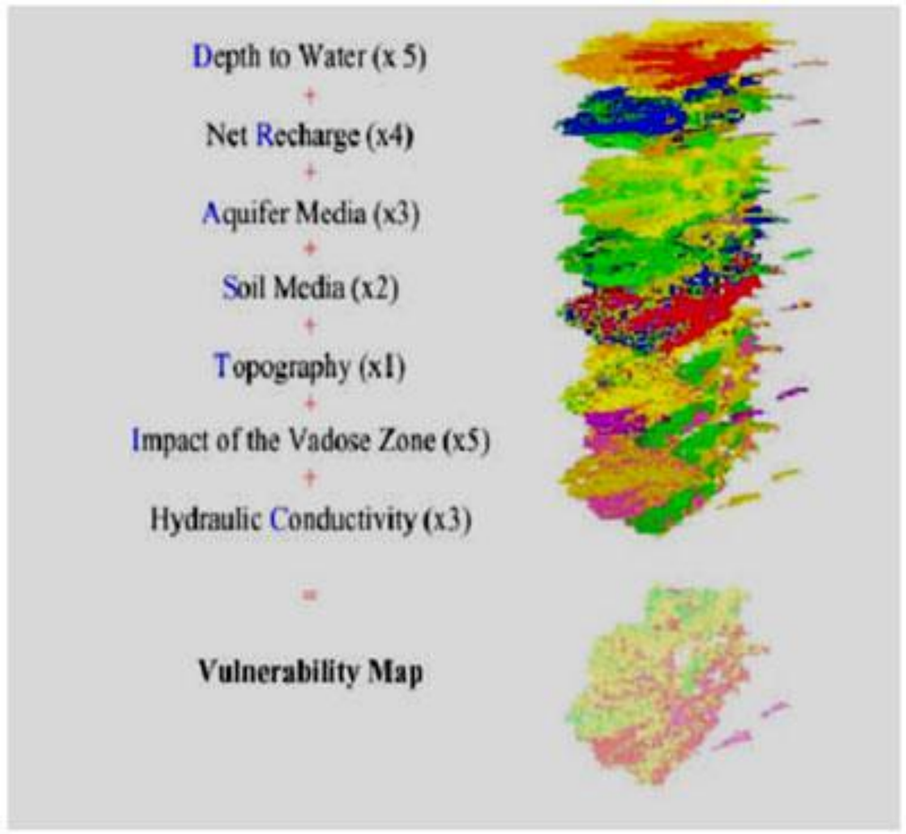
Delineation of Watershed



DRASTIC method

- Applying the DRASTIC method to monitor the pollution of ground water.





Study Areas and Results

- The Dead Sea

  "Groundwater vulnerability assessment and evaluation of human activity impact (HAI) within the Dead Sea groundwater basin, Jordan"

  Ahmad Al-Hanbali and Akihiko Kondoh

- Jerash

  "GIS based Hydrogeological Vulnerability Mapping of Groundwater Resources in Jerash Area – Jordan"

  Nezar Hammouri and Ali El-Naqa

- Russeifa

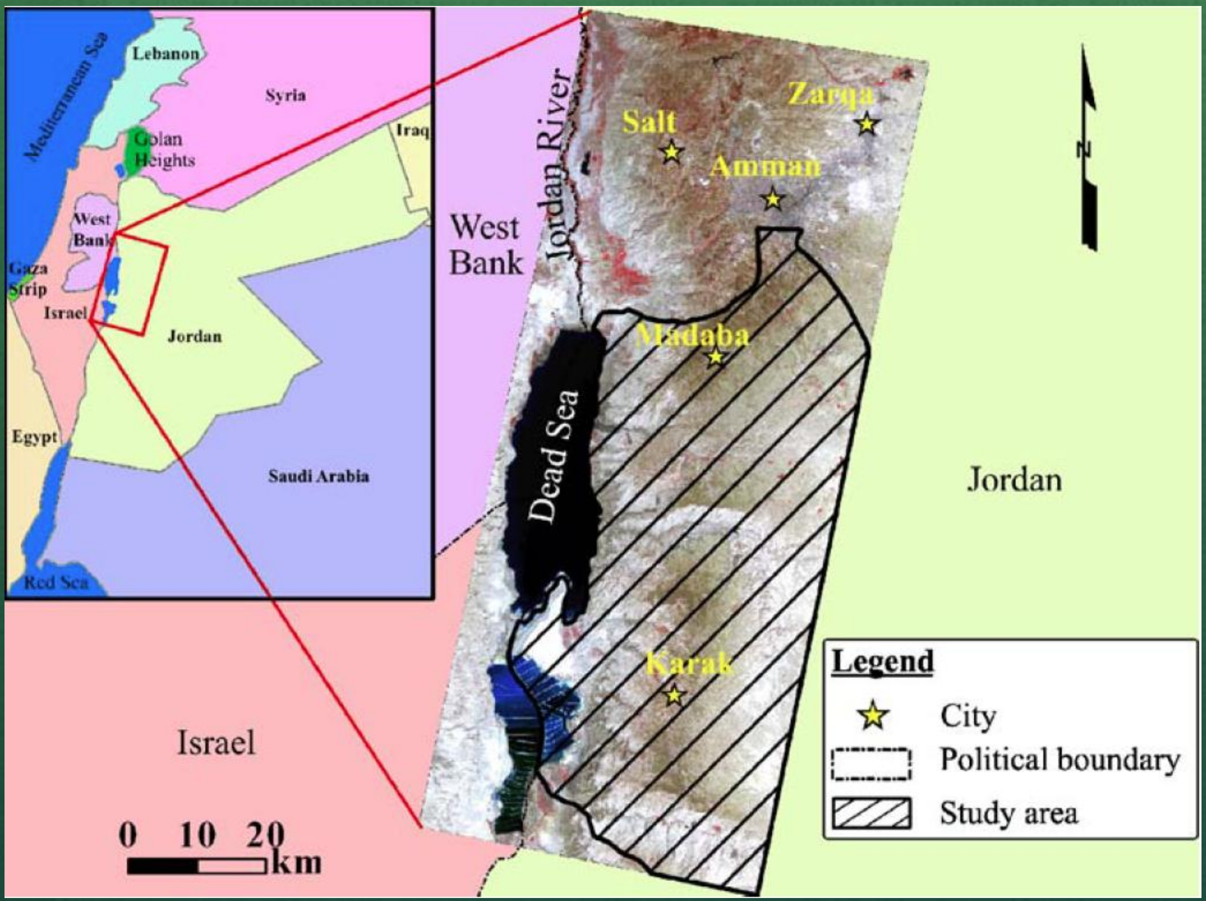
  "GIS-based evaluation of groundwater vulnerability in the Russeifa area, Jordan"

  Ali El-Naqa, Nezar Hammouri, and Mustafa Kuisi

Study Areas: **Dead Sea** Jerash Russeifa

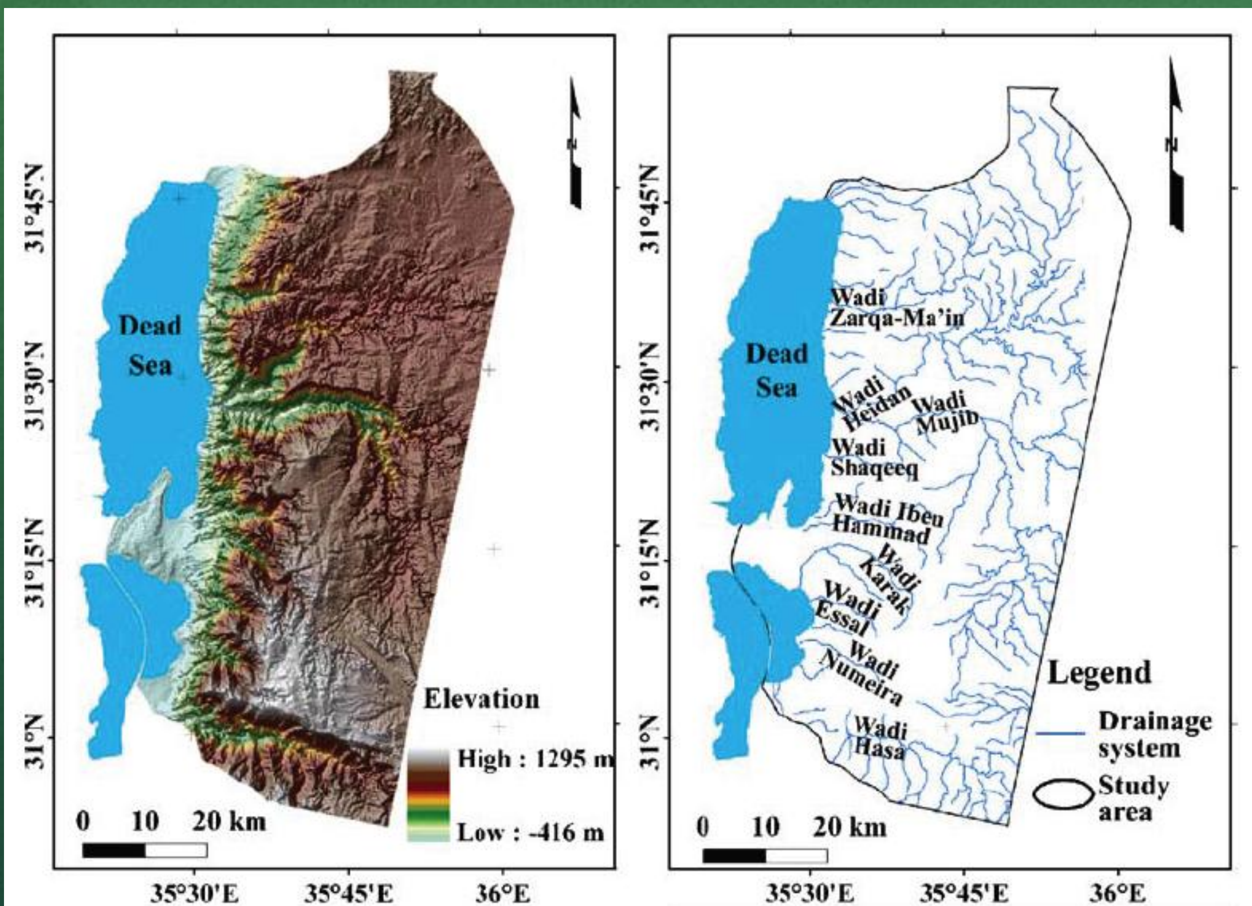
Location of the Study Area within Jordan

Covers 4,483 square kilometers (1,731 square miles)



- Climate is arid to semi-arid
- Average rainfall of 335 mm/year (13.2 in/year)
- Western portion receives 75 mm/year (3.0 in/year)
- Seattle, WA receives an average rainfall of 940 mm/year (37 in/year)
- Boise, ID receives an average rainfall of 310 mm/year (12.2 in/year)

Topography and Drainage System of the Study Area

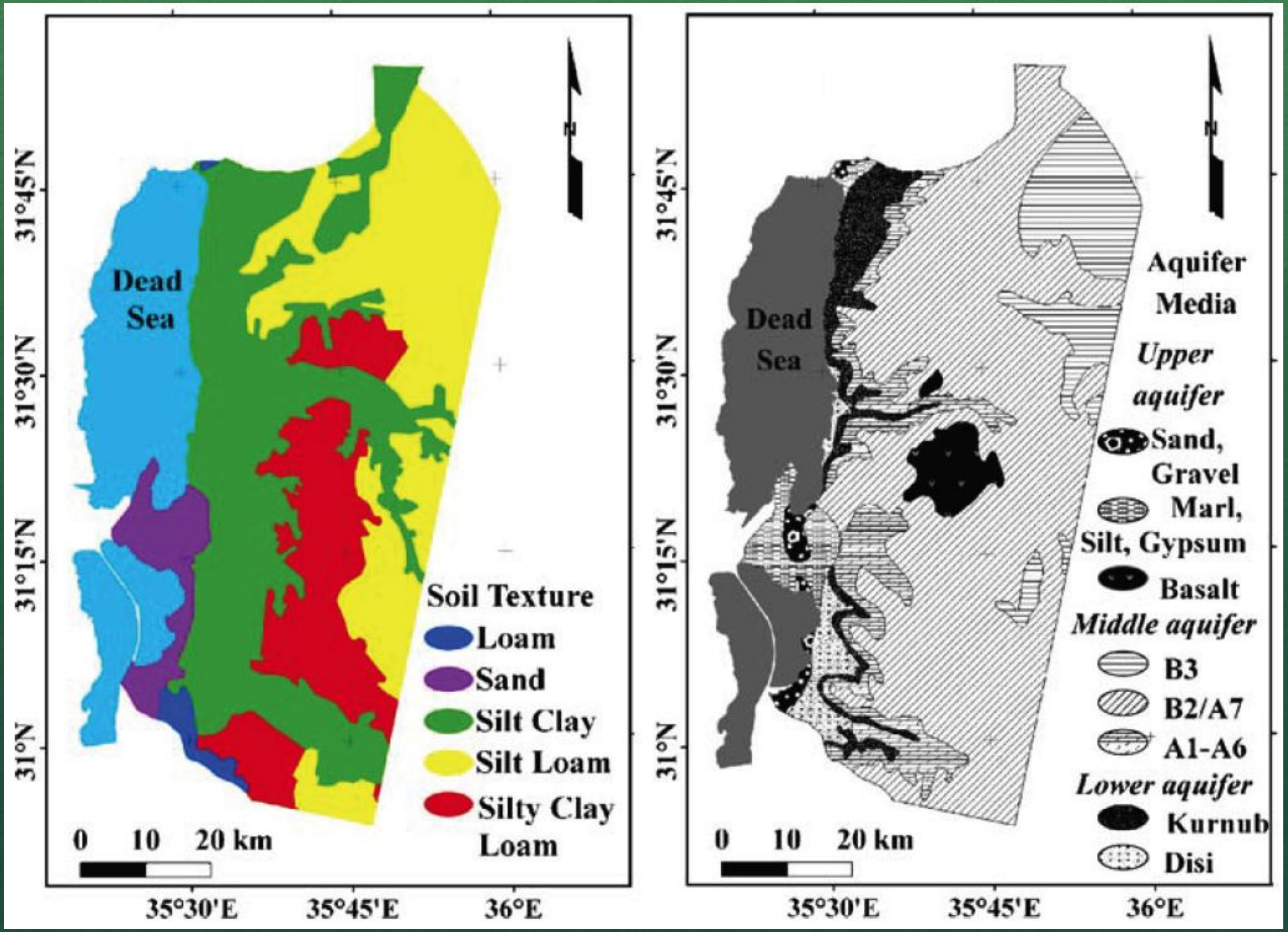


Average slope in the study area is 5.5% but ranges from 0% to 57.5%

There are three major aquifers in the study area

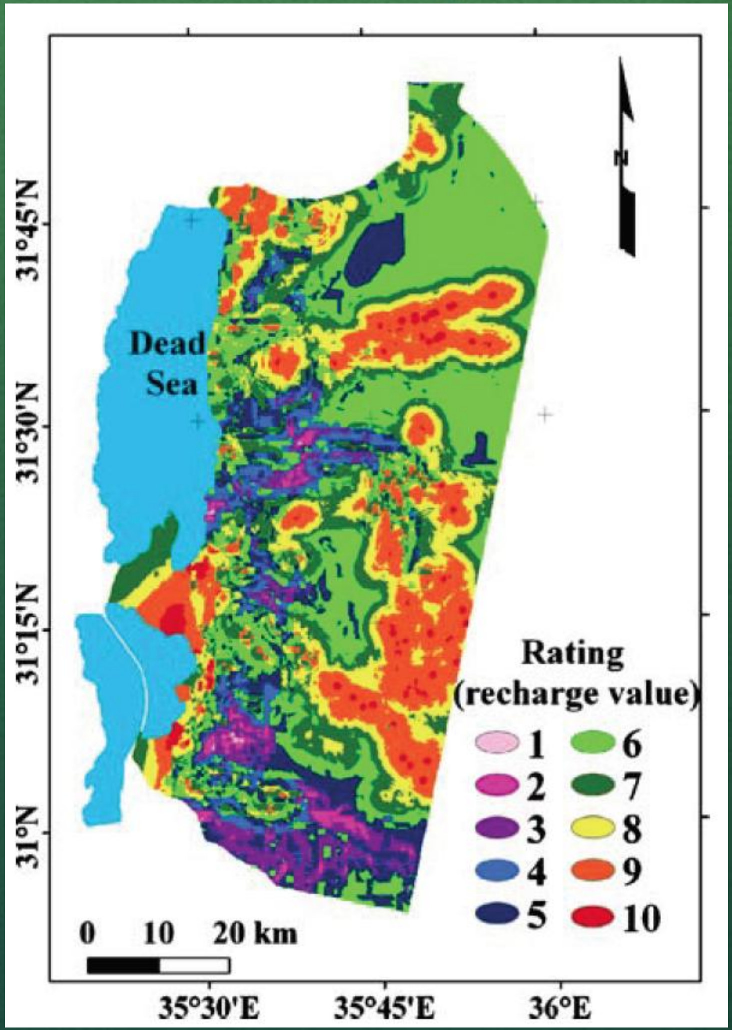
The study area is characterized by numerous faults, where it is assumed precipitation infiltrates directly into the groundwater

Soil and Aquifer Media in the Study Area



Application of the DRASTIC Index

- Data was obtained for each parameter in the study area, which was then divided into sub-regions by value or category
- Each of these sub-regions were then assigned a rate in the index
- Special consideration was given to determining the recharge value, due to the predominance of faults in the area
  - Recharge value was calculated using a combination of ratings for rainfall, slope, soil permeability and the average distance between the fault and drainage systems

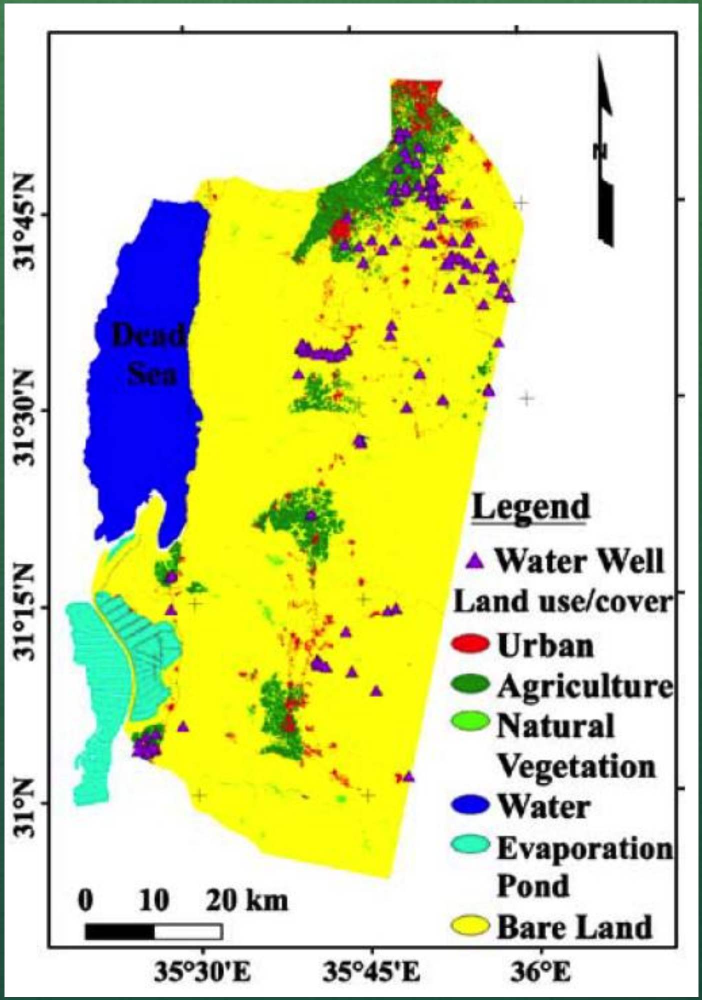


Application of the DRASTIC Index

To evaluate the impact of humans, six land use classes, LU, and their corresponding rates were assigned to the study area.

Land Use	Rating
Urban	8
Agriculture	8
Natural Vegetation	2
Water	3
Evaporation Pond	7
Bare Land	1

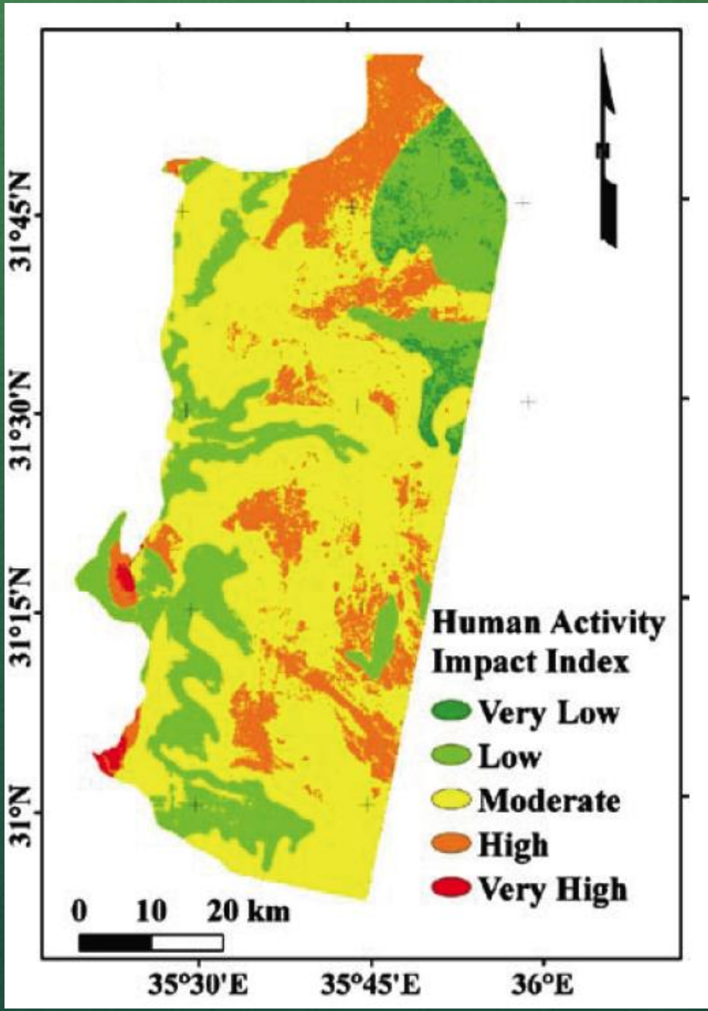
Human Activity Impact (HAI) Index = 5D + 4R + 3A + 2S + T + 5I + 3C +5LU



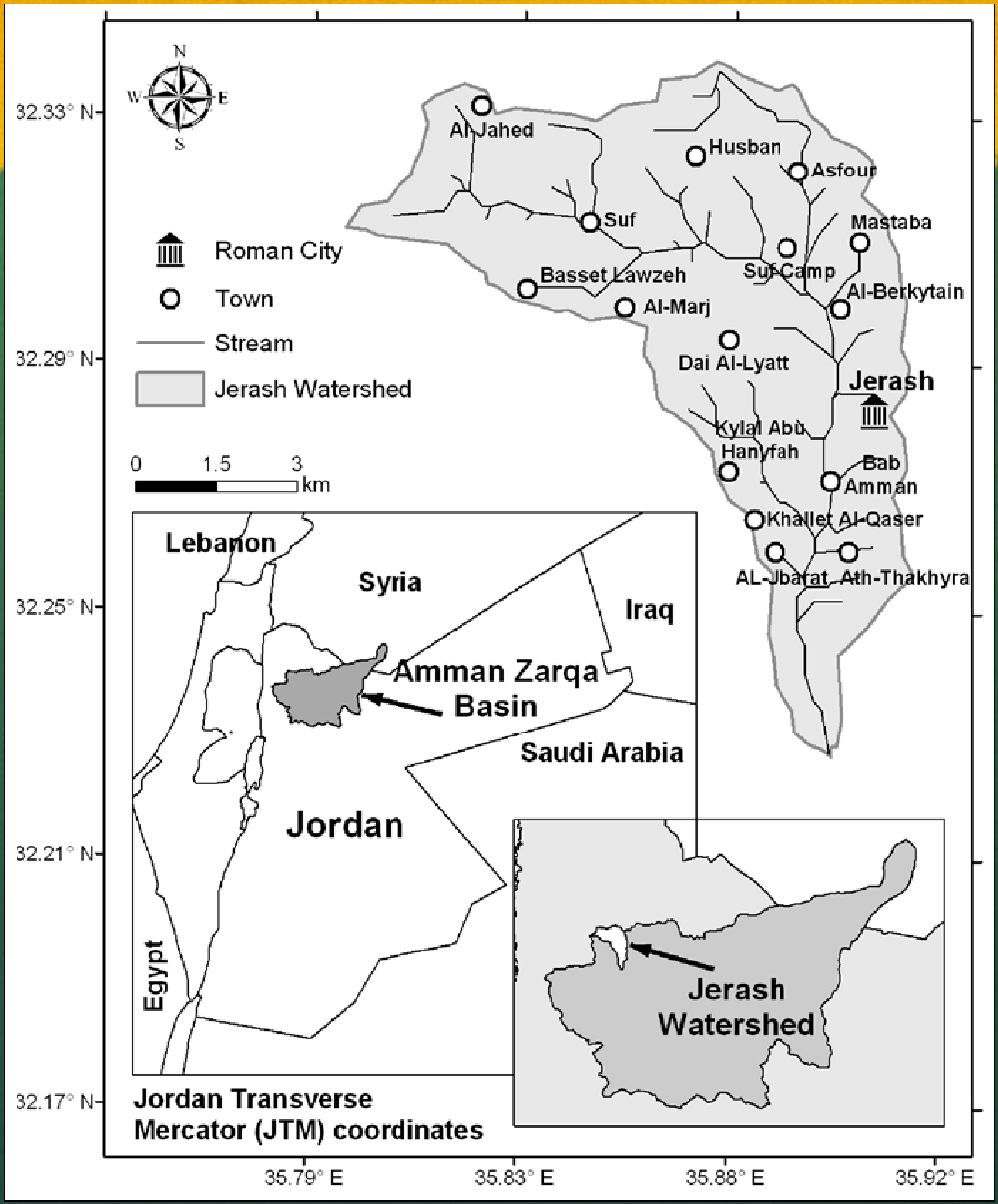
Analysis and Results

The resulting index scores were divided into five range values of groundwater vulnerability: very low, low, moderate, high, and very high.

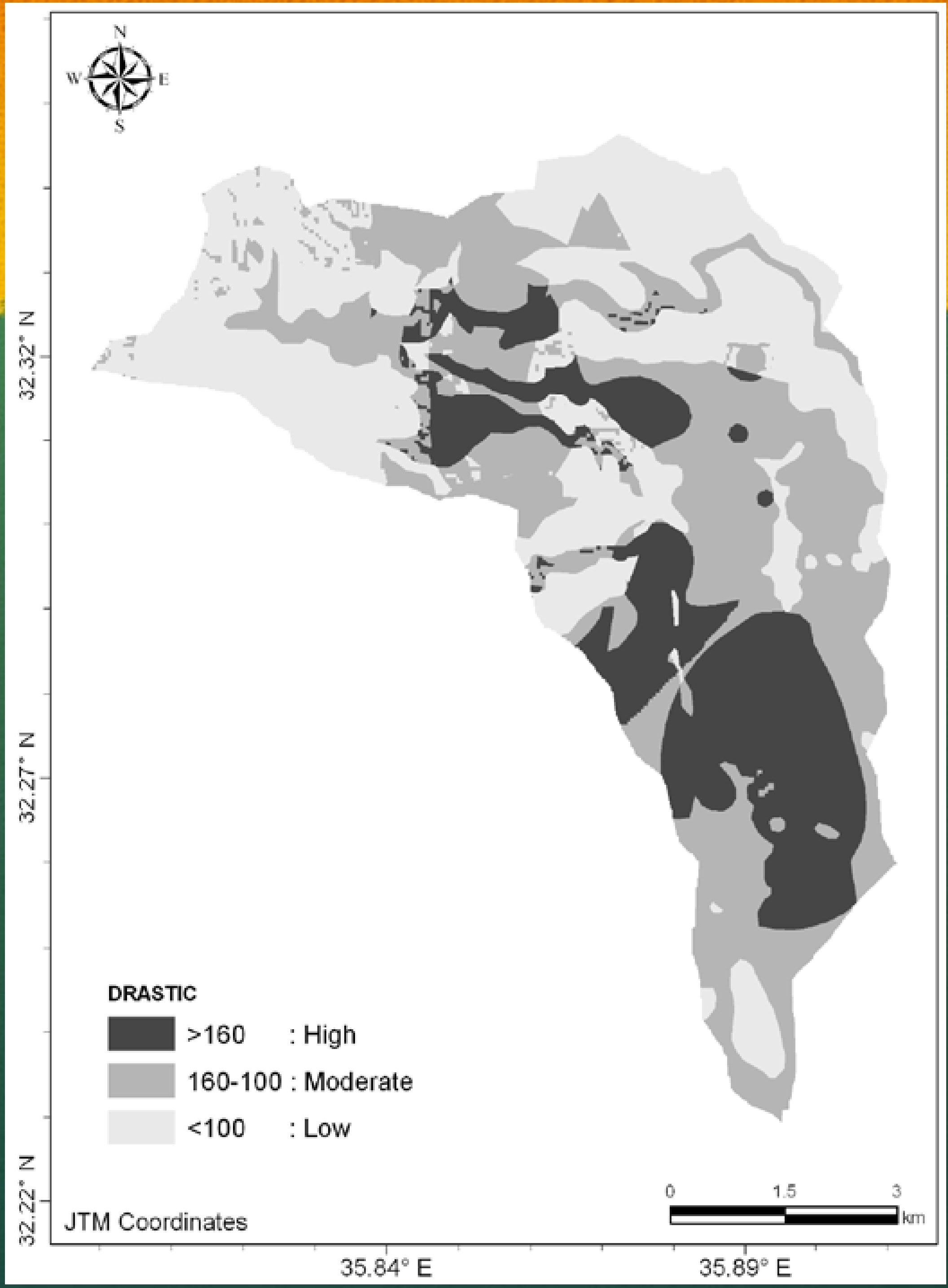
Human Activity Impact Index		
Vulnerability	**Area (km^2)**	**Area (%)**
Very Low	157.3	3.8
Low	953.7	22.8
Moderate	2,409.8	57.6
High	647.7	15.5
Very high	16.6	0.4

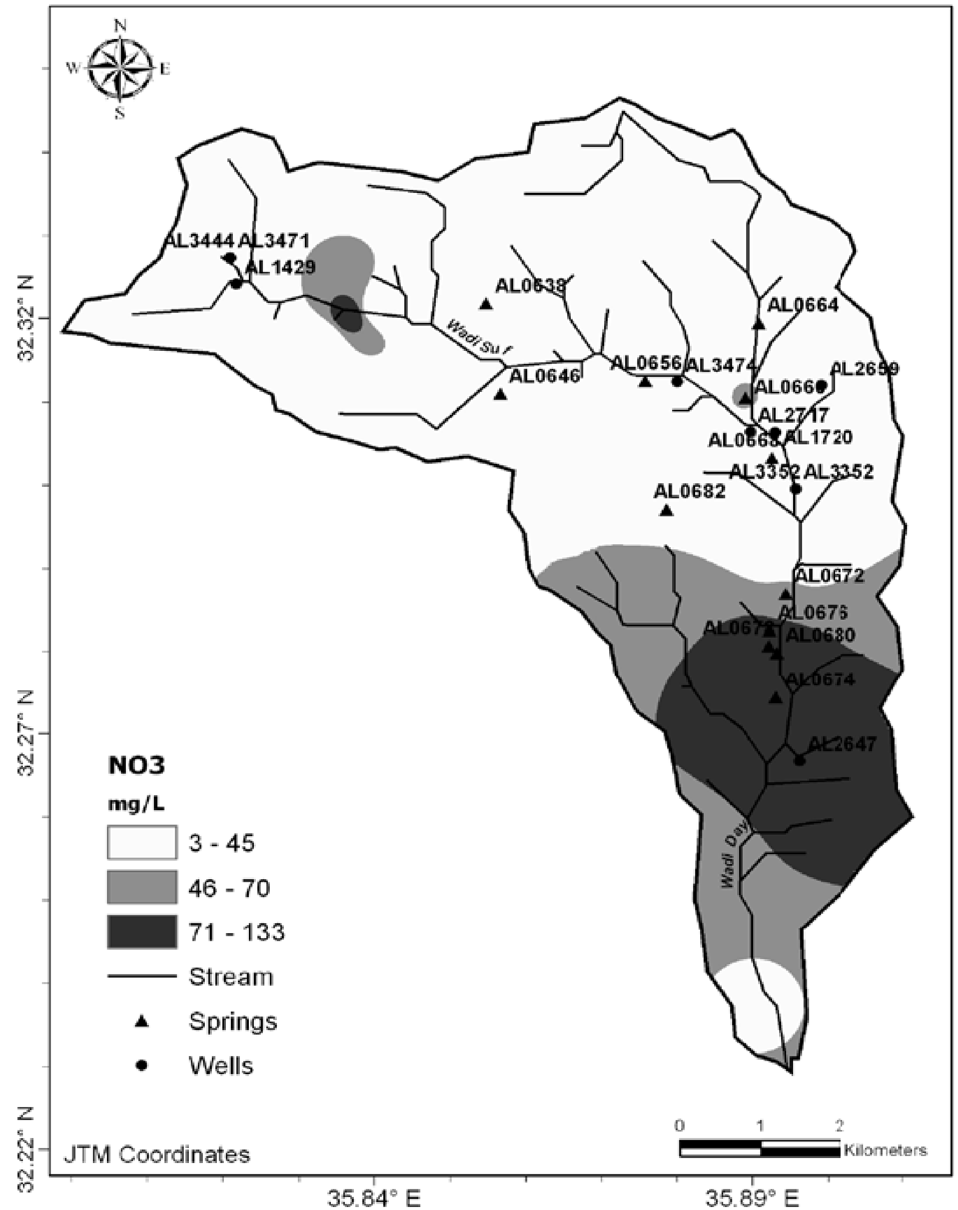


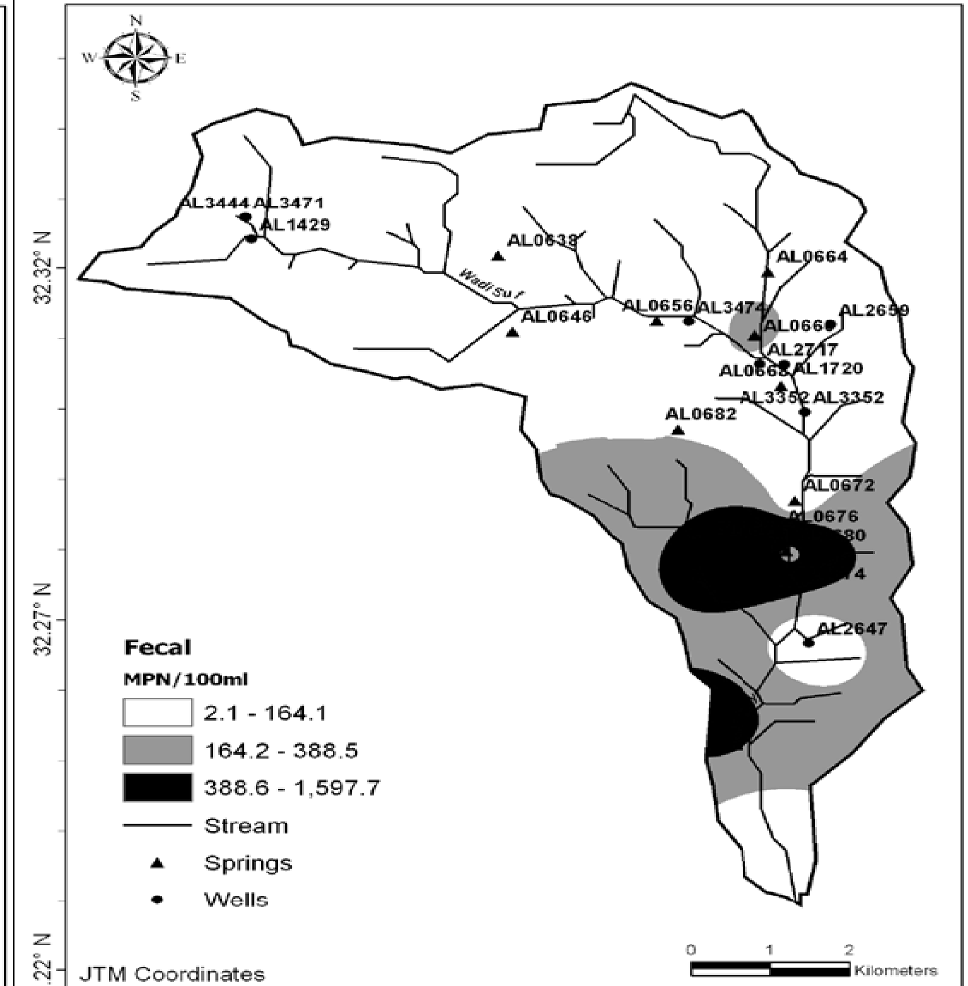
- Along Jerash watershed, there are 7 wells and 6 springs issued from this aquifer.
- The total recharge to this aquifer is about 4.5 million cubic meters .
- The specific capacity of the aquifer ranges from 0.01 to 12 m3/hr with a transmissivity ranging between 0.3 and 100 m^2/d and the hydraulic conductivity varying from 0.003 to 2.7 m/d

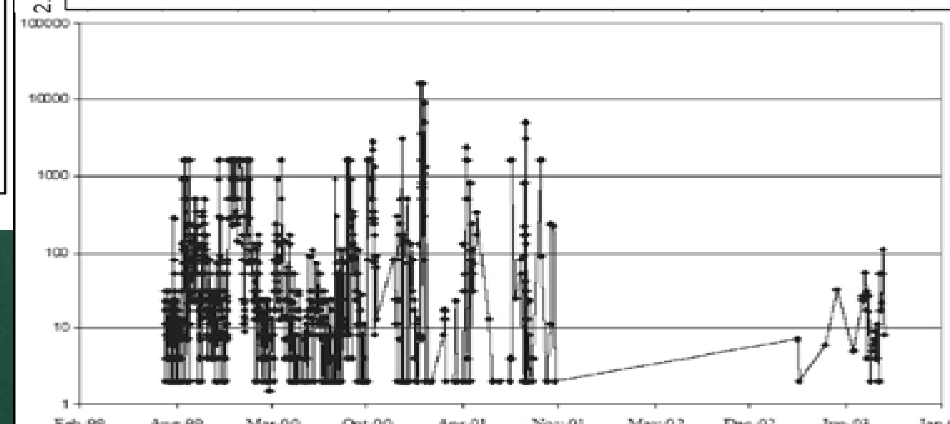


- Wastewater and agricultural practices are the dominant source of contamination in the watershed.



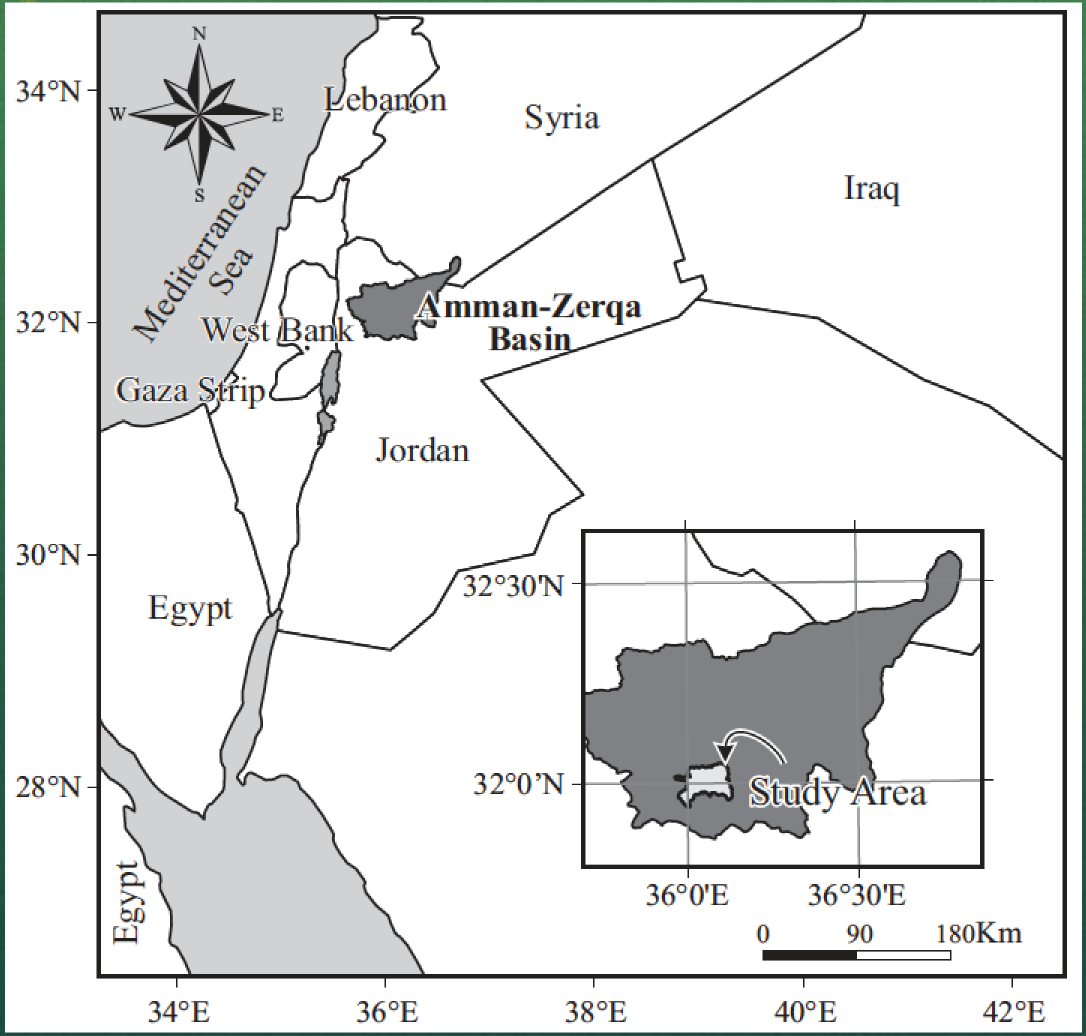






indicates that nitrates levels exceeded the permissible limit of the Jordanian Standard JS286 norm (45 mg/l). *By comparing nitrate distribution map with DRASTIC maps, it is also found that areas with high nitrate concentration are correlated with high vulnerability areas in both models.*

Location of the Study Area within Jordan



Objectives

- The ultimate goal of vulnerability maps is the subdivision of the area into several hydrogeological units with different levels of vulnerability

- To assess the vulnerability of groundwater to contamination in the vicinity of the solid waste disposal site at Russeifa area by combining the DRASTIC model with GIS

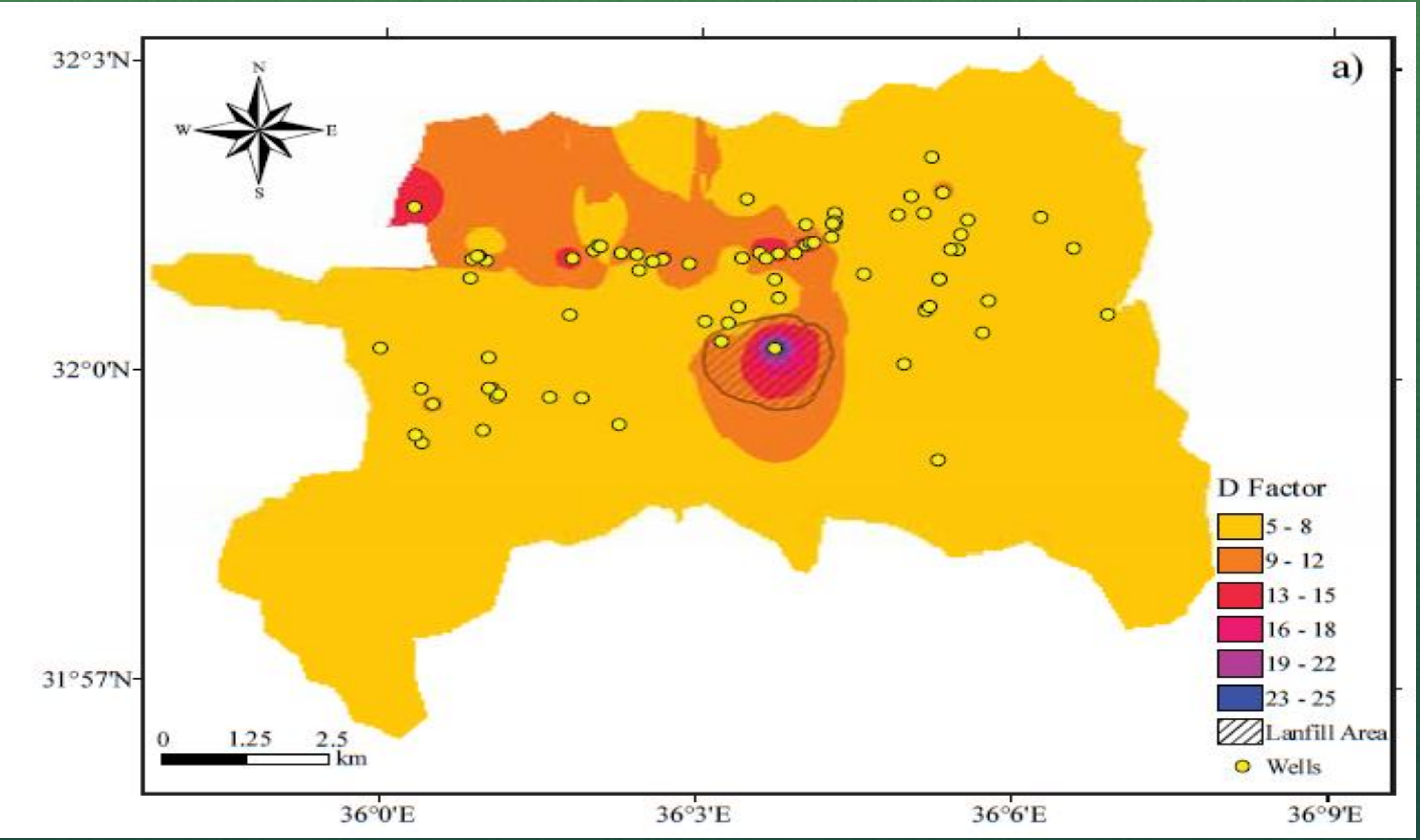
Vulnerability Mapping Model

Combination of DRASTIC model and GIS were used to produce the vulnearability map for groundwater contamination around Russeifa landfill and this involves:

1. Collecting hydrogeological and geological data
2. Standardizing and digitizing source data
3. Constructing an environmental database
4. Analyzing the DRASTIC factors
5. Calculating the DRASTIC index for the hydrogeological settings
6. Rating these areas as to their vulnerability to contamination

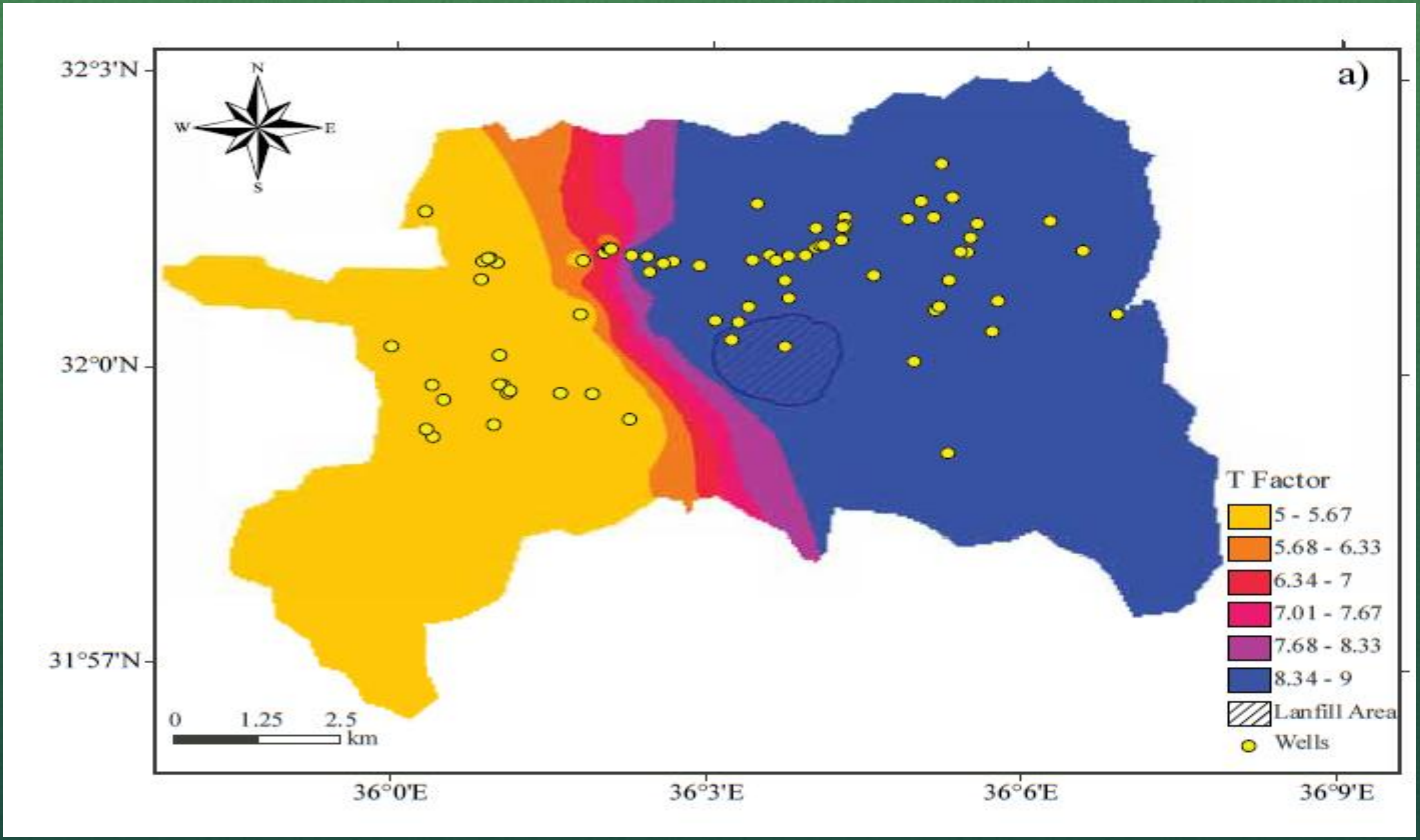
Results

The grid layer for depth to water was generated by computer subtraction of water-level elevation data sets from land surface elevation, The depth to water table is in the range from 30 m to 60 m from the ground surface



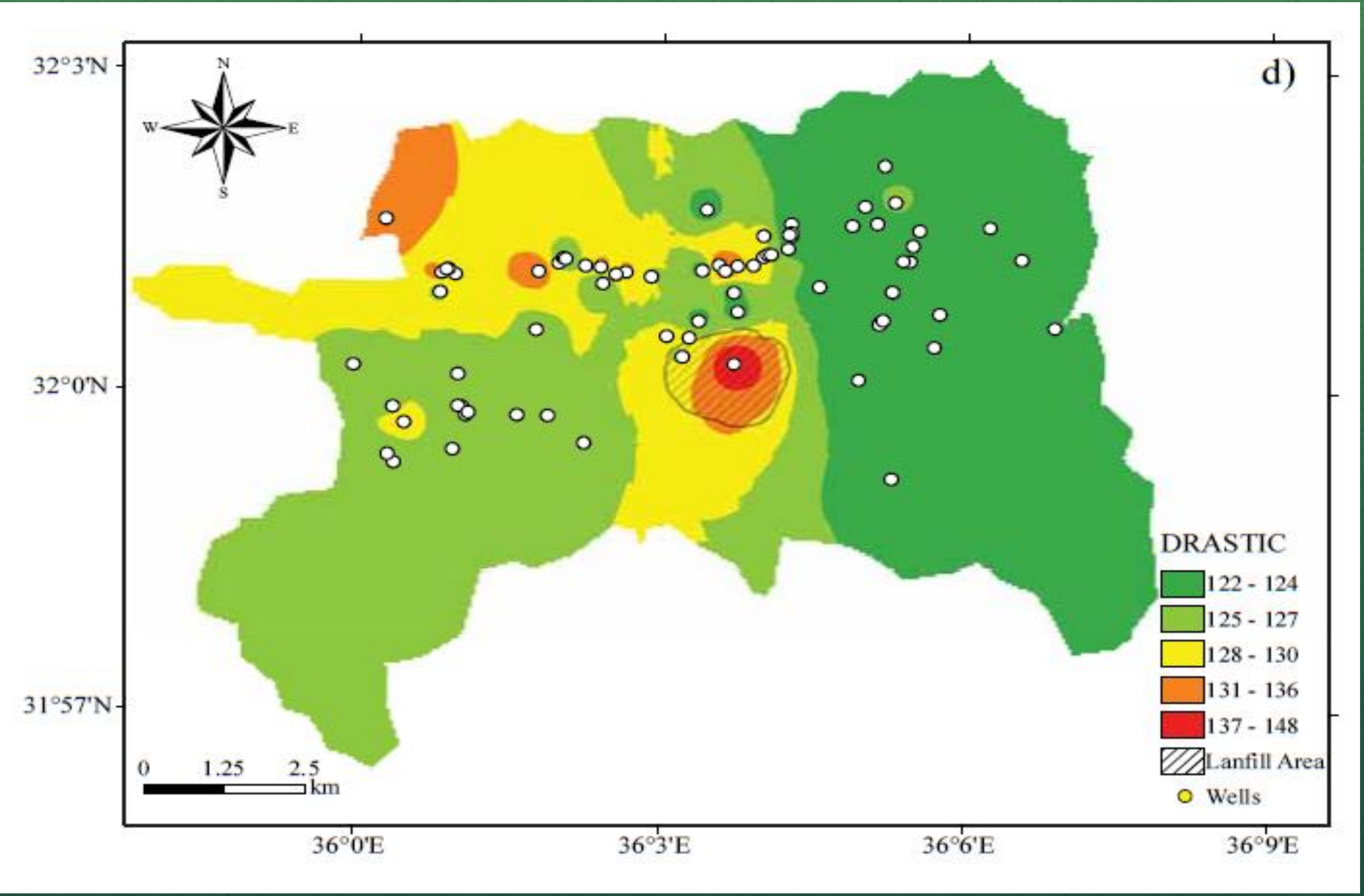
Results

The grid layer for the topography of the landfill was generated from a DEM, to calculate percent slopes. Most of the slopes in this study were in the range of 2 to 12 percent.



Results

This map shows moderate to high vulnerability (101–200) , with the most vulnerable areas to groundwater contamination –indicated by the highest DRASTIC indexes– located close to the landfill area



Study Conclusion

- The vulnerability index of Russeifa area indicates that groundwater resources in the surrounding area are susceptible to pollution to a moderate degree by the Russeifa landfill

- The vulnerability map has a range from the most vulnerable for contamination to the least vulnerable

Shukran