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Assessment of Groundwater-Level Susceptibility to Degradation Based on Analytical Network Process (ANP)

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Abstract

Groundwater resources are among the world's most important and vital supplies which are highly required for continuation of human life as well as wildlife. The growth of world's population and the occurrence of climatic drought in recent decades have put a severe strain on these blessings all over the world so that most of the aquifers have dried up and the depth to groundwater in wells has deepened severely. In the present study the Analytic Network Process was used to extract degradation risk zones of groundwater in Marand Plain. To do this, all the effective factors including precipitation, air temperature, land use, soil permeability, flow direction, proximity to rivers and groundwater exploitation via wells and qanats were used. After construction of the database in GIS environment, the structure of the network was designed in Super Decision software. Clustering and pair-wise comparisons of the elements were executed based on the results of the Expert Knowledge questionnaire and the priority weights for each cluster and parameter was extracted consequently. Finally, the priority weights of the criteria were applied on the map layers and the final degradation risk map created overlaying all the maps. According the final output of the study, the Eastern and Western parts of Marand Plain have the highest and lowest susceptibilities respectively. It's also found that the groundwater decline trend mimics the surface topography and flow direction in which has an East-West pattern.

Keywords: Susceptibility Assessment, Groundwater Degradation, GIS, ANP, Marand Plain

Introduction

Water is the basic element for the sustenance of life. Groundwater is one of the main sources of fresh water over the world. Approximately 99 percent of all liquid fresh water is in groundwater aquifers and at least a quarter of the world's population draws its water from these groundwater supplies (Jackson et al., 2001). Groundwater resources are important for the socio-economic development, especially in arid and semi-arid regions (Tili-Zrelli et al., 2012). The contribution from groundwater is vital; perhaps as many as two billion people depend directly upon aquifers for drinking water, and 40 percent of the world's food is produced by irrigated agriculture that relies largely on groundwater (Morris et al., 2003; Gazioğlu 2010, 2014; Ülker et al., 2018). This blessing is now facing geographical issue and almost every region of the world is under water crisis (Mahmoud et al.,

2013a). Besides The population growth and increased demand for fresh water, the climate change impacts in recent years have brought about severe depletion in groundwater resources around the world. Groundwater depletion is primarily caused by sustained groundwater pumping (Konikov, 2013). It is found in many places that the rate of groundwater extraction is higher than the recharge rate which causes many environmental problems such as, encroachment of saline water, land subsidence, reduction of the yield capacity of the aquifer system and also deterioration of quality of groundwater (Ganguli, 2011a). Today, with an estimated total global withdrawal of 600–700 km³ yr⁻¹, in one sense groundwater is the world's most extracted raw material (Foster & Chilton, 2003; Kaya, et al., 2017). Recent evidence shows that groundwater supplies are diminishing, with an estimated 20% of the world's aquifers being

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over-exploited, some massively so (The United Nations World Water Development Report, 2014). Since the water demands are almost entirely met by groundwater and considering the side-effects of its overuse, therefore the study of groundwater withdrawal is very important.

There are a wide range of researches done on the issues of groundwater level changes and its side-effects worldwide: Mahmoud et al. (2013b) used the Geographic Information System to study the susceptibility of Lahore's ground water to degradation. In this study a depression zone in the aquifer was identified below 38m which goes on to expand after 2004 persistently with an average rate of about 24.5 Km² per year. The expansion trend in the depression zone has also identified consequences of recent developments in the study area and increased flow of Ravi in 2010. Al-Rawabdeh et al. (2013) applied a Drastic model in GIS environment for assessing aquifer vulnerability in Amman-Zerqa Groundwater Basin in Jordan. The Drastic index map showed that only 1.2% of the basin's total area of 3792 km² lies in the no vulnerable zone and about 69% is classified as having low pollution potential. The results also suggest that almost one third of the AZB is at moderate risk of pollution potential. Nayak et al (2015) mapped the ground water fluctuations in Bina basin applying GIS. In this research the Interpolation of pre and post monsoon groundwater levels was carried out for the year 1995, 2000, 2005 and 2010. Finally, the water table fluctuation maps were generated showing the fluctuation in the pre monsoon period between the years, 1995-2000, 1995-2005 and 1995-2010 and the areas under rising/falling trend of groundwater table were delineated. The results revealed that the groundwater table in the central to northwest part of Bina watershed is declining in recent years. Shalini et al. (2012) used GIS to analyze the groundwater level and rainfall variability trend in Jharkhand state (India). The sum of least squares method was adopted to analyze the relationship of groundwater level variability with the rainfall trends. The analysis revealed that this region during the post-monsoon season exhibit shallow depth of water level (2-3m) which declines up to 8-10m during pre-monsoon in the month of May. The south-

eastern region showed an increase in the rainfall over the years, yet the average water level was very deep indicating large water losses due to runoff. Ganguli (2011b), studied the groundwater withdrawal and land subsidence in west Bengal (India). The study aimed at measurement of the region's land subsidence due to groundwater exploitation. It is found from the observation that the rate of decline of static water table, the depth of total aquifer system and the hydrogeological characteristics of the aquifer control the rate of subsidence of the area. The results suggested that the estimated average rate of land subsidence is 6.13 mm/ year for 1 m drop of static water table. Masoudi et al. (2009) applied GIS for assessing the groundwater degradation hazard in Mond Miyani Basin (Iran).

The hydrogeological and climatological characteristics and those anthropogenic activities related to irrigation farming were used to create the hazard indicator maps. The final hazard classes were defined on the basis of hazard scores arrived at by assigning the appropriate attributes to the indicators and the final hazard map was prepared by overlaying different hazard indicator maps in the GIS, deploying the new model. The final Hazard Map showed that moderate hazard areas (70.8% of the plains) are much widespread than areas under severe hazard (13.4% of the plains). Akbari et al. (2009) studied the ground water decline of Mashhad Plain aquifer using GIS. They analyzed about 70 piezometer wells of the study area between 1987-1997 and 1997-2007 and created water level layers through interpolation technique using geology, topography and mountain-plain limit maps. Also water level hydrograph were drawn in Excel software. The result of classification of groundwater level maps indicated that groundwater table decreased about 30 meters in central and western regions of aquifer.

Bilesavar (2013a) studied the relation between the groundwater level fluctuations and the geological formations of Marand Plain (Iran). The groundwater depth and flow direction maps were created using the piezometric datasets of 50 observation wells of the study area in the period of 2002-2012. The results indicated that the southern and western parts of the study area

are in the highest and lowest zones of degradation respectively. They suggested that the region's groundwater flow direction which has a South to West trend is the key factor affecting groundwater decline.

Considering groundwater importance in every aspect, identifying the susceptible areas to degradation of a given region is a pivotal element for managing and conserving these vital resources. In the present study the main objective is to extract groundwater withdrawal risk zones of Marand plain by means of ANP and GIS.

Materials and Methods

Study Area

Marand region is located in north-west of provincial capital Tabriz, northwest of Iran (45-15 to 46-50 East and 38-18 to 38-46 North).

With an estimated area of 826 square Km, Marand Plain is located in the southern parts of the region. It is known as a part of catchment area in Caspian Sea in the northwest Iran (Najib, 2002a). Most of the region's population live in the plain and rely on the region's Agriculture-Based economy (Najib, 2002b).

Receiving a medium annually raining of 236mm and a medium temperature degree, annually 10.9C, Marand Plain is a member of semi-arid regions. Almost all of the area's water need is provided from groundwater sources. Based on the reports of the Regional Water Organization, Marand Plain is among the six critical regions in East Azerbaijan province in which any exploitation of groundwater sources is prohibited due to severe decline in water level in the recent decades (Fakhri et al., 2015). The location of the study area has been manifested in Figure (1).

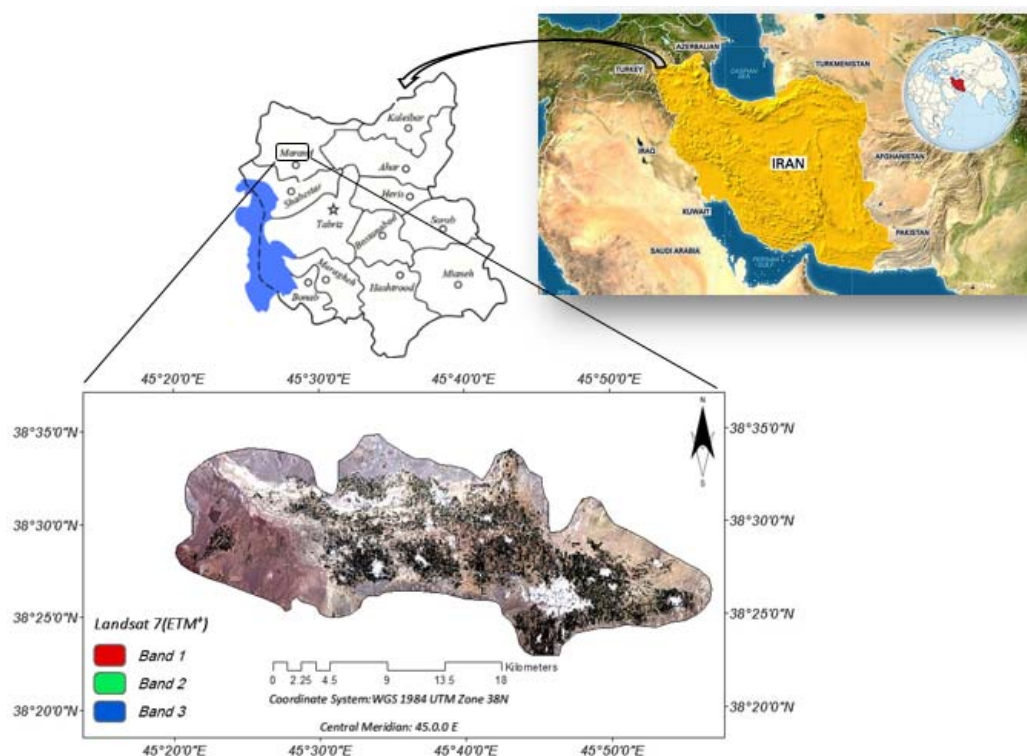


Figure 1. Geographic location of the study area, Marand Plain

Analytic Network Process

The ANP is one of the most completed multi-criteria decision making method which has been presented up to now and was frequently used by the researchers for different purposes

(Mahdavi et al., 2013). The Analytic Network Process is a generalization of the Analytic Hierarchy Process. AHP is a well-known technique that breaks down a decision-making problem into several levels in such a way that

they form a hierarchy with unidirectional hierarchical relationships between levels (Azizi et al., 2014a) but the basic structure of ANP is an influence network of clusters and nodes contained within the clusters (L.Saaty, 2006). So the main innovation of the ANP is its network structure, which enables interactions between elements situated in different clusters and dependencies between the elements in the same cluster to be taken into account (Azizi et al., 2014b). Here ANP method was used to obtain the priority weights of the research factors in four steps.

Step 1

At the first step the effective factors of the subject were determined considering the local characteristics of the study area, viewpoints of the experts, previous studies and accessibility to the data. Table 2 shows the used criteria and their descriptions.

Steps 2 & 3

After classifying the elements into appropriate clusters, the network structure of the ANP model was designed based on the interrelations and feedbacks of the elements and clusters. Fig.2 illustrates the ANP network designed in Super Decisions software.

The model was Designed in Super Decisions 2.8 and developed according to the simple network structure where 8 environmental indicators were applied and clustered in three main groups including factors relevant to the Topography, Climate and Hydrology

Step 4

In the final step the pair-wise comparisons were conducted. In ANP approach the comparisons are done through fundamental scales. The Fundamental Scales used in the judgments have been illustrated in Table 1. The priority weights of the clusters and elements were calculated through pairwise comparisons (Figure 3) which was done according to the results of the expert-knowledge questionnaire.

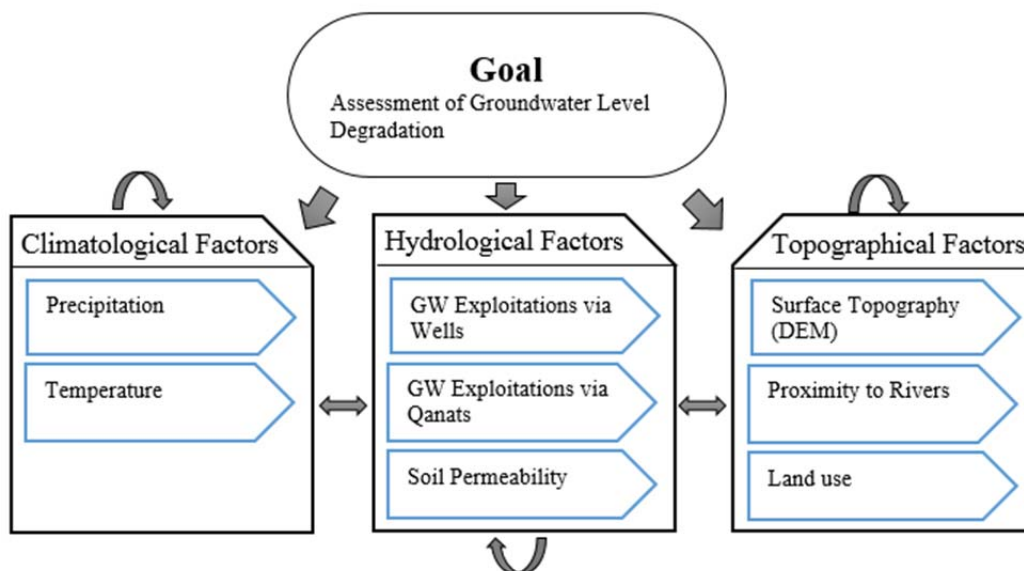


Figure 2. Structure of the ANP model for assessing groundwater susceptibility to degradation.

Table 1. Fundamental Scales for absolute numbers used in ANP decision making method (Saati, 2006)

1	Equal Importance
3	Moderate importance of one over another
5	Strong or essential importance
7	Very strong or demonstrated importance
9	Extreme importance
2, 4, 6, 8	For Intermediate Values

Table 2. List and description of the criteria used in the study

Criteria	Description
Precipitation	Rainfall infiltration-recharge is one of the most essential groundwater resources (Wu and Zhang, 1994). It is considered as an important factor affecting the ground water level through its recharging role. Direct recharge to ground water from precipitation results from the infiltration of precipitation into the soil and below the root zone, hereafter referred to as "deep percolation": generally, the greater the precipitation, the greater the deep percolation and recharge (Orr, 2002). Even small changes in precipitation may lead to large changes in recharge in some semiarid and arid regions (Woldeamlak et al, 2007). Areas which receive much precipitation have a good potentiality to recharge the water table thus aren't at high risk of degradation of ground water and vice versa.
Temperature	Warming trends may affect global evapotranspiration patterns, which have direct implications for the sustainability of surface and subsurface-water resources (Barnett et al, 2008). However, higher air temperatures are likely to increase evapotranspiration, which may result in a reduction in runoff and SWC in some regions (Chiew and McMahon, 2002). Air Temperature and evapotranspiration are particularly important because they directly affect groundwater recharge and indirectly affect human groundwater withdrawals or discharge.
Groundwater exploitation via wells and qanats	Groundwater discharge is the loss or removal of groundwater from an aquifer, for example to rivers through base flow, as spring discharge or through groundwater abstraction (Bloomfield et al, 2013). Wells and Qanats are the main water sources of the study area which provide a majority of the area's water supply for different purposes such as domestic, agriculture and industry (Faridpour, 2014).
Land Use	Land development usually induces large changes in flood peak and infiltration properties, thus affecting the entire hydrological environment of the area. Land use changes associates with changes in both surface and ground water patterns and in this way affects ground water recharge (Jinno et al, 2009). Most groundwater originates directly from excess rainfall infiltrating the land surface. Thus land use has a major influence on both groundwater quality and recharge rates (Foster & Charlet, 2014).
Soil Permeability	Permeability is a measure of how easily water can travel through porous soil or bedrock (U.S. Geological Survey, 2015). Soil permeability affects the infiltration rate of water and controls the recharge process of the water table. Estimated groundwater recharge is lowest in areas overlain by thick, low permeability materials (Geological Survey of Ireland, 2012). Areas with lower rates of soil permeability have greater susceptibility to water table degradation and vice versa.
Proximity to Rivers	Rivers have a great influence on the aquifer recharge process through water infiltration. The nearer areas to the rivers, the higher rate of water infiltrates thus in these parts the water table level is in better condition than the farther areas.
Flow Direction	Groundwater moves relatively slowly travelling at a rate between a Fraction of an inch and a few tens of feet per year, depending on how permeable the aquifer is (Hernandez & Gailbraith, 1997). The horizontal direction of ground-water flow is generally perpendicular to the contour lines and water flows down the slope of the contours in a manner analogous to the flow of water down the slope of the land surface (Wozniak et al, 2005). Since the Flow direction of the study area mimics the Surface Topography (Bilesavar et al, 2013b), the DEM layer used in representation of the flow direction.

Geographic Information System

After assessing groundwater, it is important to simplify results of the study for policy makers and other stake holders. So, nowadays, using other sciences such as geographical information system (GIS) has been increased. GIS is a management tool that has grown since the late 20th century. In the past 10 years, the number of GIS users has substantially increased. GIS technology has previously facilitated laborious

procedures (Shamsi, 2005; Assaf and Saadeh, 2008; An et al., 2012). Geographic Information System dubbed "GIS" is known as a robust mean to analyze geographic data as well as environmental phenomena.

It has the capability of Capturing, storing, checking, integrating, manipulating, analyzing and displaying data which are spatially referenced to the Earth. This is normally

considered to involve a spatially referenced computer database and appropriate applications software” (Fazal, 2008). GIS technologies facilitate the decision making process based on their analytical capabilities with spatial information. The Geographic Information

System software was used in this study to analyze the spatial datasets, create the input layers (Figure 4) and finally export the output map based on the results of the analysis.

Table 3. The Priorities obtained for the Network’s Elements and Clusters through ANP

Clusters	Elements	Weights
Climatological (0/25)	Rainfall	0.13
	Temperature	0.10
Hydrological (0/32)	Exploitation via Wells	0.18
	Exploitation via Flumes	0.08
	Soil Permeability	0.05
Topographical (0/43)	Land Use	0.13
	Proximity to Rivers	0.08
	Flow Direction (DEM)	0.25
	Total	1

Results

All the criteria layers which were created in Arc-GIS10.2 software, were reclassified and overlaid based on the priority weights obtained through ANP. The priority weights of both clusters and elements have been shown in Table 3.

The outputs of the study (figure 5) illustrate the zones of Marand Plain which are likely to groundwater degradation. The results showed that of the total 658 km², an area of about 123 km² (19%) lies in the “Very Low” susceptibility class whereas 186 km² are located in the “Low” class with a coverage percentage of 28. The vulnerability map shows about 22% of the area is classified as having Moderate decline potential and about 94 km² are within the “High vulnerability zone”. Only 17% (112 km²) of the study area lies under the area of “Very High” vulnerability zone.

Discussion and Conclusion

The present study aims mainly at the assessment of groundwater susceptibility to degradation applying multi-criteria decision making system. Geographic Information

System is known as a spatial Decision Support system which integrates spatial datasets with MCDM processes to tackle complicated spatial problems.

Groundwater withdrawal occurs when the discharge rate exceeds the recharge rate. A variety of factors controls the recharge and discharge processes of aquifers including Topographic, Hydrologic and Climatic factors. According to the results Eastern parts of the study area consists of the critical zones, sites with high and very high categories (31% of the study area), are more vulnerable to degradation, consequently, need to be managed more closely, whereas the Western zones with low potentiality are less susceptible to groundwater degradation., in which the influence of groundwater flow direction, which is in the east-west path, is lucid. In other words, in spite of receiving the highest and least amounts of precipitation and Temperature respectively, the eastern parts of Marand Plain have the maximum potentiality of groundwater degradation and this is just because of the role of both groundwater abstraction and flow direction beneath the ground which transfers the infiltrated waters from east to west.

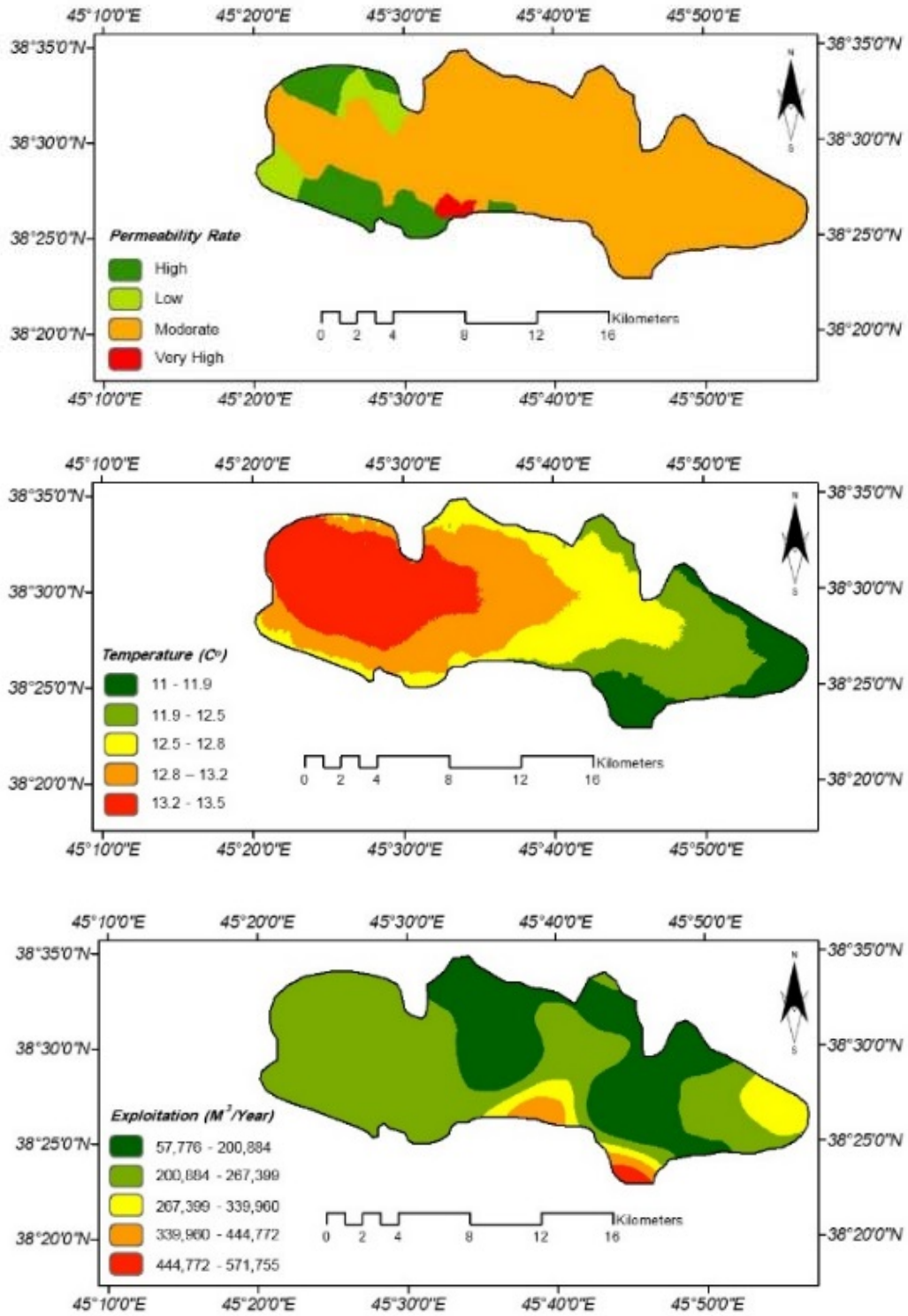


Fig 4. Illustration of the criteria layers. The input layers used in this study: Rainfall (1), Temperature (2), Exploitation Via Qantas (3), Exploitation Via Wells (4), Soil Permeability (5), proximity to Rivers (6), Surface Elevation (7) and Land Use (8).

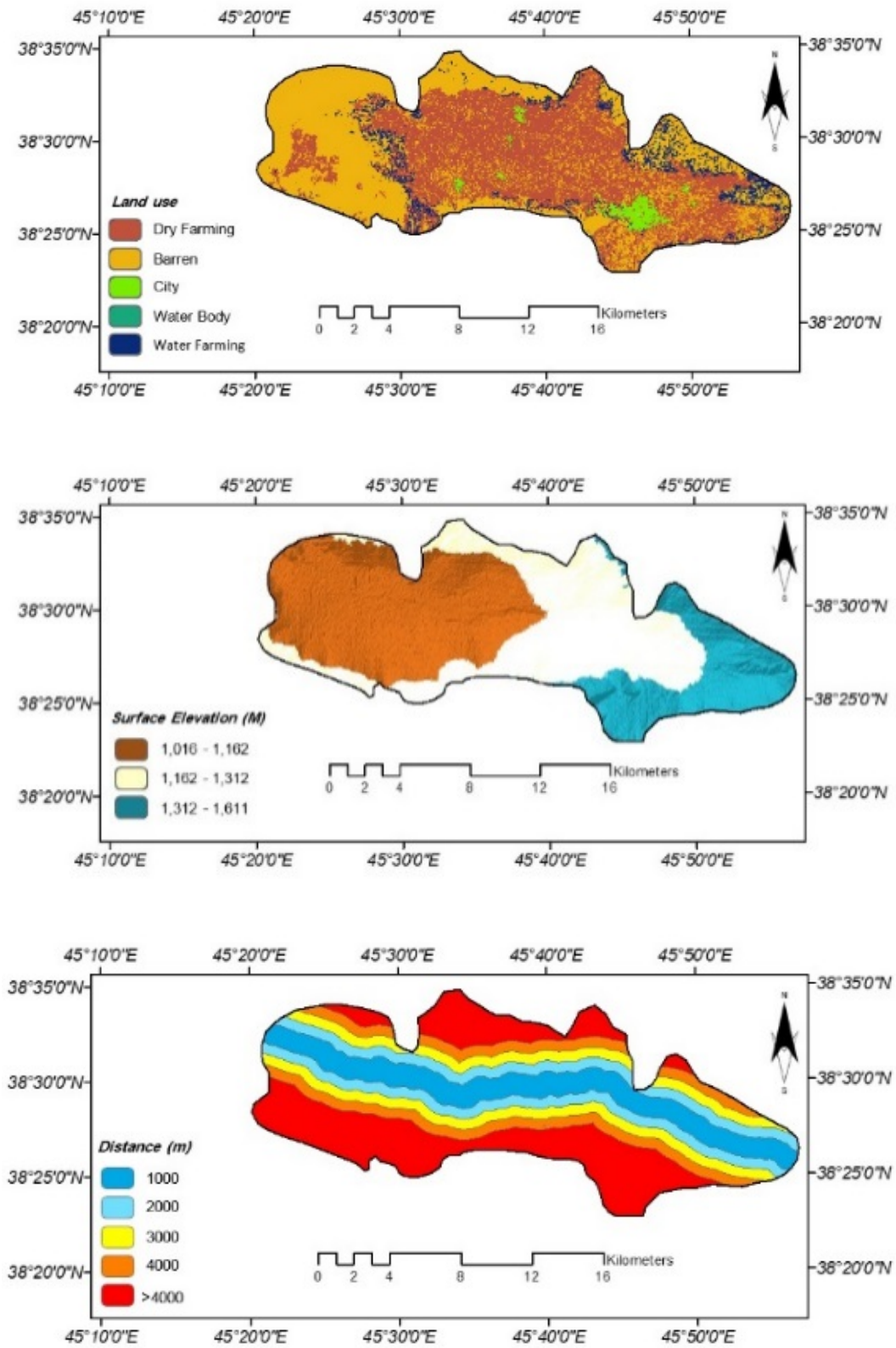


Fig 4. Cont.

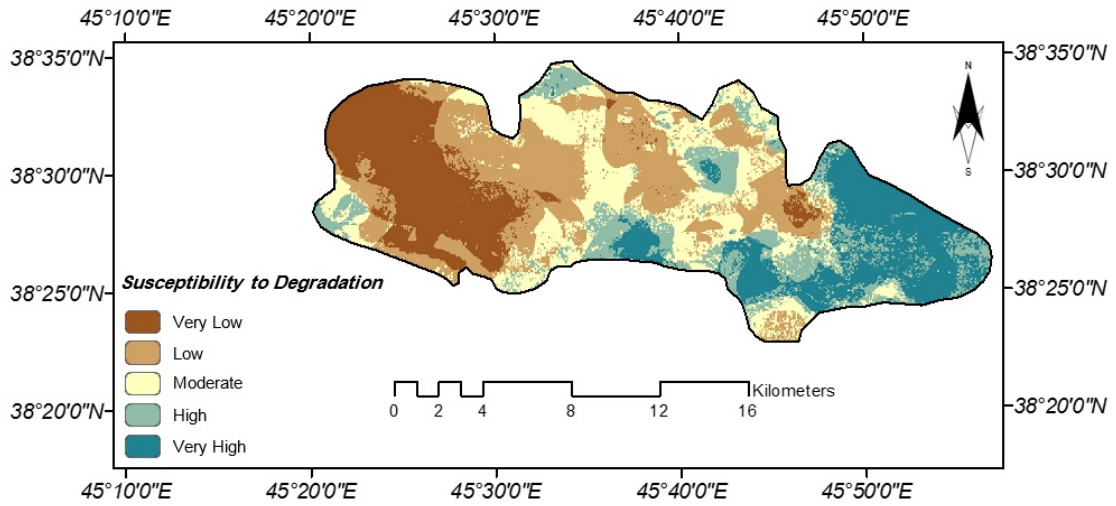


Fig 5. The Susceptibility Map Classes of Ground Water Degradation

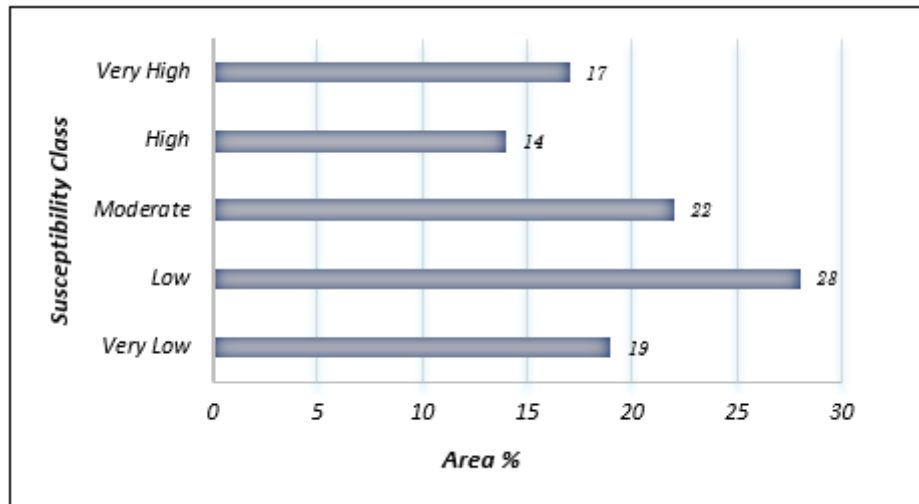


Fig 6. The area percentage of the study area related to each susceptibility class

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