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The Role of Groundwater Vulnerability in Urban Development Planning

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Abstract: Groundwater resources in most places of Iran are considered to be one of the important drinking water supplies for civilians. In city of Tehran, 25% of drinking water is being supplied from groundwater. This fact would enforce the requirement to protect and conserve groundwater resources in the city for its further development plan. Municipality of Tehran, District-22 has been designed for the latest and the ultimate development boundary of the city, which is being constructed in the north-west part of the city. The groundwater resources of the District are considered as main drinking water supplier for its future short term population. Hence due to the importance of groundwater of the District, the vulnerability to nitrate contaminant is being examined by means of Drastic Model. The results obtained, indicate that due to regional environmental characteristics, vulnerability index varies in different parts of studied area. so the eastern and south eastern parts of the District have experienced the highest vulnerability. Besides comparing the results with nitrate concentration reveals that correlation has been approximately 61% and among the drastic layers, precipitation layer has been determined as the most effective parameters for final drastic index layer of studied area. In this regard, concerning the vulnerability map, urban land application, including residential and commercial in mentioned parts should be prohibited.

Key words: Groundwater, Vulnerability Index, Urban Environment, Drastic Model

INTRODUCTION

In recent years, water resources conservation in Iran has been highly considered due to the increasing trend of population as well as decrease of water resources accessibility for different users, specially drinking purpose. In this respect, groundwater resources play a vital role to supply drinking water particularly in urban areas, which necessitate taking sufficient and safe water for citizen's consumptions. This is nearly a general role in different metropolis depended on groundwater, hence It can be generalized in Tehran as a specific Metropolis which has a depending rate of 25% to groundwater. During recent years, Tehran with a population of 7 millions is being faced to such a problem as a chronic and basic issue [1]. On the basis of comprehensive water resources studies, groundwater potential to supply drinking water has been estimated 250 million cubic meters per year, but in drought conditions due to the decrease of surface water flows, groundwater will be overexploited and naturally affected aquifer level [2]. At the time being, due to the rapid growth of population in Tehran, surface water is not sufficient to supply water needs in different sectors, therefore exploitation of groundwater should be considered as a solution. According to the increasing trend of Tehran population, urban development plans are the first priority, which is necessarily considered by planners and managers. In this regard, development of the new-established municipality of Tehran District-22 has been ultimate case to meet residential and commercial applications requirements [3]. The District-22 is limited at the northwest part of Tehran with 1400 meters mountain by north, Kan River by west, Tehran-Karaj highway by south and rocky Karavan-Sara by east (Fig. 1). In master plan of District-22, various land applications have been determined and amongst them totally 23% have been allocated to residential and commercial land application [4] (Fig. 2). Regarding deficiency of water resources in Tehran metropolis, It is immediate necessity to provide drinking water for predicted population (1,000, 000 people) of the District 22, so groundwater resource plays a vital role which should be exploited optimizely by priority setting between water users in the different sectors as well as groundwater potential in sewage discharge well and non saturated soil media. At present, different methods including G.O.D.S., A.V.I. and DRASTIC models have been introduced globally to identify groundwater contamination vulnerability and amongst them, the drastic method is the most appropriate for urban environment application [5]. The study has been done in Tehran in 2004.

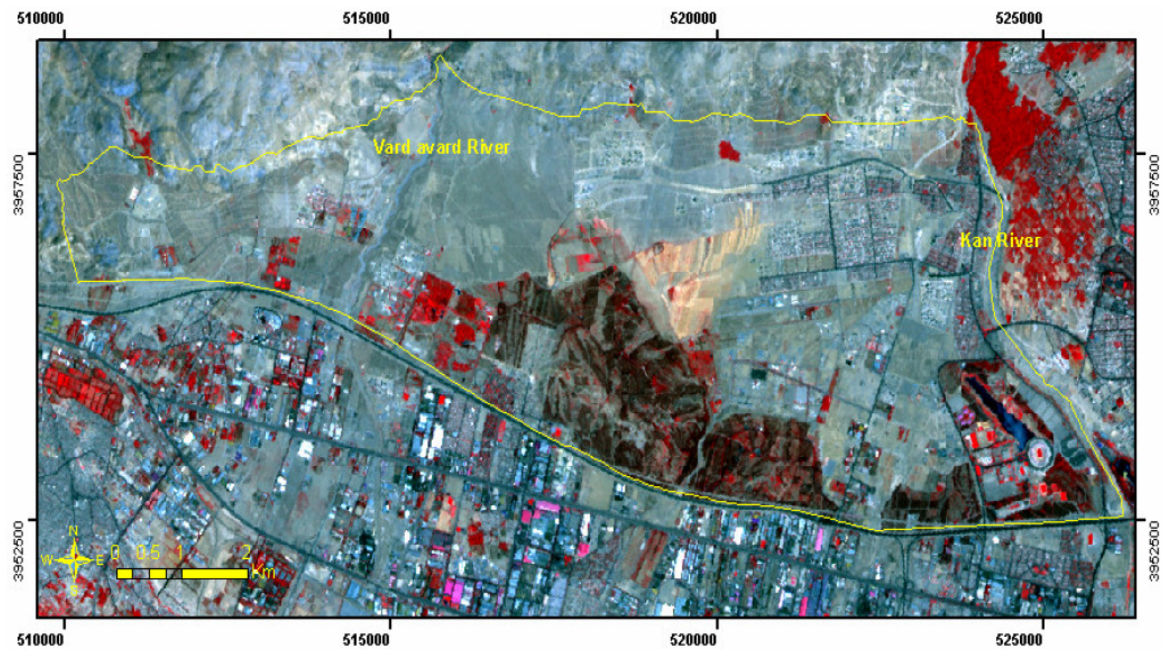

Fig. 1: Satellite Image of the Studied Area (Tehran District 22)

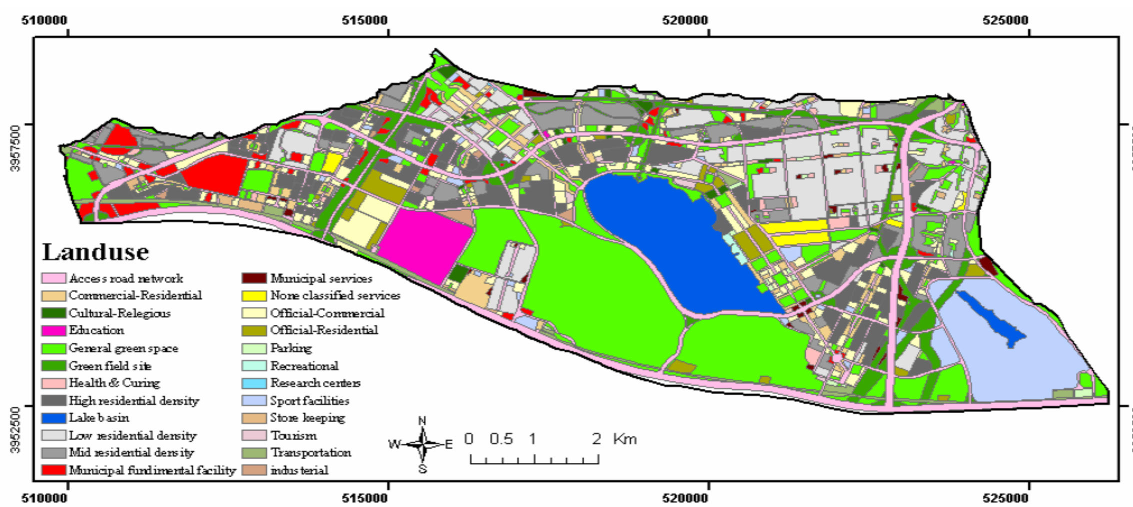

Fig. 2: Urban Development Plan in the Studied Area

MATERIALS AND METHODS

Groundwater contamination vulnerability of studied area is investigated by means of drastic method. In drastic method, seven hydro-geological factors associated with groundwater pollution potential, are considered. This model is applied associated with the studied area and then the drastic equation has been calculated as follows [6]:

Dr. Dw + Rr. Rw + Ar .Aw + Sr. Sw + Tr. Tw + Ir. Iw + Cr. Cw = D R A S T I C Index

Where:

D, R, A, S, T, I and C are the seven parameters, where "r" is the rating value and "w" is the weight associated to each parameter. Drastic index represents groundwater vulnerability. Table 1 shows the weights and rating value of drastic parameters. It is necessary to point out that in this investigation much software associated to Geographical Information System (GIS) including Arc view version 3.2a; Arc GIS in addition surfer 7 software have been applied in order to produce input thematic maps for modeling. Also for identifying the accuracy of drastic outputs, final drastic map has been precisely compared with nitrate concentration in groundwater of studied area by means of "Curve Expert 1.3" software [7, 8].

In final step, for detecting the influence of rating assigned to each data layer following equation has been utilized [9]:

$$W_{pi} = (P_{Ri} * p_{Wi} / vuln_i) * 100$$

Where:
P_{Ri} = Ratings of layer "p" assigned to the subarea "i"
P_{Wi} = Weights of layer "p" assigned to the subarea "i"
$vuln_i$ = The vulnerability index
W_{Pi} = Effective Weight for each subarea

Table 1: Assigned Weights for Drastic Features

	Feature	Weight
D	Depth of water table	5
R	Recharge	4
A	Aquifer media	3
S	Soil media	2
T	Topography	1
I	Impact of the vadose zone	5
C	Conductivity of the aquifer	3

Generally, the main stages of groundwater vulnerability determination in the studied area can be summarized as follows:

* Setting up and running the drastic model
* Investigation of nitrate concentration in groundwater and comparing with drastic results
* Determination of actual weight for data layers separately by means of sensitivity analysis
* Utilization of drastic results for optimizing the land uses of the District- 22 master plan

RESULTS

The aquifer of the studied area has been placed between Kan and Karaj rivers. Among the rivers that flow through the studied area, two seasonal rivers including Kan and Vardavard are important to recharging groundwater aquifer, so that Kan River has more influence than Vardavard. The origin of groundwater is referring to separate deposits, which have been derived from erosion of north heights formations. Main parts of aquifer were covered to alluvial "series C" which have capability of proper water permeability and reserving. On the other hand, groundwater aquifer level is shown annual changes. Due to the weather condition and hydraulic gradient of groundwater flows and also different uses, so at withdrawal and exploitation seasons especially for potable, agriculture and industrial purposes, groundwater level will be decreased considerably. Some of characteristic of drastic parameters in the studied area are explained as follows:

Depth to Groundwater (Dr): Depth to groundwater has been computed using piezometric field data. Totally depth of the water table from topographic surface and unsaturated alluvial zone varies between 70 to 80 meters. Therefore coefficient of rating for this factor is considered equal to 1 (Dr = 1) regarding mentioned classification of depth to groundwater.

Soil Media (Sr): Soil media include upper parts of ground, which cover averagely around 6 feet, or less soil type and texture play a considerable role on water permeability. As it has been shown in Fig. 3, by using soil permeability zonation map, rating coefficient was optimized and computed.

Topography (Tr): The thematic map of slope has been produced according to the drastic rating coefficient of slope parameter in studied area. The map shows slope degrees increase from south toward north of studied area. Regarding to Topography parameter, it is also expected that south parts have more vulnerability comparing with north parts (Fig. 4).

Recharge (Rr): Generally, net recharge has direct relation with amount of precipitation. In order to determine annual precipitation of the area, existing data taken from near stations including Mehrabad, Kan, Karaj have been applied. By using interpolation of precipitation data, Index of rating coefficient 8 and 9 was calculated regarding two classified precipitation of 180-250 mm. and more 250 mm. throughout the studied area.

Hydraulic Conductivity (Cr): On the basis of groundwater potential, flow direction and hydrological flow map; eastern and southwest parts of the region have great hydraulic conductivity comparing to northern and northwest parts which are included least amounts.

Vulnerability Map: According to the characteristics of drastic parameters in studied area and integration of seven layers, drastic index has been produced (Table 2). Results are shown in Fig. 5. In this Figure the studied area classified in eight levels of vulnerability in which classes 87-93 and 128-139 present least and most vulnerability respectively. Distribution of each class demonstrate that class 5 (average) is included the most expansive area in comparison with other classes. Based on the results obtained, there is a 61% correlation rate between measured nitrate concentration and estimated drastic factor in groundwater, which shows the meaningful trend of correlation (Fig. 6).

Table 2: Groundwater Vulnerability

Class	Drastic index	Vulnerability levels
1	87-93	Insignificant
2	93-101	Very low
3	101-107	Low
4	107-112	Relatively low
5	112-117	Moderate vulnerability
6	117-123	Relatively high
7	123-128	High
8	128-139	Very high

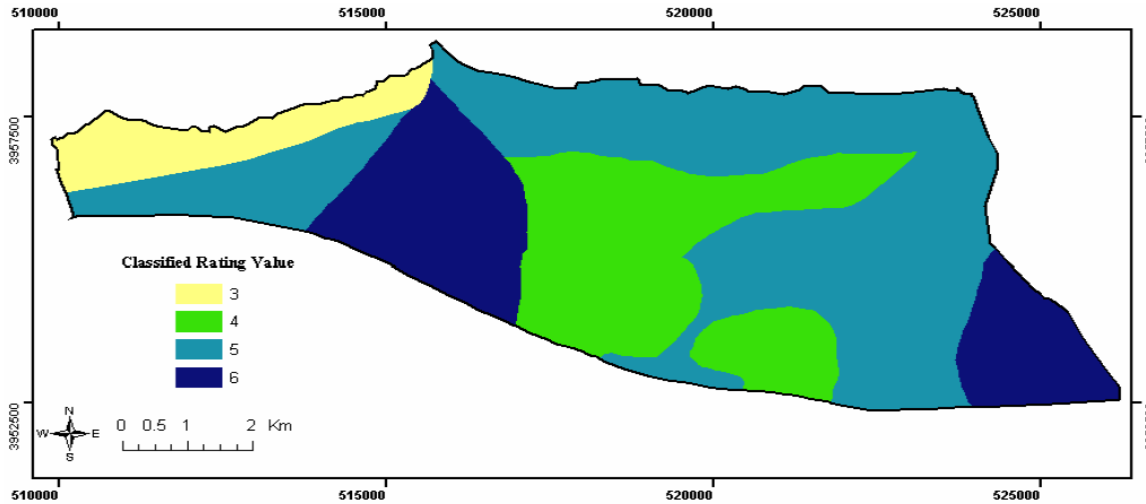

Fig. 3: Distribution of the Soil Rating Value in the Study Area

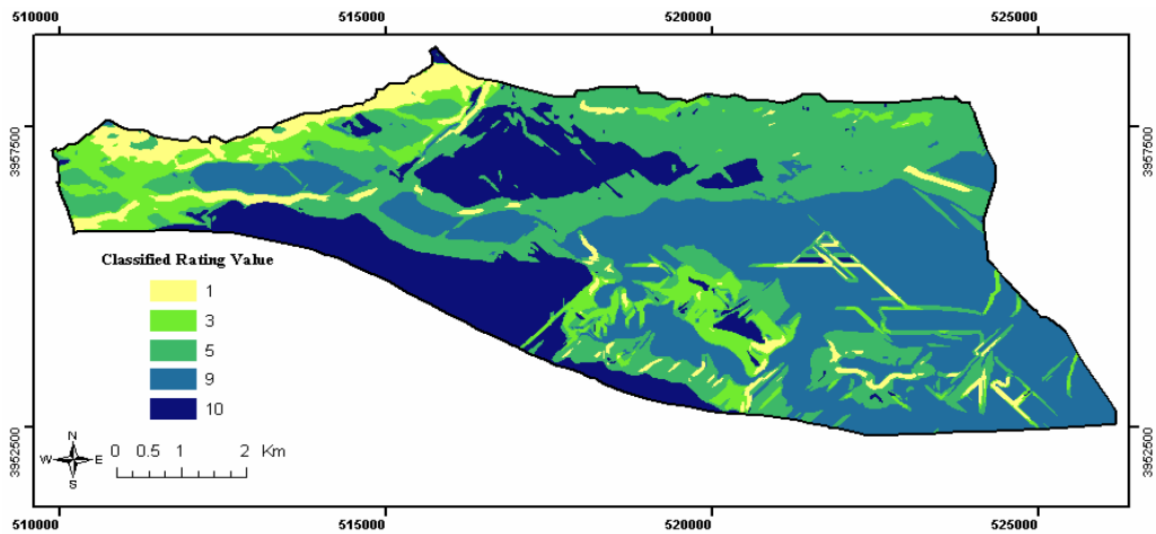

Fig. 4: Distribution of Rating Value for Topographical Condition

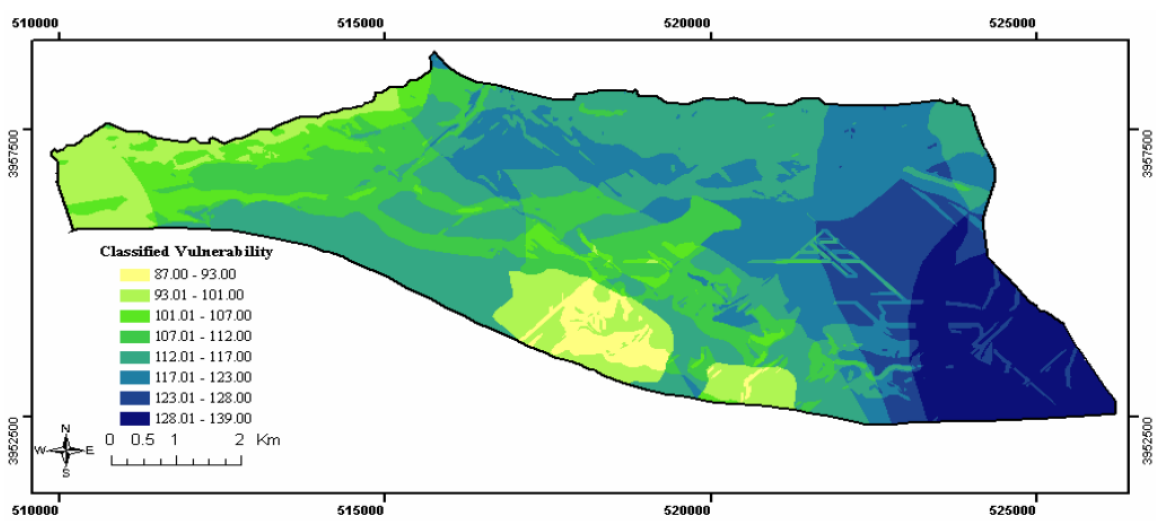

Fig. 5: Groundwater Vulnerability Classification of the Studied Area

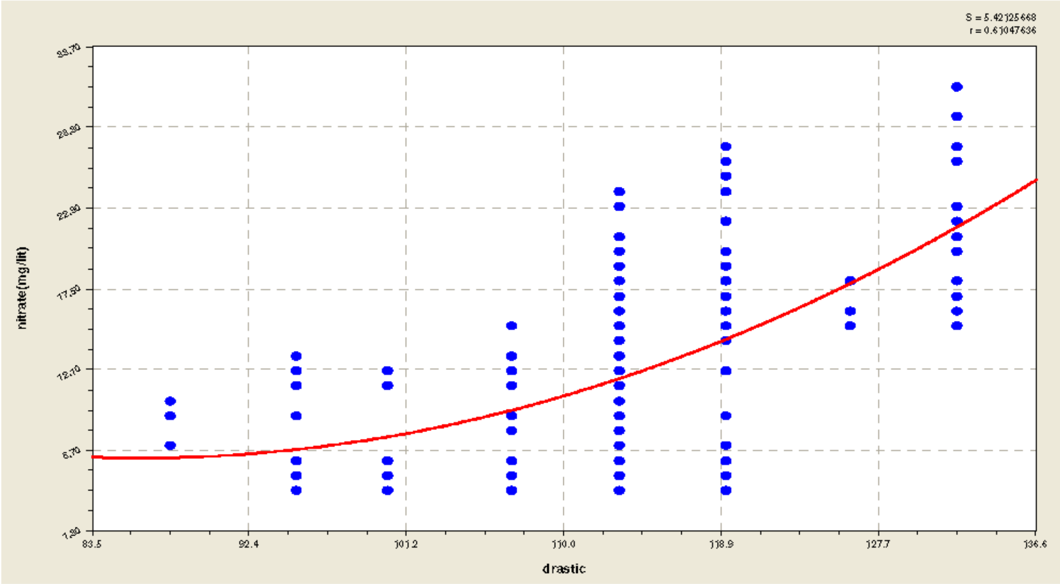

Fig. 6: Regression between Nitrate and Drastic Values of the Studied Area

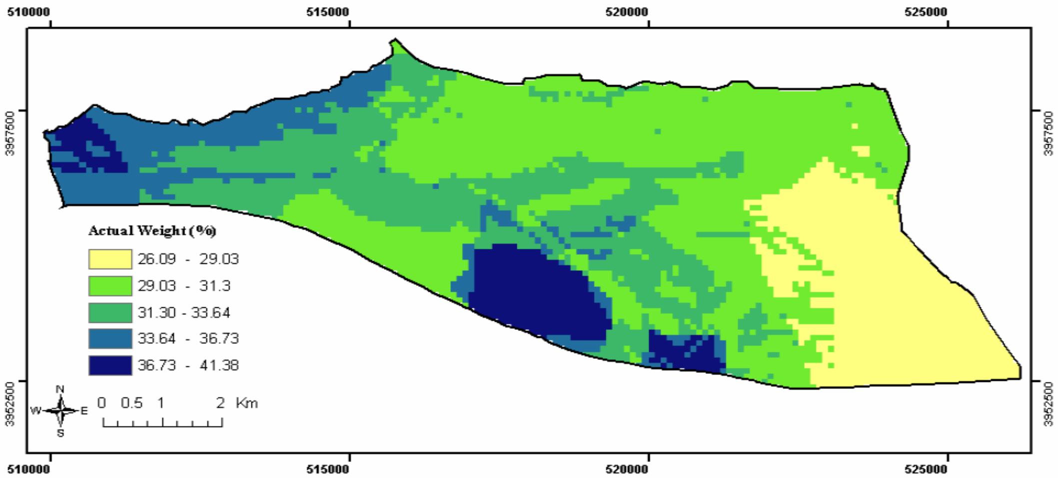

Fig. 7: Actual Weight of Net Recharge in the Studied Area

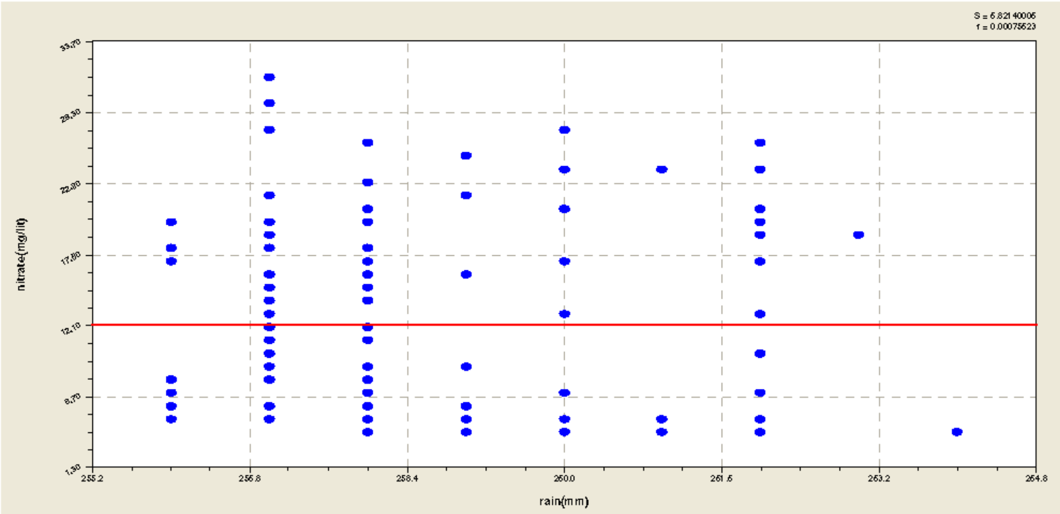

Fig. 8: Regression between Recharge and Drastic Values of the Studied Area

Although the sensitivity analysis reveals that net recharge has the maximum weight in final drastic index layer, changes of drastic index is most affected by depth factor (Fig. 7). As it is shown in Fig. 8 there is a very low correlation factor between drastic factor changes and recharge changes.

DISCUSSION AND CONCLUSION

Aquifer pollution vulnerability map represents that eastern and south-eastern parts of the studied area are more vulnerable to groundwater contamination than others due to the low slope, high hydraulic conductivity, loam-clay soil type (and other regional characteristics of drastic parameters). Moreover, southern parts of the area are less vulnerable than others, which are included 20% of studied area. It is due to the specific landform, low depth of the water table and also resistant geological structure's (including analogue conglomerates with sandy stone and clay layers which in conglomerate have proper cements).

Marginal parts of north-west have relatively low vulnerability owing to high slope classification (15-30% and more than 30%), loamy clay soil type and other specifications of drastic factors (parameters). On the other hand, overlaying the master plan on vulnerability map represents that some land uses which are predicted to contaminate groundwater, have been placed exactly on very high vulnerable area to groundwater contamination. For instance, south-east parts of area have the most vulnerability, whereas in the master plan, land uses including high, middle and low residential density have been anticipated.

Therefore lack of mitigation measures in these parts will lead to negative significant impacts on groundwater. Besides, around Kan River and Chitgar Park area there are places in where, some wells have been considered to supply drinking water for population but have got degrees of high and very high vulnerability to groundwater contamination. Hence, in order to conserve groundwater resource and supply healthy drinking water, it requires replacing incompatible land uses to the regions with less groundwater vulnerability.

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