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The evaluation of the risk of quality of underground wells of Ardabil plain to heavy metals

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Abstract

Water is vital element for human being and due to anthropogenic activities; its health for drinking is threatened. Heavy metals in water can pose threat on people. Heavy metals can move in food chain and can have harmful effect on the life of creatures in earth. This study applied fuzzy inference system to evaluate the heavy metals risk in rural drinking water in Ardabil plain. To do this, the information of rural water and wastewater company of Ardabil is used. To implement the mentioned model, at first all 6 heavy metals including Chromium, Cadmium, lead, Manganese, copper and Zinc are evaluated in all zoning regions and then membership functions of each metal were drawn in MATLAB software and then via if-then rules, the final map of risk was provided. The results showed that about 18% of the region had low risk and 55% with average and 27% with high risk. The majority of pollution in the studied region is dedicated to north and some regions of south. For validity evaluation, the results of 62 areas as industrial townships and factories are applied, the results of validation show that about 70% of investigated areas were in high risk and it showed high validity of model.

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Introduction

Water is one of the necessary compounds for all plants and animals (Vanloon, 2005). Thus, its pollution is much more important than soil and air. Based on specific features of water, this element has unique features and is recognized as the most effective solvent in combination with various materials (WHO.2005).

More than one billion people in the world don't have any access to suitable drinking water and two to three billion people don't have access to initial health services. Three to five million people per year die of water-relevant diseases (Kumar and singh, 2006). In the developing countries and third world, the consideration is mostly focused on finding underground water to supply required drinking water, agriculture and industry water. The qualitative maintenance of aquifer is less considered. (Pawar and Robertson *et al,* 1995: Datta *et al,* 1997; Kangarogh and Gunay, 1997;).

Surface water (sweet water lake, river and river of valley) and underground water (water of well and Qinat) are natural resources of water. Today, one of the most important environmental issues is water pollution (Vodela *et al,*1997;Ozturk *et al,* 2009). Heavy metals are main pollutants of water resources (Marcovecchio *et al*, 2007). However, heavy metals are main indices of monitoring the changes in water environments. Based on industrial anthropogenic activities, heavy metals in water environments are increased seriously and major global concern is created (Khodabakhshi *et al,* 2011; Ghasemi *et al,* 2011).

Heavy metals are important group of pollutants and despite organic pollutants, natural processes as biological analysis cannot eliminate them from the environment. Some of these metals are necessary for growth, development and health of live creatures but others are not necessary and are toxic element in live creatures (Underwood, 1956).

The metals toxicity depends upon their concentration in environment. By increasing the concentration of metals in environment and reduction of soil capacity to maintain heavy metals, they penetrate into underground water and soil solution. Thus, these toxic metals can be cumulated in live tissues and be transferred via food chain. Cadmium is the most serious pollutant in the modern era (Wang *et al,* 2009). Due to its bad health effects, copper is classified as an important pollutant (Borah *et al,* 2009).

Zinc and iron are necessary elements and are non-toxic (EPA, 2005).

Lead is not one of the rare and necessary elements in live creatures and no biological performance is recognized for it but it can have harmful effect on health (Botkin and Keller, 2005) and it is considered as a neurotoxin (Thomson and Perry, 2006).

High concentration of cobalt causes death and various compounds of Nickel can cause cancer (Dunnick *et al,* 1995). These pollutants can influence the structure of live creatures' communities and also can eliminate a species of ecosystem or increase of opportunistic types.

The concerns regarding heavy metals are increased in drinking water (Ahmad, 2009; Yeh, 1976). Today, heavy metals in water is a global problem (Sekabira, 2010). Heavy metals have always been in the body of human being and this is proved in recent decades. Heavy metals can cause toxic impacts as cancer, genetic mutation and teratogen (Tong *et al,* 2000; Jarup *et al,* 2000; Thomas *et al*, 2009; Putila *et al,* 2011).

Pollution of heavy metals is a major environmental concern at global level based on its rapid economic development (Wang *et al*, 2003; Nriagu and pacuna, 1988; Wang *et al,* 2001). Based on the production and consumption at macro level and lack of rules, heavy metals as pb, Zn, Cd, Hg and Cr in environment can enter mostly via wastewater irrigation, disposal of solid waste, sludge, exhaust of cars and sediment (Wang *et al,* 2005). Thus, heavy metals in industry, urban runoff can be collected continually in environment. Since 2005, the events of health regarding heavy metals pollution are increased mostly all over the world (Gao and Xia, 2011).

Environment protection agency (EPA) and hazard quotients (HQ) are widely applied to describe the non-cancer effects of heavy metals by comparing the exposure to the reference dose and evaluation of health hazards (Mari *et al,* 2009; Granero and Domingo, 2002).

Risk evaluation is a complex process associated with uncertainty (Li *et al,* 2006). To control the metals toxicity and evaluation of environment risk, identification of heavy metals of biological samples is useful to identify exposure to hazard (Pereira *et al,* 2004: Goulle *et al,* 2005; Wang *et al*, 2009; Ashe, 2010; Sanders *et al,* 2012).

One of the best ways to avoid underground water pollution is identification of vulnerable aquifer and its management and vulnerability is defined as penetration and distribution of pollutants from earth level to underground water system (Nikqojaq, 2010). Maintaining water quality in terms of concentration of heavy metals and probable pollution control of resources requires planning and required researches in this regard and to achieve this aim, it is required to determine existing condition of concentration of heavy metals in drinking water resources of Ardabil plain villages. Based on the various pollutant residential, agriculture and industrial resources into underground water of Ardabil region, the risk of supplying drinking water sources of rural areas of Ardabil town to heavy metals was evaluated.

Various studies have been conducted regarding the evaluation of heavy metals pollution and fuzzy logic in evaluation of heavy metals risk as Saberi nasr *et al*, 2013; Deng and Chen, 2014; Mourhir *et al*, 2014.

Not study has been performed regarding the evaluation of heavy metals risk and this study deals with this issue.

Materials and methods

Based on country divisions, Ardabil plain is located in the center of Ardabil province in the North West of Iran and in eastern part of plateau of Azerbaijan.

It is bounded on north to Meshkinshahr and on south to Kosar town and on east to Khatolars of Bargherodagh and on west to Sabalan Mountain Figure 1.

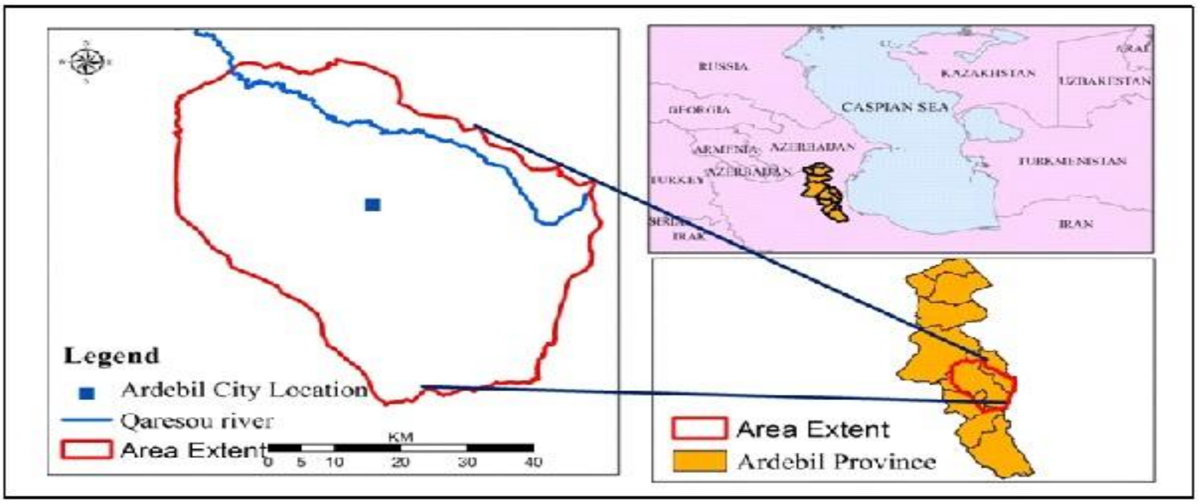

Fig. 1. The location of region in Iran and Ardabil town.

The volume of underground inflow to plain is 137 million m3, about 32million m3 of raining and runoff penetrate into soil and returning water of wells, springs and irrigation channels is about 51 million m3. Of the sum of wells, springs of Ardabil plain, about 204 million m3 are harvested for various consumptions, surface evaporation of aquifer is about 1 million m3 and plain drainage is about 25 million m3 and about 2million m3 of underground water of plain is removed. Thus, the change of volume of reservoir is about 12million m3. Thus, the sum of inflow and outflow is about 232 million m3. Based on the latest statistics, 0.8% of existing wells are dedicated to industrial consumption, 8% drinking consumption and 91.2% agricultural consumption (Ramazanpour, 2010) Figure 2.

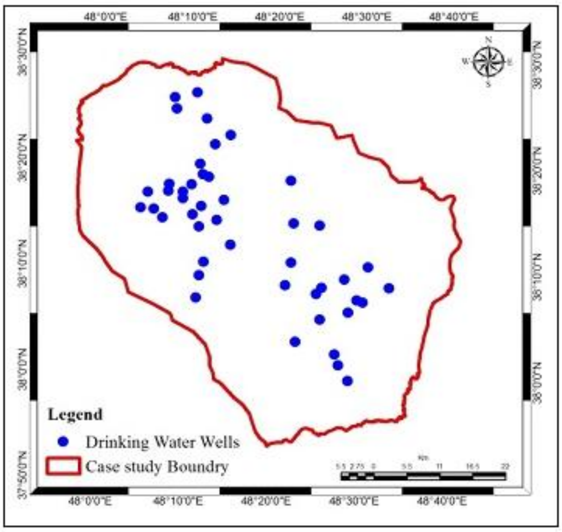

Fig. 2. The location of wells of rural drinking water.

Study methodology

This study evaluates the qualitative condition of drinking water of villages in Ardabil town in terms of heavy metals in drinking water supply wells of villages for one year and two dry (summer) and high seasons (spring) as……underground wells. The required data of the results of sampling of heavy metals are from rural water and wastewater company of Ardabil province and sampling is done by standard method (2008) and atomic absorption Perkin elmer to measure heavy metals.

For qualitative zoning of aquifer risk to heavy metals pollution, Mamdani fuzzy inference system method is applied. At first the heavy metals (zinc, copper, chromium, Manganese, lead and Cadmium) were determine din the studied wells. Then, the data were entered Matlab software and membership function of each heavy metal was drawn. These membership functions were trapezoidal. Output membership function to draw the pollution hazard was based on World Health organization standard. Later, if-then rules were determined to provide pollution condition of region and general risk in the region. To formulate the relationship between input variables, fuzzy common operator is used. Finally, the mentioned items entered fuzzy cell software (Ramazani, 2011; Yanar, 2006). This software can read Raster maps and implementation of fuzzy inference system on maps is possible. Each of values of heavy metals as generalized Raster map to the entire region entered the mentioned software environment and after applying rules on them, the final map showed pollution risk of various regions of studied area to heavy metals.

Results

Basic maps to implement FIS model

To implement fuzzy inference system model, at first the initial maps of each metal should be generalized to the entire region. To do this, interpolation models in Geographic information system is used. The information enters as points into system and indefinite pints are interpolated via normal kriging function. This can reduce uncertainty of the model results and it is used to have risk distribution as schematic view and avoid point display of final risk. Maps 4-7 to 7-12 show the zoning maps of mentioned metals in the region Figure 3,4,5,6,7,8.

The implementation of fuzzy inference system model

Fuzzy logic applies specific rules for simulation of various processes and reduces error coefficient and uncertainty in model process. The consistency of fuzzy inference system with human mind is one of the advantages of this system. Thus, the input for system is as the data with certainty and under fuzzification process, the criteria are fuzzificated and the required output is as certainty data. This process causes that the results of model is consistent mostly with the humanistic perception. The fuzzy inference system acts based on if-then relations and applying relations on membership functions of each criterion. The type of fuzzy inference system in this study is Mamdani fuzzy inference system in Matlab software. At first, to formulate the model, we determined the membership functions of each criterion based on linguistic variables. The charts 4-7 to 4-12 show the membership functions of each of criteria.

Membership functions

Figure 9 shows input and output membership functions for fuzzy inference model in zinc, copper, manganese, lead, cadmium and Chromium:

The final map of risk of model implementation

To determine the if-then relations (fuzzy rules), the studied standards and criteria maps and sources as Saberi Nasr, 2013 are used as corresponding mixed cellular matrix. In this model, 729 if-then rules in fuzzy inference system are used. Table 1 shows some of the fuzzy rules.

Table 1. Some of If-then relations in fuzzy inference system.

Final risk	Cadmium	Lead	Manganese	Chromium	Copper	Zinc		No
LOW	Good	Good	Good	Good	Good	Good	If	1
LOW	Good	Good	Good	Good	Mediate	Good	If	2
LOW	Good	Good	Mediate	Good	Mediate	Good	If	3
LOW	Good	Mediate	Good	Mediate	Good	Good	If	4
Medium	Mediate	Mediate	Mediate	Mediate	Mediate	Mediate	If	5
Medium	Mediate	Mediate	Bad	Mediate	Mediate	Mediate	If	6
Medium	Bad	Mediate	Mediate	Mediate	Mediate	Mediate	If	7
Medium	Mediate	Mediate	Bad	Mediate	Bad	Mediate	If	8
High	Bad	Bad	Bad	Bad	Bad	Bad	If	9
High	Bad	Bad	Bad	Mediate	Bad	Bad	If	10

Table 2. The probability distribution of subsidence in region.

Share (%)	Area (km2)	Title
18	513.07	High risk
55	1532.39	Average risk
27	750.38	Low risk

For mapping the risk probability of heavy metals based on fuzzy inference system, Fuzzy cell software is used. This software establishes a relationship between fuzzy programming in Matlab software and Raster maps in GIS software to implement fuzzy inference system model. After introduction of layers and determination of membership functions and if-then rules, the mentioned model is implemented and Figure 10 shows final map of fuzzy inference system. Based on the this model, the majority of region has average and high risk and north and south regions have high risk and central and marginal regions in eastern and western and southwestern areas have low risk. Table 2 shows risk probability of fuzzy inference system in the region.

Evaluation of the results of model

To investigate the validity of results of model, the consistency of final map to some products and industries is investigated and the results are as follows:

Industrial regions

Industrial regions and factories and townships are main factors of pollutants, namely heavy metals. Due to using pollutants, the relevant outflow is also polluted and some of the pollutants can move in soil and reach underground water. To evaluate the impact of various industries on pollution risk of rural drinking water, the final map of risk is analysed to industries areas and the results are observed as Figures 11,12 and Table 3. Thus, we can say:

1. There are three industrial townships in the region and three of them are in high risk. Regarding Industrial Township 2 in Ardabil, based on movement of underground water to northwest of township, high risk is created in these regions.

2. Of 14 chemical industry points in the region, 8 points, 8points, of 24 points of food industry, 16 industries, 14 metal industries, 11 industries are at high risk of pollution and the rest of areas in the path of underground water to the rights with high risk.

3. Vegetable oil factory, Artavil tyre rubber manufacturing, ethylic alcohol production, chemical fertilizer warehouse, glue and chemical materials production are at high risk of drinking water pollution to heavy metals.

Table 3. The percentage of validity of various industries in final map of risk.

Percentage at high risk (validity of results)	Number at high risk	Total	Industry type	No.
50	2	4	Industrial regions and townships	4
60	8	14	Chemical industries	5
67	16	24	Food industry	6
79	11	14	Metal industry	7
100	1	1	Vegetable oil factory	14
100	1	1	Artavel tyre factory	15
100	2	2	Chemical materials	18
100	1	1	Ethylic alcohol factory	19

Discussion

Zoning cadmium pollution shows high pollution in south and southeast of Ardabil town. In these areas, there is no specific industry except poultry farming. In north east around Ardabil city (industrial town 1), high values of Cadmium are observed and due to the presence of industries as dairy products, glue and husbandry and namely vegetable oil (high pollution of factory and its waste can be observed easily).

The highest concentration of Chromium pollution is in northern and North West areas. Based on high pollution, there is high consistency with industries and factories as Artavil tire factory, industrial slaughters of Ardabil, Leather Company of Moghan, Oil national company utilities and molding workshop as the consistency of PVC factory with high pollution in North West and chemical fertilizer warehouse in southern section.

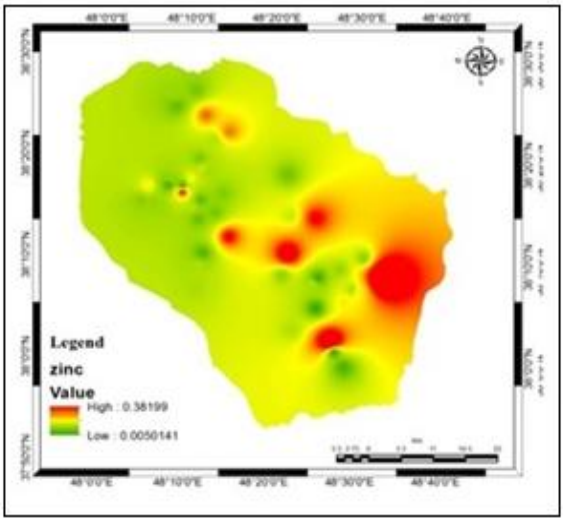

Fig. 3. Zoning map of copper.

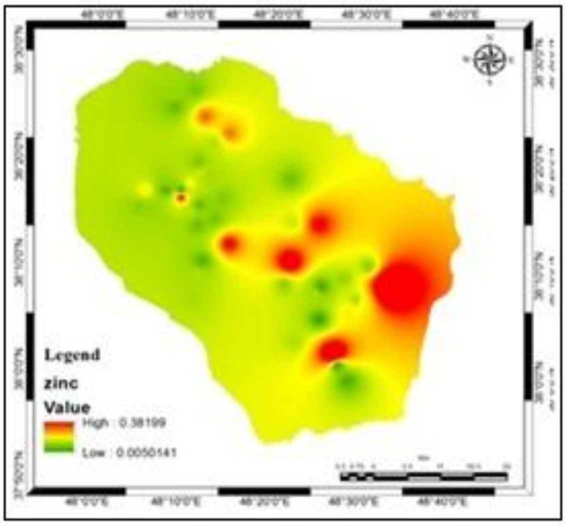

Fig. 4. Zoning map of Zinc.

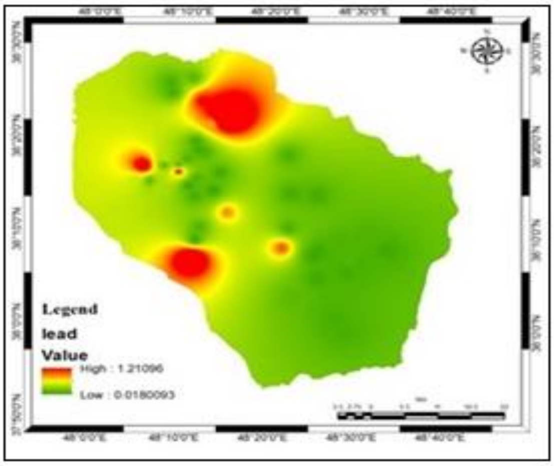

Fig. 5. Zoning map of Lead.

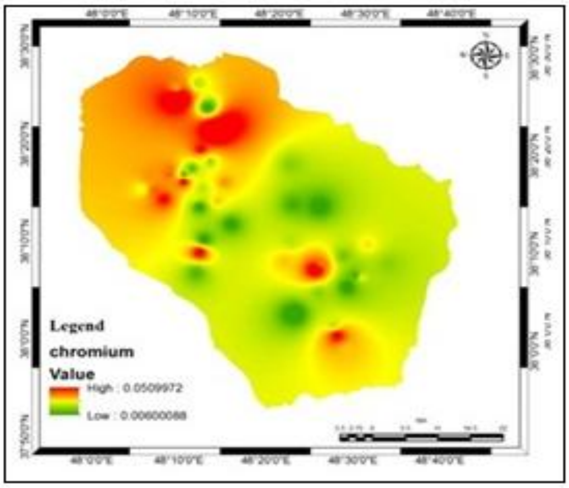

Fig. 6. Zoning map of Cadmium.

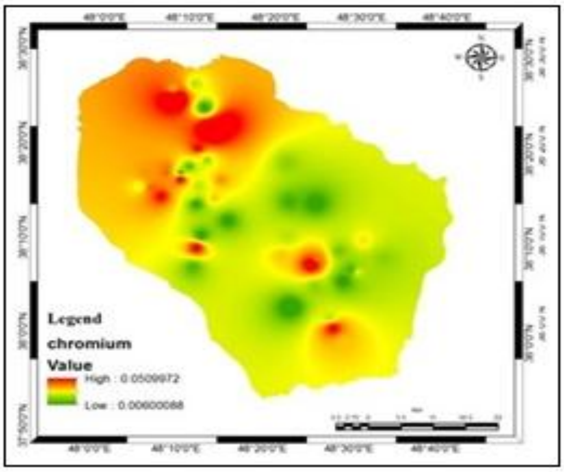

Fig 7. Zoning map of Chromium.

The concentration of lead in north and north east regions has the highest pollution and based on the proximity of these regions to landfill in Ardabil town and industrial slaughter's and Artavil factory of tire, high concentration of lead of wastage influence of these industries to underground water is the main reason.

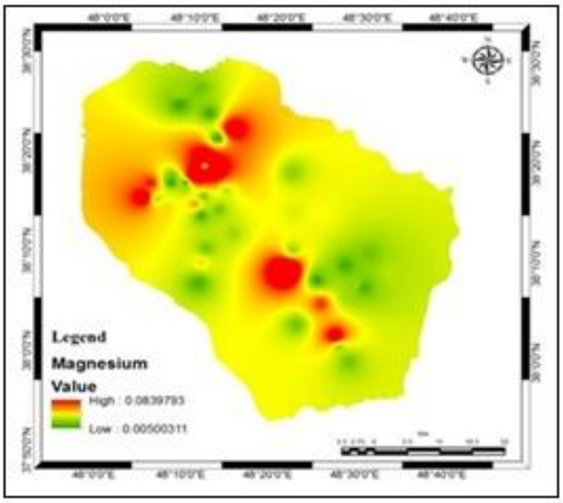

Fig. 8. Zoning map of Manganese.

The highest concentration of zinc is in southeast regions and in central areas, zinc is observed as point. Molding and dye industries are the major factors in dispersion of zinc and in these regions, metal cutting factories, cutting device production, Azar Teflon and metal industries have high consistency with the regions with highest zinc concentration. The highest concentration of copper distribution is in southern and southeast areas in villages. Chemical fertilizer warehouse, ethylic alcohol factory, Artaviltyre and industrial slaughter's are effective in increasing concentration of this element.

The highest concentration of Manganese is observed in central and northern areas and in North West areas, pollutions are observed as point. The increase of concentration is due to using manganese organic com pound as pesticides as Maneb- Mancozeb, disposed wastage and natural storage. Molding, PVC factories, reservoir and utilities of Oil Company and industrial slaughters of Ardabil are in these regions.
Also, we can find that fuzzy inference system is highly applied in determination and evaluation of heavy metals risk and it is consistent with the results of studies as Deng and Chen , 2014; Saberi nasr *et al*, 2013; Mourhir *et al*, 2014.

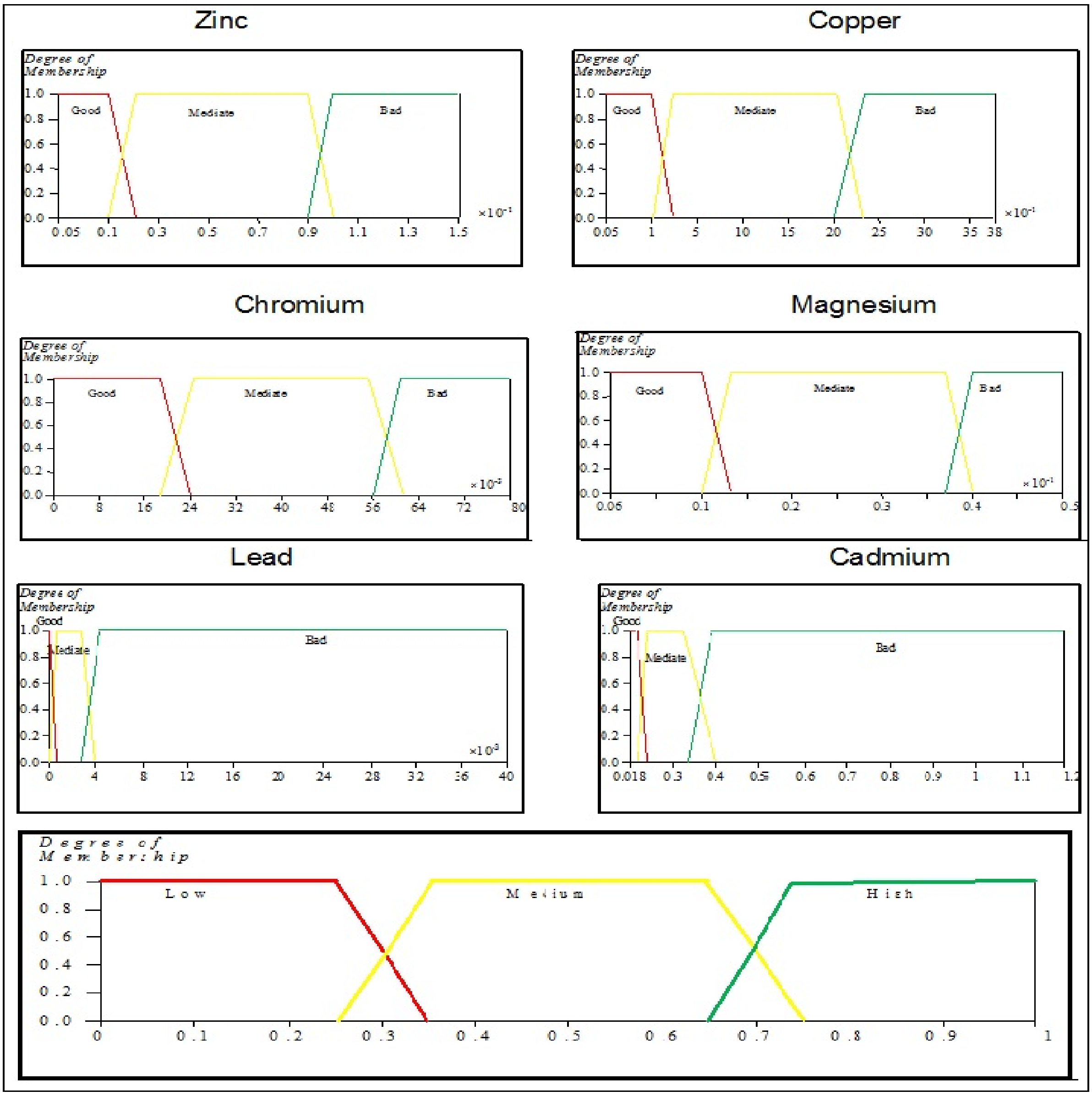

Fig. 9. Input and output membership functions for various metals.

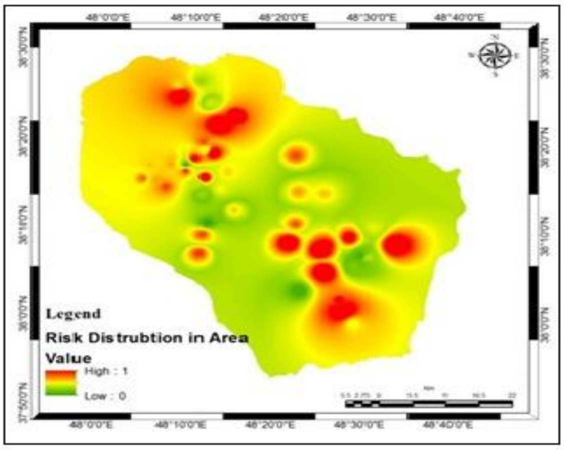

Fig. 10. The risk distribution of heavy metals in studied area.

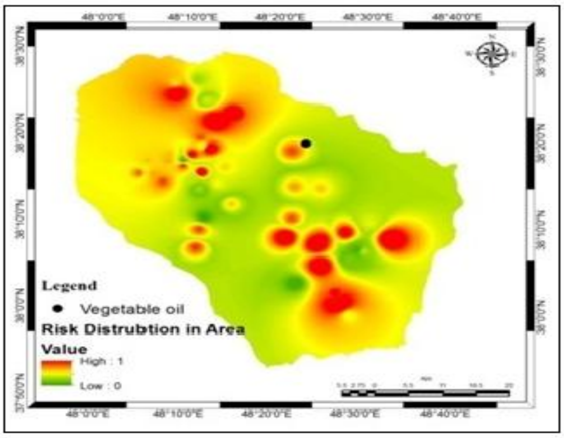

Fig. 11. The location of vegetable oil factory in final map of pollution risk to heavy metals.

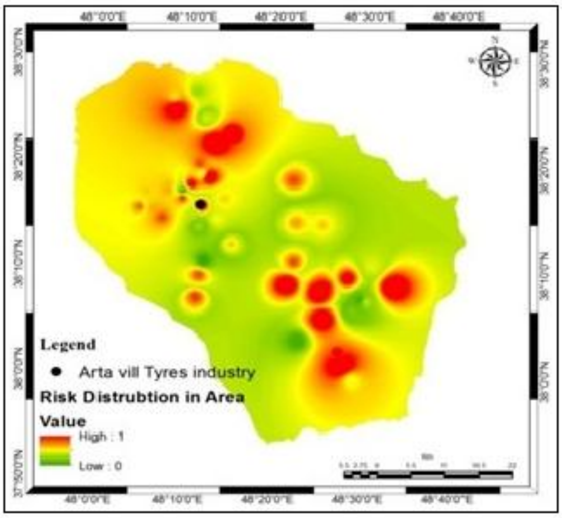

Fig. 12. The location of Artavil tyre factory in final map of pollution risk to heavy metals.

Conclusion

Based on final map of risk, 18% of region had low risk and 55% moderate risk and 27% high risk. The results of the map of risk of rural drinking water pollution with heavy metals show that major part of pollution is dedicated to north and south of region.

The final map of heavy metals risk shows that major part of pollution in the north of region shows is due to Artavil Tire factory, industry slaughter's in Ardabil, Metal industry factories and namely the leachate of waste landfill in Ardabil city around Taleb Qeshlaghi village. Also, southern areas due to dye, molding industries, chemical fertilizer warehouse and factory, Ethylic alcohol factory and resources as poultry and husbandry workshops are the main factor of high risk of pollution of rural drinking water to heavy metals. If we consider pollution distribution, this issue is observed that pollution changes in northern and southern areas are consistent with the movement of underground water. If we consider the pollution distribution, this issue is observed clearly that pollution changes in northern and southern areas are consistent with the movement of underground water as this movement in western and southern areas was at first to east and then to northwest based on the slope of region and this issue showed transfer of pollutions with the direction of underground water from southern areas to northern areas.

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