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Assessment of Pollution Potential and Contaminants of Mashhad Plain

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Abstract

Groundwater is a vital natural resource for the economical and secure provision of potable water supply in both urban and rural environments. It plays a fundamental role in human well-being, as well as that of many aquatic ecosystems. The rapid growth of urban areas has supplementary effects on the groundwater quality due to over-exploitation of resources and inappropriate waste disposal actions. The sources of pollutants that cause groundwater contamination are different; in addition to natural processes, practically every type of human activities may eventually cause a loss on groundwater quality. The Mashhad plain is located in the north-eastern of Iran, in heavily polluting sources and a serious threat for the health of groundwater supplies resources. This paper identified the major sources of groundwater pollutant and estimates their contamination potential in the Mashhad plain unconfined aquifer. In this research, at first, a list of the most important contaminant sources in the Mashhad plain has been prepared. For this purpose with the collection of information regarding potential pollutants in the area and with field surveys, monitoring, sampling and analysis of water and pollutants, the volume of pollution and the risk level of contaminants is determined. The results showed the highest pollution potential in the case-study area is belong to population centers and then industries in the Mashhad plain. It should be noted that the analysis of samples was conducted in 2012 and all the information, maps and statistical tables presented in this article, have been taken from studies in the regional water company of Khorasan Razavi.

Keywords: Pollution; Contaminant; Unconfined aquifer; Mashhad plain

Abbreviations: COD: Chemical Oxygen Demand; BOD: Biological Oxygen Demand; GIS: Geospatial Information System

Introduction

Water sources available for drinking and other some purposes must possess the high degree of purity, free from chemical contaminations and microorganisms. The groundwater is a vital natural resource for the economical and secure provision of potable water supply in both urban and rural environments. It also plays a fundamental role in human well-being, as well as many aquatic ecosystems.

Most concern over groundwater contamination has centred on pollution associated with human activities. Human groundwater contamination can be related to waste disposal (private sewage disposal systems, land disposal of solid waste, municipal wastewater, wastewater impoundments, land spreading of sludge, brine disposal from the petroleum industry, mine wastes, deep-well disposal of liquid wastes, animal feedlot wastes, and radioactive wastes).

Large quantities of organic and chemicals compounds are manufactured and used by industries, agriculture, and municipalities. These man-made organic and chemicals compounds are of most concern. These compounds occur in nature and may come from natural sources as well as from human activities. In many locations, chemicals have contaminated groundwater for many decades, though this form of pollution was not recognized as a serious environmental problem until the 1980s [1].

Contamination of groundwater can result in poor drinking water quality, loss of water supply, degraded surface water systems, high clean-up costs, and high costs for alternative water supplies, and/or potential health problems [2].

Because groundwater generally moves slowly, contamination often remains undetected for long periods. This makes clean-up of contaminated water supply difficult, if not impossible. If a clean-up is undertaken, it can cost thousands to millions of dollars.

The vulnerability of groundwater, especially of groundwater supplies, to existing or potential sources of contamination underscores the need for a systematic, detailed process by which these potential threats can be recorded and evaluated-an inventory of groundwater contamination sources. Groundwater contamination inventory is an indispensable part of any comprehensive groundwater protection strategy. Before appropriate protection measures can be designed and implemented, groundwater contamination and its sources must be identified and assessed, and their impacts on groundwater quality determined. An inventory of the number, type, and intensity of potentially contaminating activities and of the extent of existing contamination of groundwater can serve a twofold purpose for groundwater protection:

- It provides government officials, planners, and managers with an understanding of the potential for groundwater contamination needed for successful management programs
- It provides basic data that can be used for the design of the type and location of various controls and of the monitoring programs

Results of a comprehensive, detailed inventory allow water managers to prioritize contamination sources according to intended purpose (e.g. to determine the level of risk to public drinking water supplies) and to develop differential management strategies to address these sources, thereby safeguarding public health and protecting groundwater in general.

Generally, Groundwater monitoring is one of the important methods supporting the strategy and policy of groundwater protection. Because no preventive control system or remedial technology is 100 percent effective or complete, groundwater quality must be monitored at key points. In general terms, monitoring is the continuous, standardized measurement and observation of the environment (UNESCO/WHO, 1978). In terms of groundwater protection, monitoring is an important device to detect groundwater contamination and to provide an advanced warning of contaminated groundwater approaching important sources of water supply. In addition, groundwater quality monitoring can help define the extent of groundwater contamination and control the quality of drinking water.

The Real Case Study

The study area is located in Khorasan Razavi province and is part of the Kashafroud river basin. The Mashhad plain area has over 16500 km^2 that about 500 km^2 is formed by plain and others are formed by heights. It is located between Binalood heights (in west and south-west) and Hezarmsjed (Kope Dagh in the North and North East). From the geological perspective, Mashhad plain is located between two geological zones in Kope Dagh and Binalood. The direction of groundwater flow in this plain varies from the North West to the southeast (in the direction of general slope of plain). The Mashhad plain despite having a thickness aquifer of alluvial deposits has negligible rainfall. Mashhad, as the representative of Mashhad plain with the average annual precipitation of 251.5 mm and the temperature of 14.3°C in the sampled period of 195-2010, has a semi-arid climate. The maximum level of precipitation in this part of Iran is in spring and the least amount is in summer. Mashhad plain is the major industrial and agricultural center and the important social-political center in Khorasan-Razavi province.

According to Zarei et al. [3] land use of the study area is dominated by rangeland and the main soil type in Mashhad basin is silty clay loam. **Table 1** is shown the area of each land use and soil classes in the Mashhad basin.

Table 1: Summary of land use and soil classification of the Mashhad basin.

Land Use Classes	Area (Km^2)	Percent of total area (%)	Soil Classes	Area (Km^2)	Percent of total area (%)
Rangeland	5331.52	53.802	Clay	2342.6	23.64
Bare soil	69.67	0.703	Loam	2918	29.45
Residential	509.85	5.145	Sandy Clay	148	1.49
Outcrop	69.73	0.704	SandyClay Loam	90.5	0.92
Irrigation Farming	867.46	8.754	Silt	703.9	7.1
Rain-Fed Farming	2983.06	30.104	Silty Clay	93.14	0.94
Orchard	77.65	0.784	Silty Clay Loam	3214.9	32.44
Water body	0.39	0.004	Silty Loam	398.3	4.02
Total	9909.34	100	Total	9909.34	100

The importance of Mashhad plain is because of providing agricultural water needs, which is above 1.5 billion cubic meters and also it is drinking and sanitation water supply in the Mashhad city (second city of Iran with a population about 3 million people), Chenaran, Torghabe, Golbahar and Shandiz cities. **Figures 1** and **2** show the location in Iran and Kashafroud river basin [4].

Figure 1: Location of study area in Iran and Razavi Khorasan.

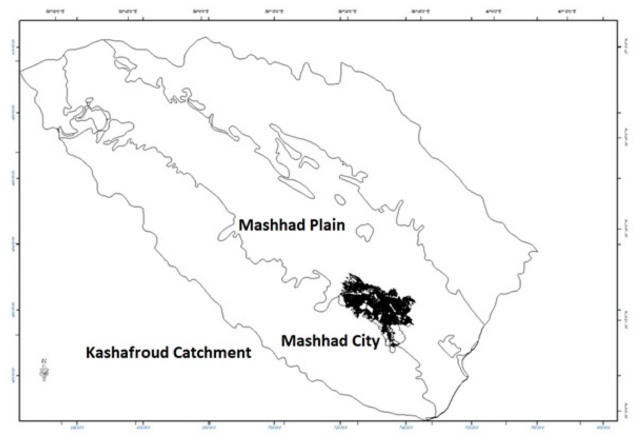

Figure 2: Location of study area in Kashafroud river basin.

Research Methodology

In the present research, we tried to identify sources of pollutants and then estimated their pollutions potential, for the purpose four steps were taken as follows:

- Classification of major pollutants, such as industrial states and distributed industries
- landfills, wastewater treatment plans, urban and rural environments
- Collection of information about water use patterns and also the quantity and quality of water and wastewater
- Field visiting and completion of questionnaires related to each pollutant source
- Analyzing the results based on the comparison of data and matching them with national and international criteria and standards

According to the design of a monitoring network, consisting of 130 groundwater source and the fourth stage of the seasonal range, sampling and testing have been conducted in the case-study area. Finally, using these results and other tests the risk levels of contaminants were estimated in the Mashhad plain aquifer.

Material and Methods

Contaminants sources identification

The sources and causes of groundwater contamination are numerous and are as diverse as human activities. Therefore the data and information of sources from relevant organizations and agencies and field visits and completed questionnaires have been identified for each source. In this study, pollution of groundwater has been divided based on the source to four categories including, rural and urban wastewater, industrial wastewater, waste disposal and effluent leachate from agricultural centers. These pollutants in the following topics have been described separately. It should be noted that the analysis of samples was conducted in 2012 and all the information, maps and statistical tables presented in this article, have been taken from studies in the regional water company of Khorasan Razavi.

Pollutants resulting from rural and urban wastewater

Residential wastewater systems can be a source of many categories of contaminants, including bacteria, viruses, nitrogen compounds from human waste, and organic compounds. The wells used for domestic wastewater disposal are of particular concern to groundwater quality is located close to drinking water wells [5].

The main urban population centers in the study area include the capital of the province Mashhad city, and cities of Chenaran, Torghabe and Shandiz, Golbahar and the number of about 157 villages that the wastewater collection network only has been implemented in the city of Mashhad and a small part of Golbahar.

According to estimates, the amount of wastewater produced in urban centers in the year of 2031 (the horizon year) will get to about 969,037 cubic meters per day that the maximum volume of wastewater is related to the city of Mashhad with 950000 cubic meters per day. Based on predicted population for the year 2031 BOD5 of the population of four million people in the Mashhad plain is estimated at about 150 million kg per day that in terms of emission intensity is relatively in the strong wastewater category **Table 2**. [4]

Figure 3 shows changes in wastewater quality from 2011 to a predicted value in 2031 in the Mashhad plain. Based on the chart with the population growth during the next 5 years, the number of such waste pollutants will increase about 1.6 times.

Table 2: Comparison of quality of urban and rural sewage in 2011 and 2031 in the study area.

Total	Rural	Urban		Unit	Parameter
		Other cities	Mashhad city		
2939711	172630	87128	2679953	Person	Population
93290	4261	3724	85305	kg/day	BOD_5
4579406	463346	133791	39,82,269	Person	Population
150789	11258	5697	133834	kg/day	BOD_5

Pollutants resulting from active industries

Based on the information come out from the industries and mines organization of Razavi Khorasan province in 2006 and also field visits and completed questionnaire, about 1430 active industries are located in the Mashhad plain that about 490 industry as sporadic industry and the remaining industries are located in industrial estates that contain the metal, chemical, and food industries. Based on the completed questionnaire, the number of factories, which are equipped with a sewage treatment system, is very limited in the plain and most industries mainly discharge their wastewater without filtration or with incomplete treatment.

According to estimations, these units are able to produce over 12 million cubic meters of wastewater per year, which the amount of the total organic load of this amount of industrial wastewater is estimated at about 13 million kg per year **Table 3**.

Table 3: Details of the wastewater industry in the Mashhad plain.

Name of industry	Total	Number of staff	Total water consumption*	Total waste produced	Sanitation Wastewater	BOD5**	Pollution load	Industrial Wastewater	BOD 5***	Pollution load	Total pollution load
Electronic	57	2834	2974	399	120	300	36	279	250	70	106
Cellulose	82	2202	858	686	94	300	28	592	250	148	176
Chemical	280	8841	8270	6202	376	300	113	5826	300	1748	1861
Food	287	19032	18855	17654	809	300	243	16845	1800	30321	30564
Metallic	532	19807	2721	2448	842	300	253	1606	300	482	734
Non-metallic mineral	62	5243	1724	1315	223	300	67	1092	200	218	285
Loom	124	7531	7200	5790	320	300	96	5470	550	3008	3104
Total industry	1424	65490	42602	34494	2783	-	835	31711	-	35996	36831

*Water consumption and produced wastewater in cubic meters per day
**Concentration of BOD_5 in ppm
***Pollution load per kg per day

Regarding **Table 3** wastewater of food industry and after that the textile effluent, have been allocated the highest levels of contamination to themselves. The kind of activity of this class of industries and requiring large hydroplanes in this group of industries are the most important reason for this problem. On the other hand, the group of electrical and electronics industries produces minimum pollution.

Based on the information obtained from Razavi Khorasan Environmental Protection Organization and study of results of the BOD5 test on 130 groundwater sources of industries, which are shown in **Figure 4**, specifies the amount of this parameter in food waste is more than the other industrial groups, regarding high-level organic matter sewage in this group of industries **Figure 4**.

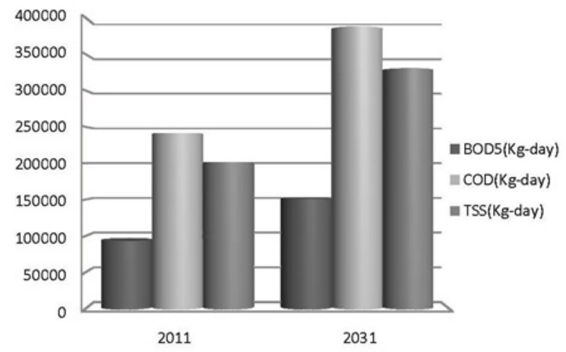

Figure 3: Comparison chart of population sewage from 2011 to 2031 in Mashhad plain.

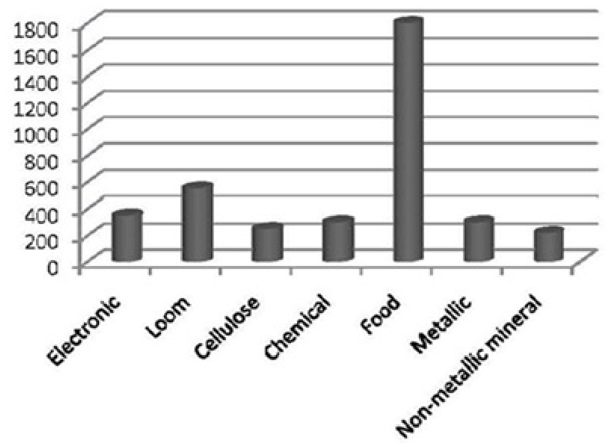

Figure 4: Comparison chart of BOD_5 of the wastewater industry in the Mashhad plain in ppm.

Pollution from landfill sites

Sanitary landfills generally are constructed by placing wastes in excavations and covering the material daily with soil. Thus the term "sanitary" to indicate that garbage and other materials are not left exposed to produce or attract vermin and insects even though a landfill is covered, however, leachate may be generated by the infiltration of surface runoff. Therefore, many substances are removed from the leachate as it filters through the unsaturated zone, but leachate may pollute groundwater and even streams if it discharges at the surface as springs and seeps [6].

Field visits show, due to lack of proper garbage collection and management systems in main parts of Mashhad plain, the waste scattered and often disposal and release unsanitary through to the environment. The Mashhad plain has main fourth places of the landfill that the most important one is the waste buried site of Mashhad city. The amount of waste produced in the Mashhad city which is the largest population place in the study area based on statistics obtained in 2009, is estimated at about 1,500 tons per day.

Considering that, the total number of rural areas that are located in the Mashhad plain area is 157 villages with total populations of 170375 in 2009. Therefore, the amount of garbage production is estimated at 68150 kg a day in this area.

In the studies that carried out to determine the quality characteristics of leachate at the site of urban waste disposal in Mashhad, different locations were sampled as follows, In addition, each location was sampled five times.

- Solid waste receiving point hall (leachate from fresh waste)
- Composting process hall (leachate produced by the composting technology)
- New landfill area
- Old landfill area

In the current research, the content of organic matter in leachate measured by indicators of BOD_5 and COD_5 those values are presented in **Figure 5**. The BOD_5 of leachate in receiving hall, compost hall and the new landfill was between 25,000 to 50,000 mg-L, and the amount of COD_5 was in the range of 80,000 to 140,000 mg per lit. These results indicate that the high level of concentrations of organic matter in leachate production of the various stages of processing municipal solid waste may place it among very strong sewage.

As it can be seen in **Figure 5**, the BOD_5 and COD_5 concentration in the old landfill leachate in comparison to the new landfill leachate has been very small and respectively about 12,000 and 25,000 milligram per litter, this indicates a stabilization of waste organic materials in old places over the time **Figure 5**.

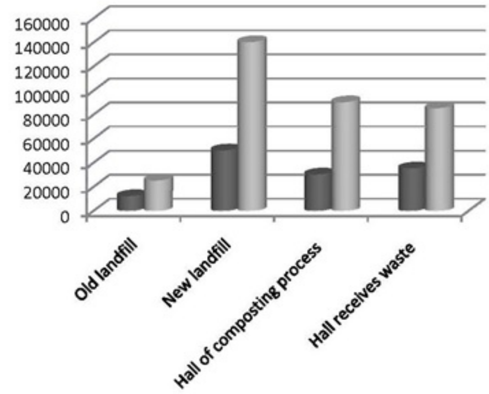

Figure 5: Chart of BOD_5 and COD_5 concentration in leachate production (2011).

Pollution due to agricultural activities

Intensification of agricultural activities with the increasing use of fertilizers and pesticides and allied livestock activities has an adverse impact on water quality. The main agricultural water pollutants are nitrates, phosphorus, and pesticides. Rising nitrate concentrations threaten the quality of drinking water, while high pesticide use contributes substantially to indirect emissions of toxic substances.

Based on information obtained, there are about 240,000 hectares of agricultural farms under rain-fed farming and irrigated farms in the Mashhad plain. Considering the myth of the farmers regarding the use of more chemical fertilizers increasing the yield of their products, so this plain fertilizers to be taken over the need of plants in the soil, therefore in this study, the pollution of agricultural land in the Mashhad plain is estimated using with a GIS system. Based on this system the amount of agricultural land impact on groundwater pollution in the Mashhad plain area was evaluated and areas that have the highest potential emissions were determined **Figure 6** [7].

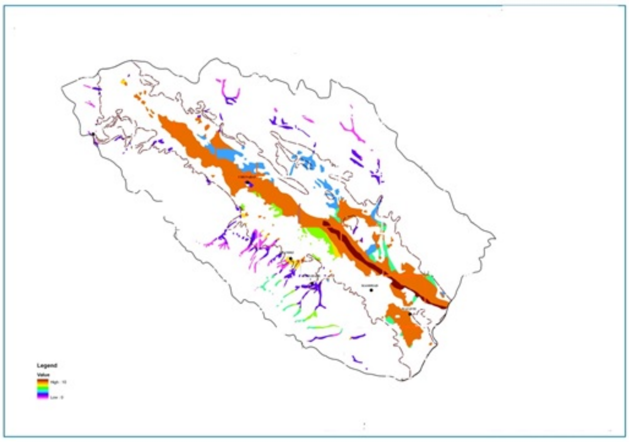

Figure 6: Determining of pollution load of agricultural lands in the Mashhad plain.

According to this map, where irrigated farming and orchards are increased, the erosion in these areas is less steep and the combination of these factors has led some of these areas in the Mashhad plain known as the areas that have high pollution potential. According to this figure in the central part of Mashhad plain and almost part of Razavieh and Ahmadabad, the emissions are highest. The reason is that most of the irrigated farming lands are also located in these areas [8]. The cities of Torghabe and Shandiz areas have a relatively low and Chenaran and Quchan can almost have high emissions pollution potential.

Results and Discussion

Assessing the vulnerability of groundwater contamination is an important issue in water resource management. Currently, due to the increased human activity, contamination of potential assessment in the Mashhad Plain has become very critical.

In order to the prevention of the groundwater contamination due to pollution sources, delineation of vulnerability in different areas of Mashhad basin is essential for protecting these vital resources. Groundwater vulnerability is referred to the tendency or likelihood for contamination to reach a specific position in groundwater after introducing in uppermost of the aquifer, and it calculates the sensitivity of the groundwater quality to an imposed contaminant load which is considered as a fundamental aspect of groundwater management.

In this research, to determine the critical areas of Mashhad basin, the drastic method was used to assess vulnerability in the aquifer. DRASTIC method, which evaluates intrinsic vulnerability, is more popular than other methods as it is capable of compatible with various aquifer types such as fractured bedrock, karstic, sedimentary, carbonate. The main purpose of using the drastic model is to map groundwater susceptibility to pollution in different areas. The drastic model developed by the U.S. Environmental protection Agency was used in this study as a predictive model.

drastic model identifies vulnerable zones based on the seven parameters representing hydrogeological features of the aquifer including: depth to groundwater (D), recharge (R), aquifer media (A), soil media (S), topography (T), impact of vadose zone (I), and hydraulic conductivity of the aquifer (C).

After ranking, giving proper weight and stacking the parameters in seven layers mentioned, vulnerability map indexes in Mashhad basin were obtained by using Arc GIS software and the drastic index was calculated between 62 to 121 Also the aquifer vulnerability of the Mashhad plain in categorized in the low, moderate and high vulnerability groups (**Table 4 and Figure 7**).

Table 4: Vulnerability index ranking.

Drastic index	Vulnerability class
62-83	low
83-95	moderate
95-121	high

Figure 7 tries to introduce that the most vulnerable areas in the aquifer of Mashhad Plain as follows:

- Northwest of Mashhad (Middle of Mashhad plain)
- Leather industrial estate range
- North of Chenaran City

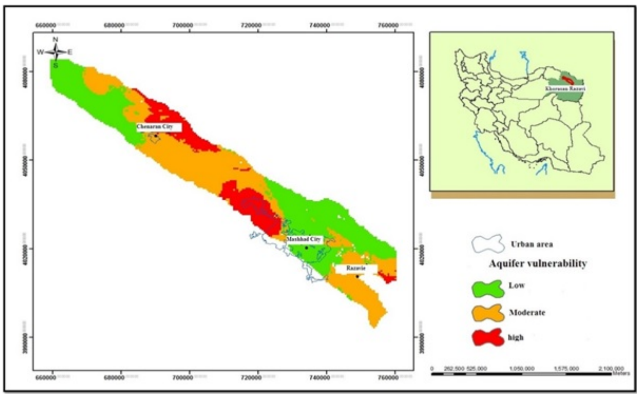

Figure 7: Mashhad plain vulnerability map.

With the help of vulnerability map in Mashhad Plain, the areas with the potential of contamination have been identified and whit based on that we can manage the quality of the groundwater table. For example, to build new industrial units in the Mashhad plain, we should try to make sure that these industries are built in less sensitive areas. Drinking water wells should drill in areas with lower sensitivity is another recommended action.

Generally, the main objective of the strategy to protect groundwater resources is maintaining natural water quality, especially for drinking purposes. The selected strategies of pollution reduction depending on the effectiveness of their projects and classified into three categories: direct, indirect and support project, which is dissected in the following.

Direct schemes

The pollution reduction from water resources projects can be used directly as a comprehensive plan in the Mashhad plain groundwater sources are as follows [9-13]:

- The pollution reduction by the construction of wastewater treatment for cities, rural area and industrial units
- Sewage disposal in the Mashhad city and towns and villages traditionally occurs through absorption wells. This, especially, in central and densely populated areas, contaminate the aquifer
- Lack of sanitary drinking water in the Mashhad plain should be noted, necessary for maintaining groundwater and accelerate the construction of network sewage collection and transmission to prevent contamination of the aquifer
- Focusing on small industries and construction of common wastewater treatment.
- Prevent unauthorized discharge of sewage
- Using special methods in the treatment to reduce the pollution load of important qualitative variables
- Transferring the location of the discharge of pollutants from water resources in critical areas
- Modification of the industrial process to make less pollution
- Water recycling and reuse of sewage and drainage water
- The pollution reduction by solid waste management

Indirect schemes

Indirect projects include projects, which by the implementation, pollution reduce indirectly. It can play an effective role in ecological restoration systems. These actions in the following topics can be defined:

- Water supply management in order to make optimal use of these resources whit special consideration to environmental aspects
- Water supply management to reduce water consumption in various sectors
- Development of infrastructure such as improvements in urban water supply systems
- Recycling and reuse of treated wastewater

Project supports

Although projects support are not effective to reduce water pollution directly, but the proper implementation of them for effect on direct and indirect projects reducing pollution seems to be mandatory. Support projects in the comprehensive plan to reduce pollution can be defined and recommend as following axes:

- Network monitoring and sampling
- Structural changes and modification rules
- Behavioral changes and capacity building of human resources, monitoring, and evaluation
- Developing a scientific and research organization

Conclusion

Due to population increases and enters the camping crowd in more seasons to Mashhad city, the Mashhad plain aquifer is one of the most important aquifers in Razavi Khorasan province. Therefore, the first step is the protection of groundwater and in the next step, strengthening of these resources is the most basic management practices for the exploitation of these vital resources.

The wastewater of industrial and manufacturing activities in the Mashhad plain is according to the type of product and production process has a very wide range of pollutants. They cause pollution and are very dangerous when it discharges into groundwater without any treatment. Unfortunately, the industrial growth is towards the west of Mashhad plain, where the potable water wells are located and recharge. The groundwater flow direction in the Mashhad plain is from west to east, which causes the contaminations enters to the aquifer, moving to the Mashhad city and contaminates the water of the potable wells.

The high density of industries in the Mashhad city and direction of groundwater flow and drinking water to the Mashhad city cause these industries (particularly industries in cities of Quchan, Kalat and Siman area) pollution of groundwater and make it damage the environment. Among the industries in the Mashhad plain, food industries that usually have the highest contamination in terms of BOD_5, have the highest contribution. It can be deduced that the Mashhad city produces the largest amount of municipal wastewater, which has been introduced in the study area. Due to the increasing population in this city waste generated, absorption into wells and provide the pollution of aquifers (except in the places that are connected to the sewage treatment system).

Sampling and case studies carried out on the water resources of this city shows high concentrations of nitrate and undoubtedly, this trend has a direct relationship with population growth. The municipal waste in Mashhad old road Nishabur, in addition, failure to comply with existing standards, has provided the high potential to contaminate water resources in the region that certainly its impact is predictable in future and long-term.

According to reports of environmental protection agency of Razavi Khorasan province, the old municipal solid waste landfill in Mashhad, have a cute problem and the risk of leachate into the groundwater aquifer exist in this area. It is important to say, the old water wells around this landfill affected from leachate and due to leakage of leachate from the pond of the layers of granite, some of the water indexes has changed. Finally, according to studies on agricultural land, excess consumption of fertilizers and pesticides is one of the major factors threatening the quality of groundwater resources in the Mashhad Plain. Based on this information, the areas that have the highest potential emission are the areas which have been irrigated under cultivation and horticultural crops, since in these sectors the poison and chemical fertilizers are more used. These pesticides and fertilizers are penetrated by the irrigation into groundwater and cause groundwater pollution.

According to Mashhad plain vulnerability map, which was prepared using the drastic method, Northwest of Mashhad (Middle of Mashhad plain), the leather industrial estate range and North of Chenaran city had the highest vulnerability in comparison to other parts of the plain. Accordingly, three categories: direct, indirect and support project, solutions have been proposed to reduce water pollution in the plain. Obviously, before conducting any of these programs, monitoring of water resources or quantitative and qualitative control of the water resources of this plain should be considered.

Acknowledgment

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