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ORIGINAL ARTICLE

The importance of protection and management of Karst water as drinking water resources in Iran

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Abstract Karst water is one of important potable water especially in arid and semiarid zones. Due to its vulnerability and high sensitivity to pollution, water resources protection is one of important measures to be observed in karst resources management. One case study in the The Maharlu Basin, Iran is discussed. Findings are used to postulate regional guidelines for establishing protection and management measures in important karst pumping fields. Suggested locations for new wells in valleys or depressions should be selected on the basis of specialized hydrogeological investigation. Recommendations for first, second and third degree levels of protection based on European standards are suggested and then defined by model. The first degree protection zone around the pumping field is recommended to be $10 \times 10\ m^2$. The second degree protection zone should be established to protect primarily from biological pollution. The third degree zone is defined to protect from chemical parameters.

Keywords Karst protection · Water management · Maharlu Basin · Iran

Introduction

Karst landforms are peculiar and spectacular. They also provide valuable scientific information. Formation of karst is due to delicate equilibrium processes, which are easily disturbed. The lack of filtration in karst conduit and fissure aquifers make them extremely vulnerable to pollution. Karst landforms need special protection and management.

The Maharlu Basin supplies more than 75% of the potable water supply for the city of Shiraz, the capital of Fars province in Iran (Afrasiabian 1993a, b). The karst resources and human activities in the area are interrelated in a complex manner. Groundwater protection measures in the Maharlu Basin must be systematic and on a broad scale to be effective.

Two main types of pollution are defined on the basis of pollution sources (Figs. 1, 2):

1) Diffuse (non-point) sources of pollution.
2) Point-sources pollution.

Non-point pollution by category

Diffuse (non-point source) pollution in the Maharlu Basin is mainly from four types of activities (Afrasiabian 1995):

(a) Irrigation
(b) Use of fertilizers and pesticides
(c) Exploitation, treatment and transport of oil hydrocarbons
(d) Inadequate sewerage systems

Protection of groundwater from irrigation constrains

Irrigation systems influence groundwater both qualitatively and quantitatively. Infiltration of irrigation water (and pumping of groundwater for irrigation) may

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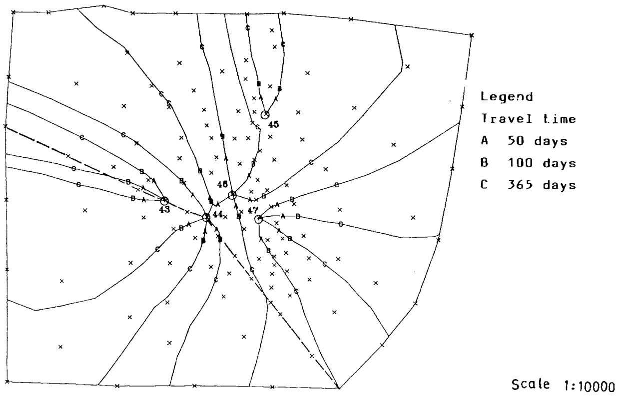

Fig. 1 Groundwater protection zone of Kaftarak Massive path line and travel time

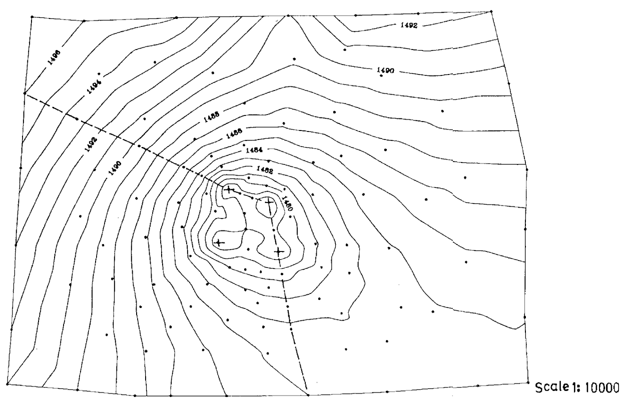

Fig. 2 Piezometric groundwater levels in Kaftarak Mountains

impact the groundwater flow-net. In most cases irrigation usage is seasonal and the quantitative constrains are very irregular in time and scale. Chemistry of irrigation water, water table fluctuations and deposition of salts on soil surface resulting from evaporation of irrigation water change groundwater quality. Protection involves better monitoring to allow establishment of withdrawal schedules with less dramatic impact and better runoff control, and perhaps planting of selected cover crops.

Protection of groundwater from fertilization and pesticides use

Protective measures consist of stating optimum doses of fertilizer and maximum doses of pesticides for different climatic conditions and agricultural products. The selection of pesticides should be based on individual kinds of soil and rock environments and local climatic conditions. Control and monitoring of activities is necessary at typical agricultural areas with different climatic conditions to set these guidelines.

Protection of groundwater against pollution from exploitation, treatment and transport of oil hydrocarbons

Oil and its derivatives are specific type of pollution sources, which can quickly infiltrate into soil and aquifers. In the unsaturated and saturated zone of the groundwater system, oil hydrocarbons spread in dissolved or ‘‘phase’’ form due to diffusion forces and by groundwater flow. In a karst system, oil pollution can quickly cause large-scale groundwater quality deterioration. Protection may require such measures as better education of oil transporters, paving near petrol stations, and penalties for large spills.

Protection of groundwater from municipal contamination

In large townships like Shiraz, with no or underdeveloped sewerage systems, liquid and solid wastes from households, offices, shops, and factories, etc., are disposed in a diffuse manner. Chemicals from wastes are introduced into the shallow water table aquifer over a large area. Therefore, construction of sewers and treatment systems, establishment of municipal and sanitary landfills, and better surface water controls and groundwater monitoring are essentials for basic protection.

Point source pollution by category

Point-source pollution can originate from many small-scale activities. Some of the most frequent and most hazardous are listed below. Respective protective measures are discussed.

Villages and small towns

Pollution on a village scale is typically a point source problem. The amount and range area of pollutants is smaller and concrete specific pollution occurrences are more easily identified. Monitoring of groundwater quality will identify types and sources of pollution. Remedial measures required may be relatively simple. For example, pumping, isolation and on-site treatment of contaminated water can be implemented once the problems are identified by a consistent monitoring program. Groundwater protection and village/town land use development planning must be integrated to save taxpayers money and best assure effective protection.

Industry

Industries typically must dispose of chemical or biological substances used as raw materials for manufacture into desired products or byproducts. These substances may unintentionally through leakage, spills, emissions, or intentionally be discharged into the environment and can reach groundwater. For example, used oil and oil products from the Ghasrodasht Cement Factory are currently placed untreated into a nearby loam pit near groundwater level of the Shiraz plain alluvial aquifer. Better protection from industrial wastes will require a persistent campaign of education, persuasion, and public involvement.

Monitoring of karst groundwater systems for better protection

A monitoring system for groundwater protection is designed either to track the release of pollutants from a potential pollution source or to track arrival of contaminants into the zone of influence of water wells. Both types of monitoring are integrated into the monitoring schemes of the Maharlu Basin. For monitoring to be successful, discharge points (wells, piezometers, Qantas and springs) must be accompanied by specially designed and constructed piezometers or other sampling devices.

Groundwater sampling is most accurate under dynamic conditions. The interval of sampling must be determined based on the source, pumping demands, and climatic conditions. Three times a year sampling based on seasonal climatic change is adequate in the Maharlu Basin; e.g., one sampling during the period of heaviest precipitation (January), another during the height of the summer irrigation season (July), and a third in the relatively dry season before heavy precipitation begins (October to December). Monitoring of yields of springs and Qantas and depth to groundwater must be established at set intervals, usually monthly.

Suggested principles of water resources protection for Maharlu

Groundwater resources exploited for drinking water supply require two levels of protection: (a) legislative and (b) technical. General principles of water resources conservation and protection must be stipulated by law, which regulates the use of harmful water materials. The law in addition to general guidelines should introduce water control authorities, protective zones, and catalogues of hazardous substances for conservation and protection (LaMoreaux 1988; Lauritzen 1988). Current provincial declarations follow general European guidelines.

The current provincial declarations for groundwater protection and utilization are adequate for the technical level. Two categories of groundwater sources are recommended for technical protection:

Dug wells, springs and Qantas for small-scale water supply to individual houses and farms, etc.
Drilled wells, dug wells, springs and Qantas for large-scale water supply to multiple water users such as towns, villages, and cities.

A 5×5 m area is sufficient as a protection zone for small-scale, individual water supply sources if the general principles of protection designated by state laws are imposed and enforced in the wider area. At this scale, prevention of oil spills is the main concern.

Protection of large-scale water supplies is recommended at three levels based on types of possible pollutants.

Protection area of first degree zone

Around the immediate pumping point for large-scale supplies, there should be complete restriction of man's activities. Recommended dimension of the protection zone for one well is 10×10 m^2. The area should be delineated and surrounded by a fence.

Protection area of second degree zone

This area is designed to protect the source from biological pollution. The boundary of this area is defined as "a set of points to measure the distance needed for a 50 day delay of a water particle in the aquifer". A time of 50 days is considered as sufficient (in Europe) for elimination of typical waterborne pathogens. Some adaptation of this zone on the basis of research for Middle East conditions is needed. Additionally, the protection area for the second degree needs to be defined when a thick, impermeable layer in the vicinity of the pumping wells covers the aquifer.

Protection area of third degree zone

This third area mainly protects chemical and quantitative parameters of the water supply source. The boundary of this area is identical with the boundary of hydrogeological catchments of the exploited source.

General principles of protection and utilization of second and third degree zones are summarized in Table 1. Preferential paths, which can bring water to the well from long distances is a difficult and costly task. Designing adequate monitoring requires special techniques like geophysics, tracer tests, microbiological analysis, etc.

Maharlu Karst protection model

Recommendations for groundwater protection system design were compiled for one important karst pumping field, the Kaftarak pumping field in the northern part of the Maharlu Basin (Afrasiabian 1988). Location of any new well fields deep into the carbonate massive will ensure safety of the groundwater source and at the same time reduce land use conflicts resulting from activity restrictions within protection zones. New wells should be located in crossing valleys or depressions, following fracture patterns, and selected on the basis of specialized hydrogeological investigations and future land use considerations.

Protection of the Kaftarak pumping area

The groundwater resources of Kaftarak anticline limestone zone have both a surface infiltration of precipitation and inflow of groundwater from the alluvial aquifer. The inflow of groundwater is natural from the Nahrazam Plain, as well as enhanced by over-pumping of groundwater from the Shiraz Plain. This part of alluvial aquifer must be protected by second and third degree protection regimes.

Special investigation is required for correct delineation of the second degree protection zone in karstic limestone terrain. Practical delineation of the area of second degree protection in the Kaftarak Massive will be strongly influenced by morphology.

Additionally, the whole area where the limestone outcrops in the massifs of Postmole and Kaftarak Mountains must be protected by third degree protection regime measures (Afrasiabian 1997, 2004).

Table 1 The conditions of land use in groundwater protection area

Man's activity	Second degree	Third degree
Quarrying and mining	Prohibited	Prohibited
Exploration drilling	Prohibited	Conditional
Building of new constructions		
Living houses	Conditional	Conditional
Industry objects	Prohibited	Conditional
Communications	Prohibited	Conditional
Dumps + Landfills	Prohibited	Conditional
Cemetery	Prohibited	Conditional
Waste water treatment	Prohibited	Conditional
Dry cleaners	Prohibited	Conditional
Fuel pumps	Prohibited	Conditional
Military objects	Prohibited	Conditional

Modeling for design of ground water protection areas

Mathematical models were for determination of groundwater protection areas of the most exploited resources. For description of flow regime and travel times around exploited wells, AQUIFEM-N was used for calculation of groundwater levels and a related graphic interface, AQPOST (as developed by Townley and Wilson 1980; Townley 1990) was used to demonstrate path lines and travel times.

These models were applied on a local scale. In all cases the aquifer was considered as heterogeneous and anisotropic. Small elements with greater permeability were used for description of the tectonic zone in the Kaftarak aquifer.

The Kaftarak pumping field

The Kaftarak pumping field is on the boundary between Sabzposhan anticline zone and Shiraz Plain. There are four pumped wells in the area with an overall discharge of 240 l/s.

The aquifer is 300 m thick in the limestone part and 200 m thick in the alluvial part. Coefficients of hydraulic conductivity were 7.5 to 10-5 in the limestone part and 2.8 to 10-5 in the alluvial part.

The Derak pumping field

The pumping field in the Derak limestone aquifer is large and extensive. A scale of 1:50,000 was used for better expression. The model of the Derak anticline zone was used for modeling of this pumping field. A new finite element grid with high density of elements in the pumping field area was used. The same boundary condition and hydrogeological parameters were applied as in the Kaftarak anticline model.

Conclusions

Drinking water from karst aquifers makes up a significant part of the worldwide supply. As karst water is water for future generations, protection efforts are necessary and careful restriction is needed. Systematic qualitative and quantitative monitoring of karstic resources is highly recommended in areas of karst exploitation to assure sustainable development and management in Iran, and the Maharlu Basin in particular.

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