Groundwater for Sustainable Development 5 (2017) 59–65

Contents lists available at ScienceDirect

Groundwater for Sustainable Development

journal homepage: www.elsevier.com/locate/gsd

Research paper

# Assessment of corrosion and scaling potential in groundwater resources; a case study of Yazd-Ardakan Plain, Iran

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ARTICLE INFO

*Keywords:*
Corrosion
GIS
Groundwater resources
Water quality

ABSTRACT

The quality of water entering into water distribution network often provides requirements for corrosion and scaling in areas lacking adequate treatment methods, which can cause serious problems. The most commonly used corrosion indices are Langelier saturation index (LSI), Ryznar stability index (RSI), Puckorius scaling index (PSI), and aggressiveness index (AI). This study aimed to evaluate the corrosion and scaling potential of water resources in Yazd-Ardakan Plain, Iran. Therefore, the corrosion and scaling potential of groundwater resources were investigated according to LSI, RSI, PSI, and AI. Spearman rank correlation and spatial autocorrelation (Moran's Index) were incorporated to assess the correlations and source identification of the variables. The Inverse Distance Weighing (IDW) and Contour interpolation techniques were also employed to describe the spatial variability and interpolate the water quality.

Results showed that the mean values of LSI, RSI, PSI, and AI were as 0.30 ± 0.31, 7.12 ± 0.57, 9.50 ± 0.69, and 12.74 ± 0.38, respectively. The positive spatial autocorrelation found for all parameters showed that all parameters had a clear and cluster spatial pattern. Moreover, the Spearman correlation indicated that the source of pollution was the same for all water resources.

In this study, most of the water resources had low to moderate corrosivity. Although each of corrosion indices depending on the circumstances can be used to describe the water quality, however, the accordance between the analyses of chemical water quality and corrosion indices can give more reliable results.

## 1. Introduction

Groundwater resources are the main water sources in different countries and provide about 60% of drinking water and 30% of agriculture water supplies in these areas (Nouri et al., 2006). The quality of groundwater resources can significantly influence the scaling and corrosion in water facilities (Fendekova et al., 2011). By considering the importance of these resources and taking into account this fact that Iran has been classified as an arid and semi-arid country, it seems essential to examine the chemical quality of water. Scaling and corrosion are from the most common indicators of water quality assessment (Edzwald, 2011). Corrosion is defined as the physical and chemical interaction between the metal and its environment which usually has an electrochemical nature resulted in the change in metal properties (Kurdi et al., 2015). This phenomenon not only can import some by-products such as lead, arsenic, etc. to the drinking water, which may lead to serious health problems, but also reduces the lifetime of pipes and fittings, whereas scaling can aid corrosion resistance in the water distribution system by creating a barrier between the conductive water and surface of the pipe (Maeng et al., 2015).

Moreover, scaling is a multi-phased process in which ions (such as calcium and magnesium) react with existing substances in water to form a film deposited on the inner surface of the tubes. The most commonly produced sedimentary layer is the calcium carbonate, which can stain pipes, block nozzles, and coat the internal wall of the pipes. Deposits can greatly affect the efficiency of boilers and heat exchangers, which substantially increase energy consumption and maintenance costs (Khorsandi et al., 2015; Kurdi et al., 2015).

Several factors can influence the corrosion and scaling processes, including temperature, hardness, pH, acidity, alkalinity, chlorine, total dissolved solids (TDS), gases, salts, and microorganisms in the water. Among these factors, the biological factors are in the secondary importance level (Hoseinzadeh et al., 2013).

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http://dx.doi.org/10.1016/j.gsd.2017.04.002
Received 18 July 2016; Received in revised form 15 April 2017; Accepted 24 April 2017
Available online 25 April 2017
2352-801X/ 

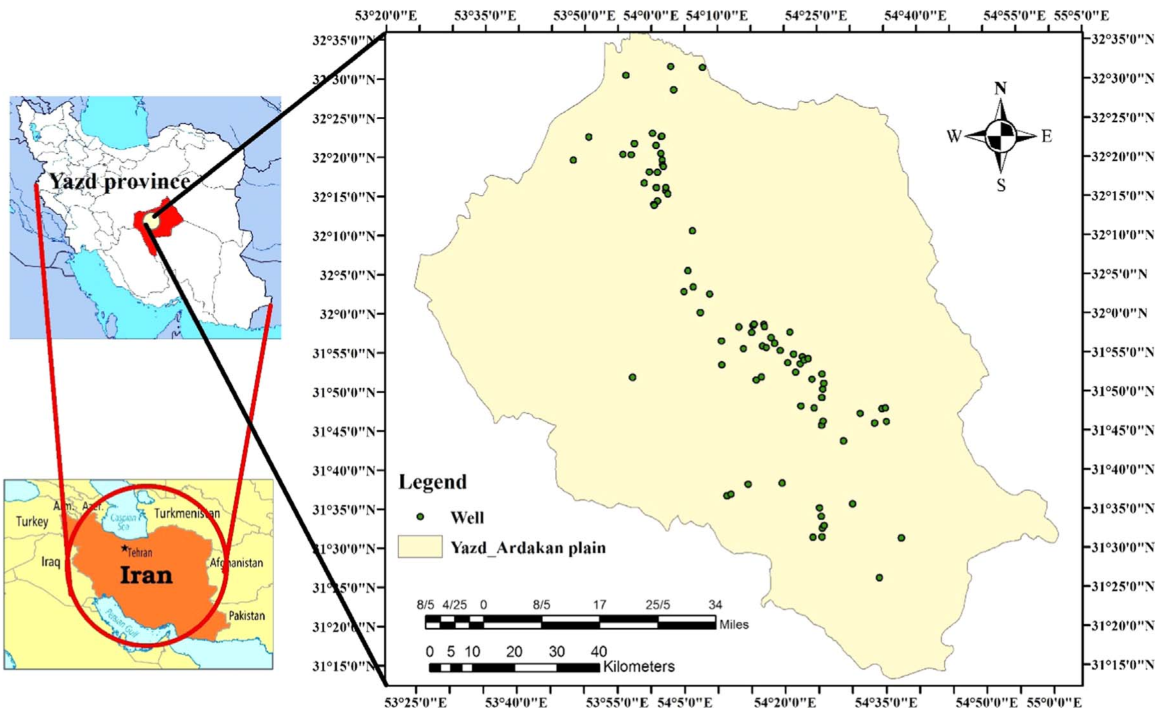


**Fig. 1.** Geographical location of water resources, Yazd-Ardakan plain, Iran.

Zhang (2005) studied the effect of disinfectant type, sulfate/chloride ratio, nitrate concentration, and magnesium hardness on iron corrosion. For the waters tested, chlorine controlled red water and microbial activity in the bulk solution better than chloramine. The changes in the sulfate/chloride ratio did not have a large effect on iron corrosion. High levels of nitrate increased the rate of chlorine decay because of free ammonia formation and increased the release of iron. Increased magnesium and zinc decreased the red water caused by high silicate.

The most important indicators used to explain the state of water corrosion or scaling are the Langelier saturation (LSI), Ryznar stability (RSI), Puckorius scaling (PSI), and Aggressive (AI) indices (Choi et al., 2015; Chung et al., 2004; Kurdi et al., 2015). LSI is probably the most widely used indicator of scale formation potential in cooling waters (Alsaqqar et al., 2014; Maeng et al., 2015). It is a pure equilibrium index, which deals only with the thermodynamic driving forces on formation and growth of calcium carbonate scaling properties (Maeng et al., 2015). PSI investigates the relationship between the saturation state and scale formation by incorporating an estimate of buffering capacity of water in the index (Puckorius and Brooke, 1991). The AI, originally developed for monitoring of water in the asbestos pipes, is sometimes incorporated instead of the LSI as an indicator of water corrosion. The AI derived from the pH, calcium hardness, and total alkalinity (Prisyazhniuk, 2007). These indicators are often used in the studies about corrosion quality of water resources. For example, Jafari et al. (2011) investigated the corrosion or scale precipitation potentials of drinking water in Anzali according to the corrosion indices, including LSI, RSI, AI, and PSI. They concluded that the Anzali water resources were corrosive. In another study, the chemical quality, corrosion, scaling potentials, and sensitivity of corrosion indices were investigated. The results demonstrated some inconsistencies in the index values and also the obtained pH range of 7.2–7.6 indicated that the water was corrosive (Kurdi et al., 2015).

Moreover, Geographic Information System (GIS) provides a flexible environment for entering, analyzing, and displaying digital data from various sources necessary for land type identification, change detection, and database development. A set of sample points representing changes in the landscape, population, or environment can be used to visualize the continuity and variability of observed data across a surface by interpolation tools (Childs, 2004; Liu and Yang, 2015). The ability to create surfaces from sample data makes interpolation, both powerful and useful.

In the last 50 years, 150 aqueducts (Qanat) in Yazd province have supplied dominant water of drinking and agriculture sections, but in recent years, exploitation of water and soil resources has been changed generally by excavation of more than 800 deep and mid-deep wells in different regions. Furthermore, an average annual drop of 80 cm in the water level of aquifers of Yazd-Ardakan Plain is the basic challenge from the viewpoints of natural resources, desertification, and their effects on human life, including unemployment and increasing immigration (Gholizadeh et al., 2013; Taghizadeh et al., 2008).

However, so far, a comprehensive study has not been done on corrosion and scaling potential of drinking water resources in Yazd-Ardakan Plain, Iran. Therefore, this study aims to analyze the corrosion and scaling potential of water resources as well as their related physical and chemical parameters in different geographic locations of Yazd-Ardakan Plain, Iran. To do so, the corrosion and scaling potential of 75 drinking resources during 2003–2015 were assessed according to LSI, RSI, PSI, and AI. GIS-based maps were also developed for the calculated indices to make accurate decisions on corrosion or scaling potential of water in the studied area.

## 2. Materials and methods

### 2.1. Study area and data collection

Yazd is one of the central provinces of Iran, which is located at the longitude of 54°20′ to 55°05′ E, the latitude of 31°15′ to 32°40′ N, and the altitude of 1190–1300 m above the sea level. This region with an area of 2491 km$^2$ has an arid climate. Here, the data of 12 years, from 2003 to 2015, related to 75 groundwater resources as aqueducts (Qanat) or wells in Yazd-Ardakan Plain has been analyzed according to corrosion indices. A total number of 1050 samples harvested from these resources were tested during this period. Global Positioning System (GPS) device in the universal transfer Mercator (UTM) coordinate system was utilized to locate water resources. Fig. 1 represents the