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Investigation of the Land Subsidence and its Consequences of Large Groundwater Withdrawal in Rafsanjan, Iran

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Abstract: Land subsidence is a phenomenon that involves the lowering or settling of the earth's surface due to various factors. The land subsidence due to groundwater withdrawal over the world has been seen in many areas. A decrease in ground water level would cause an increase in effective stresses at clay layers which results consolidation of lower layers. Since about 1980, it has been proven that Kerman Province subsidence in Iran is due to extensive ground water withdrawal. Overdraft of groundwater, an increasing of about 6 times since 1969 to 1999, has caused a decline of about 28 m in groundwater level. The rate of subsidence recently is about 5-15 cm. for decline of about one meter in groundwater level. In Rafsanjan area, many problems such as increase in the salinity of groundwater, land subsidence and consequently earth fissures and cracks in buildings are caused by groundwater withdrawal.

Key words: Land subsidence, groundwater, Rafsanjan, Iran

INTRODUCTION

Mostly underground and out of sight, the effects of groundwater over-pumping and declining water tables are difficult for many people to envision, much less conceptualize. The most apparent and tangible manifestation of excessive groundwater pumping seems to be the political and public policy debates the issue provokes. In other words, the most obvious effect of groundwater overdraft in Central Iran is the Groundwater Management Act (Fahmi, 2004). With the increasing occurrence of land subsidence and resultant earth fissures in certain areas of the Central Iran, the consequences of dropping water tables become distinct, physical and sometimes dramatically visible. Land subsidence and fissuring provide tangible evidence that the over withdrawal of groundwater has geological as well as public policy consequences.

There is no doubt that water is among the most precious of natural resources. In many parts of Iran such as arid and semi-arid provinces, the pressures of agricultural and industrial development are producing a surface-water scarcity. At the moment in most places of this country, groundwater can be found within a relatively short distance below the ground surface. The pervasive and seemingly abundant supply of groundwater has led to its indiscriminate and sometimes excessive use (NRCS, 2005). However, this use can have diverse and often wide ranging effects on the local and regional hydrology and ecology (Alley, 2003). These interdisciplinary aspects of groundwater utilization have brought into question the concept of safe yield, defined as the maintenance of a long-term balance between the amount of withdrawal and the amount of recharge (Sophocleous, 2000). Thus, the issue of groundwater sustainability has arisen (Alley and Leake, 2004). To what extent can a region's groundwater resources be exploited without unduly compromising the principle of sustainable development? Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Anonymous, 1987).

Subsidence may occur from one or more of several causes, including withdrawal of fluid (water, oil, or gas), application of water to moisture-deficient deposits above the water table, drainage of peat lands, extraction of solids in mining operations, removal of solids by solution, application of surface loads and tectonic movements (including earthquakes).

Over 150 areas of contemporary subsidence are known, some with as much subsidence as 10 m in countries such as Mexico, Japan and the United States. The best-known example of oil-field subsidence is the Welmington oil field in Los Angeles County, California, which has experienced 9 m of subsidence (Mayaga and Allen, 1969). Many more areas of subsidence are likely to develop in the next few decades as a result of accelerated exploitation of natural resources in order to meet the

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demands of increasing population and industrial development in many developed countries of the world (Barends *et al*., 1995).

Land subsidence induces very serious economic and social problems, which unfortunately appear much later after the commencement of the subsidence event and when most damages are irreversible. Principal problems caused by the subsidence are differential changes in elevation and gradient of stream channels, drains and water-transport structures, failure of water-well casings due to compressive stresses generated by compaction of aquifer systems, tidal encroachment in lowland coastal areas and in areas of intensive subsidence, development of tensional or compression strains in engineering structures (Rahmanian, 1986).

Rafsanjan, a land of subsidence: Subsidence and earth fissures are geological events that are accelerated by man through a long-term extraction of groundwater and they represent a disruption of a natural equilibrium. Underlying groundwater is pumped and the land settles and subsides. Under certain circumstances fissures then develop. Using and eventually overusing its groundwater resources have been a way of life in Rafsanjan Traditional irrigation systems of Qantas can be sensible in comparison with this pump-and-consume legacy in explaining Rafsanjan's pistachio planting growth and development and its current level of civilization. Land subsidence and related problems are then consequences that cannot be ignored. By some measures, Rafsanjan's subsidence problem has been a long time coming, since the beginning of the last decades. As a result, the water table in various areas of Rafsanjan dropped significantly, areas that may now be affected by land subsidence.

MATERIALS AND METHODS

Study area: Rafsanjan county located near central Iran, has an area of totally 21378 km^2 with 7262 km^2 plains and with a general elevation among 1400-1500 m above the sea level. This area is located between longitudes 54-30, 57-20 E. and latitudes 27-00, 31-00 N. (Fig. 1). The study area is locally divided to three plains of Rafsanjan-Kabutarkhan, Anar-Koshkuieh and Nugh plain. Rafsanjan city is located at the southern part of the study area, with a population of 138000 and Anar city is located

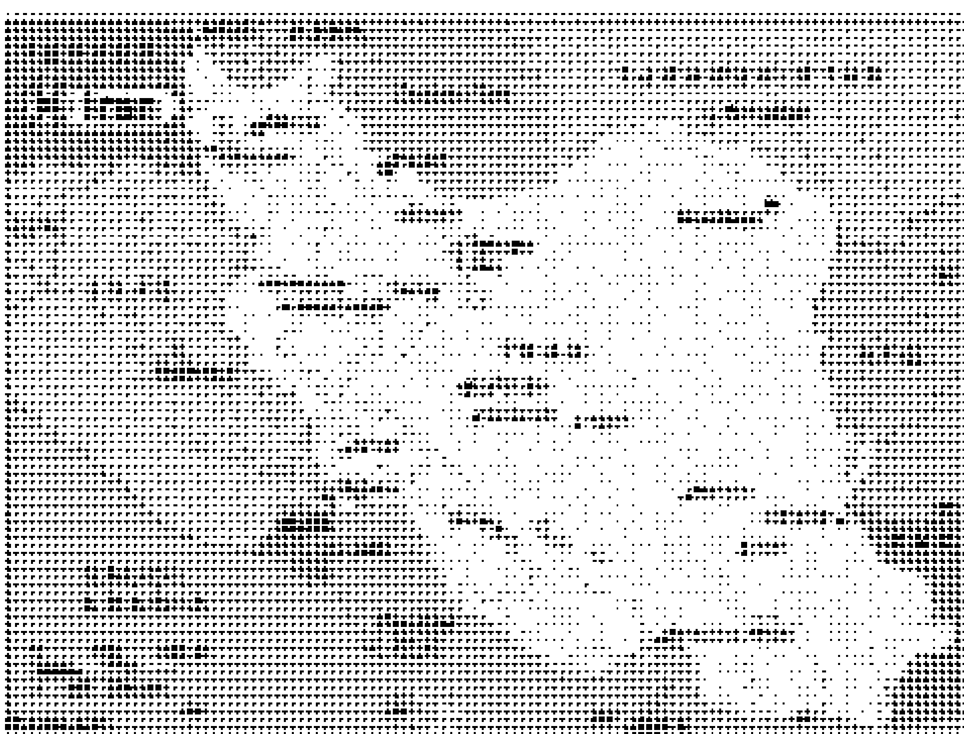

Fig. 1: Geographical location of the study area in central Iran

in the northwest of the area with the population of 26260. The main agricultural product of the study area is pistachio and many wells have been drilled to develop the agricultural lands for the mentioned production. (Khamehchiyan, 1995). This study is started from 2004 which has taken two years to get the present results.

Climate: Rafsanjan is located in an arid region of Iran (Fig. 1). Its summer is too hot and winter is cold and dry. Record maximum temperature in summer is 43°C and minimum is -18°C. Yearly rainfall is 95 mm in Rafsanjan city and 240 mm in mountains. Rainfall in plane is equal to 80% of hillside rainfall and 34% of height rainfall.

Hydrogeology: Rafsanjan plain watershed from hydrology and hydrogeology view point has a direct relation to Bardsir, Kabutarkhan and Bagein plains. However because of the hydroclimatic conditions there is no any considerable surface flow in this area. Most important flood routs of the study area included; Kabutarkhan e Hejin flood rout, with 9 million m^3 per year, Giudory flood rout, Shoor flood rout, Masine flood rout, Ghalandary flood rout and Tererj flood rout as well. Giudory flood rout conducts totally 50 million m^3 of the water resources per year to Rafsanjan, Koshkuieh and Anar plains.

These flood routs have very important role in recharge of groundwater aquifers in Rafsanjan plain. Unfortunately because of continuously drought in recent years, the rate of recharging in aquifers has been decreased. More recharging afforded the more withdrawal of groundwater and decrease of water content of wells (Rahmanian, 1986).

The used methods: In this study the required data has collected from the irrigation section of the agricultural organisation of Kerman province, Iran. The collected data were classified in different period and analysed with statistical methods to find their relations with the main parameters such as agricultural demands and drought period of the climatic changes. After statistical analysis the field techniques has used to find the accuracy of the gained results from the other documents such as maps, aerial photos and the other collected data in the field. The used data for this research was the extracted data from GPS stations which is related to the Iranian National Cartographic Centre (NCC). For the study area subsidence and fissures with the ground water levels changes according to the regional water organization of Kerman province were recorded during two years field investigations.

RESULTS

Groundwater utilization: Traditionally during last thirty years, 226 Qanats (Kariz) were taken responsibility for agricultural and drinking water requires in Rafsanjan region. But with population growth and agricultural developments in this area, many wells drilled and almost all the traditional irrigation system of Qanats become dried. Recently near to 1800 wells with 850 million m^3 discharge of water per year is extracted from Rafsanjan aquifer, Anar-Bayaz and Nugh plain aquifers which is caused some geomorphologic affects on Rafsanjan and it,s environments (Khamehchiyan, 1995).

On the basis of the less numbers of the extracted wells in last decades, the percentage of drinking, agricultural and industrial wells have been increased 3.53, 96.33 and 0.14%, respectively in the study area.

Groundwater level variation: Unexpected water withdrawals has caused high decline of groundwater level in Rafsanjan. Contours of groundwater level in the recent years compare with 1974 shows that 28 m decline of the groundwater level. In the most cases (60%), wells displacement or making them deeper was not effective. In some areas groundwater level declination for the recent years is reported to 50 m fall.

Groundwater reservoir: The value of the groundwater withdrawal is estimated more than 200 million m^3 per year in Nugh and Rafsanjan plains, which is annually deduced from Rafsanjan plain aquifer. The volume of useable supplies in 1975 was recorded about 20 million m^3 which reaches to 8 million m^3 now and total of this volume can not be supplied.

Groundwater quality: Because of the groundwater level declination and decrease of rainfall, salinity of water is increasing, as in the most regions where water quality for the agricultural uses of the pistachio farms was suitable with degree of salt, but in the recent years with an acceleration of salt it is not optimized for the farms. The result shows that recently the solution degree of salts increased three times more than last decades. The volume of dried residual in Anar-Bayaz wells is more than other regions, so in some of wells it reached to 30000 m g^{-1} per litre. It can be concluded the rate of salinity has increased to 45% between 1972-2002.

Land subsidence: This geomorphologic features of subsidence and fissure were firstly reported by the local farmers in 1977 due to declination of their water wells.

Land subsidence in Rafsanjan has caused accelerated damages on buildings, roads, vital networks and the other installations. This effect is shown obviously in the city.

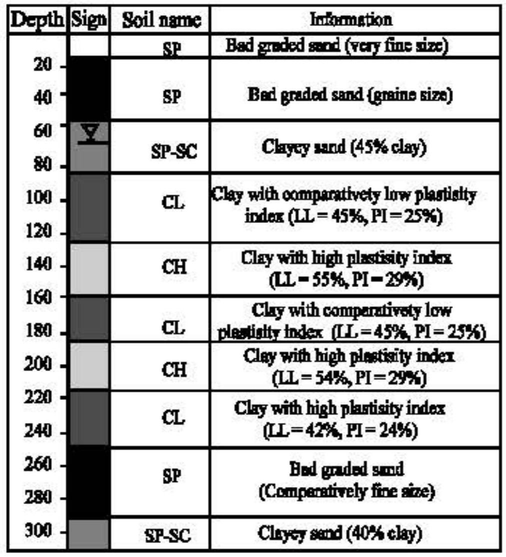

Fig. 2: Ground profile in Nugh plain (Fahmi, 2004)

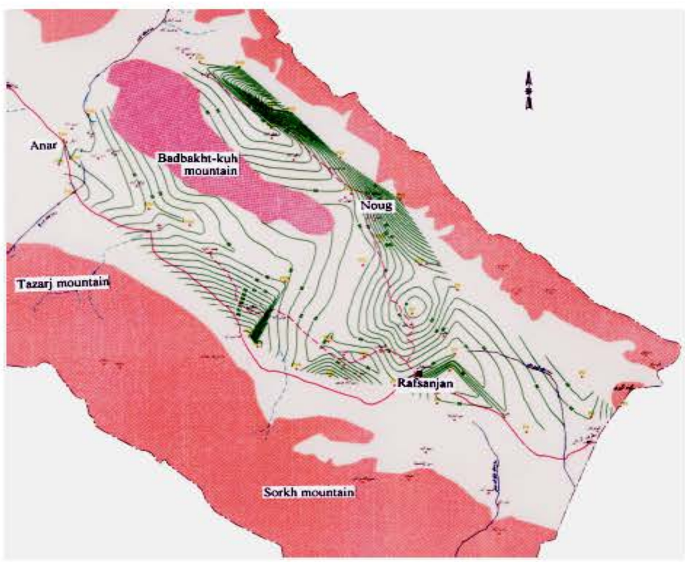

Fig. 3: Contours of land subsidence in Rafsanjan plain during the 8-month period

The opening of some cracks in buildings reach to 10-15 cm that Rafsanjan resident named it dorom. Due to damages of water pipelines distribution s ystem in the recent years, flexible pipes are using. Figure 2 shows ground profile in Nugh plain that was provided from deep well. According to this profile the thickness of comparatively high plasticity clay layer is about 150 m. Declining of groundwater level in the sandy layers causes increasing in effective pressure and this leads to settlements and finally subsidence. Due to special conditions of soil such as high plasticity behaviour the amount of settlements are large. Drainage condition is bilateral and so consolidation time of the clay layers is comparatively low. So in a short time (several years) large subsidence take places as a Geotechnical-Environmental problem.

Figure 3 shows contours of land subsidence in Rafsanjan plain. The amount of land subsidence in the center of plains is more than hillsides because of more thickness of layers and more decline of groundwater level in the center of plain (Mousavi and Shamsai, 2001).

DISCUSSION

An important water issue in Rafsanjan Iran, is the use and overuse of groundwater. The implicit, sometimes explicit message of the groundwater laws, regulations and conservation campaigns is that we need to take care of our groundwater resources to ensure the continued growth and development of the study area. Much less is heard about managing groundwater to avoid land subsidence and earth fissures. In fact, the groundwater issue is discussed in terms that suggest that the threatened consequences of groundwater over use are temporary and redeemable. What is suggested is that the groundwater situation is a temporary condition that can be fixed. And in some cases this might be true.

Yet the fact remains that relatively large portions of the central Iran have subsided due to excessive groundwater pumping and with subsidence often comes fissuring. Fissures slice across lands causing environmental damage and threatening structures and disrupting human activities. These are assuredly not temporary effects. Fissures pose threats to both agricultural and urban areas in Rafsanjan. The moment many scientists and officials stress the need for more research to be done to better understand the occurrence of subsidence and fissuring in Rafsanjan and such areas. This then will lead to better tracking of such occurrences, from predicting and early identification to monitoring and remedial actions.

For the study area it can be concluded; as water is pumped from an aquifer, the water occupying the spaces between the rock particles is removed and the water level, described as the water table, drops. Without the water, the particles then become more tightly packed together. In other words, the particles compact and consolidate. With the continued pumping of groundwater without adequate recharge, the sediments become increasingly compressed causing the land to settle or subside. In the study area because of an accelerated extraction of groundwater subsidence occurred gradually over wide areas. Although different factors determine the occurrence and extent of land subsidence but for the study area, Rafsanjan, the main factor of course is associated chiefly with excessive groundwater withdrawal, but other factors also contribute to the situation. For example, when compressed, fine-grained sediment silt and clay compacts more than coarse-grained sediment composed of sand and gravel.

According to the gained results of this research we know that the most effective way to reducing of subsidence is decreasing withdrawal. So there are several ways to reach to this aim:

- Management of aquifer withdrawal.
- Use from new technologies in agricultural and irrigation systems.
- Provide water to these regions from other locations, for example from Karoon River in the west of Iran.
- Prevention of the illegal wells.
- Prevention of the salinity wells that don't have economically agricultural profits.

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