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Land Subsidence and Fissuring Due to Ground Water Withdrawal in Yazd-Ardakan Basin, Central Iran

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***Abstract*—**The Yazd-Ardakan basin in Central Iran has two separated aquifers. The shallow unconfined aquifer is supplies 40 Qanats. The deep saturated confined aquifer is the main water storage. Due to over-withdrawal, water table has been decreasing during last 25 years. Recent study shows that the shortage of the aquifer is about 16 meters and land subsidence is 0.5 - 1.2 meters. Long deep cracks are found just above the aquifer and devour the irrigation water and floods. Although the most cracks direction is NW-SE and could be compared to the main direction of YA basin, there is no direct evidence for relation between land subsidence and the huge cracks. Large-scale water pumping has been decreased the water pressure in aquifer. The pressure decline disturbed the balance and increased the pressure of overlying sediments. So porosity decreased and compaction started. Then, sediments compaction developed and made land subsidence and some huge cracks slowly.

***Keywords*—**Land subsidence, Iran, Yazd, aquifer

I. INTRODUCTION

YAZD-ARDAKAN field with 60km length and an average width of 15km is located between Yazd and Ardakan, the main cities of Yazd Province. The study area situated at 25km north of Yazd and 10km south of Meybod at the coordinates 31°10' - 31°56' N and 54°10' - 54°12' E. The highest elevation is 1218 meters from sea level. In this densely populated area, water has been highly using by industrial, agricultural and urban activities during last 25 years. So water table has declined 16m and as a result, land subsidence occurred in this area. Recent study indicates that land subsidence is 50-120 cm which has made some large destructive consequences such as desiccation, destruction of water wells and casing, drying wells, changing the channel slopes and surface drainage, creating long deep cracks and barren lands, slumping at edge of the aquifer, damaging the structures and roads, power lines and water and gas pipelines. If land subsidence goes on with the current speed, the problems may cause a crisis. Land subsidence and fissuring, the morphological characteristics of the earth and the faults has been studied in this research.

II. MATERIALS AND METHOD

Some important information was gathered during the field work including alluvial sediments composition and size, cracks length, depth and direction. Satellite images were used for recognition the range of subsidence. Many fracture zones and cracks were studied using compass and their direction and length well determined. The coordinates was calculated by GPS. The relevant diagrams were drawn by appropriate software. Some stratigraphic column of drilled water wells prepared by Yazd Regional Water Company has been used for verifying the sediments composition. [1] Furthermore, data of groundwater level in local wells were collected and classified. Four alluvial samples were gathered in different places at depth of 1-15 meters and sent to the laboratory for XRF and XRD analysis.

III. DISCUSSION

The NW-SE trend of Yazd-Ardakan basin is the same as the regional major faults direction. The active Northern Yazd Fault passes from among the basin where has replaced the young alluvium (Fig. 1).

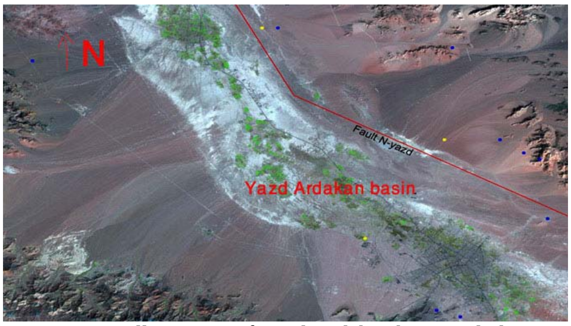

Fig. 1. Satellite image of Yazd-Ardakan basin including Northern Yazd Fault and urban areas, Scale 1: 270000

The largest aquifers in Yazd Province which are sufficient for drinking, agriculture and industry are located in Yazd-Ardakan basin, Central Iran (Fig. 2). The water of these aquifers is exploited from the Qanats (Kareez) and deep wells simultaneously. There are two separated aquifers. The shallow unconfined aquifer supplies 40 Qanats. The deep saturated confined aquifer is the main water storage.

The depth of the deepest aquifer is up to 400 meters but the final depth at the bedrock contact is estimated at least 500 meters based on geophysical data. The maximum discharge rate for water well is 148 liters per second and the rate of shortage is 1 meter annually.

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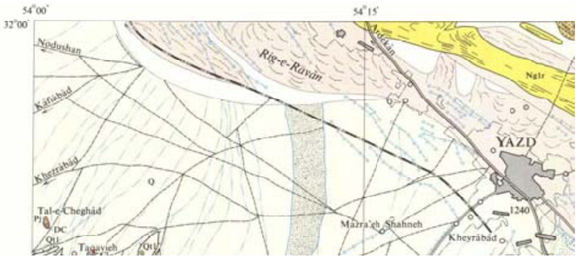

Fig. 2. A portion of Yazd-Ardakan geological map
Scale 1: 250000, GSI [2]

There are 100 piezometers in YA basin. A piezometer is a small-diameter observation well which is used for the measurement of hydraulic head of groundwater in aquifers. The deepest piezometer in this area has 414 meters depth. Groundwater level has changed in this well during a 20-year period has shown in fig. 3.

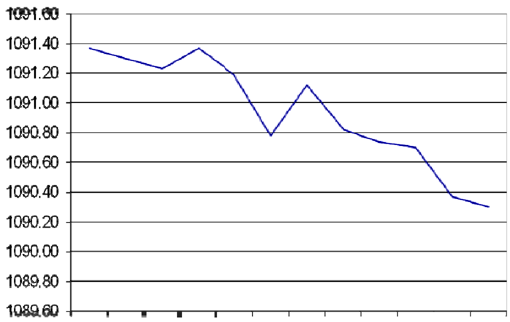

Fig. 3 Hydrographic changes in the underground water level in a 20-year period from 1985 to 2005 in the deepest piezometer at the east of YA basin.

The rate of reliable and allowed withdraws of an aquifer over a year, depends on dynamic store or charge that takes place during the same year. According to the Center for Groundwater Studies in Yazd the reserve water in YA basin was 6264 million cubic meters in 1992 with 188 million cubic meters deficit. With the same withdrawal rate, it will be charged for the next 33 years. After 18 years from 1992, much more withdraw declined the water table. In fact, relatively large portions of the Central Iran have subsided due to excessive groundwater pumping and fissuring often comes among subsidence. [3] Over-withdrawal has increased the pumping costs and reduced charging rate of wells and Qanats. Also it has caused land subsidence and fissuring. Recent study shows that the shortage of the aquifer is about 16 meters and land subsidence is 50-120 centimeters. Due to warm arid regional climate, the average annual precipitation is less than 75 mm. So the existing water resources are faced with the following risks:

Decreasing the water table due to illegal withdraws and extra usage by agricultural and industrial activities has changed chemical composition of the groundwater, the salty aquifers development, sweet and salty water confliction, reduction the soil permeability and water wells contamination due to their proximity to urban, industrial and agricultural areas furthermore, gradual land subsidence and subsequent fractures could be a widespread danger for buildings and facilities. Creating long deep cracks on the ground and damaging the structures and roads are some evidences of destructive consequences in the region. The growth of wells casing in fig. 4 indicates the land subsidence rate.

Fig. 4. The growth of water wells casing due to land subsidence

Deep cracks, Fig. 5 which are found just above the aquifer devour the irrigation water and floods. Flood control is usually expensive and requires building the flood dams and other measures.

Fig. 5. Deep cracks in YA basin Eslamizadeh, A. 2009 [4]

The Deepest wells in operation, has 400 m depth and dug in 1985. Depth of preliminary water table in confined aquifer was 60 meters during the drilling period but in 2004, it fell down to 80 meters. It means the water level has dropped about 20 meters during 19 years. (Yazd Regional Water Company). [1]

The components of the aquifer are fine-grained sand, silt and less clay material. Four clay samples collected in different places at depth of 1-15 meters and sent to the laboratory for XRF and XRD analysis. The results indicate that the clay samples are mostly Ca-Mg bearing montmorilonite. The XRF analysis result is shown in table 1.

TABLE I XRF ANALYSIS OF FOUR CLAY SAMPLES OF YA BASIN

%	AE1	AE2	AE3	AE4
Fe_2O_3	5.56	5.58	4.50	5.07
Al_2O_3	10.83	10.20	11.82	11.33
SiO_2	42.40	42.35	42.7	41
CaO	12.95	13.18	10.05	11.75
MgO	0.001	4.25	6.90	5.80
K_2O	1.75	1.75	1.60	2.70
Na_2O	1.06	0.96	1.21	1.31

The deep cracks occur in particular types of clay named very heavy clays. The cracks cause the air flow freely to evaporate excess soil moisture. [5] The underground water level in the study area has dropped averagely one meter per year and fissuring due to ground water withdrawal causes soil moisture losing in the deeper parts. The clay and silty parts of aquifer have been influenced by congestion forces more than sandy part. Water table decline can also decreases the sediments thickness above the water table. The both factors have intensified the land subsidence rate in the area.

The most cracks direction is NW-SE and could be compared to the main direction of YA basin (Fig.1).

The most fractures in the eastern and western parts of YA basin and around villages which are shown in Fig. 3 and 4 have the same trend. These fractures have broken the local roads. Fissuring in Yazd-Ardakan Road (Sento Road) can be seen in Fig. 5.

Fig. 3. fractures at the west of study area

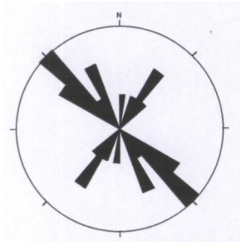

Fig. 4. fractures at the east of study area

Fig. 5. Fissuring in Yazd-Maybod main road

As it is shown in the rose diagrams, Fig. 6 and Fig.7, the fractures direction in the north and southern parts have the same pattern but they are different from the fractures in east and western parts of the YA basin.

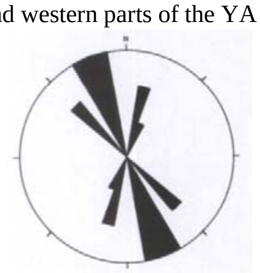

Fig. 6. Fractures at the north of study area

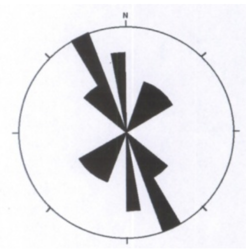

Fig. 7. Fractures at the south of study area

Resulting fractures in a layer can be divided to tensile and shear groups. Tensile stress is that trying to separate the layers and when the layer is finally broken, broken parts may shift significantly. Shear stress is that trying to slip layers, the separated layers may slip along the fracture surface considerably. Generally in study area two main factors such as subsidence and tectonic agents have been caused these fractures (Zare Mherjardy A. et al., 2007). [6]

The important factor of subsidence in the study area is groundwater extracting. In the areas with uncontrolled exploitation of underground water and a negative balance, increases affecting stress of soil is the main factor of compaction ground layers. Effective stress at any depth of soil is calculated from $p_i = p_t - p_h$ which p_i is the effective stress, p_t is the total stress and p_h is the hydraulic pressure in each region. If p_h reduces or p_t increases the amount of the effective stress will increase. In the most aquifers due to increased exploitation of water resources we are confronted decreasing water table in unconfined aquifers or reducing pressure in confined aquifers. Both cause reduce of p_h and as a result increase of p_t cause subsidence of layers. As a result of subsidence, fissures will be created on the surface that is mainly tensile and radial type with no particular trend. Generally, it is believed that the fissure is initiated as a relatively narrow crack that is formed when the induced tensile stresses exceed the tensile strength of the soil. Earth fissures develop near the margins of subsidence bowls and/or in the vicinity of a buried rock pediment edge. [7]

Considering that fractures in the study area have a clear trend, the subsidence can't be considered as a main agent for regenerator of them. Of course, the fractures are located within the wells can be attributed to subsidence caused by cone-fall.

The faults are the most important tectonic elements in the region. There is Naein-Baft Fault in the west and Kharanaq Fault in the east (Fig. 8) Aghda-Rahmat Abad Fault located in the western boundary and the Northern Yazd Fault exists in the eastern boundary of YA basin. The last one is considered as active fault.

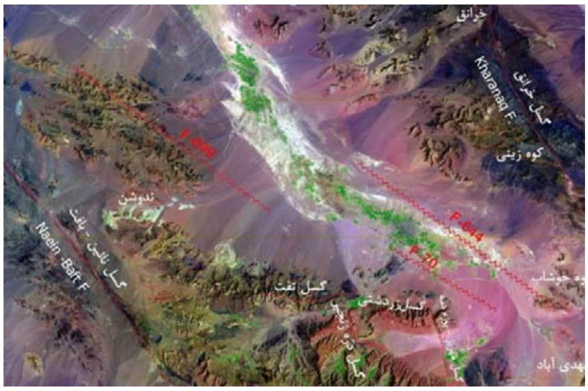

Fig. 8. Aligned Yazd-Ardakan basin between two parallel faults. Naein-Baft and Kharanaq Faults have created a shear zone with their motion to the right.

Naein-Baft and Kharanaq Faults with their activities cause changes in geological structures. Existence of fractures and fissuring in YA basin can be considered a result of their active tectonics. [8] The two faults are parallel with a movement to right create a shear zone (Fig. 9).

Fig. 9. A fractures that shows operation of a shear zone.

Shear zones, are the narrow regions with almost parallel margins related to non-coaxial deformation. There are all scales from flake limit to microscopic in shear zones. Their characteristics change in the range of ductile to brittle. In fact, many areas of fault can be considered as shear zones.

Soil deformation under differential settlement may evolve into ground faulting if water withdrawal continues. When a crack has completely developed, the tensile zone shifts towards the center of the graben, creating a new area for potential cracking and faulting. [9]

There are certain trends in fractures existing in YA basin that indicate effect of tectonic factors in the region.

The specific form of young fractures (Fig. 9) from the past two decades reinforces the above theory. Moving two active mentioned faults in the west and east of the area have created an important deformation. [10]

In western part of the region, creating travertine zones, folding Neogen sediments, hydrothermal alteration, igneous activities, rotation of the folds axis and concentration of the secondary faults are some evidences of Naein-Baft Fault activities. In the eastern region, creating specific lineaments in mountain, displacement of the rivers direction and sedimentary formations, concentration of secondary faults and earthquakes events in the adjacency are the important signs of Kharanaq Fault activities.

IV. Conclusions and Recommendations

Increasing in exploitation of water resources with water table decline in the study area has decreased the hydraulic pressure and increased the total tension which created land subsidence and fissuring. Long deep fractures cause high evaporation of the soil moisture in the lower parts. As a result with a higher rate of soil drying, cracks have become wider and deeper. The clay and silty parts of aquifer have been more compact and along with descending of water table and increasing the thickness of overlying sediments, land subsidence rate have exceeded. Land subsidence is greater in central part of the basin where more wells there are.

Radial fractures in wells within the area have mostly extension type. These fractures have been formed due to over-withdrawal and decreasing of water table. On the other hand, more cracks have NW-SE direction that is similar to extension of YA basin. Considering that all these fractures have a distinct trend, it is impossible that subsidence created all of them. Generally the fractures have been created by two main factors: subsidence and tectonic agents resulting from active faults. [11] Efficiency indicator of water usage is an important requirement for efficient use of water in Yazd Province because implementation of this goal has an important role on the effective utilize water in agriculture. Non-standard extraction of groundwater and lack of accurate statistics of underground water caused the challenges in water.

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