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Subsidence Hazard Zoning of Jiroft Plain, Southeast Iran

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Abstract:- This paper deals with subsidence hazard zoning in Jiroft plain which lies at 28º 15´ to 28º 50´ northern latitude and 57º 40´ to 58º 00´eastern longitude in SE Iran. In order to evaluate this hazard, firstly, geological, geomorphological as well as hydrogeological conditions of the plain were studied and, secondly, location and causes of subsided sites were investigated and, lastly, hazard assessment and zoning was undertaken. In this region, clay dehydration as a result of over-exploitation and groundwater-level decline is considered as the cause of subsidence which has inflicted damages to structures, roads and cultivation fields. Subsidence is manifested as open and wide fissures. The main criteria for zoning include the presence or absence of fissures, the extent of water-table drop, the kind of deposits (presence, absence and purity of clays) and the original depth of water table. In general, four zones were separated and mapped which include high, medium and low-hazard zones as well as a hazard-free zone. In the end, land-use recommendations are offered for each zone.

Keywords:- Jiroft plain; Ground Subsidence; Hazard zoning; Over-exploitation; Ground Fissures

I. INTRODUCTION

As a result of human intervention, ground subsidence is becoming a common geological hazard across the world. In Iran, wherein overabstraction of groundwater resources during the past decades has taken place, many cases of subsidence have been reported (e.g. [1], [2], [3]).

This paper addresses ground subsidence and fissure hazard in Jiroft plain which lies at 28º 15´ to 28º 50´ northern latitude and 57º 40´ to 58 º 00´eastern longitude, in SE Iran (Fig. 1). There are over 100 villages and two towns (Jiroft and Anbarabad) collectively with about 300000 residents in this plain. The people are mainly dependent on agriculture for their living.

This plain is bordered from the north and east by Jabal-e-Barez high mountains and from the west by Esfandaghe low mountains and hills (Fig. 2). Two hills are considered as the southern border of it.
Jiroft plain slopes from north, east and west towards the center and from thence it slopes gently southwards. The region is arid in climate with humid and mild winters and dry and hot weather in other seasons. The average yearly precipitation in the plain is about 190 mm, but the high mountains at the north and northwest receive up to about 350 mm precipitation.

The rivers flowing into this plain include Halil (from northeast) and Shur from the north. Also, more than two dozens of ephemeral and seasonal streams arrive from north, northwest and west. The Halil river receives all these flows along its route towards the southern outlet of the plain.

II. DISCUSSION

A. Geology

The Jiroft plain is considered as the eastern part of Jazmurian depression which is the forearc basin of the Makran subduction zone [4], [5]. The Jabal-e-Barez mountains in the north and east belong to the Urumie-Dokhtar belt of Iran which in this region is predominantly composed of Eocene volcanic rocks and some dioritic intrusions of Miocene age. The western mountains which belong to the Sanandaj-Sirjan belt of Iran are mainly composed of Precomberian and Paleozoeic metamorphic rocks and Jurassic detrital, carbonate and cherty deposits as well as tuffs and diabases. The bordering low hills in the south are composed of friable Plio-Quarternery conglomerates [6]. In addition, there are several hills scattered across the plain comprised of Oligocene flyshes, Eocene volcanics and Oligo-Miocene Qom formation. These three units are the bottom rocks of this alluvial aquifer as well. Qom formation is composed of basal conglomerates, sandstones, gysiferous marls and reefal limestones [6],[7]. Pliocene deposits which are mainly composed of conglomerates are uplifted by Jiroft and Sabzevaran faults at the south and comprise a part of the plain's aquifer.

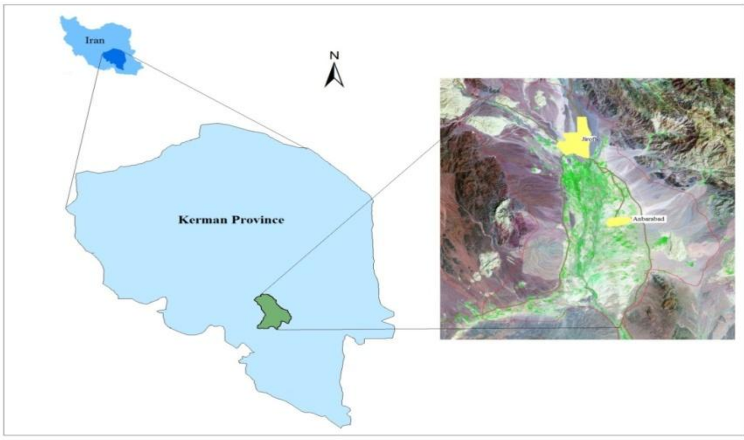

Fig.1: Location map of the studied area

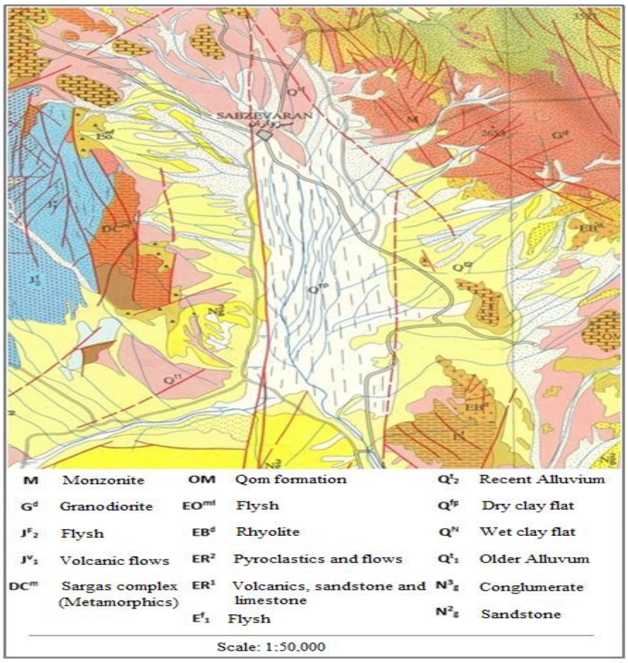

Fig. 2: Geological map of studied area

The majority of this plain's surface is covered with Quaternary alluvials which included alluvial fan, flood plain and playa deposits. The formers are composed of gravels and the latter one is made up of clays.
The borders of the plain with the surrounding mountains are faulted [8]. Also, two main north-south active faults which include Jiroft fault at the west and Sabzevaran fault at the east, strike along this plain (Fig 2). They are considered as two segments of a long north-south fault system in eastern Iran, named Nayband fault [9]. The central part of the plain which is mainly covered by clay flats may be considered as a pull-a-part basin created by these two right-lateral active fault segments.

B. Geomorphology

This plain is covered by several geomorphological units (Fig. 3), including the alluvial fans (at the east, north and west), a clay-flat playa, Halil's flood plain, uplifted mounds and scatterd hills [10].

Although, presently the Halil river crosses the plain and leaves it at the south, but according to the geomorphological evidence, it was formerly blocked at the south by the hills uplifted by the aforementioned active faults. So, as a result of this blockage, clays were deposited and created the playa. However, after a while, continued activity of the faults opened a route for the river to exit from the plain. This led to the incision of the clay flat along the north-south direction of flow and formation of a flood plain.

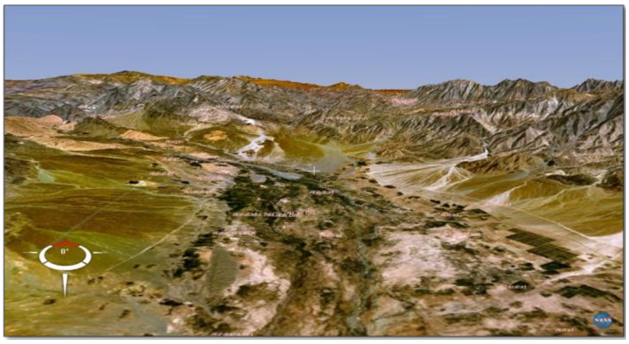

Fig. 3: Back: Jabal-e-Barez mountains. Left and right: alluvial fans, center: clay flats and flood plain of Halil river

C. Hydrogeology

Ground subsidence and creation of fissures in Jiroft plain has a close link with its hydrogeology. In this plain, groundwaters are accumulated in coarse alluvials resulted from the erosion of nearby mountains. A major part of the atmospheric precipitation in mountains infiltrates into the ground and enters the plain via borderline faults and alluvial fan heads. The other part which forms surficial flows partly recharges the aquifer after entering the plain. Recharge by direct precipitation over the plain is negligible.

The aquifer at the south of Jiroft town has been artesian up to about 10 years before (2003). But as a result of heavy pumpage, artesian wells dried out. The aquifer under the central clay flat is confined, but in alluvial fans it is free [11], [12], [13].

The geological logs of some wells indicate that the total thickness of clay layers increase southwards [14]. According to studies undertaken, the aquifer in the central part of this plain is leaky in character [15], [16]. The iso-potentional map (Fig. 4) reveals that ground water flows from the north, east and west towards the central part and thence flows southwards. The iso-depth map for the 1999-2000 water-year (Fig. 5) displays that the water table in the central part is about 20 meters in depth which increases towards the peripheral alluvial fans. In many places, the water table lies at 20-40 meters depth. The maximum depth (80 meters) has been measured at the southeast corner where there is not a major source of recharge.

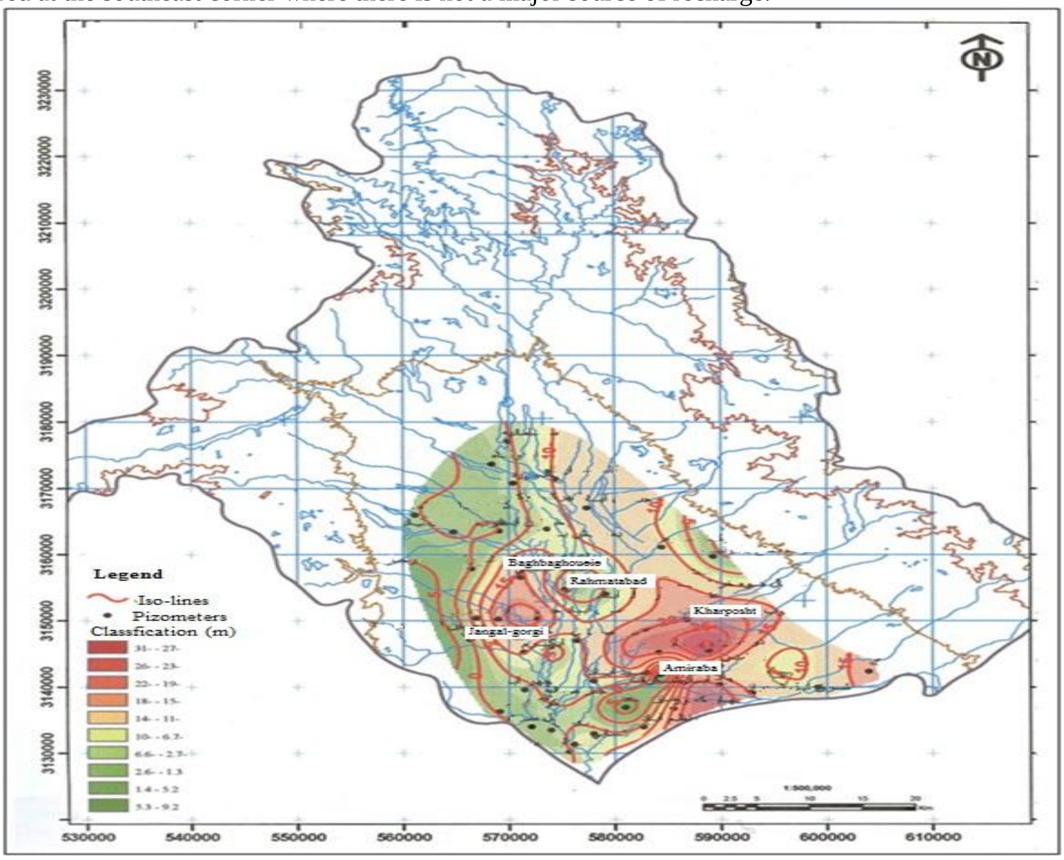

Fig. 4: Isopotentional map of the studied area

From the point of subsidence hazard, groundwater level fluctuation is of utmost importance which is over 20 meters in subsided areas, reaching up to 40 meters in the southeast. The rate of water table fall in the western part of the plain has been less than its eastern part. The density of drilled wells (Fig. 6) is the main cause. The water table drop in the central part of the plain is about 10 meters which seems too low if compared with the density of drilled wells. Recharge of the aquifer by Halil river explains this contradiction.

Fig.7 is the unit hydrograph of the alluvial aquifer of Jiroft plain for a 24-years period (1986-2010). According to it, the water table fall has taken place almost continuously during this period, although it has risen to some extent from 1993 to 1995 which has been a wet period. As Fig. 7 indicates, the average drawdown for the whole aquifer has been 14 meters, meaning 1.8 meters fall per year.

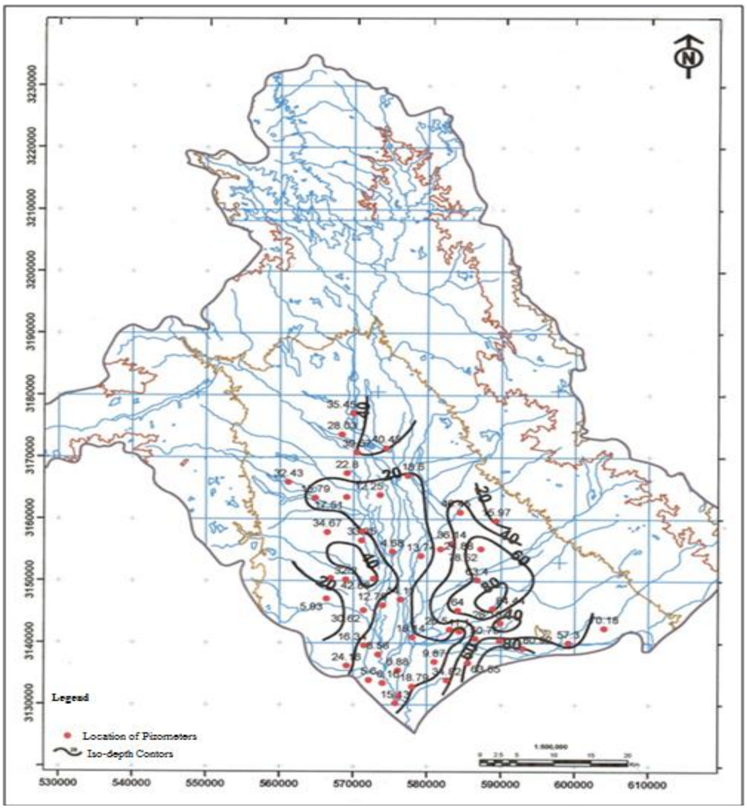

Fig 5: Isodepth map of studied area

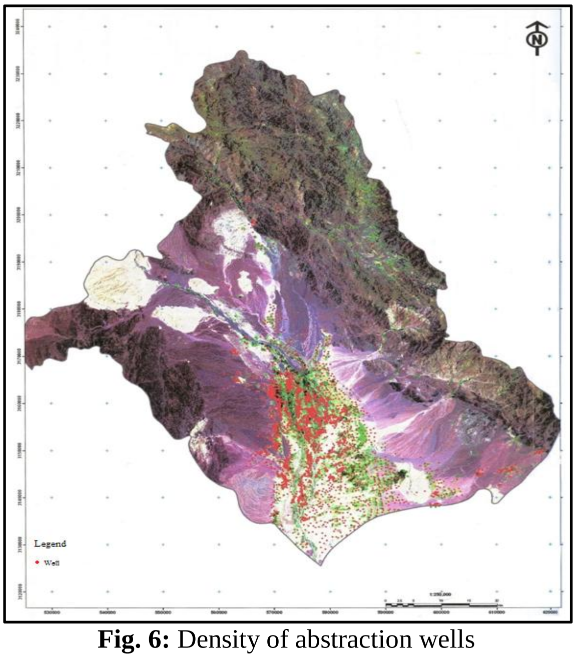

Fig. 6: Density of abstraction wells

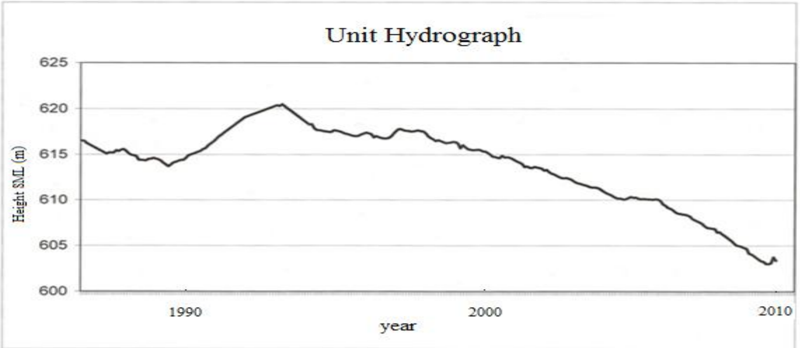

Fig. 7: Unit hydrograph of the aquifer during 1986-2010 period

Also, it is necessary to mention that the alluvial aquifer of Jiroft plain contains almost high quality waters. The electrical conductivity of groundwater at recharge areas in the north and east is about 400 micromohs/cm. In the central parts it reaches 800-1200 micromohs/cm which increases up to 2800 micromohs/cm in the discharge areas at the south [16], [17].

D. Location and causes of subsidence

In Jiroft plain, the ground subsidence fissures were recognized in three areas. The first area, lies at the south of Anbarabad town in the central part of eastern half of the plain. There are several villages in this area and examples of fissures are shown in Fig. 8.

The second area which is very limited in extent is located in the western part of the plain, just around Hosseinabad-e-Dehdar village. The third area lies in the southwest and includes several villages such as Bolboluieh, Jazfatan and Daranabad.

Based on field studies, the common characteristics of these areas include the blockage of surficial streams by active faults which have created stagnant environments. So, the clays settling in these conditions are porous (supposedly forming a house-of-cards structure). The other characteristic is that they have been saturated until the past decades. In this plain, the main cause of ground subsidence and appearance of fissures is contraction of clays as a result of dehydration, i.e. water table drop has led to contraction of surficial saturated clays and creation of fissures [10].

In many locations across the world increase in grain-to-grain pressure of the aquifer has been introduced as the main cause of subsidence but, this type of subsidence commonly manifest itself as the apparent rise of casings (because compaction takes place mainly along the vertical direction). So, fissures are sparse and are caused by differential subsidence due to difference in the thickness of layers. In contrast, clay dehydration occurs volumetrically (along all three directions) and fissures are much more common and scattered over the land surface (not in specific directions). In all, although aquifer compaction due to increase in grain-to-grain pressure may have a role in this plain, but clay dehydration is the main agent.

E. Assessment and Zoning

The appearance of fissures in Jiroft plain has posed several problems, including:

1) Damage to agricultural lands, gardens and problems in irrigation and human activities as well as the mobility of agricultural machineries (Fig. 9).

2) Damage to roads (Fig. 10) and buildings (Fig. 11).

Fig. 8 two examples of fissures created in the studied area

Fig. 9 Fissures in agricultural lands leading to their abandonment

Fig. 10 Fissures in roads

Fig. 11 Damages inflicted to buildings as a result of subsidence

Preparation of hazard zoning map based on hazard assessment is a prerequisite for combating the hazard. The ground subsidence hazard map of Jiroft plain (Fig. 12) was prepared by considering the following criteria:

1) Presence or absence of fissures and other indicators of subsidence
2) The extent of water table drop in subsidence-prone locations.
3) The kind of deposits (especially the presence of clays).
4) The original depth of water table (as a result of high water tables, clays have previously been saturated and have become contraction-prone).

So, in a specific location, the more the deposits are clayey, the higher is the original water table, and the more the water table has dropped, the severe the subsidence hazard would be. Hence, in order to prepare the ground subsidence hazard map of Jiroft plain, the following criteria were taken into consideration:

1) Sediment type - the presence of surficial or near-surficial thick clays is a key factor. Purity of clays is also important.
2) Presence or absence of fissures.
3) Water table depth (originally and at present).

According to the above criteria, four types of hazard level were identified and mapped (Fig. 12)

1) High-hazard zone - In this study, a place was considered “high-hazard” if:

a. It contains ground fissures
b. Surficial sediments are composed of comparatively pure clays

c. Originally, the water table has been high (marshy conditions) and as a result of settling in stagnant water, they are very porous and expanded.
d. The water table has been dropped over 10 meters. The high-hazard zone is located in eastern, western and southeastern parts of the plain (Fig. 12)
2) Medium-hazard zone – A place was considered "medium hazard" if:
a. It lacked fissures during the date of field studies (Nov. 2011).
b. The surficial sediments are clayey and totally or partly wet.
Although this zone lacked fissures in 2011 year, but if the current watertable drop continues in the future, the fissures would appear in this zone too. According to Fig. 12 a large part of the plain lies in this zone.
3) Low-hazard zone - Places which lie in this zone have at least one of the following conditions:
a. The possibility of severe water table drop in this zone is low (for instance, due to lying adjacent to Halil river).
b. The clays are impure and their contraction extent is limited.
c. A clay layer lies beneath a relatively thick cover of coarse deposits.
4) Hazard-free zone – The subsidence hazard in this zone is almost absent, because:
a. It lacks fissures.
b. It is composed of coarse alluvial deposits.
c. Originally, the water table has been deep.
A number of villages as well as Jiroft town lie in this zone.

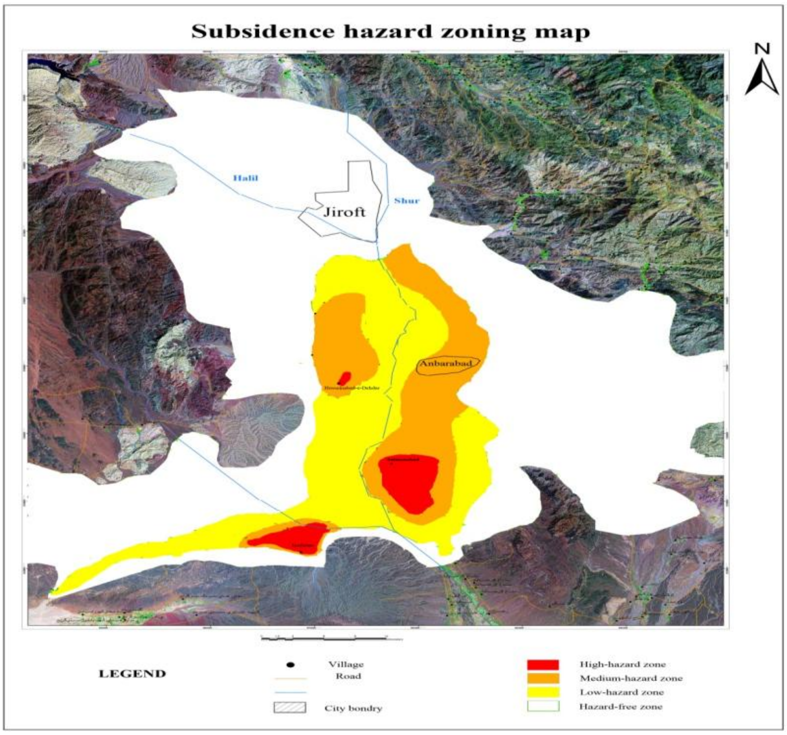

Fig. 12 Subsidence hazard zoning map of Jiroft plain

III. CONCLUSIONS

The According to this study, the ground subsidence in Jiroft plain is manifested as ground fissures. The fissures were identified in three areas (south of Anbarabad town, west of the plain and in the southwest). The main causes of fissure appearance are water table drop and the consequent contraction of surficial clays which have formerly been wet.

The fissures have caused damages to buildings, roads, gardens and agricultural lands. In the hazard zoning map which is presented, four zones (high hazard, medium hazard, low hazard and hazard free) were identified. Development in high-hazard zone must be undertaken with regard to this hazard. So, the structures must be hazard-resistant. However, if the present trend of water table fall continues in the future, fissures would appear in the medium-hazard zone. It is recommended that the structures in this zone be built hazard-resistant too. The low-hazard zone is only negligibly hazard-prone. Although, it is not susceptible for fissure appearance, but the possibility is not zero. The common (cheaper) structures may not be hazard-resistant in this zone. The hazard-free zone is not prone to fissure formation, and human activities can be undertaken without any regard to subsidence hazard.

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