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Studying the Effect of Drought on Water Resources over Two Decades and Occurrences of the Sinking Phenomenon in Minab Plain

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Abstract

Extraction of water from underground sources is on the increase, especially from basins stored by non-strengthened alluvium, sediments and from shallow areas of the sea. This results in sinking on the surface and leads to ground subsidence. In recent years, the Minab Plain, like many areas of Iran has faced drought, which has led to more uptake of subterranean water; this lowers the underground water level and results in sinking which appears on the surface as a sinkhole following subsidence. A field study of this sinking phenomenon involves the following procedure: Firstly, the analysis of the drought occurrences in the area including features of water table, sediment and bedrock. Secondly, the consideration of exploitation of the subsurface water; and finally, identification of the different forms of subsidence in the area from the information acquired above. Statistics from the Sheikh Abad rain-gauge station (covering a period of 27 years) were used for this investigation. Data on precipitation are presented with the decimal method and the standard precipitation index, an index that shows any decrease of climatic rainfall in the area. This data shows that in recent decades there has been less than normal rainfall and that the area has undergone a period of intense drought. In most parts of the plain new alluvium was formed at a depth of 2-3 meters from the surface, the sediment of which often constitutes large grains, which gradually changed to form finer sediment in the form of sand, silt and clay containing salt-water. Therefore, it can be said that with increasing depth, the sediments become tinier (smaller) with an increase in salinity. All of the wells in this area have settled on washed silt sediment and have a high density around the rivers of the Minab area. Because of recent droughts and the drying up of the water supply canals of Minab dam, the digging of wells has increased from 164 in 2002 to a current figure of 607 dug wells. Critical factors related to occurrences of subsidence, are that the existing alluvium covering with the varying thickness up to 150 meters has formed small-grain, silt clay-silt loam soil, which has increased surface subsidence following extraction of underground water over the past two decades.

Keywords: Underground water, Droughts, Sinking phenomenon, Minab Plain, Subsidence.

بررسی تاثیر خشکسالی‌های دو دهه اخیر بر منابع آب زیرزمینی دشت میناب و وقوع پدیده فرونشینی

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چکیده

افزایش روزافزون برداشت از منابع آب زیرزمینی ، علی الخصوص از حوضه‌هایی که با رسوبات تحکیم نیافته آبرفتی یا نهشته‌های کم عمق دریایی انباشته شده اند منجر به فرونشست سطح زمین و یا به عبارتی نشست عمومی زمین می گردد . جلگه میناب نیز همانند بسیاری از مناطق کشور در دو دهه اخیر مواجه با خشکسالی بوده که این امر منجر به برداشت بیشتر از آب‌های زیرزمینی و افت آب زیرزمینی را به دنبال داشته ک نتیجه این امر نشست عمومی زمین و بروز چند سطح فرونشستی و چاله‌های فرونشینی بوده است. برای بررسی پدیده فرونشینی ابتدا وضعیت خشکسالی منطقه مطالعه شد سپس مشخصات رسوبات سفره‌های آبدار و سنگ کف ، نحوه بهره برداری از آب‌های زیرزمینی منطقه در دوره مورد مطالعه مورد توجه قرار گرفت. هم‌چنین با مطالعات دقیق میدانی اشکال مختلف فرونشست در منطقه شناسایی و در نهایت اطلاعات جمع‌آوری شده مورد تجزیه و تحلیل قرار گرفت. برای بررسی خشکسالی در این مطالعه از ایستگاه باران سنجی شیخ آباد (با طول دوره آماری ۲۷ سال) و با استفاده از داده‌های بارندگی، روش دهک‌ها و شاخص بارش استاندارد استفاده گردیده که نمایانگر کاهش ریزش‌های جوی در منطقه می‌باشد بطوری که در دو دهه اخیر بارش خیلی کمتر از نرمال بوده که معرف خشکسالی شدید در منطقه می‌باشد. اغلب نقاط دشت از سطح زمین تا عمق چند متری از آبرفت‌های جدید تشکیل یافته‌اند ، این رسوبات اغلب دانه درشت بوده و به تدریج به طرف دریا به رسوبات دانه ریز ماسه‌ای سیلتی و رسی دارای آب شور تبدیل می‌شوند بطور کلی می‌توان گفت که با افزایش عمق، رسوبات دانه ریزتر شده و املاح آن‌ها افزایش یافته و شورتر می‌شوند. تمامی چاه‌ها در این ناحیه بر روی رسوبات شسته شده سیلتی قرارگرفته و دارای بیشترین تراکم در حواشی رودخانه میناب می باشند. بعلت خشکسالی‌های دو دهه اخیر و خشک شدن کانال آبرسانی از سد میناب، حفر چاه‌ها بطور فزاینده‌ای افزایش یافته و از ۶۰۷ حلقه چاه حفر شده ، ۱۶۴ حلقه در سال ۱۳۸۰ حفر گردیده است. عوامل بنیادی در رابطه با وقوع فرونشینی وجود آبرفت پوشش به ضخامت متغیر تا حداکثر ۱۵۰ متر که به طور عمده از خاک‌های دانه ریز سیلتی رسی و سیلتی ماسه‌ای تشکیل شده و افزایش افت سطح آب زیرزمینی (۵ تا ۱۷ متر) در نتیجه برداشت بی‌رویه ناشی از خشکسالی در طی دو دهه گذشته می‌باشد.

کلمات کلیدی: آب زیرزمینی، خشکسالی، پدیده فرونشینی، دشت میناب، فرونشست.

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Introduction

In recent years, human activity has induced the formation of new sinkholes, which presents a hazard to life and property. Changing agricultural patterns have led to the opening up of thousands of deep wells in recent years, and increased water extraction in excess of the sustainable yield of the aquifer. This exploitation of underground water sources through excessive use is the main contributing factor to the problem of a lower subterranean water level that induces a state of isostatic imbalance. This finally causes general subsidence in the plains in certain areas with particular geological conditions. This sinking can have an impact on the hydrology and bedrock of an area. Therefore it is necessary to study this issue and determine a strategy to control the exploitation of subterranean water to prevent further imbalance of the water levels.

The increasing extraction of underground water sources, especially from basins that hold non strengthened alluvium sediment or shallow areas of the seabed results in surface settlement, which can induce ground subsidence. Sinking of the ground surface happens in many parts of the world particularly in delta areas, where populated cities are often located. This obviously has the potential to cause tremendous damage (Mahbubi Ardakani, 2006). The Minab Plain, like other areas of the country has faced drought in recent years, and this has increased demand for water supply leading to a higher consumption of underground water. This over consumption has caused the appearance of several sinkholes and occurrences of subsidence.

According to research, between 1950 and 1985 more than 6500 sinkholes were formed in the USA. In Orlando, at least 140 sinkholes were identified between 1961 and 1986 (Wilson and Beck, 1992). In this study, the main contributing factors to this phenomenon were found to be as a result of drawing on the underground water supply during oil production and gas mining operations, draining ooze, and from the formation of muddy land (Pewe, 1990 and Waltham and *et al.*, 1989). Aliyari (2002) in a study of sinkholes in Hamedan found that the main factor to cause these sinkholes was an intense decrease of water level. Heidari (2004), by microscopic analysis of thin sections tested dissolubility in Hamedan, and Amiri (2006) in a study of sinkholes in Hamadan diagnosed that the dissolubility factor of an area was the most important contributing factor in the formation of sinkholes.

Saadati and Mohamadi (2004), through an investigation in the Hamedan area concluded that distribution of subsidence and sinkholes was related to areas that intersected with fault lines and are associated with the processes that surround the faults. Parvizi (2006), in a research on sub-surface structure, determined that the main factor in the formation and acceleration of sinkholes in Kaboodar Ahang and Famenin Plains was the existence of a fault-zone in the lime bed alluvium that was 100 and 150 m thick and had resulted in a significant decrease in the level of the underground water table over the past two decades. Along with the cases mentioned above, there have been other studies that detail the phenomena of subsidence and sinkholes in the Famenin Plain (Naseri, 2006), This study identifies factors that effect occurrences of these phenomena (Khanlari, 2006) and the formation of sinkholes on the

Jaber Dares Plain in Ilam has also been researched (Haji Karimi, 2006). Most sinkholes in the Hamedan region of the central plain in western Iran have developed in partially unconsolidated sediment overlying Oligo-Miocene limestone. Analyses of hydrologic and hydrogeological conditions from 1988 to 2008 show that conditions were favorable for sinkhole development (Heidari *et al.*, 2011). During the last two decades, the Lesina Marina affected by subsidence, has increased exponentially from 1999 to 2009 (Dolores Fidelibus, 2011). The number of sinkholes (locally known as *obruks*) has increased rapidly in recent years near Karapınar, located in the semi-arid Konya Closed Basin in Central Anatolia (Doğan and Yılmaz, 2011). A preliminary sinkhole susceptibility analysis has been carried out in a stretch of 50 km^2 in an area of the Ebro valley alluvial evaporite karst (NE Spain) (Galve *et al.*, 2008).

Considering the outcomes of decreasing groundwater levels and subsidence occurrence: Ground subsidence occurs when the surface sinks as a result of some changes below the ground level (Cooke and Doornkamp, 1999). The appearance of ground movement is often manifested as large-scale expansion, unlike subsidence, which creates small forms such as sinkholes, cavities and gaps. Ground subsidence has been reported in different forms, either as a deep holes or sinking of the ground or subsidence by one of the wonderful geological phenomenon, in various parts of the world.

1. Ground Subsidence: Ground subsidence usually occurs in the plains areas as a result of a basic factor such as the over consumption of water form too many wells in a small area that has lowered the water table. Therefore decreasing the underground water level, as a result of long term consistent use of water with a lack of any compensation for the dwindling reserve causes a decrease in the level of underground water and subsequent change of the pizometeric pressure; the hydraulic gradient in the subterranean layers decreases and so the speed of the vertical water flow is accelerated.

In addition to exploitation of wells, the fine-grained particles move among the layers, and some is evacuated from the wells. These factors lead to destruction of the upper layers, and finally the upper section of this sediment gets substituted for lower layers and subsidence occurs (Sanayie, 2006).

2. Subsidence at a deep level leads to sinkholes, which is compounded by a plurality of wells and this causes sinkholes. Incidentally, in areas where the bedrock consist of marl sediment and is fine grained, the concentration of wells and the establishment of general depression in areas of fault lines or centers of cone symmetry. While the fine-grained particles are transferred in layers, some of the sediment is extracted from the well, thus the primary core exists to create a sinkhole (Sanayie, 2006).

The greater the subsidence; the greater is the damage to humans and buildings. There are additional problems such as the destruction of roads and power lines and damage to waste water, buildings, irrigation systems and, most importantly, to the means to extract subterranean water. In addition, problems are created with regard to oil and gas, mining, organic soil drainage and salty minerals dissolving under the ground. This study concerns the effect of factors that cause a decrease in the level of ground water, primarily the effect of drought and drainage on the subsided ground of the Minab Plain.

Study Area

The Minab Plain is located in 56 º 48΄ - 57 º 15΄ E and 26 º 1΄ - 27 º 27΄ N. It covers a total area of 1378.8 square kilometers and its plain has an area of 788 square kilometers. The maximum height of this plain is 50 meters and its minimum is zero. The main river is the Minab River (Fig. 1).

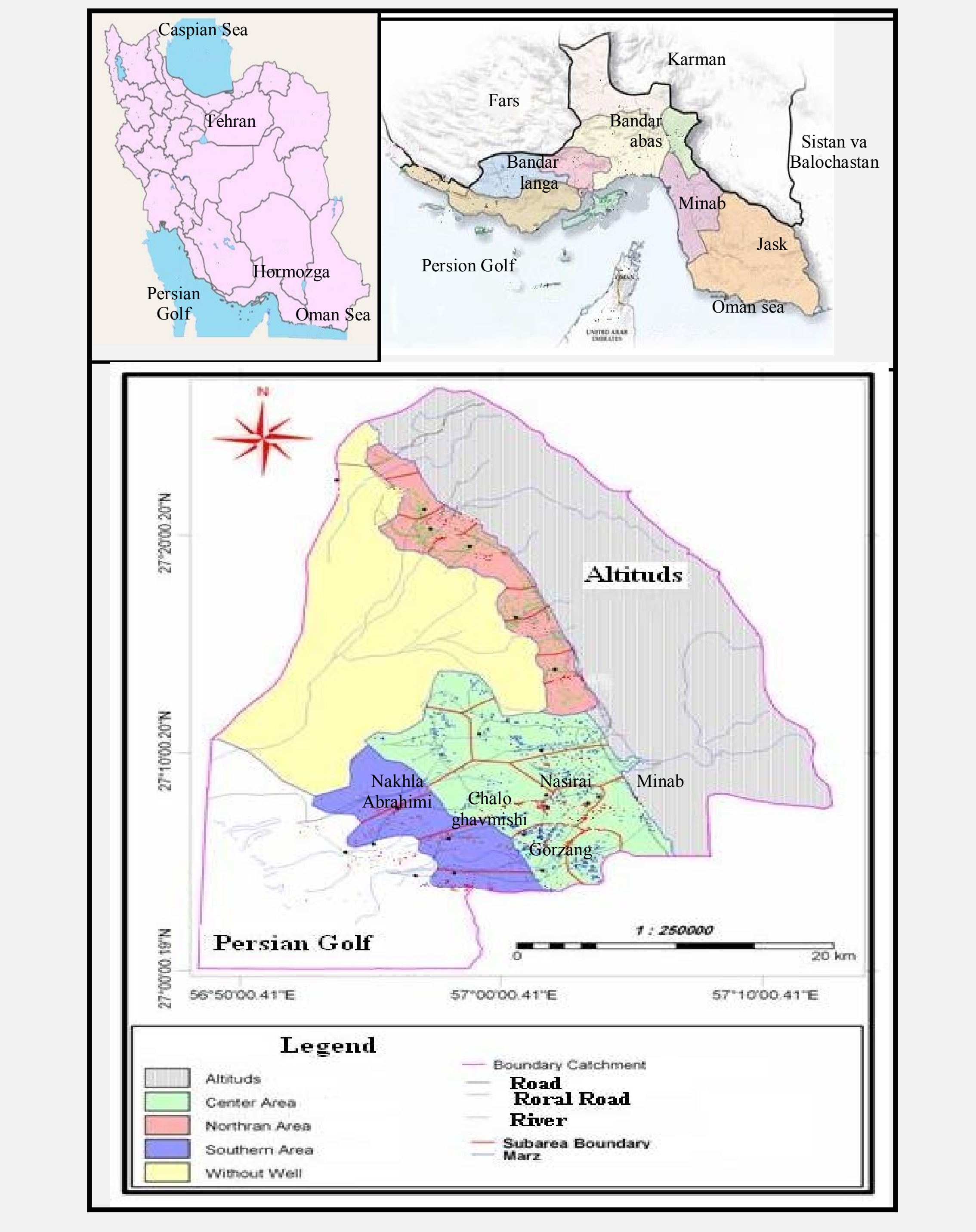

Figure 1. The location situation of study area and subsided porous ranges of earth.

This study was unable to cover areas where there was a high density of gardens and due to other constraints such as time and cost, so it was necessary to check those areas which had the most probability of subsidence and to use existing local .information. Thus the central area of the Minab Plain, which extends to about 174 square kilometers and involves the highest density of wells in the area, was chosen as the case study area. The studied area is located near the "Makran Zone".

Materials and Methods

To identify any phenomenon, it is necessary to find the components of the system in which it has been made. To do this, firstly, the previous studies dealing with other areas were considered and research relating to that area and, then, features of the water table, sediment and bedrock, and exploitation of the water source were examined. In considering the information of ground subsidence at special range information regarding surface sinking and its situation, local guides were employed to identify areas in which settling of the ground had appeared, they began to collect and record information using GPS (Fig.1).

The observation area was located at 56º 59′ 14″ E and 27º 7′ 6″ N, and at about 1.5 kilometers southeast of Choloo Ghavmishi village. In the north of Choloo Ghavmishi village and not far from a site of prior subsidence as a result of a declining level of water, the surface was porous and full of holes (Fig. 1).

Also, different forms of subsidence were identified and considered by exact field studies; finally, the information was analyzed to identify those factors that caused settling in the area.

Results

A) Studying drought in the Minab area:

Drought is a climatic abnormality that has an effect on human life and other creatures. Subsurface drought may appear two or three months later than climatic drought. To consider the intensities of drought periods, data on precipitation and underground water levels of the Minab plain were used. The intensity and duration of drought periods was studied using current methods of calculation.

Long-term drought, evident in Hormozgan Province since 1999 continues today and could have long-term consequences on water sources and agriculture. In winter 2005, when the holding capacity of the dam reached its limit due to abnormally high rainfall, it was expected that the drought problem would be solved; however, 2006 had a record high level of drought. To consider the role of the subsurface water source on drought in the Minab plain, climatic variations and hydrology have been analyzed over a 15 years period (1993-2010).

The results of climatic abnormality and water showed a high correlation between independent climatic variations and the amounts of decline. Also, maps appear to show the adaptation high-fall ranges of the water table with most agricultural areas dependent on a supply of subsurface water. So, meteorological drought, which occurs as a result of decreased water from the atmosphere (rainfall) causes hydrologic drought. This decreases amounts of available water to maintain soil moisture and quickly results in a lack of water available to plants around the roots and this can be compounded by high evaporation and perspiration. Finally, as a result of a decreased water source and lowering of the sub surface water level as a result of extraction, water supply to farms and for domestic consumption becomes unavailable due to subsurface drought in Minab and Bandar Abbas as well as the surrounded villages.

Studying drought using precipitation data: To investigate drought in this study, the Sheikhabad rain-gauge station, near Minab City was used, which is one of the oldest stations in the area with 27 years of records.

Through observing amounts of monthly and yearly precipitation in records from Sheikhabad station it was determined that the highest amount of rainfall was 519 millimeters in 1982-1983. The lowest rainfall was 30 millimeters in 2004-2005. This difference between the two figures presents a high ratio for most months of the year, reaching 40 percent, which represents the rainfall pattern pertaining to deserts.

As shown in Figure 2, regarding precipitation data from the Sheikhabad station during 1981 to 2008, there was a descending linear process of rainfall. Figure 3 indicates moving means that include records of 3, 5 and 7 years. As seen, between 2002 and 2003 the curves are below the line of yearly precipitation average, representing a decrease in atmospheric precipitation, which is below the normal range.

Studying drought using decimal method: In the decimal method, long-term precipitation distribution, from the smallest to the largest numbers are arranged and divided in to ten sections and each section is nominated as a decimal. The first decimal indicates the amount of precipitation which is less than ten percent and the second decimal indicates precipitation amounts which are less than twenty percent, and so on (Table 1).

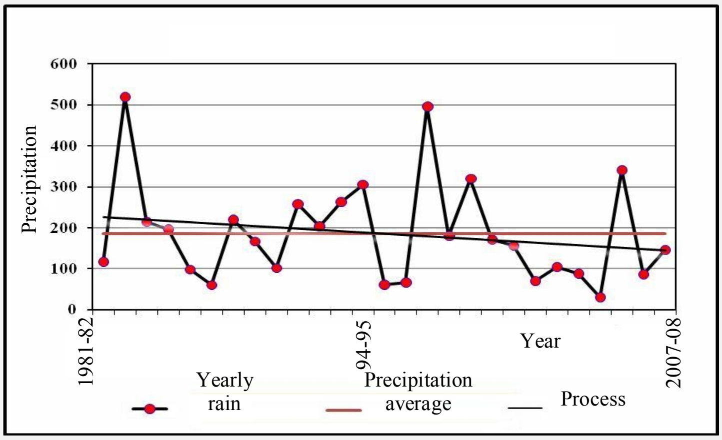

Figure 2. Changes of yearly rain fall in Sheikhabad station during 1981-2008.

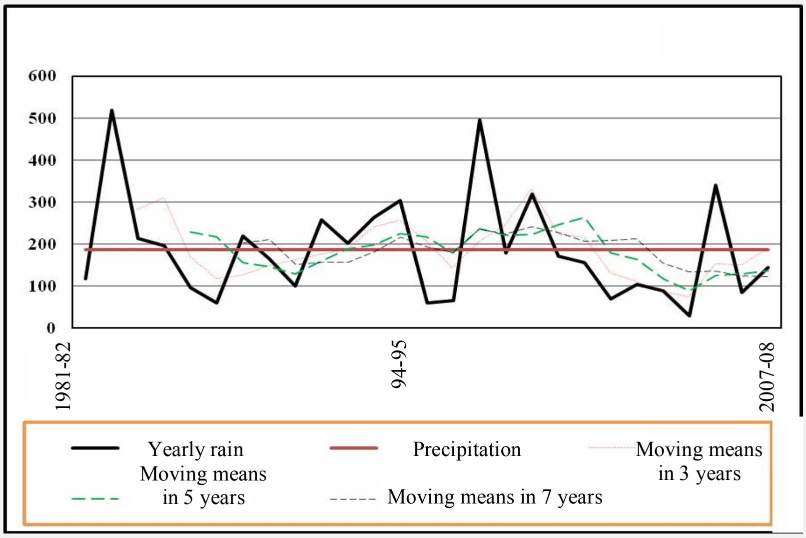

Figure 3. Moving average including 3, 5 and 7 years in Sheikhabad station (1981-2008).

Table 1. Category of drought based on decimal method.

Index classifications	Drought situation
Larger than 40%	Normal
30 to 40 % decimal 4	Week drought
20 to 30 % decimal 3	Middle drought
10 to 20 % decimal 2	Intensive drought
Less then 10 5 decimal 17	So intensive drought

Considering Figure 4 shows the amounts of yearly precipitation in Sheikh Abad station during 1986-1987, 1994-1995, 1995-1996, 2001-2002 and 2004-2005 and that they were less than normal (precipitation amounts less than the second decimal) are an indication of severe drought.

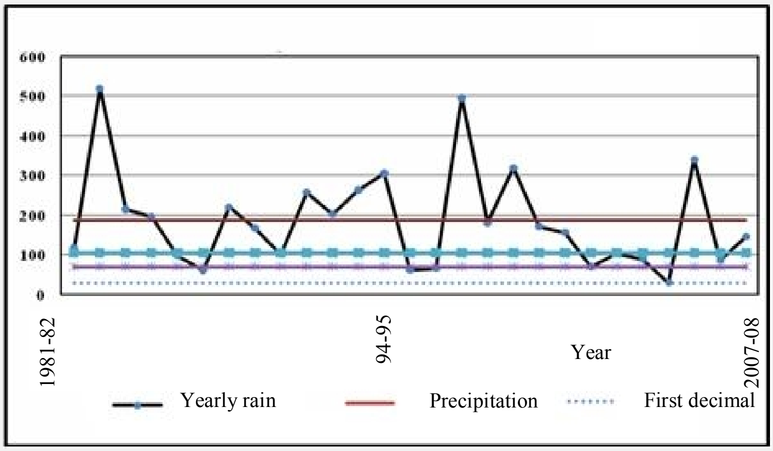

Figure 4. Variations of precipitation and drought in Sheikhabad station (1981 – 2008).

Studying drought using the Standard Precipitation Index (SPI): The Standard Precipitation Index is an indicator that is used based on the possibility of precipitation for different time scales, also it can predict the result of drought conditions drought occurs and helps to approximate the intensity of a drought (Noohi and Asgari, 2006 and Shirmohamadi and *et al.*, 2004). In a recent study, the drought situation of an area was calculated using the SPI method on a12 month in scale. As seen in Figure 5, medium to severe drought occurred was recorded for the following years; 1986 to 1987, 1995 to 1996, 2001 to 2005 and 2007. Therefore there is evidence that drought has been in existence for a number of years and that it continues.

B) Deposits and hydrous layers of the Minab plain

Recognition of the deposit features of an area is one of the basic considerations necessary for an analysis of land structure in the Minab plain.

Analyzing the sediments of Minab plain using geotechnical methods: The internal and external forces that shape the land were identified by digging into the ground (using the geoelectrical method). Wells were dug using excavation machines which was done to determine the behavior of the subsurface water.

Geological materials in all the basins of the Minab River are mainly composed of quaternary alluvium sediments and the hard formation of tertiary and colored mix. With use of geologic sections and stratigraphic columns, the geological materials of the Minab Delta it can be determined that subsidence has affected the flow of the Minab River and the subsurface water. The remaining facieses are an alternation in sandstone with middle weak and seldom hard, fine grain density and full of porosity (Fig.6).

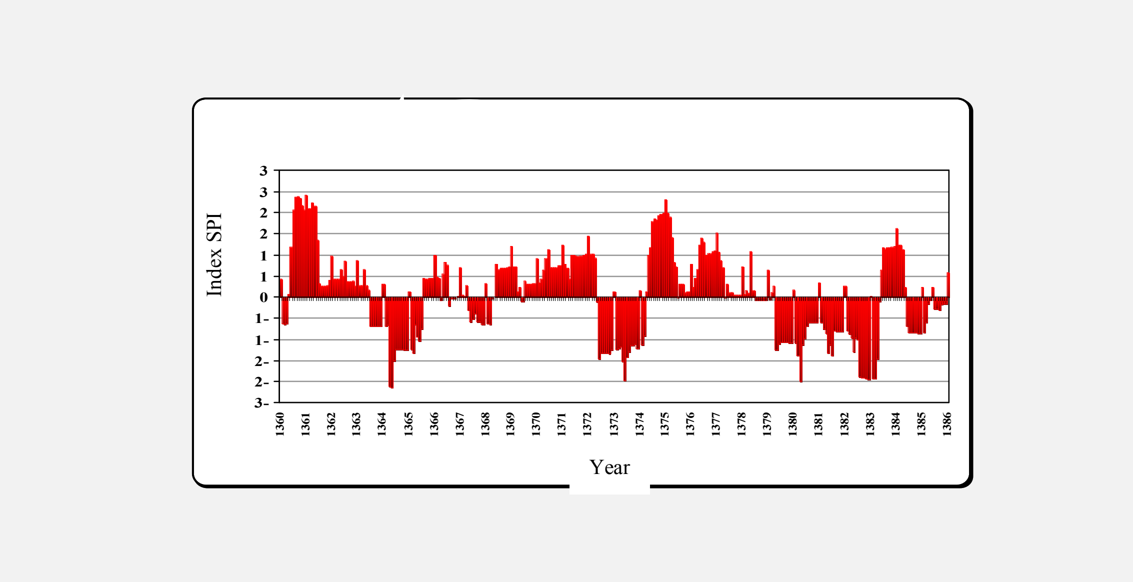

Figure 5. Areas drought situation, using SPI method in 12-month scale

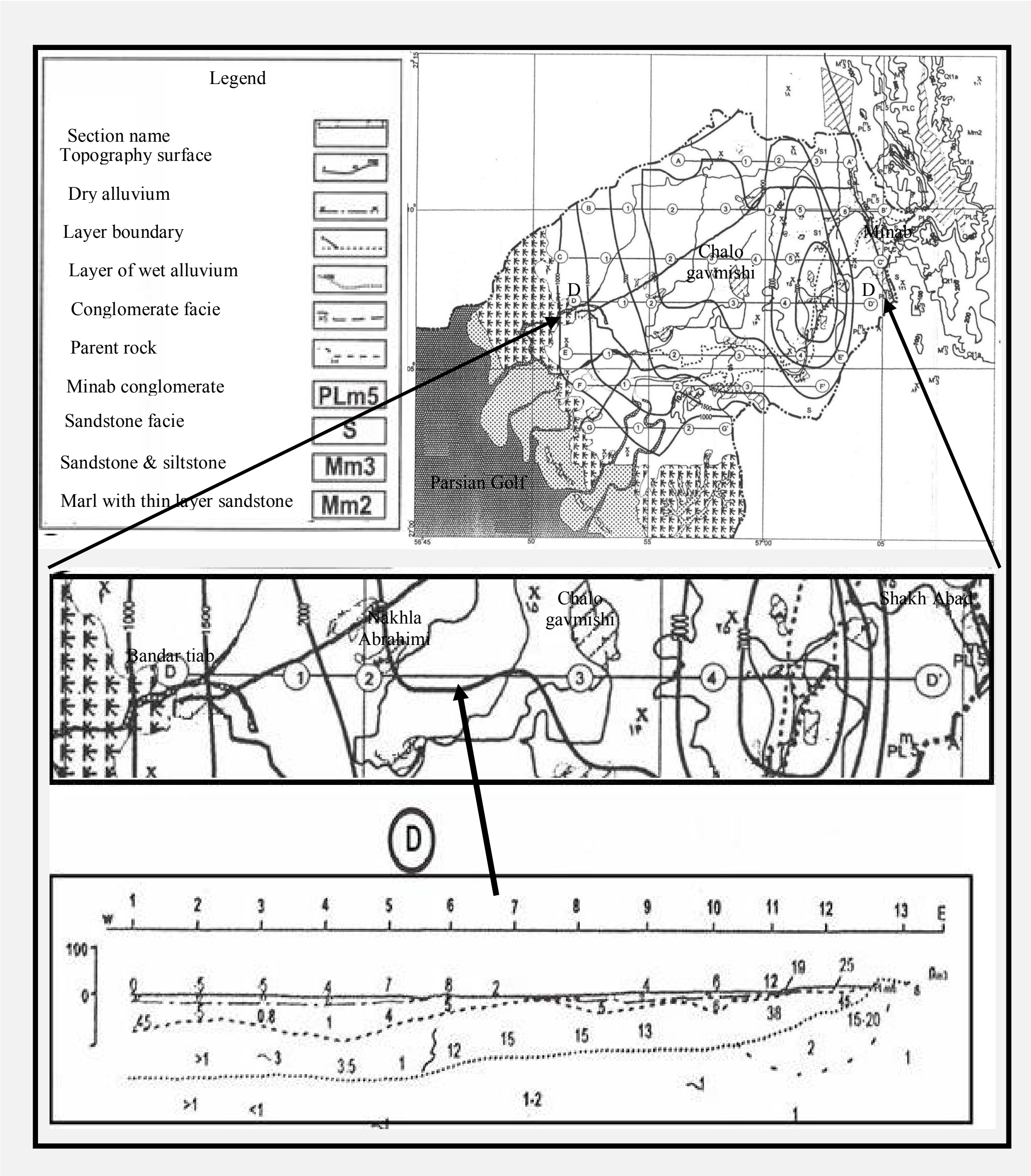

Figure 6. Geological cross section using the geoelectric method.

Inter layers mostly involve shale, marl, sandy marl which are erosive, formless and hard, destructive materials that have resulted from the sediment that is basically fine grain like silt, clay large and small sand, a little clay or silt gravel and sand.

Geoelectric studies: Through analyzing the symbol pattern of sound devices, which have been performed on geological formations near exploratory wells, the results are summarized as follows:

Limonite clay deposits had a resistance less than 10 ohm meter. Fine grain alluviums in salty water had about 10 ohm meter regarding the low resistance of these sediments it seems that the aforementioned deposits are made of clay and sand or large grain sediments including salt water which contributes to less resistance in the deposits.

Mid grain alluviums have an electrical resistance of between 20 to 40 ohm meters and at lost butler; large grain alluviums have a resistance of more than 70 ohm meter. In this area the bedrock is often made of conductor formation, which indicates clay marl deposits. These sediments are established by a geophysical method and transmitting lengths AB=100 meters, AB=400 meters, AB=600 meters which considers 25, 50, 150 meters of horizons (Fig.6).

Particular conductive resistance with AB=100 meters often indicates areas with new alluvium sediments. From conductive resistance, the deposits of north west and south sections mostly have the some manner and are fine grain made of sandy clay and silt, but in the eastern and central sections of the Minab Delta the sediments are large grain however the parent rock of this section like other sections is made of third period marl; in geological terms this suggests the sea having advanced towards the East in a past era.

Particular conductive resistance AB=400 meters suggests that alluvium deposits are greater, including rivers sand gravels. Particular conductive resistance AB=600 indicates that a large part of the plain is covered in fine grain or mid grain sediment including silt clay and marl.

This reach shows that in southwestern Minab (the study area) there is an alluvium basin with a maximum approximate thickness of 150 meters, which indicates alluvium sediment of the Minab River. Generally, deposits of the Minab Delta are conglomerate, clay silt and small and large sand. To understand the quality of the sediment we will describe a geological cross section of the area's subsidence (section D) on a map with the same the clones of area in the Minab plain.

- Section D: In this profile, two upper strata of sediment have been formed which include clay and sand. The main alluvium horizon indicates sandy-clay, mid to fine grain alluvium. In this section, Cenozoic farcies parent rock includes shale and marl. In a range of divining 11 and 12 under the alluvium deposits and above the rock head, there is a sustainable stratum, which seems to be the Minab conglomerate (pLm5 in Fig.6). In this section, the thickest alluvium sediment is 150 meters.

Describing the geological cross sections of dug pits using the physical method

To consider the features of change in sediment based on existed exploratory wells, two geological cross sections were provided, whose situations are indicated in Figure 7.

Cross-section D D′: The direction of this cross section is East–Southwest–North and it is 24 kilometers in length. Divining results include p23-p21-p43-p28. The height of the subsurface water level in p28 from the Northwest increased to 5/77 meters and to Southeast in p43 is 5/77 meters from sea level. Generally, from divining p28 to p21, the variations in the water surface reached approximately 2 meters. In this cross section, the topographic form of the water table from p21 is placed at the highest and the lowest depth. This condition can be related to parent rock position in the river, which continues in a quiet subsided slope from p 21 to the Southeast (Fig.8).

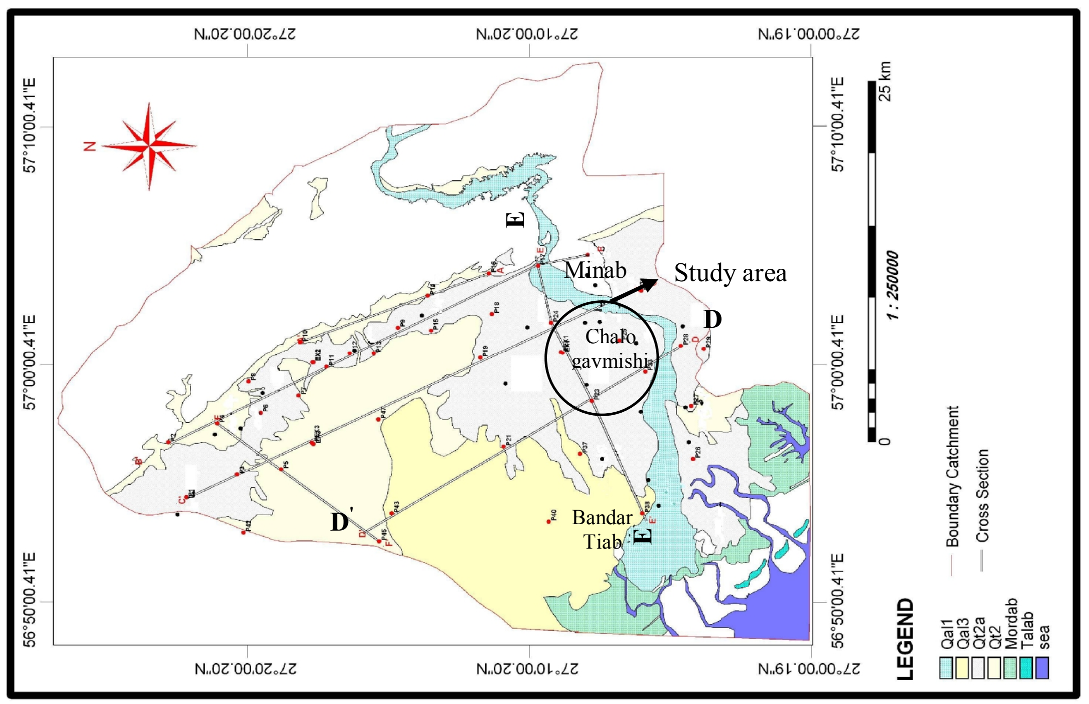

Figure 7. Situation of geological cross section of dug wells using physical method.

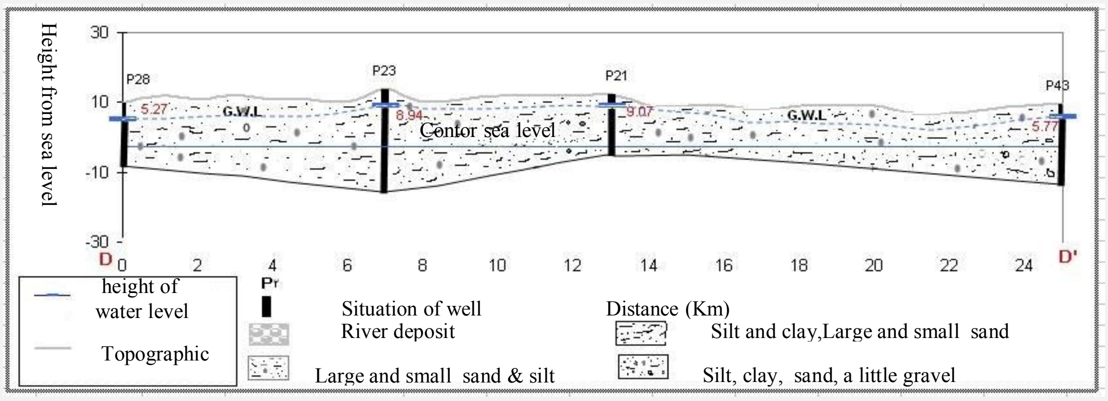

Figure 8. Cross section D-D´: geological cross section of dug pits using physical method.

Cross section E E': this cross section runs in the direction of Northeast–Southwest. Strata of this cross section include – divining p 23 – p28 – p17 – p24; the height of underground water level in a dividing p 17 was 14/2 meters in April 1997, it decreased gradually to the Southwest in divining p 23 to 8/94 and in p 28 to 3/74 meters declined from sea level. The level of subsurface water follows the topographic features of the area. From divining p17 to p24, a cavity is formed then in p23, it becomes a relief shape and, towards p28, settles at sea level with a mild slope. Additionally, in the central areas and near villages such as Mahmoodi and Gurzung some surface gaps were observed during visits which were probably the result of ground subsidence from exploitation and a falling water table level (Fig. 9).

Due to this comparison a general conclusion can be made that alluvium by the side of the elevations, especially at the entrance of the Minab River, changes to a plain and in the range of the northern alluvial fan, it is large grain and a mix of pebbles, gravel sand and a little silt and clay; gradually the thickness of the sediments decreased towards the sea and changed to fine grain silt, sandy and clay deposits. In further study of the stratigraphy column, an exploratory well was made to determine the internal delta (p12) (Fig. 10).

Features of the hydrous layers

The results of digging the exploited determined the plain alluviums as follows: most areas in the plain show that new alluvium has been formed below the surface, these deposits are in the eastern border parts of the plain and, especially at the entrance of the Minab River towards the sea, they gradually change to fine grain, sandy silt clay including salt water sediment. Below the surface alluvium around the Minab River, particularly at the primary parts of its entrance and northern areas, there are larger grains of alluvium in southwesterly and southeasterly directions. Digging at a greater depth suggested that most parts of the plain (except the Minab River's entrance to the plain) there was fine and mid grain sediment, which contained salt water.

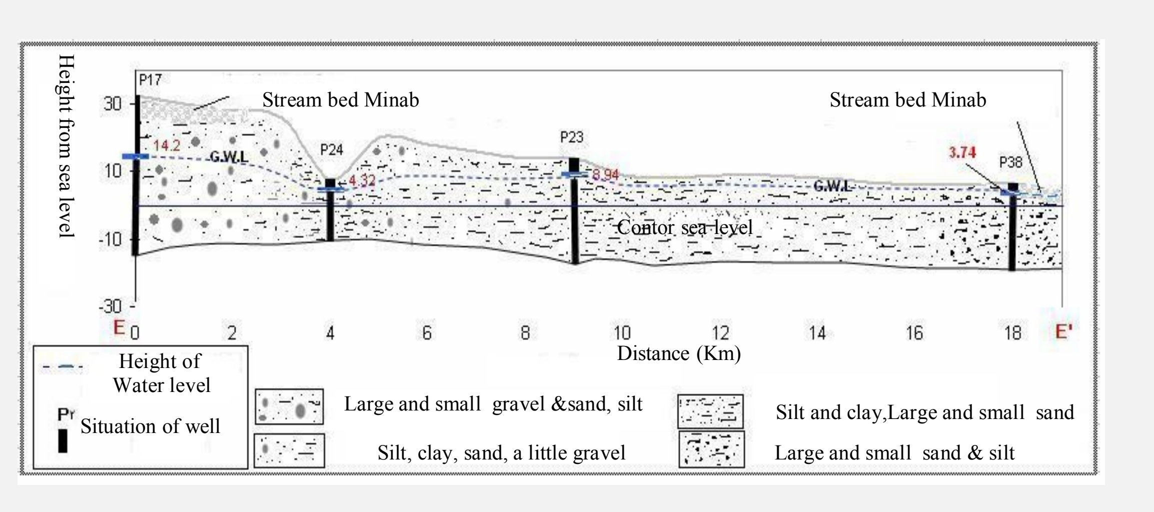

Figure 9. Cross section E – E: Geological Cross section of dug pits using physical method

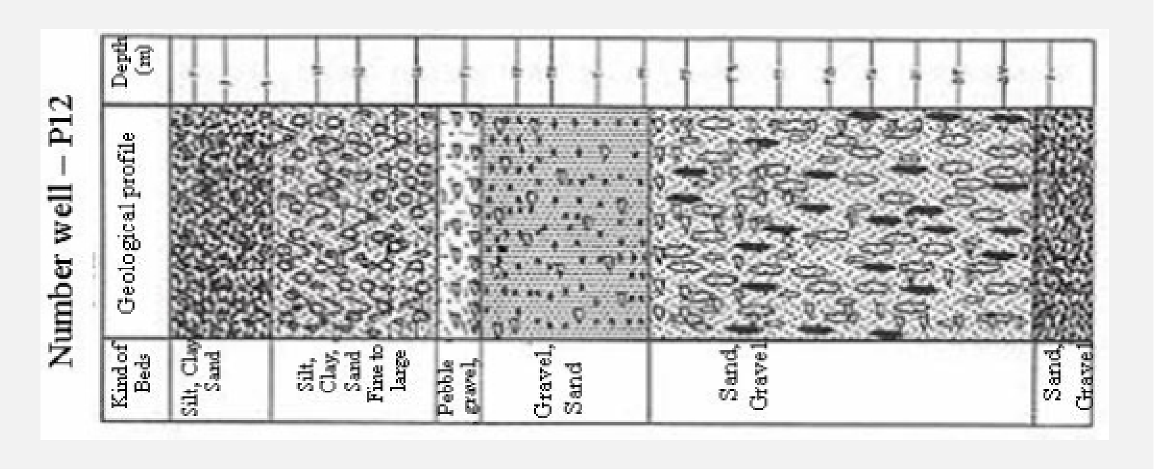

Figure 10. The column of stratigraphy 1, the exploratory well of internal delta (subsided area) (p21)

In summary, it can be said that, with increasing depth, the deposits became smaller and the content increased. This situation has occurred in a deep well of Nakhl Ebrahimi, where water reached a depth of 45 meters. The alluvium is quite fine grain (clay silt and a little sand) and water that flows at about 12 liters per second. Therefore the exploitation of the well and other artesian wells shows the existence of the water table under pressure at central and southeastern areas regarding the features of a deep controlled well near the river in these areas is made up mostly of large grain, rubble, stone gravel and sand. The depth of the well is 85 meters and the contact level for pit water is around 20 meters.

C) Studying the subsurface waters of Minab plain

The cycle and regiment of an area of precipitation affects the annual water source of underground water in the Minab plain. But the effect only takes place after a two or three month delay; this means that the rainfall maximum is received in January and February the maximum of subsurface water level occurs in April and May. In rainy years, in which there is higher level precipitation, it was observed that the hot season began with a delay of the highest level of underground water in Minab plain in September and October. This is an important factor concerning extracting the water from wells in the studied area.

Wells: Based on updates of Hormozgan Areas Water Company (2003-2004), 1268 wells were dug in the Minab plain, 793 of which were active since statistics were taken. Of these less than 2 percent were used for drinking, 3.15 percent for industrial uses and more than 94 percent for agriculture (such as irrigation for farms and gardens). Based on recent information the digging process in Minab plain was almost in balance before 2002 but, after that, it showed a sudden significant increase, so that in excess of 25 percent of all wells dug in the Minab had been dug after 2002. This indicated drought and cutting water from the canals of the Esteghlal

Dam (Fig. 11). Yearly extraction volumes from the updated statistics of the Hormozgan Areas Water Company were estimated at around 138 million m^3 per year.

The normal depth of pits was 27 meters, the deepest being 120 meters in the central zone and the least was 1 meter deep in the southern zone of the Banzerk-Kolgh Kashi area. According to the latest information from the Hormozgan Areas Water Company (AWC), the average depth of water level in the wells is 11.24 meters, and the highest recorded depth was 40 meters, located in the northern zone of Tiror and the least depth of water level is recorded as 0.3 meters in the southern zone of Sarbaran.

Study of the situation of underground waters in central area (subsided area)

This is an area of 174 km^2 of the central part of the Minab plain. All wells in this area are located on washed silt deposits and are densely distributed around the Minab River basin, wells in this area, based on updating information of AWC in Hormozgan Province include 607 wells of which 376 pits were dug since taking statistics. Because of recent drought and drying out of the irrigating canals of the Minab Dam, digging wells in this range since 2002 indicated increasing growth from previous years so that, from 607 pits dug since 1922 until 2007, more than 27 percent (or 164 wells) were dug in 2002 (Fig. 12). The average in the central section of the Minab plain is 27.6 meters and the maximum and minimum depths have been determined at 120 to 2 meters respectively.

According to wells observed (p16, p17, p18, p19, p21, p23, p24, p 25, p30, p31, p32) in the central area (Fig.7) the average height of subsurface water level in this section, based on updates of Hormozgan AWC, was estimated to be about 8/83 meters from sea level and the amount of yearly variation for under ground water level from1997 to 2007 is correlated with an increase in wells dug due to drought that exceeded the normal level of subsurface water in the area (Fig. 13).

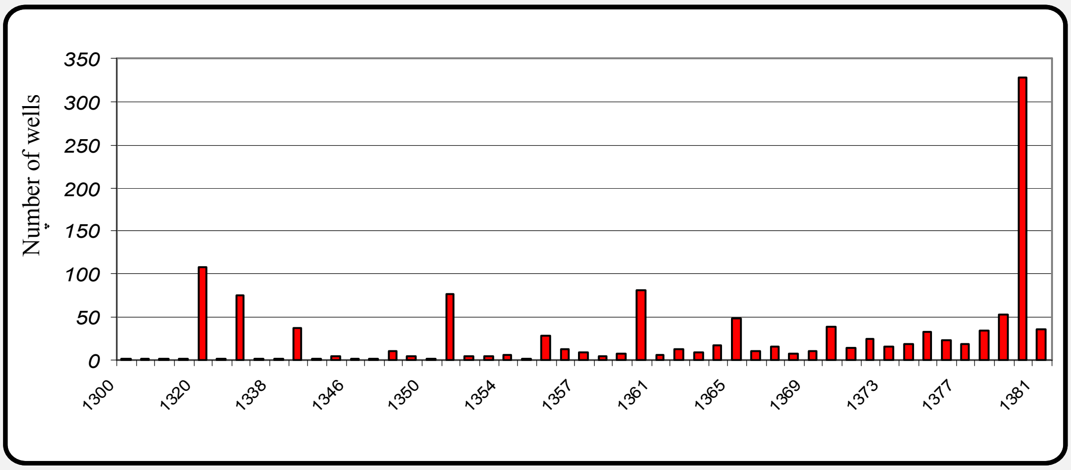

Figure 11. Total numbers of digging wells in Minab plain based on digging year

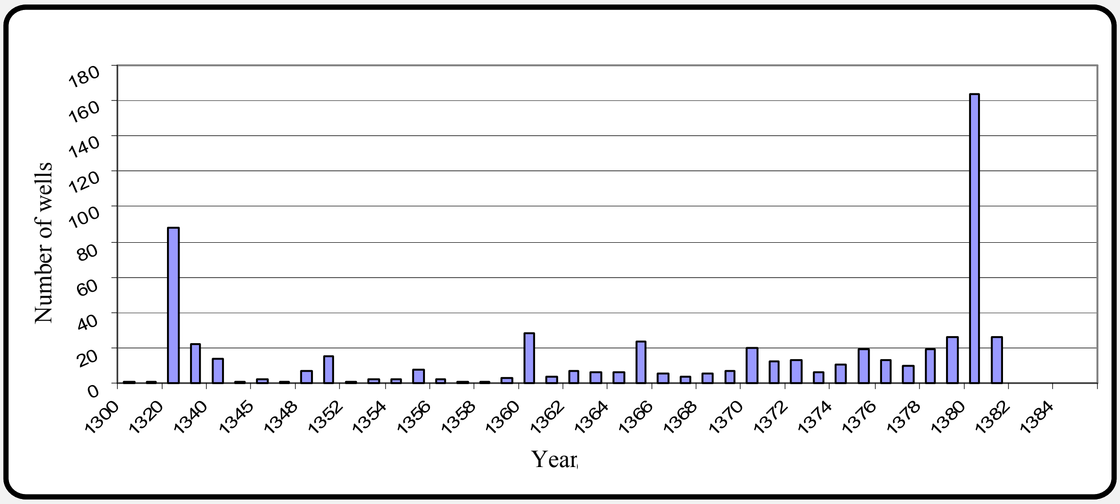

Figure 12. Dug wells based on digging year in central area of Minab plain.

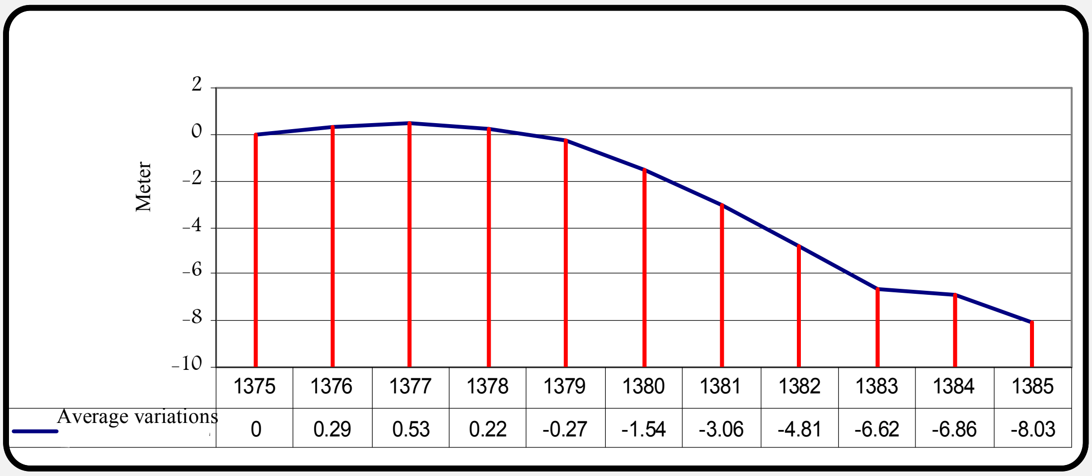

Figure 13. The average of yearly variations for height of water level in central area during 1997 to 2007

The mean depth of underground water level in central part of plain was estimated at around 10.64. Existing statistics show that the number of dug wells along with Minab River had higher water levels and these decreased with distance from the river.

Analyzing the situation of digging in central area of Minab plain

The mean depth of digging in the central area of the Minab plain was around 28.6 meters. These numbers indicate that most pressure of exploitation for under ground waters of Minab plain was from the northern and central areas with 396 and 376 active wells, respectively. However, the highest level of decline of the subsurface water level (8.03) was in the central area.

Considering the volume of water which had flowed to the irrigated canals only for farming over a ten year statistical period (1996-2007) it had a descending trend from the primary statistical period to the end of statistical course and this suggested that it was to compensate for the shortage of surface water used in farming. Based on recent information, after the advent of the drought phenomenon, digging wells showed a rising trend in all areas of the Minab plain so that the amount of exploitation of underground water for use in agriculture reached an excess of 94 percent since 2002, and just 6 percent remained for other uses such as drinking water and industrial use.

Situation of subsurface water level in Minab plain

Generally, most of the numbers on the contour line for underground water were 23 meters from sea level in the central area. On average, in villages including Dehvasati, Nasiraie and Cholo Gavmishi, because of drought, less nourishment and increased water extraction from wells of the area, the subsurface water-table significantly declined and caused a hydraulic depth line. In addition, exploited water from this area was used for irrigating gardens and farmlands located in the South of the plain and some part of it affected these areas again. This phenomenon has increased the difference of underground water levels in exploited and farm zones and made reversed plowing.

Hydrograph indicates water table of Minab plain

Since April 1987, after digging wells and completing monthly behavior net measurements, the hydrographic unit was mapped continuously and regularly. The number of observed pits in recent measuring behavior is 48 wells of which 39 pits have completed statistics; the Tisin net area is 655.885km^2.

In a current study, a hydrograph has been mapped for a 10 year balanced plain unit to sheet period (1997-1998 to 2006-2007) (Fig. 14). Because of a decreasing volume of atmospheric precipitation which, in spite of fluctuating levels of rainfall, there was a significant declining process overall and winter precipitation in the years 1998-19997 and 2005-2006 with 461.7 and 366.9, respectively (recorded at Minab synoptic station). These were greater than the yearly precipitation mean (187.3) rainfall without having any affect on the descending process of the hydrograph. During these times the subsurface water level decreased to 12.58 meters above sea level in April in the year 1997-1998 and to 6/89 meters in November during 2007-2008. It meant that the ground water level lowered by 5.69 meters.

Winter precipitation in 1998-1999 exceeded 461 millimeters, approximately 2.5 more than the average of yearly precipitation on plain surface. This led to a rising level of water to 13.03 meters above sea level in April of the same year. From that time, until the end of the year 2000-2001 because of the continuing effect from the last year, the hydrographic process shows a lower decrease at the beginning of the year 2001-2002, in spite of atmospheric precipitation higher than the yearly average on plain in the same year. Because of subsequent repeated drought and increase in the extraction from the wells and the closure of the irrigated canals towards Minab Dam, the descending trend was more severe and this pattern continued to the end of the balance sheet period. The height of the water level declined less than 7 meters which means a 0.57 meter decrease in water level.

The amount of yearly rainfall during the 6 year period from the beginning of the year 2001-2002 till November 2007-2008 was equal to 0.88 meters and more than 1.6 over a 10 year course, which results from recent drought and continuing exploitation in excess of the capacity of the regional water table and closure of the irrigation canals.

D) Documents of subsidence and causes of subsidence in area

Ground subsidence is observed in two manners.

1. Ground subsidence and gaps and the creation of Cavities: Some subsidence and gaps were observed in a range of about 100 meters wide and 1 kilometer in length with 1.5 kilometer space in the East and South of Cholo Gavmishi village (Fig.1). Older subsidence had occurred nearly 3 to 4 meters below the surface and the newer sinking was evident alongside areas of prior subsidence as deep perpendicular gaps (similar to ploughing), they appear as crushed shapes (Figs. 15 and 16).

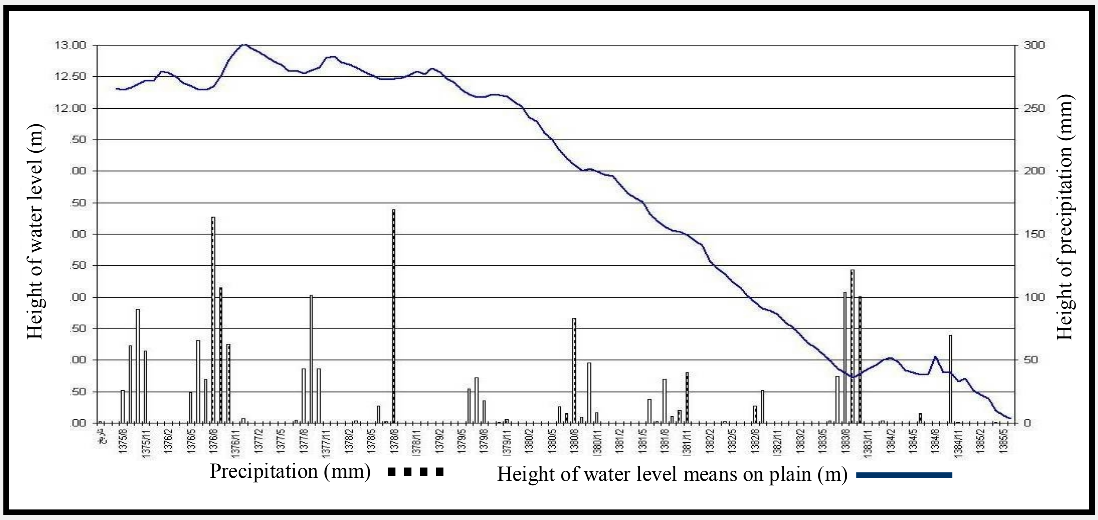

Figure 14. Hydrograph of plain unit for 10 year balance sheet period (1997-2007).

2- Porosity of the earth and the creation of sinkholes: Other documents have reported a lowering of the water table to affect the porosity of the ground. Increasing the number of wells in the Minab plain particularly since 2001 and the dried up irrigation canals of the Minab Dam have resulted in drying up much of the surface water and declining levels of water in the pits. This

Figure16. Existed longitudinal gaps in both sides of subsidence.

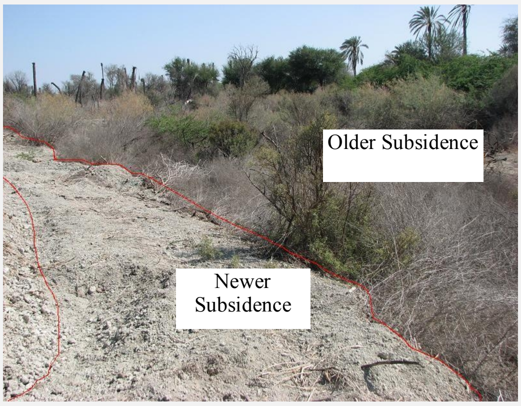

Figure 15. Range subsiding to the left.

remaining pit water does not have enough efficiency. 1 kilometer Northeast of Cholo Gavmishi village and not far from areas of prior subsidence with geographical coordinates: 56º 59′ 21″ E and 27º 8′ 32″ N. The surface of the ground, as a result of the falling water level, has become full of holes which are called porous (Figs. 17 and 18). Water used for farming penetrates the holes and significantly decreases irrigation efficiency.

Discussion

Considering the causes of subsidence in the studied region

As mentioned before and according to maps and statistics from Hormozgan AWC, there were more than 607 wells in the central region of the Minab plain, with the distribution of the wells showing a higher density surrounding the Minab River. However, according to the map (Fig. 1) and the situation plan of pizometric wells on the

Figures 17 and 18: Existing porous which are similar to holes whith more than 1 meter depth.

plain, this range has been located among wells, numbers, 23, 25 and 33 and among villages: Cholo Gavmishi, Nasiraie and Goorzung. The highest density of wells for exploiting water was in the eastern part of this region and in particular around the Minab River, and the range of subsided ground was about 4 km to the West of the Minab River.

The above wells had the highest decline at the central region during 1997 till 2007, so that of the pizometric wells, 25 and 33 recorded more than a 17.56 and 17.74 meter drop in levels of subsurface water (Table 2 and Figure 19).

As a result, at the end of the balance sheet period the level of water was more than three meters below sea level and the highest decline correlated to increasing numbers of dug wells in the range and dried up irrigated canals of the Minab River since 2001. However in pizometric well number 23, this level of decline was due to a lower density of pits in the area that reached 5.13 meters. So it would be expected that, according to recent information, the greatest amount of subsidence was in the above range.

It can be noted that this phenomenon has occurred in the region and the surrounding area. However, due to the extent of the area and the existence of gardens and plant cover that require high costs, there wasn't the possibility to consider the whole area and, of course, it is necessary to undertake accurate research in the area. But, increasing exploitation of the

Table 2. Variations of subsurface water level in November at pizometric wells 23, 25 and 33 during balance sheet period.

Pizometric well number	**P23**		**P25**		**P33**	
Month / Year	Depth of water level in November	Height from sea level	Depth of water level in November	Height from sea level	Depth of water level in November	Height from sea level
The amount of depression for water level during 1997 – 2007	5.13	-5.13	17.56	-17.56	17.74	-17.74

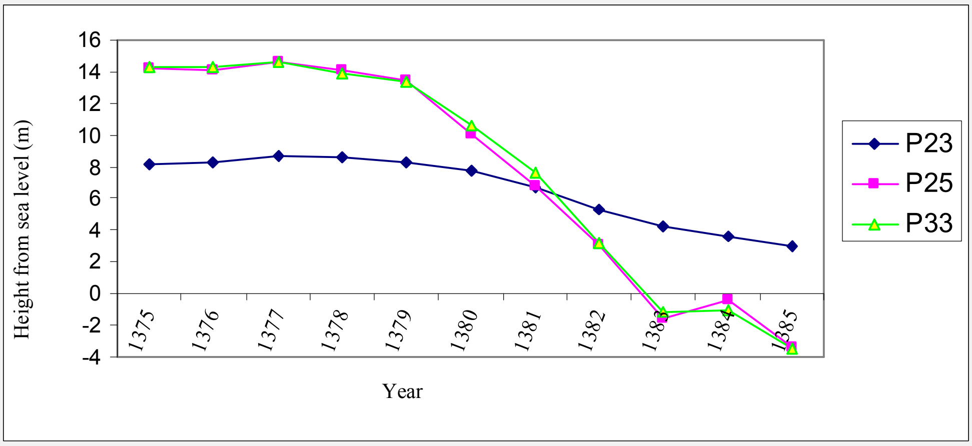

Figure 19. Variation of underground water level in November at pizometric 23, 25 and 33 during a 10 year period (1997-2007).

subsurface water level, and even continuing the current rate of water exploitation, can result in permanent elimination of absorbability from the water table. In addition to the drying out of the farmland and gardens because of a decreasing water table level and exploitation of the underground water resource, damage to buildings and technical structures in the region can also occur. So that, sudden subsidence of the ground can ruin rural buildings and the existing roads face a danger of subsidence and even it may expose people to threat.

Conclusion

One of most important natural factors in the acceleration and creation of subsidence and making sinkholes in the area is variation in the underground water level, finally establishing a continual imbalance between vertical stress and prevented forces in the soil. The continuation of this process causes the development of holes in the alluvium mass in both vertical and horizontal directions. Effective factors are transferring the tenacity resistance materials, moisture and thickness (diameter) of components and the dimensions of splits and holes in the parent rock. Contingent extended factors include the speed of water flow into the soil, the rock head and the thickness of materials.

Heidari *et al.*, (2011) proposed that in Hamedan the sinkholes developed in groundwater discharge areas near the base of karstic Oligo-Miocene limestone zones with major groundwater circulation. Results of Dolores Fidelibus (2011) show that a tight spatial correlation between the sinkholes and the canal reveals that the subsidence phenomenon has been induced by local hydrogeological change caused by canals in the coastal evaporite aquifer. The results of Doğan and Yılmaz (2011) show that the formation of sinkholes was triggered by a combination of natural and human causes. Galve *et al.*, (2008) found that three types of sinkholes could be identified on the basis of their markedly different morphometry and geomorphic distribution: large subsidence depressions, large collapse sinkholes and small cover-collapse sinkholes.

In the Minab plain, according to subsurface maps and documents based on decreasing the underground water level as a result of drought and increasing exploitation which have caused ground subsidence, this can be described as follows:

- Omitting the strength of resistance to enter the ceiling of the holes into the rock head that previously had a water supply.
- Increasing the vertical velocity of underground water flow from the surface to deep inside the alluvium mass because of increasing hydraulic gradient in a vertical direction as a result of pizometric pressure variation.
- Increasing the extent of variation for underground water level which results in water flow on the rock head and causes draining of the upper alluvium mass.
- Creating a vertical nourishment phenomenon and easing vertical circulation from the surface to deep down and reaching to split and gap system and holes existed in the rock head (Parvizi, 2006).

Therefore, the basic factors relating to occurrences of subsidence are due to: the existing alluvium core with a variation in thickness of a maximum of 150 meters that includes generally fine grain silt – clay and silt – sandy soil; and increasing the flow depression of subsurface water level as a result of irregular extraction because of drought in the past two decades. In this area, because of a severe decline of water level, the hydraulic gradient has increased so that the water table system has become unstable. This fact results in decreasing water pressure to keep the weight of the upper layers and to increase the pressure entered on the fine grain stratum, so that the layers become less than the amount of influence and porosity. In addition, this fact causes an increase in the speed of subsurface water flow and washes away the small particles which results in the formation of holes (porosities) that contribute to occurrences of subsidence.

References

Abvarzan, Consultant Engineers (1994). Plan of Water Source and Aquifer Development, Minab, Esteghlal Dam Region, Geology Researches, Force Ministry Hormozgan. Areas Water Company, BandarAbas. Hormozgan

Abvarzan, Consultant Engineers (1994). Plan of Water Source and Aquifer Development, Minab, Esteghlal Dam Region, Hydrology Researches, Force Ministry Hormozgan. Areas Water Company, BandarAbas. Hormozgan

Aliyari, A.R. (2006). One Dimensioned Echoing of Vertical Electrical Sound Age Dates to Identify there Dimensioned Abnormal in Hamedan. Central Region, Conference to Study Sinkholes in Karasti Areas, Force Ministry and West Karst Organization for Studies and Researches. Kermansha, Iran

Anderson, M. P. and W.W. Woessner (1992). Applied groundwater modeling. Simulation of flow and adjective transport Department of geology and geophysics. University Wisconsin. Academic Press, San Diego.

Amiri, M (2006). The Effect of Solving Rock Head and Draining During the Accuracy of Hamedan Sinkholes, the Conference of Studying the Dangers of Sinkholes in Karesti Regions Force Ministry and West Karsts Organization for Studies and Researches, Kermansha, Iran

Cooke, R.U. and J.C. Doornkamp (1999). Geomorphology in Environmental Management, Translated by: Shapur Gudarzinejad, Tehran: SAMT publication.

Heydari , M.R., R. K. Gholam, and A.R. Taleb Beydokhti (2004). Considering Solvability the Carbonate Stones Around Hamedan Power Plant, Third Conference of Geology and Iran Environment, Boalisina University, Hamedan

Doğan, U. and M. Yılmaz (2011). Natural and induced sinkholes of the Obruk Plateau and

Karapınar-Hotamış Plain, Turkey Original Research Article *Journal of Asian Earth Sciences*, 40(2): 496-508.

Dolores Fidelibus, M. et al. (2011). Human-induced hydrogeological changes and sinkholes in the coastal gypsum karst of Lesina Marina area (Foggia Province, Italy), *Engineering Geology*, 118(1-2): 1-19.

Galve, J.P. et al. (2008). Development and validation of sinkhole susceptibility models in mantled karst settings. A case study from the Ebro valley evaporite karst (NE Spain), *Engineering Geology*, 99(3-4): 185-197.

Heidari, M. et al. (2011). The formation of cover collapse sinkholes in North of Hamedan, Iran Geomorphology, 132(3-4): 76-86.

Hossainipoor Kooveei, H. (2000). Water Quality Analysis of the Sarchahan Plain Aquifer, Hormozgan, Iran, MSc. Thesis in Water Resources, ITC, the Netherlands.

Khanlari, G.R (2006). Methods to Study Sinkholes and Identifying Effective Factors on their Behaviors, Conference to Study the Dangers of Sinkholes in Karsts Areas, Force Ministry. West Karest Organizations for Studies and Researches, Kermansha, Iran.

Karimi, H (2006). Formation Way of subsided Sinkholes in Jaber Dareh Plain, Ilam Province, Conference to Study the Dangers of Sinkholes in Karsts Areas, Force Ministry. West Karest Organizations for Studies and Researches, Kermansha, Iran

Mahboobi Ardakani, A.R., and S.A. Hashemi (2006). Considering Causes of General Ground Subsidence and Sinking Wells in Famenin Plain with Special Attitude on Situation of Shahid Mofateh Power Plant, Conference to Study the Dangers of Sinkholes in Karsts Areas, Force Ministry. West Karest Organizations for Studies and Researches, Kermansha, Iran

Naseri, H. R. (2006). Overview on Subsidence Phenomenon and Sinkholes in Hamedan Famenin Plain, Conference to Study the Dangers of Sinkholes in Karsts Areas, Force Ministry. West Karest Organizations for Studies and Researches, Kermansha, Iran.

Noohi, K. and A. Asgari (2006). Studying Droughts and Periods to Come Back the Rain Days and Droughts in Ghom Region, *Agriculture Drying and Drought Magazine*, 15: 17-28.

Parvizi, F (2006). Identifying the Sinkholes Phenomenon and Subsiding the Lands of Kaboodar Ahang, Hamedan Famenin Plains, Conference to Study the Dangers of Sinkholes in Karsts Areas, Force Ministry. West Karest Organizations for Studies and Researches, Kermansha, Iran.

Pewe, T.L. (1990). Land subsidence and earth fissure formation in Arizona caused by groundwater withdrawal: A review, *in* Higgins, C.G., and Coates, D.R, Groundwater geomorphology-the role of subsurface water in earth-surface processes and landforms: *Geological Society of America Special Paper*, 252: 219-233.

Saadati, G., and B. Mohamadi (2004). Tectonically Situation of Subsided holes in Hamedan, Central Plain Third Conference of Geology and Iran Environment, Boalisina University, Hamedan

Safdari, A. A., and et al(2004). Area Classifying for Severe Drought in Karon Region with the Assistance of SPI Index in GIS Space, *Magazine of Drying Down and Drought Agriculture*, 7: 45-61.

Sanayie, M. A. (2006). Studying the Exploitation of Under Ground Water Sources and Causes and Side Accidents of Subsidence Phenomenon and Making Sinkholes in Hamedan Plains, Conference to Study the Dangers of Sinkholes in Karsts Areas, Force Ministry. West Karest Organizations for Studies and Researches, Kermansha, Iran.

Shirmohamadi, R. and colleagues (2004). SPI Application to Consider Space and Time Drought Patterns and Begging the Criticize of Raining in Khorasan. *Scientific Bulletin of Climatology Institute*, 3(4): 154-161.

Waltham, T. *et al.* (1989). Ground Subsidence , karst and cavernous rocks in engineering and construction, Blackie, Glasgow, Springer.

Wilson, W.L. and B.F. Beck (1992). Hydrogeologic Factors Affecting New Sinkhole Development in the Orlando Area , *Florida,Ground Water*, 30: 918–930.