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ORIGINAL RESEARCH PAPER

Modeling and zoning of land subsidence in the southwest of Tehran using artificial neural networks

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ABSTRACT: The earth's surface, due to its natural conditions and its structure is always changing and reshaping. One of the created deformations is the land subsidence. This is the most dangerous events which can be seen in most urban areas especially in the agricultural plains today. This study aims at zoning land subsidence and recognition of geometrical factors in southwest of Tehran. To estimate and predict land subsidence, all the effective subsidence factors were identified. Among the factors, nine most important factors including, downfall of groundwater, thickness of clay, depth of groundwater, annual discharge of water from wells, the distance of well to each other, slop, elevation, land use and geology were evaluated. Ultimately, three variables were selected as the most important variables. For modeling and zoning these factors, artificial neural network using Matlab software and Arc-GIS software for creating primary layers were used. The results indicate that the main cause of subsidence is excessive removal of underground water resources. Since the use of water resources in agriculture is accounted for the highest percentage of consumption and also because a large part of the study area have an agriculture land use, therefore the underground water drop and agricultural land uses are the most susceptible areas of land subsidence occurrence.

KEYWORDS: *Artificial neural networks; Geomorphological components; Land use planning; Subsidence; Tehran*

INTRODUCTION

Study of natural hazards in urban areas is of great importance. Urban areas need to recognize the geomorphology and climate- control of environment (Maquaire *et al*., 2009), due to Population growth and expansion of urban areas which led to use water resources and increasing of underground water harvesting (Xue *et al*., 2005; Phien-Wej *et al*., 2006). By reducing surface water, people tried to seek ways to exploit underground water. As a result of insufficient attention to the manner of the revitalization of the underground water reservoir, people try to extract these underground vital resources (Zektser and Lorne, 2004). One of the major causes of this problem is human negligence and their insufficient knowledge in groundwater extraction (Shemshaki, 2005). Southwest of Tehran is a part of plain of Tehran-Shahriar which include low land slope up to quite smooth with fine sediment and impermeable texture. Increased construction and population expansion and also excessive removal of underground water supplies, resulted lowering the water level and consequently led to land subsidence (Sun *et al*., 1999; Hu *et al*., 2004; Teatini *et al*., 2006).

The destruction of bridges, roads, marine structures and municipal facilities and etc., are some of the damages which are caused by land subsidence (Pakravan, 2007). From 1925 onwards, many land subsidence around the

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world have been studied and evaluated (Jakson *et al*., 2004). Bouwer (1977) performed a study on land subsidence due to groundwater extraction and presented a report associated with this phenomenon which clarified the relationship between pumping the water level and land subsidence. In different reports, Hultberg (2000) from American Society of Geological Organization studied the geological phenomenon of subsidence as well as different tools and methods of measurement in Texas, America.

Wolkersdorfer and Thiem (1999) examined land subsidence in the northeast of Saxony and by comparing other land subsidence around the world stated the ratio of subsidence to the decline level of groundwater levels up to 9% in the world. Wei (2006) has investigated the subsidence in Shanghai- China, and found the land subsidence in this area a very serious threat to urban structures. In his study, he confirmed that the reduction of exploitation of groundwater is the only way to stop land subsidence.

Galloway (2000) from UNESCO tried to introduce the case studies from around the world about the land subsidence. Forester (2006) with the use of interferometric method and Radar Images estimated the subsidence in south west Otaha and has compared three regions which had the highest subsidence.

Chatterjee *et al.* (2007) have used the Based Location Technique to measure land subsidence and method of difference and combination of Interferometry Radar (Radar Interference measurement) technique in the city of Calcutta in India. In Iran, several cases of subsidence have been reported. In Iran and in areas such as, Mashhad, Iranshahr, Zararnd-krman, Rafsanjan, Mahyar, Mobarake, Golpayegan, Ardakan, Yazd, Hamedan, Nazarabad, Arak, Nahavand, Natanz and other places land subsidence have been reported (Morseli, 2008).

Tabatabaei Aghda and Mohseni Nasb (2015) reported that in addition to underground water harvesting, tectonic factors are also counted among the main causes of subsidence in Rafsanjan plain And he strongly believes that this factors should not be overlooked. Mosavi (2003) conducted a full review in Rafsanjan plain land subsidence using global position in system (GPS) for estimation of subsidence in this area. Bani Asadi (2007) performed modeling of subsidence in Kerman Plain. Morseli (2008) in his thesis, investigated the land subsidence due to groundwater levels drop in the plains of Varamin's. Akbari studied the land subsidence caused by the extraction of groundwater in the plain of Mashhad Using Time Series Radar Interferometry technique and compared the geodetic observations (Akbari *et al*., 2009). Alipour (2007) also studied the land subsidence with Radar Interferometry method. There are several methods for monitoring land subsidence.

Given the above background, the purpose of this research is modeling and mapping of land subsidence. This study has been carried out in southwest of Tehran, capital of Iran during 2010 to 2011.

Study area

The study area is located in southwestern city of Tehran-Iran. The geographical location of 35 degrees and 31 minutes to 35 degree and 41 minutes of north latitude and 50 degrees and 58 minutes to 51 degree and 22 minutes of the east longitude in the southern foothills of the Alborz mountain range in south-west of Tehran (Fig. 1).

According to the survey by National Geology organization, range lands in southwest of Tehran are located in Municipal areas of 16, 17, 18 and 19. These range lands are along the ring road of Tehran and between Azari to Azadegan highway with Ayatollah Saeedi intersection are faced with the problem of subsidence. Southwest of Tehran includes residential areas, too many farmlands and different industrial areas with semi-arid climate.

During 1991 to 2004, too many elevation impressions were made from different parts of southwest of Tehran. It is defined that these part of lands were experiencing subsidence during that period of time. Southwest of Tehran is located at the end of Tehran's plain. Among the prominent features of this area, it can be pointed out that the flat and low slope and sedimentary soil quality of large part of this area espacialy towards the south of region (Fine alluvial deposits) and also excessive harvesting of groundwater, land subsidence is considered one of the issues and crisis of these lands.

MATERIALS AND METHODS

In order to evaluate and estimate the amount of subsidence, 9 variables including: drop in groundwater, thickness of clay, land use, geology, groundwater depth elevation, slope and wells relative distance to each other and the annual discharge of water from wells, were used. For this purpose, the required maps for each of the criteria were developed in digital geographic

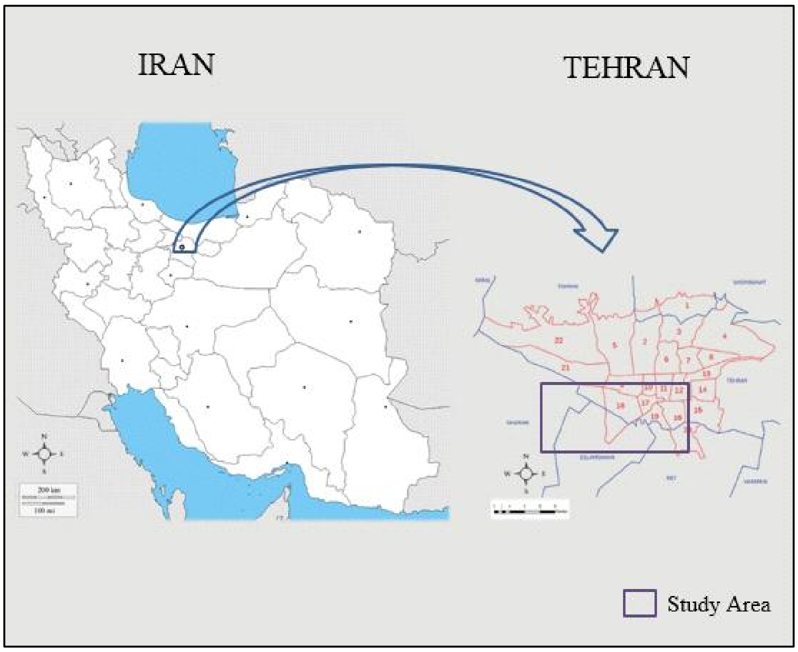

Fig. 1: Scope of Iran and Tehran Province

information systems. Data required for mapping criteria was received from various sources such as, library, field work, as well as information obtained from the National Geology organization and finally the required output map were extracted in Arc GIS software. Along with using Arc GIS software, a series of graphic work was done by Cad map software. Data related to wells were categorized in excel software and then into the GIS system. SPSS software was used for statistical analysis. The method of Artificial Neural Networks (ANN) will be used for zoning and modeling of land subsidence.

Artificial Neural Networks

Neural Networks can be called, with high tolerance, an electronic model of the human brain neural structure. Neural Networks is a network structure consisting of interconnected elements which are called Neurons and each Neuron has inputs and output and performs a relatively simple and local operation. Generally, Neural Networks learn their performance during a learning process. Essentially, learning and training of brain is based on experiences. Electronic model of natural neural networks are based on the same template and how such models deal with issues is different with computational methods that would normally have been taken by the computer system. It is known that even the simplest animal brains are able to solve problems that the computational methods do not reach the desired result for solving them. An Artificial Neural Network (ANN) is an idea for processing information which is inspired by biological nervous system and process the information just like the brain (Kumar, 2004). A key element of this idea is the new structure of information processing system. The system is composed of a large number of highly interconnected processing elements which act together to solve a problem. ANN's, like humans, learn by example. ANN is set for a specific task such as pattern recognition and classification of information, during a process of learning. Biological learning systems involve adjustments to the synaptic connections that exist between the associated neurons. This method is also known as ANN (Deb, 1999). The following properties characterize a neural network:

1) Network structure: manner of communication between neurons
2) Network training method: Determining the weights of neurons interface

3) Mobility function of each neuron

The neural network consists of small data processing components, called neurons or nodes or unit (Basheer and Hajmeer, 2000; Abraham, 2005). Each neuron is related to other neurons via a directional interface with its own weight. Weights are the representative of the information needed to solve a problem.

Neural networks can be used in various cases which include: Storage and data review, shapes groping, performing a general mapping of a set of input to a set of output, Grouping similar forms and optimization and determining the answer despite multiple constraints. Each neuron in a neural network has a certain status depending on the entries that are received.

For example, neuron γ shown in Fig. 2, receives data from neurons x_1, x_2, x_3, which the reply mobility (output answer) of these neurons are respectively x_1, x_2, x_3.

Weight connection between neurons x_1, x_2, x_3 and neuron γ respectively are w_1, w_2, w_3. Net input of y inputs to neuron γ are equal to the sum of weighted data from neurons y_1, y_2, y_3, which means that Y reply mobility relating to neuron y is expressed as function of net input of this neuron so that the Sigmoid stimulation function will be used in deterring of reply mobility of y (Picton, 2008).

y_i=Activation function

$$\sum_{j=i}^{n} W_{ij}$$

RESULTS AND DISCUSSION

According to the research and the important affecting variables gained on land subsidence in District 9, the factors with most influence on land subsidence were exerted and are followed in order of priority:

Rate of water loss

This variable was prepared by using data obtained from National Geology in Arc GIS environment. According to this map, district has a water drop between 49/72 to 7/74 meters.

Clay thickness

Another factor affecting the subsidence area is thickness of clay. And to achieve the importance of these variables on land subsidence, the thickness of the clay in the District was obtained and the related layer was built. According to the resulting map, the minimum and maximum thickness of clay was between 36/81 to 72/38 meters.

Annual discharge of water from wells in the area

The third considered factor is Annual discharge of water from wells in the District. Data on these variables was extracted from the information received from Tehran Regional Water Organization and the relating layer was made in Arc GIS environment. The minimum and maximum water withdrawals from wells in the area

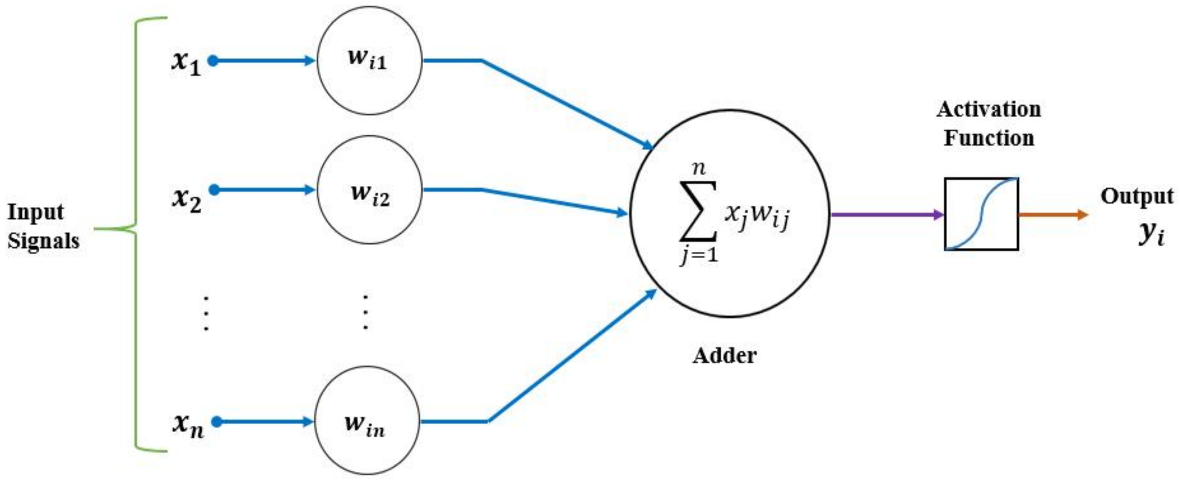

Fig. 2: Structure of an artificial neuron

are between 31 cubic meters to 2 million cubic meters per year.

Depth of groundwater

This map was calculated based on the accounts of information on the earth's surface to the groundwater level and then by subtracting the obtained number from the height of the area, the desired layer was created by entering the result of the difference into Arc GIS Software. The minimum and maximum water depth was between 0 and 114/142 meters.

Slop

Slop was introduced as one of the variables used in the model. The study area is in a flat and low slope and the minimum and maximum slope is between 0 to 4/88 degrees.

Height

Height was the next variable used in the model. The relating map of this variable was made based on the topographic map of the area. The Minimum and maximum height were between 1044 to 1278 meters.

Geology

Type of geological structure of the area or in other words, the type of sediments is also another significant variable which affects the land subsidence. Overall deposits of this area are composed of three types of young alluvial, old alluvial terraces and new alluvial terraces.

Wells distance to each other

The map relating to this variable was made in Arc GIS environment using data of wells position in the area. The minimum and maximum distances between the wells were 14/78 to 6900/04 meters.

Land use

Based on aerial map of the area, the relating land use map was made in the Cad map environment. Generally, the study area is divided into built-up and agricultural areas (Municipal and industrial).

The current subsidence

Land subsidence was used as the dependent variable in the model. This variable is based on field observations which were conducted by the National Geological Organization and also the field data obtained by the GPS device. Based on observations, the maximum amount of subsidence in the area was 16 cm which was seen mostly in the South and South West area. After calculation and some correction on these data the map was built in GIS environment (Fig. 3).

A dbf file was created from every obtained map in Arc GIS environment and then entered into SPSS environment and finely were prepared to transfer into MATLAB environment (Kia, 2014).

Nine intended variables introduced as input to the model and this environment chose and introduced a number of data as the random number data as the train data (including 70% of data) and a number of others as a test data (including 30% of data). Finally land

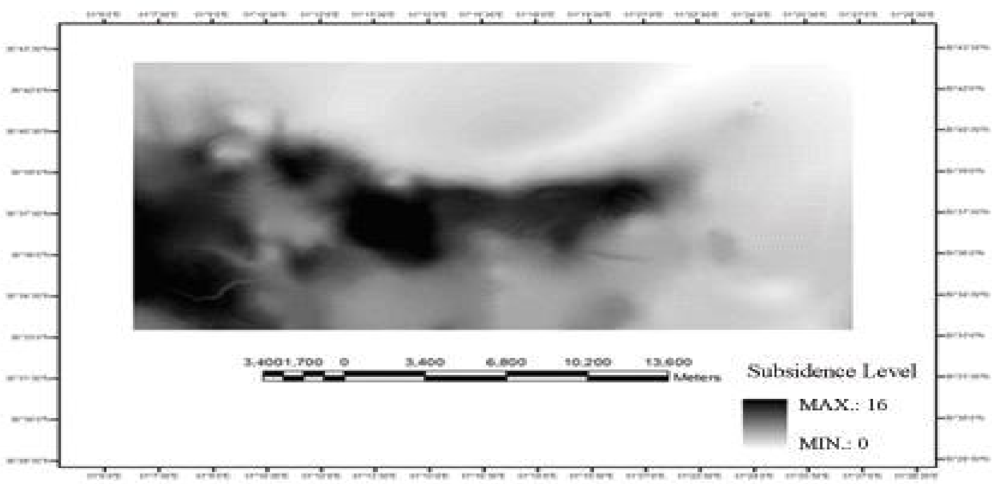

Fig 3: Subsidence spectral existing map

subsidence was introduced as a goal. Then, according to the given statistics, based on the Feed Forward Back Propagation (FFBP) the network carried out the modeling with four different architectural. Among these architectures a grid showing the highest correlation, was selected as the optimal network and the output map was designed based on this architecture. The inputs of the model include 9 input variables and 54 360 records from each element and objective data (land subsidence). Fig. 4 shows the FFBP network.

Implemented model based on fourth architecture

Optimized architecture is based on two hidden layers, 50 hidden neurons and 9 inputs. The Model Run time was 40 minutes and 25 seconds based on fourth architecture. The correlation for training data was 0/94 and 0/93 for test data and the validation0/93 and 0/94 for all data as shown in Fig. 5.

According to different architecture that was based on FFBP model, a network that showed the highest correlation, was selected as the optimal network.

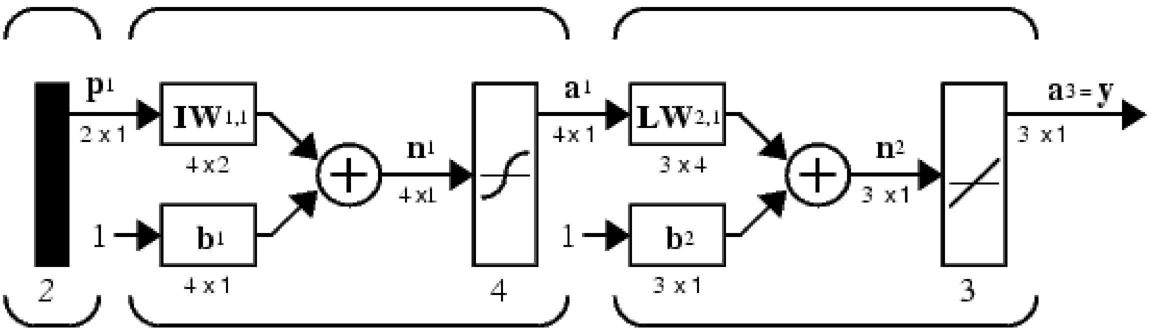

Fig. 4: The structure of the neural network FFBP

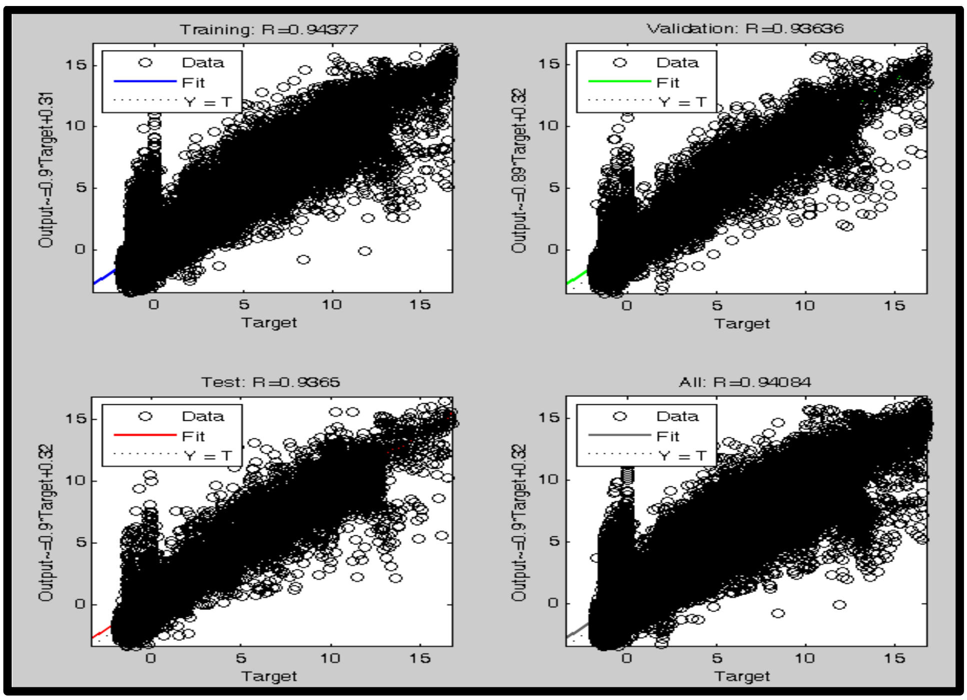

Fig. 5: Implementation of FFBP model based on third architecture

Between four implemented architecture, the best chosen architecture was architecture 2-50-50-9 with the 0/94 of Correlation.

In Table 1, the different architectures which were used to implement the Model are presented with their correlation.

Based on running the Model in the neural network and according to the best neural network architecture, a final map in GIS environment was designed and built based on natural fractures (Fig. 6). As seen in the map spectral output model, the minimum and maximum subsidence is between 0 and 16.

Land subsidence or gradual ground subsidence may arise as a result of various factors. One of the most important and effective factors is the excessive removal of underground water resources and reduced levels of aquifers in areas affected by subsidence.

Another important factor is the thickness and type of sediment which affects the intensity of this phenomenon.

Table 1: The correlation of different network architecture

Architecture	The correlations of neural network model forecast maps		
	The correlation coefficient (r)		Network training time (min.)
	Training data	Test data	
2-10-10-9	0/81	0/80	15/56
2-20-20-9	0/86	0/84	25/33
2-40-40-9	0/81	0/80	31/15
2-50-50-9	0/94	0/93	40/25

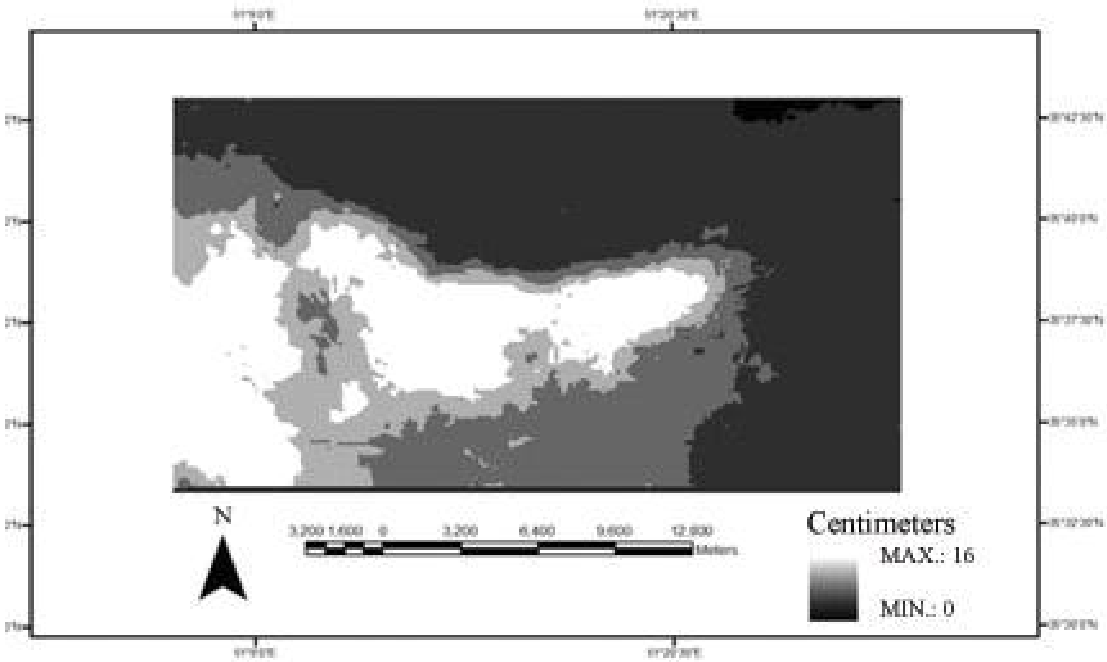

Fig. 6: Spectral map of implementation of the model

Anyhow, land subsidence is one of the major topics which engage most of the urban, industrial and agricultural area nowadays. As it is observed in the map 5, the most subsidence with 16 centimeter in depth is in the predicted range of southwest and west which is shown with bright color. The subsidence in this area is divided to 5 levels of very low, Low, medium, high and very high subsidence. An area with very low subsidence, 77% and an area with very high subsidence, 20 % had covered the total targeted area. Table 2 and Fig. 7 show the amount of subsidence associated with each level. According to the conducted studies and the results obtained, the most important factors that influence land subsidence has been identified and were compared with the output map of model implementation and a graph was prepared for each of them in which the correlation of each variable with the predicted land subsidence is showed. Comparison of subsidence with the drop in groundwater: The obtained R was 0/82 which shows a strong and significant correlation between subsidence and groundwater loss.

Table 2: Information related to Model output map

Levels	Rate of subsidence (Meter)	Area (Hectare)	Area (%)
1	0 to 1	0000/423	0/77
2	1 to 4	0000/26526	48/73
3	4 to 8	0000/9648	17/72
4	8 to 12	0000/6836	12/56
5	12 to 16	0000/10927	20/07
Total	-	0901/54424	100

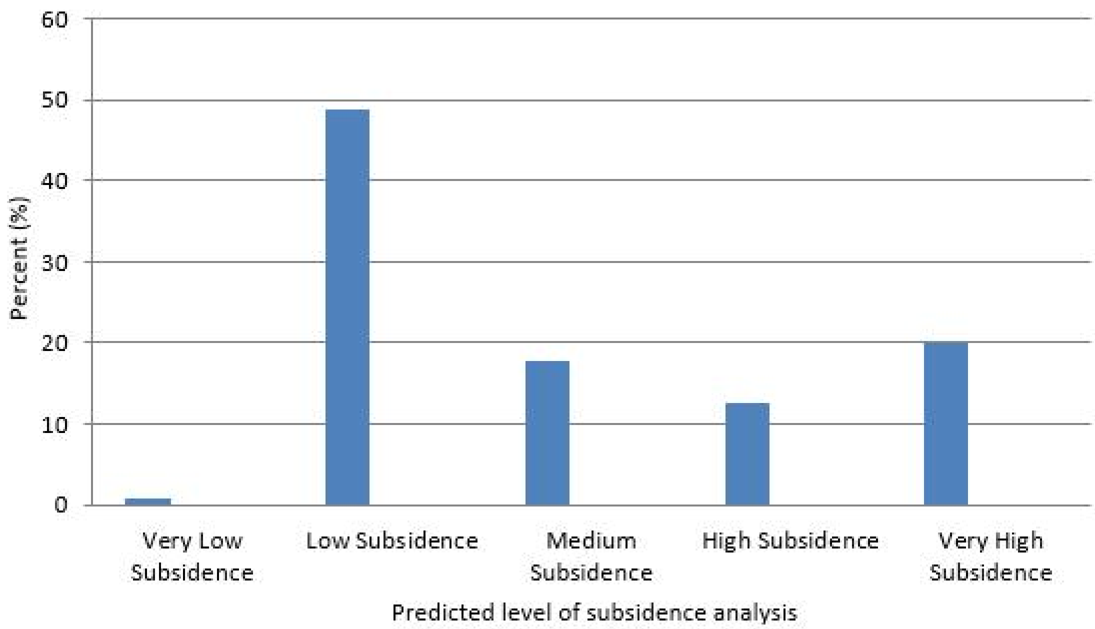

Fig. 7: The area relating to level of predicted subsidence

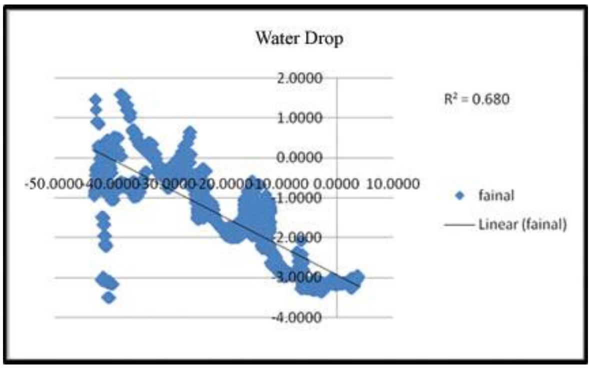

Fig. 8: Correlation Chart between the amounts of subsidence in the predicted model with the drop of groundwater in the area

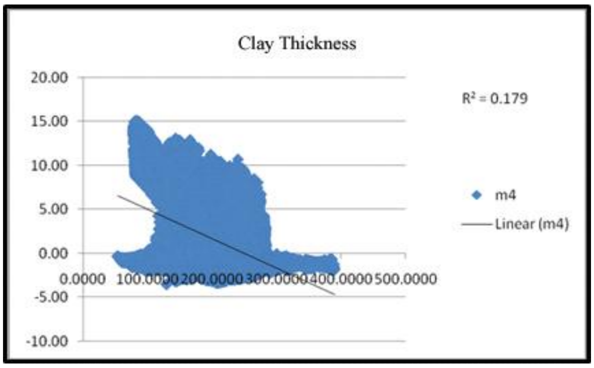

Fig. 9: Chart correlation between the subsidence in the predicted model and thickness of clay

Comparison of these two variables is the reason to confirm the effects of excessive groundwater withdrawal and the water drop on the subsidence phenomena. Fig. 8 shows the correlation.

Since the studied area is located in an area with agricultural, industrial and municipal use with the need of water, therefore the excessive groundwater extraction had caused land subsidence in some part of this area.

The study also showed that excessive withdrawal of groundwater is the major factor of land subsidence and the result can be observed from the obtained high correlation between land subsidence and groundwater drop.

Comparison of the land subsidence map with thickness of clay

The correlation between the predicted subsidence and the thickness of the clay in the area in SPSS environment indicated that obtained R is 0.41(Fig. 9).

This low correlation is the reason for the lack of a significant and strong relationship between these variables and the subsidence of the area.

As a result, it is confirmed that the thickness of the clay had no strong impact on land subsidence.The obtained correlation of 0.41 between area subsidence and thickness of clay confirms that clay thickening has no effect on land subsidence, while changes in groundwater level with correlation of 0.82 were identified as the main factor influencing subsidence.

Comparison of the rate of land subsidence and land use

To obtain the correlation between predicted land subsidences with land use, the data relating on these variables were converted to point file in the GIS environment, then the output was entered into SPSS environment the result of R was 0/60 which showed a meaningful relation with subsidence phenomenon.

As to prior information, most of the studied area is agricultural land and directly depending on water, whit the expansion of arable land, water withdrawals from various sources will be increased and results in water drop in the affected area. The results of the correlation between land subsidence and land use showed a significant relationship with this phenomenon in southwest of Tehran.

CONCLUSION

According to the performed study, to prevent and deal with land subsidence, different strategies have been proposed. The most important of these proposals are as follow:

- Monitoring, management and more inspections on the methods of withdrawal groundwater resources in sensitive municipal and agricultural areas
- Decreasing and stopping water pumping water in areas that is at risk of subsidence
- Invigoration of city lifeline in areas affected by subsidence
- Artificial water recharge of underground aquifer to raise the Piezometric water level
- Public awareness in proper utilization of water from groundwater resources in urban areas
- Limiting the amount of water taken from underground sources and preventing illegal construction and digging wells
- Change in the pattern of water use in agriculture and industry sectors

- Conduction research projects and monitoring the incidence and prediction of subsidence
- Using remote sensing system and satellite imagery to identify areas where subsidence happened in order to prevent the progression of this phenomenon in sensitive areas

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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