Research Journal of

Environmental Sciences

ISSN 1819-3412

Academic
Journals Inc.

www.academicjournals.com

Research Journal of Environmental Sciences 6 (4): 146-155, 2012
ISSN 1819-3412 / DOI: 10.3923/rjes.2012.146.155

Subsidence Hazard Map in Sirjan Well Field

[1]Arash Ziaie, [2]Kaveh Kumarci and [1]Alireza Ghanizadeh
[1]Sirjan Industrial University, Civil Engineering College, First Kilometer of Baft Road, P.O. Box 78185439, Sirjan, Iran
[2]Sama Technical and Vocational Training College, Islamic Azad University, Shahrekord Branch, Shahrekord, Iran

Corresponding Author: Arash Ziaie, Sirjan Industrial University, Civil Engineering College, First Kilometer of Baft Road, P.O. Box 78185439, Sirjan, Iran Tel: 009803454220076

ABSTRACT
Withdrawal of oil, gas and water from underground reservoirs; dissolution of limestone aquifers; underground mining activities; drainage of organic soils and hydro compaction are some example of the mechanisms by which earth deformation can occur. A decrease in any under ground liquid and gas pressure, will causes an increase in effective stresses at clay layers which results the consolidation of lower soil layers and it will cause subsidence, earth fissures and other kind of land settling phenomenon. Modeling of this behavior is possible using finite element technique and the related computer software. Theoretical amount of land subsidence in different points of Sirjan well field are achieved and after adopting with field data, turned to a subsidence hazard map in this paper.

Key words: Subsidence, ground water, consolidation, withdrawal, WTAQ

INTRODUCTION
Nowadays nature is more interfered by human mostly because of industrial needs of his life such as removal of oil, gas and water from underground reservoirs, also other underground mining activities; dissolution of limestone aquifers and hydro compaction of dry soils. More interfere the nature, more undesirable influences (such as subsidence, earth fissures and sinkholes) will appear (Fig. 1-4). Land subsidence is setteling of the land surface due to removal of subsurface support. This phenomenon may cause earth fissures, collapse of infrastructures, change flood patterns, break pipes and lines and also it may cause the contamination of ground water (Sahuguillo *et al.*, 2005), also detrimental of canals, levees and dams may been accrued due to intersecting of the resulted earth fissures and these structures. Coastal subsidence is a kind of important problems which may accrue in coastal regions such as Long Beach in United States, California, the greater Houston, Texas, metropolitan region and Santa Clara Valley, California Holzer and Galloway (2005). In these areas flooding causes either permanent submergence or more frequent flooding. There are so many examples of notable subsidence and its secondary effects due to extensive ground-water pumping in different parts of the word, such as: southwestern United States, (Leake *et al.*, 1995), Bangkok, (Phien-Wej *et al.*, 2006) and AntelopValley, California (Ikehara, 1995).

Having a semi-dry climate, Iran, is also one of these arias especially in its desert provinces such as Yazd and Kerman. Sirjan, a city in western south of Kerman which different land deformation

Fig. 1: Deformation in well field in Sirjan land

Fig. 2: Sinkhole in Sirjan welll field land

Fig. 3: Earth fissures in Sirjan (more than 1 km long)

Fig. 4: Sirjan earth fissures (more than 1 m width)

shapes in it are studied in this paper, is one of the most important areas that are suffering from earth subsidence and its destructive results. Field gathering data is compared with the numerical results of simulation models to confirm the findings also. Other studies in this area was conducted recently by the author to predict a model to simulate the future settlement of a single well under operation based on finite element formulation and also to predict the future fissures in Sirjan land (Ziaie and Rahnama, 2007; Ziaie *et al.*, 2009).

First steps of estimate the soil deformation is started more than seventy years ago, when Biot's consolidation theory (Biot, 1941) made it possible to calculate a three-dimensional consolidation value by its special assumptions and this study is continued by now. When the groundwater level decrease, pore-water pressure and inter granular stress of the porous-medium of soil will be decreased and it will appear as soil consolidation. This consolidation will be permanent and irreversible because of exceeding the yield strength of the granular skeleton of the media. These conditions may happen frequently for all aquifer systems in seasonal cycle of recharge and discharge and it will cause minor elastic (recoverable) expansion and compression and respective uplift and subsidence (on the order of millimeters to meters) of the land surface. To quantify this causality, an elastic-plastic consolidation deformation model was built and extended later (Amelung *et al.*, 1999; Hoffmann *et al.*, 2001; Bawden *et al.*, 2001; Lu and Danskin, 2001; Heywood, 1997; Heywood *et al.*, 2002).

Jacob (1940) derived the water supply of a pumping well in a confined aquifer systems which was related to the granular skeleton matrix. First evaluation of subsidence was delivered by Larson (1984), using the initial finding an assumptions of this field. In all of the compaction, consolidation and subsidence formulation, aquifer storability may be determined by related water, compressibility and porosity matrix. Elastic (recoverable) or inelastic (unrecoverable) compaction of an aquifer depends on the magnitude of the pressure change and stress history that occurs in aquifer due to groundwater drainage. Results also show the relationship between the stages of surface subsidence and the corresponding periods of groundwater level decrease.

Because the greatest amount of compaction of sediments and the resulted land subsidence and earth fissure occurs at this interval as the water level declines, the initial conditions are changed by time and it can causes a new phenomenon which called earth fissure. When this grate rates of subsidence accrue in the land of two neighboring area with different soil characteristics, for example different soil permeability, condition of bed rock or depth and other characteristics of the soil layers, the magnitude of land subsidence (that are functions of soil characteristics), differ from each other in these two neighboring areas. Theoretically at the sharing border of them two value of subsidence exist, so an earth fissure should be accrued at this border to let the different parts having their own value of subsidence. Using the other studies of the author, an example of hazard map in the mentioned area is presented in this paper. This kind of maps may be a useful guide for making true decision of urban, agriculture and industrial improvements.

MATERIALS AND METHODS

Withdrawal of oil, gas, water and any other fluid from a porous granular media can cause a decrease in the volume of the reservoir system and pore-fluid pressures and it also cause an increase in effective stress (the difference between the total stress and pore-fluid pressure) which may cause a deformation in porous media that will tend to land subsidence. As it said before, bedrock and aquitard condition which may exist within or bounding the aquifer, also depth and other characteristics of the soil layers are all affecting the compaction because of their effects on soil compressibility and also storability matrix. Therefore, water from acquitter storage is derived from deformation of the matrix and accordingly, aquitard storability and drainage control the compaction and land subsidence of the systems. Whenever we have the differential land subsidence, earth fissures will appear. Although there are no methods of quantifiably predicting the exact probability and exact magnitude of earth fissures but the locations of potential fissures may be predictable in specific areas if enough information about the subsurface, material properties and groundwater levels are available.

However, as long as subsidence continues (even if the groundwater levels should rise and stabilize), fissures will continue to occur and the magnitude of the fissures vary with the depth to groundwater, type of surface material and some other different elements as present amount of groundwater removed, basin depth, volume of runoff from precipitation, soil condition and human intervention. There are some kind of different methods of attempt to categorize the probability of future subsidence and fissures. Based on stress-strain theory of the soil elements, these methods analyze the potential hazard using an analytical method, based on stress-strain theory of the soil elements. Also magnitude of the warning time and duration may be achieved in some of these methods.

The basic formulation presented here is based on Biot's consolidation theory. In the theory of Biot the soil skeleton treated as a porous elastic solid and the laminar pore fluid are coupled by the conditions of compressibility and of continuity. As excess effective stress due to water withdrawal in whole scale is small, behaviour of soil skeleton was assumed to be elastic but it should be noted that pore water pressure variation is still function of time, depth and other properties and boundary conditions and it can be determined by WTAQ software. This software shows the water level around a single pumping well using a numerical method in base. More information about this program is given in previous papers of the same author. In these computations cylindrical coordinates were assumed and when water is pumped out from the aquifer through wells, both radial and axial flow can take place which are symmetric. In order to simulate this condition by finite element the exact behaviour should be achieved by actual mathematical equations (Reddy, 1984; Smith and Griffiths, 1992). Final governing equation is expressed as:

$$\begin{Bmatrix} q_r \\ q_z \end{Bmatrix} = \frac{1}{\gamma_w} \begin{bmatrix} K_r & 0 \\ 0 & K_z \end{bmatrix} \begin{Bmatrix} \frac{\partial u_e}{\partial r} \\ \frac{\partial u_e}{\partial z} \end{Bmatrix}$$

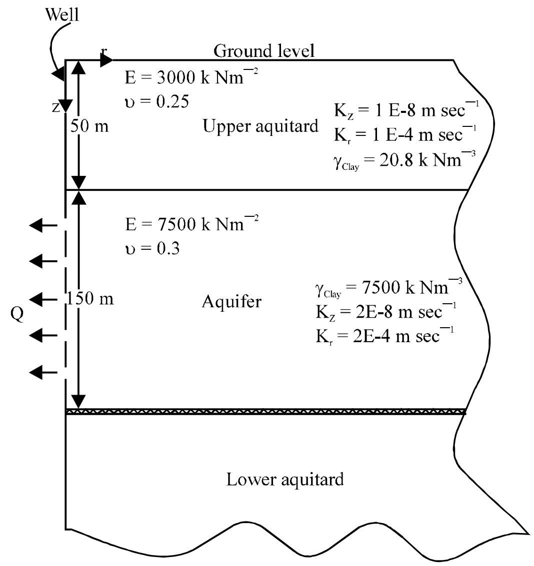

Fig. 5: Sirjan aquifer soil profile

where, q_r, q_z = volumetric flow rates per unit area into and out of the element, K_r, K_z = Coefficient of permeability in redial and axial directions, respectively. The values of these coefficient and soil profile of the aquifer are shown in Fig. 5.

At the other hand for fully saturated soil and incompressible fluid condition, outflow from an element of soil equals the reduction in volume of element. Hence:

$$\frac{K_r}{\gamma_w}\frac{\partial^2 u_e}{\partial r^2}+\frac{K_z}{\gamma_w}\frac{\partial^2 u_e}{\partial z^2}+\frac{d}{dt}\left(\frac{\partial u}{\partial r}+\frac{\partial v}{\partial z}\right)=0$$

As usual in a displacement method σ,ε are eliminated in terms of u,v so that the final coupled variables are u, v, u_e. In above equations, if $\theta \geq 0.5$, the system will be stable without any condition, in the Crank-Nicolson type of approximation, θ is made equal to 0.5, or in Galerkin approximation θ is equal to 0.67. By using θ = 0.5 in Crank-Nicolson method, after summarizing and combination of the equations the final equation can be written as follows:

$$\begin{bmatrix} KM & C \\ C^T & -\frac{\Delta t}{2}KP \end{bmatrix}\begin{bmatrix} r_{n+1} \\ u_{e_{n+1}} \end{bmatrix}=\begin{bmatrix} -KM & -C \\ C^T & \frac{\Delta t}{2}KP \end{bmatrix}\begin{bmatrix} r_n \\ u_{e_n} \end{bmatrix}+\begin{bmatrix} 2F \\ 0 \end{bmatrix}$$

Therefore, values of unknown can be calculated at time $t = t_{n+1}$ based on known parameters at time $t = t_n$. For initial conditions at time t = 0 all values are known.

After finding governing matrix equations for a single element, the assembled matrices for total elements can be obtained and boundary conditions can be introduced. Solving such equations (Drever, 2005) at any time, horizontal and vertical deformations (u, v) at various nodal points can be found and strain values for each element can be calculated. In a single pumping well under operation ground water level draws down causing a hydraulic gradient that cause the well ground water flow. There are some different analyzing models for this flow such as Moench that is a combination of Neuman and Boulton model by assumptions that, uniform aquifer and constant pumping rate, constant physical properties (Najmaei, 1990). Solving the above equation, applying the initial conditions, theoretical magnitude of subsidence will be achieved so (Ziaie and Rahnama, 2007; Schwartz *et al.*, 2003).

The developed computer program based on Biot's three-dimensional consolidation theory is used in this study to predict the settlement of Sirjan land, using the computer program (WQAT) for achieving the future underground water table of the related aquifer. At the next step, different conditions of the soil of this area are applied on the model and finally subsidence in deferent part of this Sirjan land is achieved and the obtain data is converted to a hazard map for this area (Fig. 8).

RESULTS AND DISCUSSION

Sirjan land is in western south of Kerman in central desert of Iran. This area is a topographically closed basin and surface-water drainage terminates in several playas the most notable of which is Sirjan Salt Lake. Fine-grained sedimentary deposits predominate in the center of the basin and within the middle and surrounding ground-water sub basin which is the source of much of Sirjan's water. Extensive ground water pumping for agricultural uses and pistachio farming in this area, beside the semi desert type climate of this part of Kerman province are the main causes of a negative water budget of this basin and also a high rate of subsidence (more than 10 cm^{-1} year) (Rahmanian, 1997; Toufigh *et al.*, 1996).

When this grate rates of subsidence accrue in the land of two neighboring area with different soil characteristics, the magnitude of land subsidence differ from each other in these two neighboring areas and earth fissure will accrued at this border. These undesired fissures which their width is variable from a few millimeters to 2-3 m, are observed frequently in Sirjan land and their production rate is growing up continuously (Fig. 3, 4). Variations in the density of failures from area to area are conspicuous and are obviously determined by more than just area differences of water-level decline and compressibility of sediments. For example, the area extent and magnitude of subsidence in the Sirjan land of Kerman providence is one of the greatest one of any area in Iran and also the ground failure is so. Part of the explanation for these density variations probably lies in differences in the subsurface conditions among the areas. Surface faults and straight to actuate earth fissures are associated with preexisting faults and subsurface zones conducive to localized differential compaction, respectively. As it said before, the continuous decrease of groundwater level in Sirjan will have some sequences as subsidence and earth fissures. Passing four main faults (Naibandan, Kuhbanan, Zagros and Sanandaj) from this area and also having the largest number of Qantas in Iran beside of earth fissures due to decrease of ground water level, Sirjan land is like to a broken shell which need so more care to behave about. So knowing about the subsidence rate, also the number, direction and expansion rate of the earth fissures in an area of this land will make a true vision for us to have a true behaviour. This study is a powerful tool to distinguish the mentioned important factors for knowing the existing condition correctly and making the future decisions truly. In this research, the amount of the subsidence in different parts of the supposed land, after about 8 years of pumping, are achieved at the first stage, applying the real existing conditions of different parts of the lands and then these achieved results are compared and corrected with the real field data. Land subsidence and earth fissures map in Sirjan land, are the result of this study. These kinds of practical maps may act as a guide map to conduct the industrial, agricultural and civil development to a true direction and a right location and it may be used as useful tools to manage of water resources in this area, too.

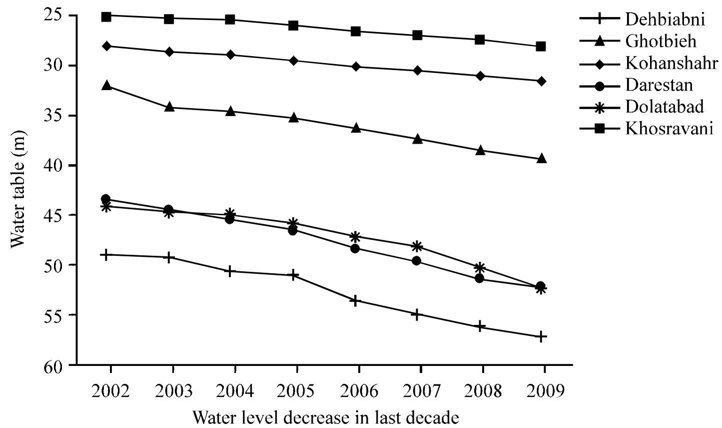

Fig. 6: Sirjan water level in past 8 years

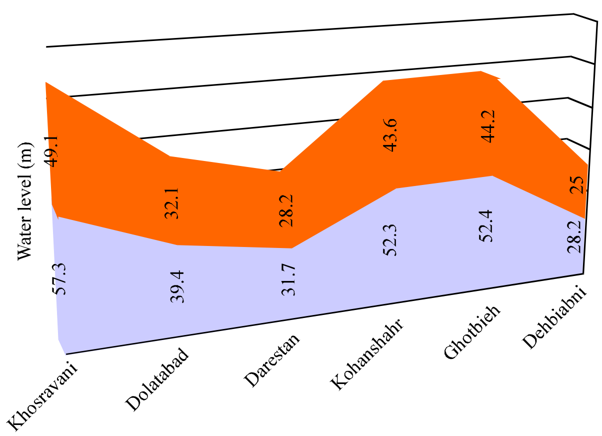

Fig. 7: Water level in Sirjan well field

The water table determined by 'WTAQ' computer program assuming a constant pumping rate in this study and also different condition of aquifer and soil profile in Sirjan land is considered to apply the model. Although water flow in axial and radial directions under axisymmetric conditions is one of the basic assumptions here, this simulation is very close to actual filed condition under pumping of groundwater through wells and the results are close to actual observations. Actual filed data of ground water decrease in last decade, (years between 2002 and 2009), are shown in Fig. 6 and 7 and the location of the measured wells in Sirjan land is shown in Fig. 8. As it is given in these data, water level in Sirjan well field has a mean of 6.54 m decrease in these 8 years and applying more complete information in this field, the number will rich to about 8 m in 8 year. In the other words, water table is decreasing with a rate of 1 m year^{-1} in this area.

This amount of water table decrease will tend to a 10 cm rate of subsidence per year in some part of Sirjan well field land, as it achieved by theoretical mentioned formulation and checked with the real field data. So we can use this method to predict the future reliable amount of land subsidence in this area (Ziaie and Rahnama, 2007). So calculating the amount of subsidence around of the production wells of this land and combine them with each other and comparing the results with real field data, hazard map of Sirjan well field land is achieved. As it is shown in this map, three areas can be seen with different colors. Each of these parts is shown a 10 cm land

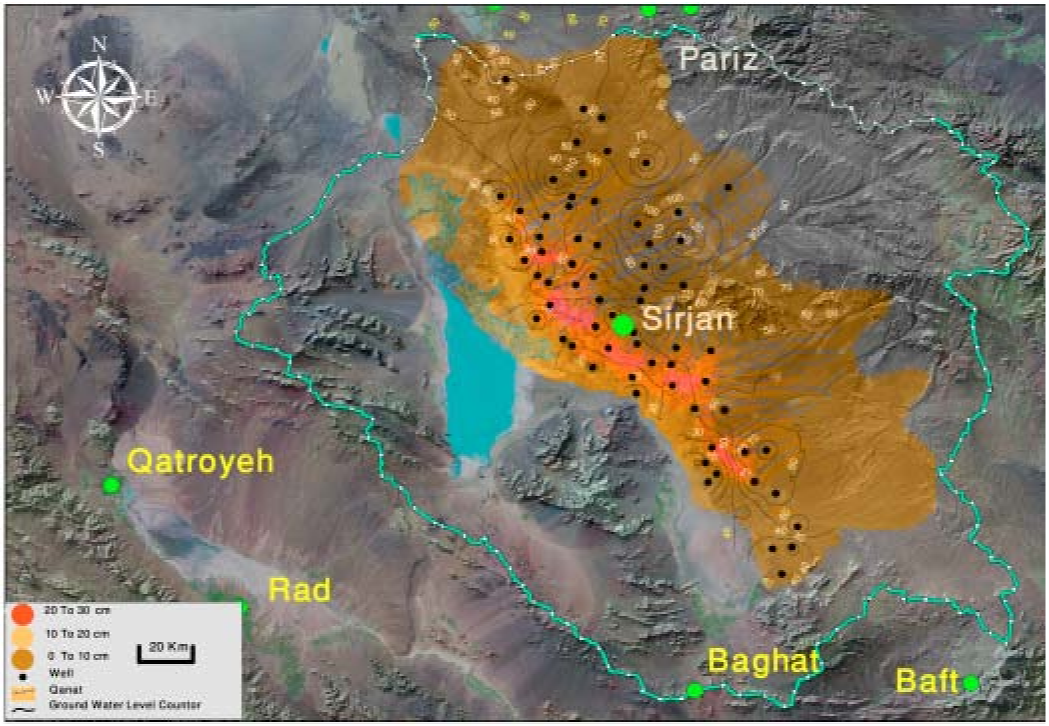

Fig. 8: Hazard map of Sirjan

subsidence value due to ground water withdrawal in an eight year time period. Future subsidence values of different points of this land may be predicted by the same way and the future land subsidence map will be achieved so. Large numbers of production Qantas and wells that make a huge amount of water withdrawal possible are shown here too.

CONCLUSION

Ground failure takes place in most lands of the areas with land subsidence that caused by ground-water withdrawal. The first failures in each area took place after subsidence began and in those areas that now have large numbers of failures, the number gradually increased as subsidence continued. Thus, in a sense, ground failure may be considered as a secondary, although relatively common, condition caused by ground-water withdrawal from unconsolidated sediments.

The developed computer program based on Biot's three-dimensional consolidation theory and using the computer program (WQAT) to achieve the under ground water table gave satisfactory results of earth settlements and fissures. The proposed method was examined and confirmed field data and at the same way the prediction of future settlement can be obtained.

In this study the relationship between the decrease of the water level of an aquifer, the sinking of the surface and the generation of subsidence is obtained. The limitation of this study is that aquifer was assumed as a confined one. This study first was developed for considering the groundwater withdrawal in a regional problem similar to assumption which the actual variation of water table level in the field as an input data in finite element analysis and then the stress- strain matrix of the different elements of the model can obtained. Finally, the strains are conducting us to predict the probable fissures location in the supposed area.

As it is happened in Sirjan, when a local control and management institution and suitable analyzed data does not exist, numerous problems such as excessive lowering of ground water levels, ground water storage depletion, land subsidence, decreased discharge, effects on base flow of rivers and springs and other potential long-term impacts to other users, potential mobilization of contaminants and impacts aquatic ecosystems may be appeared due to intensive use of ground water. As it said before, most of these problems can be avoided, corrected or at least mitigated with a comprehensive groundwater management program. This presented result is an example of a tool to avoid the mentioned problems in the studied area.

ACKNOWLEDGMENTS

Thanks are due to Sirjan Industrial University and also other colleagues because of their kind supports and also all of the persons who gave us permission to made some of their studies, results and illustrations been reproduced in this paper and an incomplete list of their names is as the following references.

REFERENCES

Amelung, F., D.L. Galloway, J.W. Bell, H.A. Zebker and R.J. Laczniak, 1999. Sensing the ups and downs of Las Vegas-InSar reveals structural control of land subsidence and aquifer-system deformation. Geology, 27: 483-486.

Bawden, G.W., W. Thatcher, R.S. Stein, K.W. Hudnut and G. Peltzer, 2001. Tectonic contraction across Los Angeles after removal of ground-water pumping effects. Nature, 412: 812-815.

Biot, M.A., 1941. General theory of three-dimensional consolidation. J. Applied Phys., 12: 155-164.

Drever, J.I., 2005. Surface and Ground Water, Weathering and Soils. 1st Edn., Elsevier, USA., ISBN: 0-08-044719-8, Pages: 644.

Heywood, C.E., 1997. Piezometric-extensometric estimations of specific storage in the Albuquerque basin, New Mexico. US Geological Survey Subsidence Interest Group Conference: Proceedings of the Technical Meeting, Open-File Report 97-47, February 14-16, 1995, Las Vegas, Nevada, pp: 21-26.

Heywood, C.E., D.L. Galloway and S.V. Stork, 2002. Ground displacements caused by aquifer-system water-level variations observed using interferometric synthetic aperture radar near Albuquerque, New Mexico. US Geological Survey Water-Resources Investigations Report 2002-4235, pp: 18. http://content.lib.utah.edu/cdm4/item_viewer.php?CISOROOT=/wwdl-er&CISOPTR=148

Hoffmann, J., H.A. Zebker, D.L. Galloway and F. Amelung, 2001. Seasonal subsidence and rebound in Las Vegas Valley, Nevada, observed by synthetic aperture radar interferometry. Water Resour. Res., 37: 1551-1566.

Holzer, T.L. and D.L. Galloway, 2005. Impact of land subsidence caused by withdrawal of underground fluids in the United States. Rev. Eng. Geol. USA., 9: 87-99.

Ikehara, M.E., 1995. Results of global positioning system surveys in Antelope valley, California. US Geological Survey Open-File Report, pp: 27-30.

Jacob, C.E., 1940. On the flow of water in an elastic artesian aquifer. Trans. Am. Geophys. Union, 21: 574-586.

Larson, M.K., 1984. Potential for subsidence fissuring in the *Phonix arizona* USA Area. Burea Oil Field Environ. Geol., 1: 291-299.

Leake, S.A. and P.A. Hsieh, 1995. Simulation of deformation of sediments from decline of ground-water levels in an aquifer underlain by a bedrock step. US Geological Survey Open-File Report, pp: 10-15.

Lu, Z. and W.R. Danskin, 2001. Analysis of natural recharge to define structure of a ground-water basin. Geophys. Res. Lett., 28: 2661-2664.

Najmaei, M., 1990. Engineering Hydrology. University of Science and Technology of Iran.

Phien-Wej, N., P.H. Giao and P. Nutalaya, 2006. Land subsidence in Bangkok, Thailand. Eng. Geol., 82: 187-201.

Rahmanian, D., 1997. Land subsidence in Kerman due to pumping of groundwater. Mahab Ghods Consult. Comp. Report, 1: 1-8.

Reddy, J.N., 1984. An Introduction to the Finite Element Method. 3rd Edn., McGraw-Hill, New York, ISBN: 0072466855.

Sahuguillo, A., J. Capilla, L. Martinez-Cortina and X. Sanchez-Vila, 2005. Ground Water Intensive Use. 1st Edn., Taylor and Francis Publishers, London, UK., ISBN: 0415364442, pp: 400.

Schwartz, F.W. and H. Zhang, 2003. Fundamentals of Ground Water. International Edition, John Wiley and Sons Inc., New York, ISBN-13: 978-0471429050, Pages: 608.

Smith, I.M. and D.V. Griffiths, 1992. Programming the Finite Element. 3rd Edn., John Wiley, UK., ISBN: 0-471-96542-1.

Toufigh, M.M. and B. Shafiei, 1996. Prediction of future land subsidence in kerman due to ground water withdrawal. Int. J. Rock Mech. Mining Sci. Geomech. Abst., 33: 344A-344A.

Ziaie, A. and M.B. Rahnama, 2007. Prediction of single well land subsidence due to ground water drainage. Int. J. Agric. Res., 2: 349-358.

Ziaie, A., K. Kumarci, A.R. Ghanizadeh and A. Mahmodinejad, 2009. Prediction of earth fissures development in Sirjan. Res. J. Environ. Sci., 3: 486-496.