MODELLING LAND SUBSIDENCE DUE TO GROUNDWATER ABSTRACTION

by

MAHMOUD REZA MOLLAEI NIA

Department of Civil Engineering

Submitted
in fulfillment of the requirements of the degree of
Doctor of Philosophy

to the

Indian Institute of Technology Delhi

Hauz Khas, New Delhi – 110016, India

June 2008

Groundwater - Aquifier
Groundwater hydrology

To my brothers, who submitted their life to keep alive Iran,
to my parents and my parents in-law,
to my sons, Mostafa Milad and Mojtaba, and above all to my wife.

Mahmoud Reza Mollaei Nia

CERTIFICATE

This is to certify that the thesis entitled **"Modelling Land Subsidence Due To Groundwater Abstraction"** being submitted by **Mr. Mahmoud Reza Mollaei Nia** to the ***Indian Institute of Technology Delhi*** for the award of the degree of ***Doctor of Philosophy*** in Civil Engineering is a bonafide record of research work carried out by him under my guidance and supervision. The thesis work in my opinion has reached the requisite standard fulfilling the requirements for the said degree. The results contained in this thesis have not been submitted, in part or full, to any other University or Institute for the award of any degree or diploma.

Shashi Mathur

Prof. S. Mathur
Thesis supervisor
Department of Civil Engineering
Indian Institute of Technology Delhi
Hauz Khas, New Delhi- 110016, India

ACKNOWLEDGEMENTS

This project would not have been possible without the help of the God and the support of many people. A holy statement says “one who would not acknowledge the people can not express thanks to God”. I would like to express my immense pleasure and deep sense of gratitude to my noble supervisor, Prof. S. Mathur, Department of Civil Engineering, Indian Institute of Technology Delhi for his inspiring guidance and utmost cooperation during the course of the present investigation, preparation of the manuscript and successful completion of my research work.

I am so thankful to the Directorate of Completion Education, Government of Republic Islamic of Iran and my parent University of Zabol for sponsoring me for higher studies at Indian Institute of Technology, Delhi. I am also thankful to Dr. Ebrahim Hajizadeh, Dr. Mohammd Kafi and Dr. Ahmad Momeni, the First Secretary of Education, Iran Embassy in India for their support during the course of this study.

I wish to express my sincere thanks to the respected Student Research Committee members and to all respectful faculty members of the Water Resources Group, Department of Civil Engineering, Indian Institute of Technology, Delhi for their support and encouragement. Thanks are also due to the staff of Civil Engineering Department especially Mr. B. Chand, Mr. R. Agrawal, Mr. Gehlot and Mr. Prasad for cooperation during the entire work.

I also take this opportunity to acknowledge my friends Mr. M. Sharifikia and Mr. A. Mohammadi, senior engineer of the Regional Office of Water (Eastern Azerbaijan State, Iran) for all the help I received in getting the data and the image processor software, and Mr. H. Noferesti and Mr. J. Bagerzadeh for their encouragement help. I would like to thank my fellow research scholars (especially Mr S. Kumar Jain) for all the help during this study.

I am forever indebted to my wife; Mrs. Safiyeh Kadkhoda who has thoughtfully managed all responsibilities; my dear sons Mostafa, Milad and Mojtaba; my parents and my parents in-law; my sister and my brothers in-law for the pain and suffering that they have undergone during my research.

Finally, I thank God who has enabled me to go on the path he likes.

New Delhi, June 2008

Mahmoud Reza Mollaei Nia

ABSTRACT

Land subsidence can be defined as the differential sinking of ground surface with respect to the surrounding terrain or sea level. Although, land subsidence occurs due to natural causes, considerable amount of subsidence takes place due to extraction of coal and ore, underground excavation for tunnels and caverns, or due to the withdrawal of groundwater, oil and gas from the subsurface zones. In this study, land subsidence phenomenon is however assumed to be due to groundwater abstraction from aquifers.

When water is exploited from an underlying aquifer, the intergranular stress (effective stress) in the solid matrix increases owing to a drop in the pore pressure assuming the total stress remains constant. This in turn contributes to compression of the soil matrix of the aquifer which eventually manifests into subsidence. Land subsidence is best understood using the theory of consolidation and it almost is non-recoverable and causes a permanent decrease in the storage volume of the medium. Subsidence has been found to be significant in confined and leaky confined aquifers however it takes place in phreatic aquifers too. The changes in saturation, and hence, in pore water pressure in the unsaturated zone contributes to subsidence, though to a much lesser degree. When soft material (layers or lenses) comprise a part of the aquifer's soil skeleton or, when aquicludes separate leaky aquifers from each other, an appreciable amount of subsidence could occur. However, in this study a methodology for prediction of the land subsidence due to groundwater withdrawal from an aquifer system underlying Salmas Plain located at northwest of Iran is developed.

A regional land subsidence model is first developed to simulate the groundwater flow in

the upper leaky-unconfined aquifer that is coupled with the lower leaky-confined aquifer through a thin aquitard and the resulting consolidation of the soil matrix is determined. It is assumed that the horizontal displacement of the ground surface is negligible. The partial differential equations for the confined and unconfined aquifers subject to hydrogeological variables and initial and boundary conditions are solved by the finite element method (FEM). The model requires geomechenical and hydrological parameters at each nodal point to obtain a reliable estimate of the land subsidence due to groundwater extraction. The hydrological parameters of aquifers such as hydraulic conductivity and the vertical uniaxial porous media compressibility are available only at a few points of the grid and hence a set of these parameters is to be determined first using inverse problem of Artificial Neural Networks inversion (InANN) in addition to a combination of a ridge function and neural networks (RFn-NN).

For the ANN inversion, the values of hydraulic conductivity at each node were assumed randomly (in the range of 2.7 to 187.3 m/d according to the field measurements) in the study area. The FEM numerical model was solved for different set of values of hydraulic conductivity lying in the above range and about 105,000 sets of data were generated. An optimal artificial neural network (ANN) architecture was trained with an optimum set of these generated sets of data and validated to predict the hydraulic conductivity at each node after inversion of the trained ANN architecture. Similarly, for a combination ridge function and neural network, the location and hydraulic head values of the 29 monitoring wells used to predict the hydraulic conductivity at each nodal point through optimization using the Levenberg-Marquart technique. The values of hydraulic conductivity obtained by two procedures were finally used in the numerical FEM model to predict the hydraulic head at each node in the domain and the hydraulic heads obtained compared with the field data. The results show that although both algorithms are capable of simulating transient flow in the aquifer to obtain the spatial groundwater head with a high amount of accuracy, RFn-NN procedure gave better results and the algorithm converges much faster compared to the InANN algorithm.

Furthermore, the Interferometric Synthetic Aperture Radar (InSAR) technique was used to develop spatially detailed maps of land subsidence between 15 Mar., 2004 and 24 May, 2004 October 20, 1993. The results indicate that land subsidence is predominant at four different regions of the Salmas Plain. Also, the regions that experience coherent signals of land subsidence are the areas with a dense population of pumping wells. Further, groundwater heads in the piezometric wells in or near the subsidence bowls show a continuous decline in value indicating that land subsidence occurs due to localized pumping.

Though InSAR technique was able land subsidence of a majority of grid points in the domain for the grid points that were not detected by synthetic aperture radar interferometry, the RFn-NN procedure was used to estimate subsidence. The spatial values of the soil matrix compressibility for entire domain were also estimated using RFn-NN.

Moreover, the regional land subsidence model developed is validated by matching the observed aquifer-head distribution available for the periods 1984-1990 and 2003-2006 with the hydraulic heads determined by the numerical model. The results show that the simulated head values compare well with the field measurements values of hydraulic head for both the aquifers. The model is also validated by conducting a comparison between the land subsidence obtained using the numerical model and those detected using synthetic aperture radar interferometry. Again, the results indicate that that there exists a good match between the computed and the detected land subsidence. The validated regional land subsidence model is then used to predict the future land subsidence for the period of 2007-2017 assuming the pumping rate and its distribution to be equal to the rate and distribution of pumping in 2007. The results indicate that the rate of groundwater-level decline in the summer season is larger than the rate of groundwater-level increase in the winter season. The total compression that occurs in the summer is much greater than any expansion that takes place in the winter due to rise in groundwater levels and a significant amount of subsidence is predicted during next decade in Salmas Plain.

CONTENTS