Chapter 16

Using Groundwater Flow Modelling for Investigation of Land Subsidence in the Konya Closed Basin (Turkey)

Naciye Nur Özyurt
Hacettepe University, Turkey

Pınar Avcı
Hacettepe University, Turkey

Celal Serdar Bayarı
Hacettepe University, Turkey

ABSTRACT

Land subsidence which is defined as gradual settling or sudden collapse of Earth’s surface, is a geo-hazard phenomenon that occurs worldwide. Land subsidence occurs in time mainly due to excessive groundwater abstraction. This problem occurs usually in semi-arid regions where the groundwater is the sole source of water. Eliminating the adverse effects of land subsidence requires careful observations on the temporal change of elevation coupled with groundwater flow modeling. In this study, numerical groundwater flow modeling technique is applied to a confined aquifer system in the Konya Subbasin of Konya Closed Basin (KCB), central Anatolia, Turkey. Groundwater head in the KCB has been declining with a rate of about 1m/year since early 1980s. Recent GPS observations reveal subsidence rates of 22 mm/year over the southern part of KCB. MODFLOW numerical groundwater flow model coupled with subsidence (SUB) package is used to simulate the effect of long term groundwater abstraction on the spatial variation of subsidence rates.

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INTRODUCTION

The term land subsidence includes both of the processes of slow settlement and sudden collapse of a ground surface. However, in many of the cases, the subsidence is a subtle phenomenon. Both the vertical and horizontal components of the displacement can lead remarkable damages. Generally, it is the groundwater pumping that cause land subsidence in compressible aquifer systems. Such systems typically comprise of basin-fill and unconsolidated alluvial aquifer systems that include both aquifers and aquitards (Galloway and Burbey, 2011). The aquifer-system compaction and the resultant land subsidence is associated with the compaction of the aquitards which may be thick confining units within the aquifer system or may be fine-grained deposits interbedded within an aquifer.

According to an assessment by Galloway and Burbey (2011), measured subsidence rates in different locations in the world range from 6 mm/year in Kolkata, India between 1992-1998 (Chatterjee et al., 2006) and 300 mm/year in Mexico City, Mexico between 2004-2006 (Osmanoglu et al., 2011) and among the 18 sites distributed globally the mean and median subsidence rate are 100 mm/year (+/- 1 sigma standard deviation is 99 mm/year) and 55 mm/year.

Either slow or sudden, motion of the ground due to subsidence is a life and property threatening process. Present and potential future hazards have been assessed by computer models which are based on basic relations between groundwater’s head, ground stress, compressibility of groundwater and aquifer skeleton, and the groundwater flow. These models use two different approaches: the first is based on groundwater flow theory (Jacob 1940, 1950) and secondly, the theory of linear poroelasticity (Biot 1941). The groundwater flow theory is a special case of the poroelasticity theory. As Galloway and Burbey (2011) states, both approaches are based on the Principle of Effective Stress (Terzaghi 1923, 1925) and the principal difference between these approaches is the way how the deformation of the skeletal matrix is treated. Conventional groundwater flow theory accounts only for the vertical deformation, whereas poroelasticity theory accounts for the 3-dimensional deformation. Therefore, the poroelasticity theory represents a better relationship between fluid flow and deformation, and is physically more realistic (Galloway and Burbey, 2011). However, the approach based on conventional groundwater flow theory is preferred in studies aiming the regional deformation because it requires much less data as compared to the approach based on poroelasticity theory. On the other hand, the poroelasticity approach is more suitable to address the local-scale deformations like ground ruptures and damaged engineering structures.

Numerical models to simulate and predict aquifer-system compaction at regional scale are based on the aquitard-drainage model which describes the relations between fluid pressure, intergranular stress and fluid flow by combining the conventional groundwater flow theory, with the principle of effective stress and the theory of hydrodynamic lag (Terzaghi 1923, 1925). These models have been developed since 1970s as the computers allowed solving large set of partial differential equations. Some of the pioneering models are described in Helm (1972, 1975, 1976), Witherspoon and Freeze (1972), Gambolati and Freeze (1973), Narasimhan and Witherspoon (1977), and Neuman et al. (1982). A comprehensive assessment of the literature using such models are given by Galloway and Burbey (2011) and Galloway and Sneed (2013).

Development of 3D groundwater flow model MODFLOW (McDonald and Harbaugh 1984, 1988) by USGS in late 1980s is a milestone in using the modeling techniques in hydrogeological problems. Soon after its initial release modules have been developed to simulate the areal compaction due to drainage of interbeds within aquifers. The Interbed Storage Package, version 1 (IBS1) developed by Leake and Prudic (1991) assumes that heads in interbeds equilibrate with aquifer head changes the
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