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Gravimetry contributions to the study of the complex western Haouz aquifer (Morocco): Structural and hydrogeological implications

Ibtissam Chouikri [a,*], Abdennabi el Mandour [a], Mohammed Jaffal [b], Paul Baudron [c,g,h], José-Luis García-Aróstegui [d,i], Ahmed Manar [e], Albert Casas [f]

[a] Laboratoire Géostructures, Géomatériaux et Ressources Hydriques (GEOHYD), Université Cadi Ayyad, Faculté des Sciences Samlalia, Marrakech, Morocco
[b] Laboratoire « Géoressources », Université Cadi Ayyad (UCAM), Faculté des Sciences et Techniques, BP 549, 40000 Marrakech, Morocco
[c] Département des Génies Civil, Géologique et des Mines, Polytechnique Montréal, C.P. 6079, Centre-Ville, Montréal, QC, H3C 3A7, Canada
[d] Instituto Geológico y Minero de España, Murcia, Spain
[e] Ministère de l'Energie et des Mines, Rabat, Morocco
[f] Faculty of Geology, University of Barcelona, Marti &Franques, S/N, 08028 Barcelona, Spain
[g] IRD, UMR G-EAU, BP 5095, Montpellier Cedex 5, 34196 France
[h] Geotop Research Center, Canada
[i] Instituto Universitario del Agua y del Medio Ambiente, Universidad de Murcia, Spain

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ABSTRACT

This study provides new elements that illustrate the benefits of combining gravity, structural, stratigraphic and piezometric data for hydrogeological purposes. A combined methodology was applied to the western Haouz aquifer (Morocco), one of the main sources of water for irrigation and human consumption in the Marrakech region. First, a residual anomaly map was calculated from the Bouguer anomaly data. The computed map provided information on the ground density variation, revealing a strong control by a regional gradient. We then used various filtering techniques to delineate the major geological structures such as faults and basins: vertical and horizontal derivatives and upward continuation. This technique highlighted news structures and provided information on their dip. The gravity anomalies perfectly delineated the basement uplifts and the sedimentary thickening in depressions and grabens. The interpretation of gravimetric filtering, geological and hydrogeological data then highlighted two types of groundwater reservoirs, an unconfined aquifer hosted in conglomeratic mio-pliocene and quaternary rocks, covering the entire western Haouz and a deep confined aquifer contained in cenomanian-turonian limestone and eocene dolomitic formations in the south. Combining piezometric and residual anomaly maps revealed that groundwater flow and storage was in perfect agreement with the structures showing a negative anomaly, while structures with positive anomalies corresponded to groundwater divides. The study of gravity gradient zones by contact analysis enhanced the existing structural pattern of the study area and highlighted new structures, mainly oriented N70 and N130. The results of this study present a common framework and provide a notable step forward in the knowledge of the geometry and the groundwater flow pattern of the western Haouz aquifer, and will serve as a solid basis for a better water resource management.

Contents

* Corresponding author.
E-mail addresses: ibtissam312@gmail.com (I. Chouikri), a.elmandour@uca.ma (A. el Mandour), Maroc.m.jaffal@uca.ma (M. Jaffal), paul.baudron@polymtl.ca (P. Baudron), j.arostegui@igme.es (J.-L. García-Aróstegui), a.manar@mem.gov.ma (A. Manar), albert.casas@ub.edu (A. Casas).

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1. Introduction

Groundwater exploitation for drinking water supply and irrigation is a fundamental factor for the socio-economic development of semi-arid areas of Morocco (e.g. Carneiro et al., 2010), as for most Mediterranean countries (e.g. Baudron et al., 2014). The Haouz aquifer system is one the main source of water for irrigation and human consumption in the Marrakech region, Morocco (Abourida, 2007). In recent years, a continuous decline of groundwater level has been observed in several areas. This phenomenon exposes the sustainability of this resource and therefore the entire economy of the region to a severe risk. Indeed, groundwater exploitation requires a detailed knowledge of the considered aquifers (e.g. Mastrocicco et al., 2010; Tazioli et al., 2012; Giang et al., 2014), whose fundamental first step is to perform a geometrical characterization of groundwater reservoirs.

In addition to stratigraphic and structural data, geophysical techniques have proven to be effective indirect methods for geometrical aspects, as for the deep structure identification in major groundwater basins (Khattach et al., 2004, 2006; Najine et al., 2006; Vanié et al., 2005, 2006; Chennouf et al., 2007; El Gout et al., 2009; Aqil et al., 2010; Farhat et al., 2010; Hssaisoune et al., 2012). At the whole Haouzplain scale, in addition to regional hydrogeological data on the unconfined aquifer (Sinan, 2000; Lyakhloufi, 2001; Razoki, 2001; Abourida, 2007), some investigations recently focused on hydrogeology based on gravimetric approaches (e.g. Rochdane et al., 2014; Karroum et al., 2014), but none of them covered the western Haouz.

The purpose of the present study is to identify the structure, geometry of the western Haouz aquifer system and their hydrogeological implications. To achieve these goals, this study uses gravity data correlated with piezometric, structural and stratigraphic data from field and boreholes. Such information is required to guide the implementation of new boreholes for agricultural use and drinking water supply, and provide a good management of groundwater in the western Haouz.

2. Study area

2.1. Geographical and climatic context

Western Haouz is a vast alluvial area covering 2800 km^2 and located 30 km westwards from the Marrakech city. It is bounded to the north by the Tensift wadi, to the south by the western High Atlas massif, to the east by the Nfis wadi and to the west by the Chichaoua wadi. For administrative reasons, it has been historically divided into two areas: Sid Zouine area in the north and Mejjate area in the south (Agence Hydraulique du Bassin de Tensift (ABHT)/ Division des Ressources en eau (DRE), 2012) (Fig. 1).

The climate in the region is semi-arid with very variable rainfall from year to year. Annual average rainfall is about 300 mm. Average temperatures can reach 25 °C with significant monthly and daily differences while average monthly evaporation exceeds 1800 mm/ month (Agence Hydraulique du Bassin de Tensift (ABHT)/Division des Ressources en eau (DRE), 2012).

2.2. Geological settings

The geological structure of the Haouz plain is mostly marked by the hercynianorogeny, that caused a superposition of extensional and compressional structures, influenced by the Atlas movements responsible for the uplift of these ranges within the plio-quaternary Haouz plain (Soulaimani, 1991). Attached to the western Meseta (Michard, 1976; Hoepffner, 1987), the western Haouz plain consists of folded, metamorphosed and eroded primary rocks, covered by post-paleozoic deposits that recorded the markers of Atlasic and posterior deformations. This caused the set up of an important tectonic basin between the High Atlas and the Jebilets range and therefore to a sediment accumulation area from the erosion of the Atlas Mountains at its uplift during the Oligo-Miocene and Pliocene. It is also characterized by a succession of eastwest to northeast-southwest trending anticlines ridges separated by flat-bottomed synclines (Ambroggi and Thuille, 1987) and a system of faults and flexures of secondary age (Fig. 2).

3. Data and methods

The gravity data used in the present study come from a former regional survey carried out in 1965 by the African Company of Geophysics (CAG), for the Moroccan Ministry of Mines and Energy. The data is available as a Bouguer anomaly map and was collected using a LaCoste-Romberg gravity-meter. The survey stations were chosen along the roads and tracks network of the study area. Planimetric and altimetric measurements of the gravity survey points were carried out using a Wild T0 tacheometer model, and based on the network of geodetic points covering the study area. Gravity data were reduced using the classical formulae of the Bouguer anomaly, in which a series of corrections were applied to the rough measurements to eliminate the non-geological causes related to gravity variations including topographic correction. Terrain correction was calculated for the short distances (Hammer zones A–C) using near station topography estimation during the gravity survey. For the middle to long distance (Hammer zones D–M) it was achieved using the 1/50,000 scale topographic coverage.

The methodology here consists in applying a set of sequential frequency filters such as horizontal gradient, multi-levels upward continuation in order to highlight the geological contacts and evaluate their dips. A better exploitation of the gravity data by emphasizing more information is compared to those provided by the residual map. The interest of such transformations was raised a long time ago and several methods of calculation were developed since then (e.g. Gérard and Griveau, 1972) and successfully applied (Khattach et al., 2004, 2006; Vanié et al., 2005, 2006; Chennouf