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Groundwater intensive exploitation and mining in Gran Canaria and Tenerife, Canary Islands, Spain: Hydrogeological, environmental, economic and social aspects

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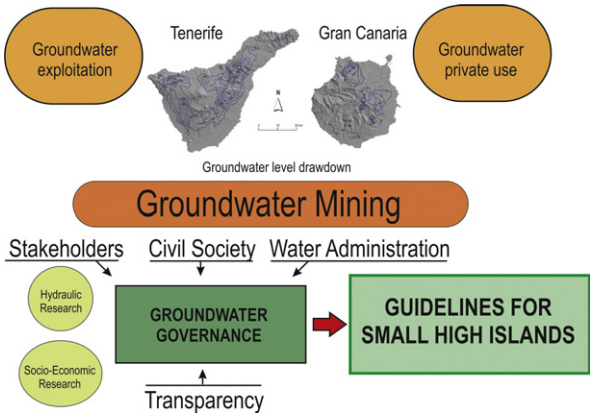
GRAPHICAL ABSTRACT



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ABSTRACT

Intensive exploitation and continuous consumption of groundwater reserves (groundwater mining) have been real facts for decades in arid and semiarid areas. A summary of experience in the hydrogeological, economic, social and ethical consequences of groundwater intensive and mining exploitation in Gran Canaria and Tenerife Islands, in the Canarian Archipelago, is presented. Groundwater abstraction is less than recharge, but a significant outflow of groundwater to the sea cannot be avoided, especially in Tenerife, due to its younger volcanic coastal formations. Consequently, the intensive aquifer groundwater development by means of wells and water galleries (tunnels) has produced a groundwater reserve depletion of about 2 km^3. Should current groundwater abstraction cease, the recovery time to close-to-natural conditions is from decades to one century, except in the mid and high elevations of Tenerife, where this recovery is not possible as aquifer formations will remain

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permanently drained by the numerous long water galleries. The socio-economic circumstances are complex due to a long standing history of water resources exploitation, successive social changes on each island, and well-established groundwater water trading, with complex relationships that affect water governance and the resulting ethical concerns. Gran Canaria and Tenerife are in an advanced groundwater exploitation stage and have a large water demand. They are good examples that allow drawing guidelines to evaluate groundwater development on other small high islands. After presenting the hydrogeological background, the socio-economic results are discussed to derive general knowledge to guide on water governance.

1. Introduction

Aquifers in arid and semiarid areas become the main source of freshwater for human activities, mostly for crop irrigation. Consequently they are often subjected to intensive groundwater exploitation (IGWE hereinafter). As a result, the natural hydrogeological functioning of aquifers is often profoundly altered and affects the ecological functions and services that depend on groundwater. This may be accompanied by water table deepening and a continuous depletion of groundwater reserves, also known as groundwater mining (GWM hereinafter). GWM has being a real fact for decades in arid and semiarid areas. World surveys on GWM can be found in Wada et al. (2010, 2012), Foster and Loucks (2011), and Margat and van der Gun (2013).

The continuous consumption of groundwater reserves has often triggered important local economic and social development in many semiarid and arid areas, so GWM is an important transient asset that has to be taken into account in water planning and governance. Important economic, environmental, social, ethical, administrative, legal, institutional, energy, and land issues are involved.

Between 2013 and 2015 the MASE project was carried out to compile what is known about the hydrological, hydrogeological, environmental, economic, administrative, legal, social and ethical points of view of GWM in Spain. MASE is the Spanish acronym of *Minería del Agua Subterránea en España* (Groundwater Mining in Spain). The MASE report (Custodio, 2015) summarizes most of the available information, and include talks with selected local persons and answers by experts to a detailed questionnaire on GWM. MASE is not a research project, but reviews current IGWE and GWM, their implications, and the benefits and costs. The results depend on very diverse factors which largely rely on local conditions. So each aquifer is unique, although general results can be obtained. They can be transferred to other similar sites. Hydrogeology is only one of factors, whose knowledge is necessary and essential for understanding and evaluating a given case, but is secondary for society. Seawater intrusion, salinization and groundwater pollution are often linked to IGWE and GWM but have not been specifically included in the MASE project. So they are not considered hereinafter. The project deals with the intensively groundwater developed areas of Spain where GWM is more important: a) the SE part of the Iberian Peninsula and b) Gran Canaria and Tenerife, which are the two main islands on the Canary Islands (Canarian Archipelago; the Canaries) from the socio-economic point of view. Hereinafter the following abbreviations will be used: GC for Gran Canaria Island, TF for Tenerife Island, and GC + TF for both islands.

What follows refers to GC + TF, which are two well-known small high volcanic islands in a semiarid area. They are in an advanced degree of water resources exploitation and approach a change of the water use paradigm, which is already starting. Their evolution follows the expected path of other small high islands from the economic and social points of view. Results and learning can be used to evaluate their state and evolution from the hydrogeological and socio-economic points of view, especially as a guide when these small high islands are in a lower stage of groundwater development. This and the discussion of the special hydrogeological behaviour and socio-economic circumstances are the main objectives of what is presented and discussed. High refers to the possibility of an elevated groundwater body and deep water tables. Small denotes a possible significant groundwater outflow along the periphery. Although other small high islands are neither mentioned nor referenced, some of them are well-known to the authors and this knowledge has been tacitly used to emphasise some aspects. A compilation of small islands hydrogeological conditions was published by UNESCO (Falkland, 1991).

Firstly a rather detailed hydrogeological description of GC + TF is provided as this knowledge is needed to understand the circumstances that condition the economic, legal, administrative, and social aspects that are presented afterwards. Finally the lessons learnt and the general results applicable to other small high islands especially under semiarid and high water demand conditions, are presented. Many references are local and relate with the authors' works when no other published or easy-to-access sources of information are available. References to support details are not included but they can be found in the MASE project report (Custodio, 2015). Most of the knowledge is derived from the different reports of the islands' Water Plans (*Planes Hidrológicos*) and related documents. They are mentioned as PH followed by the indication of the island and the year.

2. Definitions and concepts

Intensive groundwater exploitation (IGWE) occurs when natural aquifer functioning and its relationships with other water bodies are significantly modified. In relatively large extent and moderate to low permeability aquifers these modifications produce a slow and progressive decrease in groundwater reserves (Custodio, 2002; Konikow and Leake, 2014). When groundwater abstraction does not exceed recharge under current exploitation circumstances, a final steady state can be attained in what refers to water quantity. Strict groundwater mining occurs when abstraction exceeds the possible recharge under exploitation conditions. The aquifer can quantitatively recover up to close-to-natural situation after abstraction ceases, provided there is some recharge, but recovery time may be long. Arbitrarily, in order to provide a temporal scale, using groundwater reserves is herein considered GWM when quantitative recovery requires at least two human generations, which is about 50 years. This includes IGWE when a large groundwater level drawdown is produced. Depletion can continue until reserves are exhausted or until the physical, water quality, or economic conditions reach a limit. Freshwater depletion by seawater intrusion is not considered herein, despite its relevance in coastal areas.

The evaluation of IGWE requires the knowledge of the actual recharge and the quantification of a validated conceptual hydrogeological model of aquifer functioning. Natural processes are uncertain, especially recharge. This is due to the unavoidable stochastic components. There is essential or non-reducible uncertainty, even if observations and measurements are accurate. Other uncertainties are due to insufficient or deviated knowledge and data and also to oversimplified or erroneous conceptual models. These non-essential kinds of uncertainty generally dominate. They can diminish with improved effort, but at a cost. There is a limit to what can be reasonably done on technical and economic grounds, which depends on local socio-economic circumstances. Uncertainty explains that different hydrogeological and water resource studies and evaluations may yield different results (Custodio et al., 2015). What is presented below must be considered in this context, so evaluations are often coarse approaches that may vastly vary from one source of knowledge to another.