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Using resistivity methods to characterize the geometry and assess groundwater vulnerability of a Moroccan coastal aquifer

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ABSTRACT

The inter-urban aquifer of Martil-Alila is located in a coastal zone where the water resources management is a major challenge because of the increasing pollutant discharges due to the strong anthropogenic pressure. Urgent, continuous and well-studied protection measures should be taken to avoid the complexity of these problems and to restore its perfect state.

In this paper, a comparative analysis of five empirical approaches (DRASTC, SINTACS, GOD, GODS and AVI) and a geophysical approach (Groundwater Protection Index - GPI) is carried out to contrast their cartographic results in order to assess the reliability of this latter. The vulnerability outputs have been correlated with geochemical and bacteriological water quality analysis which validate the results of the GPI approach in our case. This last has the advantage of being based on abundant, well-distributed, recent and reliable geophysical field data and, thence, it is more useful in comparison with the results of traditional empirical methods where data is often lacking or insufficient.

1. Introduction

Worldwide, policy makers and researchers admit that it is essential to establish efficient and effective strategic plans to enhance available water resources and to protect them qualitatively and quantitatively. In arid and semi-arid areas, groundwater resources receive special intention due to it vital role in water supply for drinking and irrigation and in the maintenance of the environmental balances.

Several countries (Canada, France, England, Italy, etc.) and confederations (United States, European Union) have developed frameworks to guide decision-making process to protect these valuable resources through the guidelines of good hydrogeological knowledge and assessment of pollution vulnerability.

Thus, the scientific community and water agencies in many Mediterranean countries (Morocco, Tunisia, Algeria, Spain, Egypt, Turkey, etc.) are promoting hydrogeological studies to produce basic hydrogeological documents to prevent water scarcity and pollution. This is specially the case of coastal and peri-urban aquifers were the accelerated socio-economic and industrial development causes increased pressure on available resources and creates a threat to the groundwater quality (Elewa et al., 2013; Güler et al., 2013; Martínez-Santos et al., 2008; Saidi et al., 2011; Salhi et al., 2008; Samey and Gang, 2008).

In the coastal area of northern Morocco, the intense demographic, economic, industrial and touristic acceleration during the last two decades have improved infrastructure and living conditions but it increases, also, the stress on a water sector that already experiences serious quality and quantity problems. In urban zones, several non-conform behaviors are observed such as the multiplication of urban and industrial pollutants effluents with poor or no treatment, the propagation of illegal pumping and the land use mutations that cause changes in the natural water systems.

The mountainous aspect of northern Morocco allows only the appearance of some restricted intra-mountainous coastal plains giving rise to the main urban poles and touristic villages extended all along the Mediterranean coast. Within this context, the Martil-Alila plain

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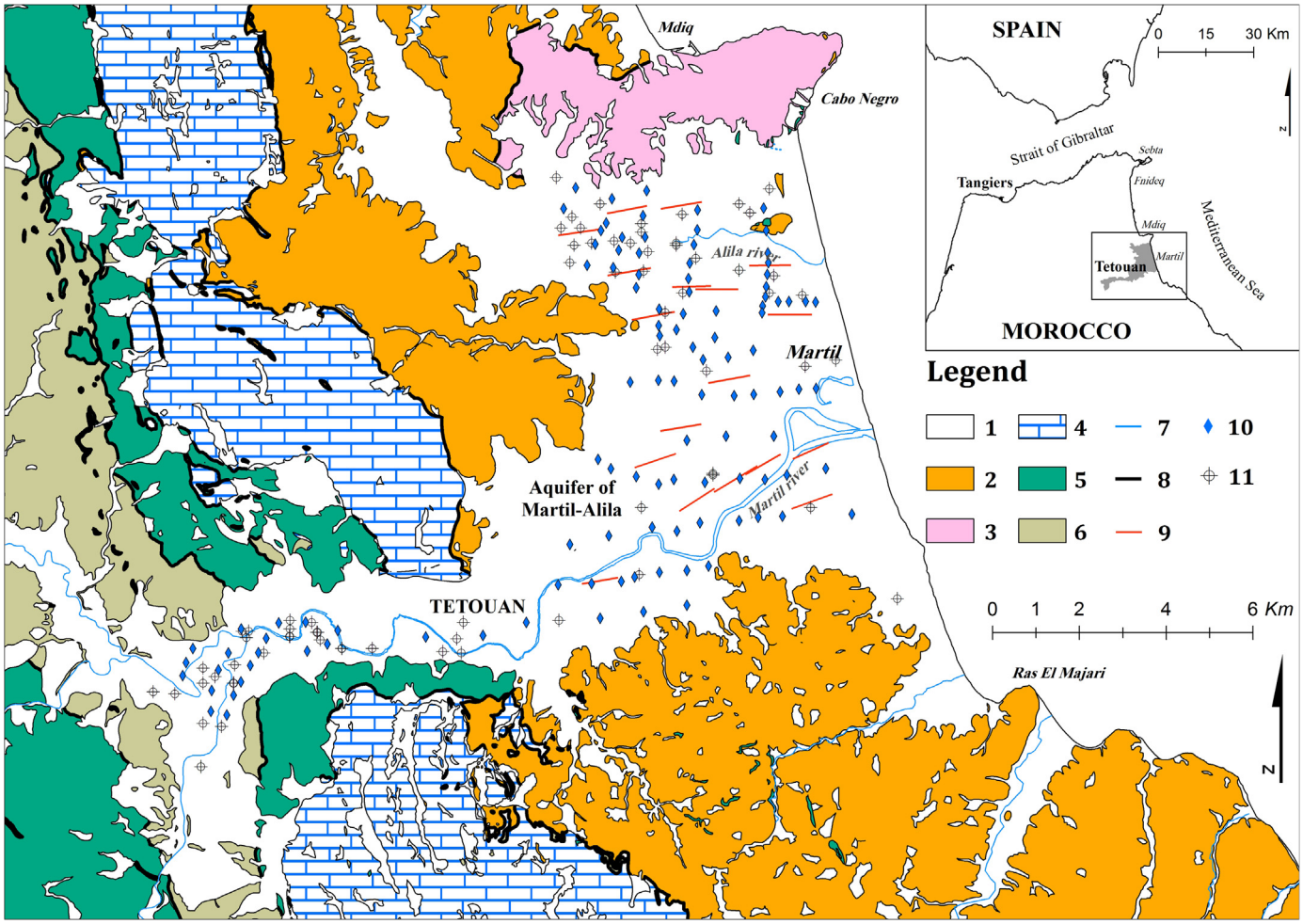

Fig. 1. Geographic situation, geologic setting of the Martil-Alila aquifer (modified from Kornprobst et al., 1985) and position of the field data used in the study. 1: Foreland; 2: Ghomarides; 3: Crystallophyllian basement; 4: Limestone chains; 5: Flysch nappes; 6: Intrarif; 7: Stratigraphic contact; 8: Fault; 9: electrical resistivity tomography; 10: vertical electrical sounding; 11: Borehole.

(administratively belonging mainly to territories of the urban communes of Tetouan and Martil) contains the most important alluvial aquifer in the area from quantitative, qualitative and strategic points of view.

The numerous public facilities throughout its watershed (dam construction, pumping, etc.) and the frequent rainfall variability has negatively affected the aquifer (piezometric decline, marine intrusion and quality deterioration). For these reasons, the principal goal of this study is to provide hydrogeological characterization of Martil-Alila aquifer and to assess the effectivity of different groundwater vulnerability methods.

1.1. Study area

Geologically, the study area belongs to the Rif Belt which forms the southern limb of the Gibraltar Arc, which itself is part of the larger Mediterranean Alpine belts. Within this context, Martil-Alila is a coastal plain, covering a surface of 100 km^2, crossed and drained by two rivers: Martil in the South and Alila in the North (Fig. 1). It is a plain of Plio-Quaternary alluvial deposits, with dominance of detritic sediments, particularly sands, gravels, conglomerates and clays which rest over a marly Paleozoic bedrock (Himi et al., 2017).

This alluvial deposits are filling a triangular geological depression that results from an extensive phase which apparently interrupted the continuity of the Calcareous Mesozoic Range, the Paleozoic "Ghomarides" complex and Flyschs nappes (Chalouan et al., 2008; Piqué and Bouabdelli, 2000).

1.2. Climatic setting

The study area is characterized by a Mediterranean tempered climate with dry summers and mild, moist winters. At the watershed level, the average annual rainfall is 700 mm approximatively and the annual average temperature is 18 °C. However, the mountainous aspect creates climatic sub-zones where conditions may diverge considerably from the general context. Thus, the average annual rainfall varies from 500 up to 1075 mm according to the geographical position within the watershed.

Trend analysis of annual and seasonal time series shows a rainfall increase since 1995–96 with frequent, intense and abundant rains causing violent torrents and floods unlike it was expected by previous scenarios based on the succession of extended dry periods during the 1970s, 80 s and first half of the 90 s. The 5-years rainfall analysis (Fig. 2) and rainfall anomaly charts (Fig. 3) report that same observation which suggest a rainfall increase in the upcoming years that could be reflected in runoff and aquifer recharge. Nevertheless, the historical records show the high probability of sudden and prolonged changes in the precipitation regime.

Therefore, seasonal rainfall variability in the Martil-Alila watershed is very significant mainly between winters and summers. Records indicate only 2% of the annual rainfall average in summers against over 42% in winters. In autumn and spring rainfall ranges between 24% and 30% (Table 1). The monthly rainfall changes significantly with trend of