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Isotopes and groundwater management strategies under semi-arid area: Case of the Souss upstream basin (Morocco)

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ABSTRACT

This study concerns the Souss upstream basin. The objective is to investigate the characteristics of surface water and groundwater, to assess the impact of artificial recharge as reinforcement of the natural replenishment and assess the renewal of groundwater under semi-arid area.

Two major water types are observed: (i) surface waters and upstream springs (least mineralized) and (ii) all groundwater samples (prevailing calcium and magnesium bicarbonate water type).

Water isotopes show a low evaporation of precipitations during infiltration. Impoverishment in heavy isotopes is the characteristic of mountain rainfalls, or of a climate colder and wetter than present. Carbon-14 activities (34–94 pmc) indicate a long residence time. The artificial recharge is low compared to the reservoir volume, due to which the renewal rate is also low.

1. Introduction

The Souss upstream watershed, situated in Southwestern Morroco, includes a plain which covers a surface extent of about 4150 km^2 and the Quaternary deposits form an aquifer that plays an important role in the economic and social development of the region. The climate is semi-arid to arid; it varies from humid to cold in winter on the summits of the Western High Atlas Mountain to the pre-Saharian to fresh in winter in the plain.

The rainfall presents a large spatial and temporal variability from 300 to 600 mm in the High Atlas to approximately 200 mm/yr in the plain. The average of potential evaporation ranges from 1400 mm in the mountains and near the Atlantic coast to 2000 mm in the plain.

The water balance of the Souss aquifer is irregular, because of the high climatic variability, but in recent decades, this balance has become in continuous deficit, due to the overexploitation of this aquifer, especially in its downstream part. The balance deficit of 160 Mm^3 predictable in 2000 was already reached at the wake of 1980, due to combined effect of drought and aquifer overexploitation. An artificial recharge of the groundwater is drawn from the Aoulouz dam. The rain water storage in excess periods allows regulating the temporal disproportion between the differences in water demand and those of its availability, preventing loss of water to the ocean, to avoid risk due to evaporation of water storage in reservoirs, to alleviate piezometric decreases and improve water quality. The use of artificial recharge from Aoulouz dam in the upstream part of the basin is due to geological conditions, high permeability and good water quality in this part of the watershed. The aim is to strengthen a share of the natural recharge, and thus to cope with continuing declines in water level and the risk of sea intrusion, and secondly to give effect to the dilution, waters being more mineralized in the medium and in the downstream parts of the watershed.

Indeed, physico-chemical data reported in the plain of the wadi Souss show a wide variation in space. In general, mineralization increases from upstream to downstream, very high at the coast and in an area near Oulad Taima (Hsissou, 1999).

Many studies (Boutaleb et al., 2000; Hsissou et al., 2002; Dindane et al., 2003; Krimissa et al., 2004; Bouchaou et al., 1995, 2005, 2008) were concerned with the whole Souss–Massa watershed and the summarized studies of the watershed. The studies demonstrated the mechanisms causing degradation of water quality in some areas of this watershed using the chemical and isotopic tools. They have also shown that most of the natural recharge in the watershed of Souss–Massa comes from the High Atlas, which receives a significant rainfall, especially in its upstream part. This article is a part of the broader issue of water in arid regions. It comes in addition to these studies. The originality is

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that it is particularly focused on studying artificial recharge as reinforcing of the natural replenishment in this part of the aquifer, which represents a recharge area, given to the high permeability and soil structure and the good quality waters in the upstream part of the watershed; to study the quality and renewal of water resources in this semi-arid region and to assist decision makers to prepare scenarios for water management in this watershed.

2. Geological and hydrogeological setting

The Souss valley (Fig. 1) is a part of the pre-African trench. It is a narrow fainting zone with recent sedimentary deposits, embedded between the High Atlas in the North and the Anti-Atlas in the South. Both the Atlasic domains are connected at a depth beneath the Souss valley in a complex manner, and are covered with thick detritic formations and calcareous marls of Plio–Quaternary deposits. These overlie a Cretaceous–Eocene syncline (Combe and El Hebil, 1977). The northern flank of this syncline largely, but only partly, outcrops the side of the High Atlas. The southern flank is seen as an alignment of hills in the middle of the valley. A general unconfined aquifer exists in the Souss plain, surmounting often one or many confined aquifers. As a whole it constitutes a multi-layered system, in which the unconfined aquifer represents the main groundwater resource.

The reservoir of the general unconfined aquifer of the Souss plain is made of formations of the valley deposits where we can distinguish at least 4 different lithological types:

(1) Souss formation: the most widespread in the plain. Its lithology is very complex; we can distinguish, nevertheless, three predominant facies (Dijon, 1969): (lacustrine, limestone–clayey and mainly calcareous marls) overlying a fluvio–lacustrine facies (sandy–sandstony and clayey) in its lower part.
The third facies is formed by more or less solidified conglomerates which constitute the near total of the formation, at the foothills of the High Atlas and toward the Eastern part of the plain. They appear as interbeddings reaching sometimes 10–15 m in calcareous marl and clayey sandstone series.
(2) Fossil beds of the wadi Souss: formed by sands, sandstones and gravels from old alluvium dating from the Quaternary.
(3) Sandstones and limestones: it is about conglomerates and sandstony and shaly limestones from the Agadir marine Pliocene, sandstone and dunes in the South of Agadir.
(4) Cretaceous outcrops in the plain: in the middle of the plain, in the Southern flank, hills of the Cretaceous syncline, the Turonian outcrops or under a thin cover, communicates laterally with the Plio–quaternary aquifer.

3. Climate overview

Due to its geographic position and its closeness to the Ocean, the study area is characterized by a semi-arid climate whose effect is relatively alleviated by the coastal oceanic influence.

We have used data from the Aoulouz and Taroudant weather centers, which are located in the study area and which possess a series of more complete data. The examination of a rain series from 1969 to 2005 (Fig. 2) shows that dry years (rainfall below average) outnumber humid and normal years. Rainfall is characterized by spatial and temporal irregularities; the Aoulouz raingage rainfall

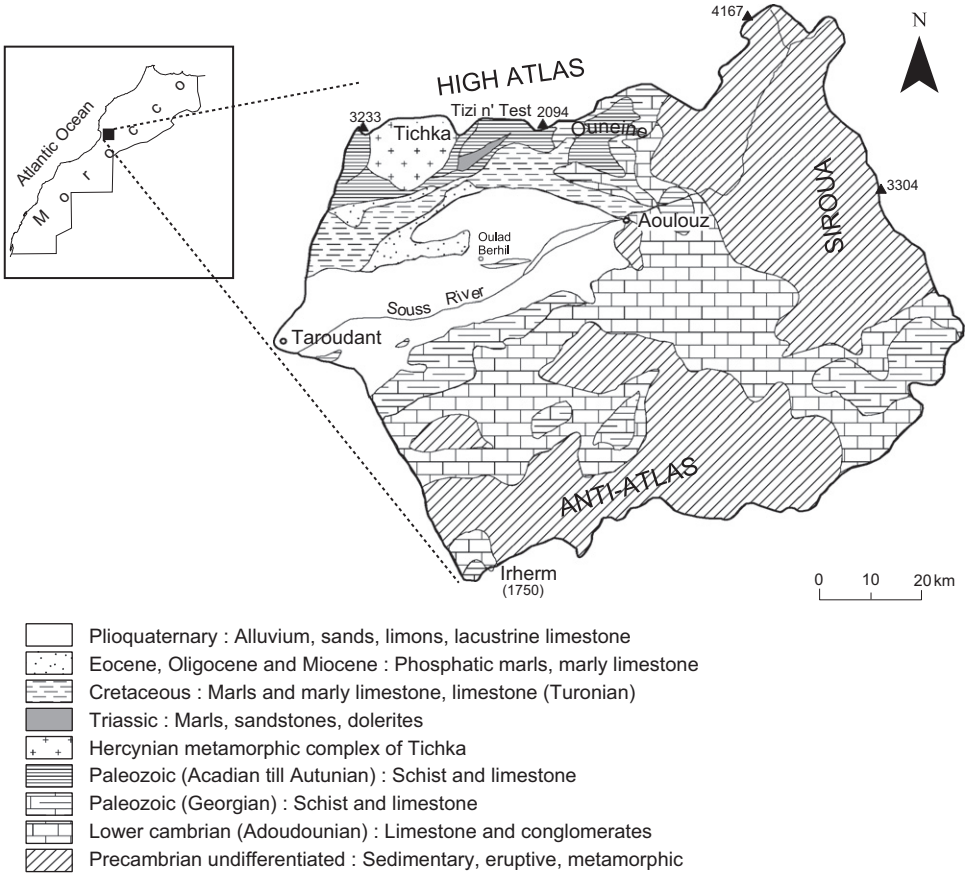

Fig. 1. Location and geological map of the study area.