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Salinization of Soils and Aquifers in Morocco and the Alternatives of Response †

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Abstract: The agriculture sector in Morocco contributes significantly to the economic development of the country; however, this sector faces several challenges. One of these important challenges is the increasing level of salinization in soils and groundwater. This has a strong impact on food security by reducing agricultural yield. The origin of salinization is usually due to marine intrusion in coastal areas, dissolution of saline aquifer rocks and infiltration of poor-quality irrigation water in the case of groundwater. In the case of soils, it is caused by irrigation with poor-quality water in poorly drained soils, and by evaporation of the water of shallow groundwater, which leads to a saline concentration in the surface layers of soils, as well as 'other' origins. Thus, many regions of Morocco are affected by this phenomenon, especially arid and semi regions with a low rainfall rate. Among the existing alternatives to contain this challenge in Morocco and in the arid and semi-arid regions in particular is the use desalination of sea water and biosaline agriculture. The adoption of the first option aims at the preservation of local production and adaptation in the context of scarcity of water resources and low quality of water for the second. The goal of this review is to present an update of the state of the salinization of Moroccan soils and aquifers and the potential alternatives to respond to these challenges.

Keywords: salinization; aquifers; soil; biosaline agriculture; water desalination

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1. Introduction

The degradation of groundwater and soil quality as a result of salinization is an increasingly worrying concern. Today, on a planetary scale, the world is losing about 10 ha/min of agricultural land and salinization accounts for 30% [1], which is 1 to 2% of irrigated land per year [2]. This is especially observed in semi and arid regions [3], where the intensive use of water resources leads to strong evaporation causing salinization of soils and groundwater [4].

This problem is also observed in Morocco, a country heavily dependent on agriculture, as it represents 19% of GDP [5], and accounts for 1/3 of national employment [6], and where the groundwater quality is very deteriorated (more than 44% is of poor quality) [7]. It is estimated that about 0.5 million ha of agricultural area is affected by salinization [8], which is 160,000 ha of irrigated areas [9]. The causes of salinization are varied: marine intrusion in coastal areas as a response to overexploitation of groundwater [4], dissolution of aquifer rocks through which water flows, or anthropogenic contamination of agricultural origin [10]. For soils, the use of saline water for irrigation is one of the main causes of salinization. In regions where the aquifers are shallow and where the waters are salinized, the rising water from the aquifers also causes soil salinization [1]. Soil salinization has been a problem of study for several years, because it is known to affect the yield of the

production of different types of crops [1]. In response to the problems of salinization of water, of soil and water stress, in semi and arid regions, such as Morocco, it resorts to biosaline agriculture and water desalination (sea water or brackish) [11]. These fall within the scope of Moroccan Water Supply Management Strategies and Water Demand Management Strategies, to adapt to environmental constraints, such as the salinization of aquifers and soils, water scarcity and the increasing water demand.

The methodology consists of reviewing the studies carried out at the spatial scale on the salinization of aquifers and soils in Morocco, determining the causes of salinization, presenting the solutions of responses to these problems as well as the possible impacts that generate these solutions.

2. Salinization of Aquifers in Morocco

The salinization of aquifers can be of natural (geological) origin, by water-rock interaction, or artificial as seen in irrigation areas. It can also be of mixed origin (natural and anthropogenic) in coastal areas where overexploitation of groundwater causes marine intrusion [3]. In Morocco, in the continental zone, most aquifers are naturally salinized (by aquifer rocks) [12]. In the coastal zone, the Moroccan coastal aquifers are among the aquifers that have experienced very high salinization by marine intrusion following the overexploitation of groundwater [10]. Two regions affected by salinization are presented: Triffa (eastern Morocco) and Foum El Oued (southern Morocco).

Case of the Triffa aquifer (eastern Morocco) [13]: the Triffa plain represents the largest irrigated perimeter of the Moulaya's basin and where the main crops grown are citrus fruits [14]. The use of the region's underground water resource is dedicated to irrigation and drinking water supply. With the expansion of the irrigated perimeter for large hydraulics, groundwater in the region has been greatly exploited. This leaded to a deficit in the water balance (-32.3 Mm^3/year) in 2010 [15]. The plain has also experienced, in the past, periods of drought which have caused a strong exploitation of groundwater, and which have caused the deterioration of water quality. A study of the expansion of salinization in the aquifers of this plain showed that a good part of the aquifer is salinized following the dissolution of the aquifer rock, and where salinity values of 6g/L and 10,000 µs/cm of conductivity were observed.

Case of the Foum EL Oued aquifer (southern Morocco) [16]: this is one of a case of salinization of coastal aquifers in Morocco. It is located in limestone formations from the Cenonian and detrital from the Plio-Quaternary. The water from this aquifer is the main hydrogeological source which ensures the various supplies (agricultural, industrial and drinking water supply) of the Laayoune region. Population growths, strong agricultural activity, the nature of the Saharan-type climate increase the demand for water and lead to the overexploitation of the aquifer. Following overexploitation of the aquifer, the bevel (freshwater and saltwater interface) leans towards fresh water which therefore implies the intrusion of sea water into the aquifer. The dissolution of the aquifer rock was also a cause of salinization. The conductivity measurement shows an increasingly significant gradient towards the coastal study area.

Many studies have been made on the salinization of continental (Tafilalet [17], plain of Bahira [10], etc.)and coastal (coastal chaouia [18], Doukkala [19], Chtouka-Massa [20], Mnasra [21], Essaouira plain [22], etc.) aquifers of Morocco. All of these studies conclude that the salinization is due, in the coastal areas, tomarine intrusion, natural salinization in the continental areas and human participation in irrigated areas.

3. Soils Salinization in Morocco

Soil is an interface in the environment and also a fundamental natural resource for development [23]. It forms very slowly from the geological materials of the earth and is the loose part of the lithosphere. On the other hand, it degrades very easily in the event of indiscreet and unreserved use. It provides several fundamental functions, such as the food function, the filter function and the biological function.

Today, with population growth, the soil is subject to inappropriate use and intensive exploitation for increased agricultural production. This aggravates, modifies and deteriorates the natural state of the soil, and therefore the fertility. Salinization is one of the forms of soil degradation. It consists of a high accumulation of salt in the soils which impact negatively the agricultural productivity of the soils [24]. A soil is said to be saline when its electrical conductivity is under normal conditions exceeds 4Ds/m or 2g/L [25]. In Morocco, it is observed in almost all the irrigated perimeters of hydraulic basins (Table 1); and it affects more than half of the perimeters in certain basins (Tafilalet, Ouarzazate). It is favored by the arid climate, agricultural intensification and excessive use of chemicals (fertilizers) [7].

Table 1. Salinization in irrigated perimeters in Morocco [8].

Irrigated Area	Area Affected by Salinity, (×1000 ha)	Percentage of Irrigated Area
Gharb	15.0	12.5
Low Moulouya	30.2	27.7
Haouz of Marrakech	24.6	29.9
Tafilalet	20.9	70.4
Ouarzazate	14.5	65.9
Tadla	19.3	24.5
Doukkala	0.6	1.0
Souss Massa	9.8	28.8
Loukkos	2.8	14.5
Bahira	21.0	22.8
Total	158.7	

4. Possible Alternatives of Response to the Aquifers and Soils Salinization

Several alternatives are recommended depending on the hydrodynamical conditions of the regions to mitigate and to overcome the problems of soil and aquifer salinization. For aquifers, M. S. Hussain, and al. gathered several of them [26] such as artificial recharge from surface water or treated wastewater, the reduction of water pumping, the establishment of physical barriers in the coasts (underground as an underground embankment, surface as the extension of the continent towards the coast), abstraction of brackish water, monitoring of marine intrusion, combined techniques, etc. For soils, we have drainage, leaching, the development of saline or salinity-tolerant crops, etc. [27]. However, the problem for this is, in arid and semi-arid regions (such as southern Morocco) where water resources are increasingly scarce and the soils threatened by desertification, some of these alternatives are difficult to employ. For example, artificial recharge cannot take place due to water scarcity (average rainfall of 200 mm/year [12]) and high demand; reduction of pumping without an additional water source; physical barriers are very expensive; leaching and drainage cannot take place without enough quantity of water; etc. In Morocco, two of these alternatives are now expanding: biosaline agriculture (BA) and seawater desalination (DS). (BA): Due to the impact of salinization leaving soils unvegetated or poorly covered, BA has therefore emerged as an alternative option [4]. It was introduced in 1997 by the IAEA (International Atomic Energy Agency) via a project in collaboration with INRA (National Institute of Agronomic Research) and ORMVA (Regional Office for Agricultural Development) of Tafilalet [28]. This first test study was carried out in Aïn El Atti, where 11 species of trees and shrubs, notably Ecalyptus camaldulensis and Atriplex lentiformis, were irrigated with highly salinized water (10 g/L). The results showed good salinity tolerance and good crop growth [29]. Other studies were conducted in other regions impacted by salinization. For example, the case of Foum El Oued where soil and water

are salinized, alternative species are tested, such as Quinoa, Pearl millet, barley, Panicum Blue, etc., and have shown very high tolerance to salinity [28]. DS: Water salinization is observed in most hydraulic basins of Morocco. However, it is more observed in the southern regions (Souss Massa, Draa-Tafilalet, Oued Ed-Dahab-Lagouira, Laâyoune-Sakia El Hamra), which are arid with important agriculture activities. The region of Souss Massa alone provide 90% of the national export of fruits and vegetables [30]. Thus, the groundwater in this region is excessively exploited to respond to the high agriculture demand and lead to salinization by marine intrusion in the coastal zone [31]. DS for irrigation (of approximately 15,000 ha) of crops with high added value, although expensive, was the alternative chosen by the state and in agreement with the farmers, to deal with the scarcity of water, to preserve it and to ensure the agricultural productivity of the region. The use of seawater here explains the precariousness of freshwater resources (even brackish) in this region. Otherwise, desalination of groundwater and brackish surface water is more advantageous than desalination of seawater. The disadvantage of desalination is the costs (energy and maintenance) it generates. This can be offset by good irrigation practice (localized irrigation), by PV supply which is very competitive and also desalinated water can be mixed with marginal water before irrigation.

With these alternatives, salinized soils and waters are therefore exploited and not abandoned, to maintain productivity and the local economy satisfy water demand and preserve aquifers. The expansion of these alternatives could even have a great impact on the economy of the country. Nevertheless, a combination with other alternatives will contribute more. Among the combinations we have the one proposed by Hussain et al. [32] which is the abstraction of brackish water, its desalination, its use (potable water or in irrigation) and the treatment of wastewater for the recharge of aquifers. The advantage of this is that it allows not only to ensure a hydraulic gradient towards the sea and to preserve the aquifers, but it allows increasing the piezometric level of the aquifers.

5. Conclusions

Morocco as an arid and semi-arid country, the deterioration of the quality of its soils and aquifers following salinization continue to be a very worrying problem. Freshwater resources being scarce, the demand being increasing especially for agriculture, the adequate alternative is to use saline water either by using it directly for salinity-tolerant crops, or by proceeding on desalination and maintaining the production of traditional crops. This was therefore the case of many successful projects in Morocco. Biosaline Agriculture is important because it allows the use of water resources with lower quality, to adapt to local climatic conditions, to use salinized soils for the development of halophyte crops (local and introduced species) and to preserve the groundwater resource against overexploitation. In fact, it contributes significantly to food security and in insuring income for rural in arid and semi-arid regions. However, there is a need to encourage research and extension programs concerning new/local crops that showed a higher potential of productivity under salinity and water scarcity conditions. The desalination of water for irrigation, combined with a sustainable irrigation strategy (such as drip irrigation), allows preserving the know-how and the local economy. The extension of these solutions could have a great impact on the problems of water stress, demand management, desertification, maintaining agricultural productivity (with high added value), maintaining employment and other environmental constraints. It can be also a progress for the framework of the 2030 SDG agenda. However, a combination with other alternatives will have more impact to these challenges.

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