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Natural resources management in Southern Tunisia: sustainable exploitation and degradation issues of the oasis agro-systems

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ABSTRACT

In Southern Tunisia, as in the major part of agro-based countries under arid and semi-arid climate, the growing water dependent-economies, the increasing scarcity of freshwater resources amplified by the frequent dry climatic episodes and the continuous aquifer decompression define huge challenges for sustainable agricultural development. Multiple environmental issues have been observed related principally to natural resources degradation. Besides to the ecological value, the decreasing of agro-systems production has crucial social, economic and health repercussions. Thus, the present study aims the assessment of the sustainability of different natural resources in the oasis lands, the principal agro-system in southwestern Tunisia. The collected data from field investigations and farming surveys have been completed by analytical laboratory work and literature review. The obtained results indicate that groundwater resources are highly mineralized with doubtful to locally unsuitable quality to be used in irrigation according to the different calculated ionic indices (EC > 3,000 μs/cm; SAR from 6.7 to 9.5; TH between 48 and 69; PI from 46% to 58%) suggesting severe recommendations to be used especially for long term irrigation. The physico-chemical analyses of the soil samples highlight, furthermore, the progressive degradation of these agricultural lands characterized by high EC values above 3.6 and 5.8 mS/cm threatening the safe production of many crop yields. In addition to the difficult natural conditions, farming practices are the most influential factors governing the distribution of water quality related issues and soil hydrodynamic and physico-chemical proprieties. A comprehensive flexible adaptation management measures are required in the study area as the degradation issues have reached tolerance limits of different ecological systems and many irreversible alteration have been observed. These strategies should be evaluated as a shared task between the different parts relative to water consumption and agro-based activities

Keywords: Water quality; Irrigation; Oasis agro-systems; Soil degradation; Southern Tunisia

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1. Introduction

Sustainable agricultural development relies on appropriate farming practices, a flexible adaptation to the unpredictable variability of weather conditions and an optimal exploitation of natural resources inhibiting overexploitation and degradation issues. However, on a large parts of the agro-based regions, and especially, in developing countries, the expansion of agricultural activities and the increasing dependency on agro-related products, and activities reveal great awareness about the decreasing productivity of these systems related principally to the progressive alteration of soil and water resources.

In Tunisia, the agriculture activities is the principal economic activity supporting social and economic pressure especially in the southern and southwestern provinces where the production of date palm, namely Deglet Nour variety, constitutes the principal source securing the livelihood of the local residents. In fact, in Tozeur and Kebili regions (SW Tunisia) the annual agricultural production of date is more than 260,000 tons representing more than 90% of the total agriculture production in the main oases of Southern Tunisia [1–3]. The total cultivated lands are about 54,000 ha of which 60% are devoted for the production of Deglet Nour variety [4] that has the highest value of quality all over the world according to Food and Agriculture Organization reports.

The growing agro-related investment, given the harsh climate conditions and the lack of perennial surface water (less than 15% of total surface water resources) [5], is challenged by quasi-perennial annual water deficit and frequent intra-seasonal dry periods [6]. Thus, the cultivated lands require constantly a volume of water to maintain humidity in the oasis system, which is permanently supplied by groundwater resources in the area represented by the multi-layered SASS (Système Aquifère du Sahara Septentrional) resources [7–9]. Indeed, the increasing expansion of these agro-systems has induced, in the last decades, a continuous loss of the hieratical regional landscape intensifying alteration of natural resources. The multiplication of the uncontrolled private cultivation network, associated with the lack of systematic monitoring of the physico-chemical proprieties of irrigation water and agricultural land and the inappropriate scheduling of the applied water volume delivered to the cultivated crops are, according to the previously published works (Carr [10]; Sperling et al. [11]; Al-Muaini et al. [12]; Alotaibi and Schoenau [13]; AL-Omran et al. [29]) the key factors altering the healthy ecological functioning of the region [9]. The cumulative impacts of the "mining behavior" on natural resources (soil and water) have resulted in a progressive reduction of loss-to-benefit ratio of agricultural development. These high risks of ecological-economic unbalance, threaten food security, social livelihood and poverty ratio in the study area. Thus, fruitful management measures should be applied that requires a baseline study assessing the evolution of these natural resources with respect to natural features and in response to the continuous exploitation. In this context, this paper focuses on the main challenges facing agriculture sustainability in SW Tunisia related to water quality issues. It evaluates, furthermore, the appropriateness of farming practices and the efficiency of the adopted management actions. It highlights, moreover, the required management plans according to farmer's knowledge, and scientific-based results.

2. Site description

2.1. Study area

The study area, in SW Tunisia (Fig. 1) characterized by hot arid climate [14]. It represents a restricted region between the sandy dunes of the Great Oriental Erg in the South and the contemporaneous salt environment of Chotts depressions (Gharsa, Djerid and Fedjej) in the North. Some geomorphic features that give a desert outfit. The region undergoes progressive degradation resulted from different factors of which the weather conditions play a leading role. In fact, the rainfall is scare and irregular with an average of about 50 mm [3,15] that may reach 100 mm during extreme events. The region is characterized by elevated temperature (exceeding 45°C and 50°C during the summer periods) and by high evapotranspiration of about 1,800–2,600 mm.

In contrast with these arid aspects, the oasis agro-systems maintain the ecological value of the area and contribute to national and regional economic dimension. Thus, the conservation of the fertility of agricultural lands is of paramount importance for local residents as well as for national agricultural and agro-industrial stakeholders. This conservation requires appropriate farming practices and efficient institutional, engineering and technical management and financial support. In the study area, since late 1990's, various management plans have been adopted at national and regional scale however different forms of degradation have been reported from scientific committee and local residents namely decreasing land productivity and water suitability for irrigation purposes. However, the old school farming techniques and the increasing of agricultural illicit farms constrains the fertility and the productivity of the cultivated land leading to a progressive abandonment of oasis (Dhaouadi et al. [16–18]; Besser et al. [19–23]). To evaluate the main purposes behind this loss of fertile lands, this paper tries, by a reviewof published data, institutional annual report, sampling campaigns and analytical laboratory work (soil, water, etc.), to outline the relevant challenges in the study area related to natural resources availability and exploitation to facilitate the analysis of the feasible options for improving resources exploitation and maintaining the sustainability of these agro-systems.

2.2. Methodology

This study has involved three major phases:

- *Literature review and data collection*: the review of previously published data is of crucial importance for assessing the evolution of the natural resources statement in the study area. Different types of data have been analyzed (published data and internal unpublished annual and monthly reports. This review is completed by a field survey and discussion with local farmers. This analysis is required for a participatory shared management

Fig. 1. Localization of the study area (Dhaouadi et al. [24]).

task. The adoption of the commonly known indigenous knowledge of the population in rehabilitation programs facilitates social acceptance and make the procedure easier and faster. The field investigation was carried out to collect soil and water samples from different agricultural lands and deep water wells across the study area.

- *Samples analysis and laboratory work*: the collected samples have been carefully packed, and transported to the laboratory.
- *Data treatment and interpretation*: the obtained data from field investigation, literature review and laboratory analyses were treated using different software namely ArcGis 10.4; Excel 2016; diagram 5.6; Aquachem, etc. The aggregation of this multi-sources data for accurate proofreading of the management strategies.

3. Ecological impacts of agricultural activities/Land degradation evaluation

The effects of man-induced activities are closely linked to the viability water-agricultural system (water availability at sufficient quantity and valuable quality for agricultural practices) related principally to the vicious cycle between land degradation and poverty. In this study area, since early 2000's, a national awareness has been emerged about the potential risks of loss of soil fertility due to some farming practices and irrigation techniques. Thus, various types of individual and public engagement have been adopted. Despite their partial efficiency, reliable statistical data were available and non-systematic monitoring was performed in an active way to bring out synthetic results. However, since the revolution of 2011, uncontrolled expansion of agricultural land coupled with unavailable data for private owners and illegal agricultural projects amplified management issues as no reliable database for these new created zones was made and especially, the creation of these oasis systems are without any administrative or scientific-based relevance. All these factors coupled with natural conditions lead to continuous loss of soil fertile of an average 1.25 ha/y according to Besser et al. [19]. The spatial distribution of these issues across the study area shows an important heterogeneity ratio that may be explained by several factors (enablers and constraints) emerging from field observations and investigations namely the inequality in access to soil fertility replenishment technologies [3,8]. This variability defines social conflicts related to the progressively observed divergence between producers able to invest in soil fertility replenishment and the major part of producers who are unable or unwilling to make such investments. They are therefore unable to sustain the quality of their farm land and enter a vicious cycle of decreasing productivity and incomes (unsustainable natural resources security) [12].

In addition to rehabilitation and amendment techniques, irrigation scheduling and water distribution calendar may deeply influence the loss of soil fertility and decreasing land productivity or at least reducing the quality of the cultivated crops. In fact, irrigation water security is one of the major constraints to livelihood improvements and socio-economic development in such agro-based region. The

irregular distribution of irrigation water and the inappropriate agriculture practices define costly system of providing water through conventional irrigation scheme. The frequent breakdown and rupture of distribution inhibit safe plant growth via modification of physiological crop proprieties and (or) soil pores sealing via important evapotranspiration of interstitial water leading to frequent gypsum crusts.

3.1. Issues challenging the sustainability of agriculture in the study area

Despite the multiple efforts made for securing safe permanent production of oasis agro-systems in southwestern Tunisia where the date palm cultivation is the major socio-economic activity, numerous environmental issues are observed and their cumulative impacts seem to reach progressively unrecoverable ecological level of pollution and mismanagement [9,26]. These key strategic changes appear in different ways as a result of complex picture of interrelations of natural cycles and socio-economic factors [3]. Some of these problems are discussed in the following sections.

3.1.1. Released water quantity

The abstraction from deep confined and semi-confined groundwater aquifers, the Continental Intercalaire (CI) and the complex terminal (CT), to meet agricultural supplies has reached higher levels of exploitation that are often superfluous [7–9,27]. The annual abstraction rate has exceeded 250% in Kebili region where it was of 90% for Tozeur region defining a quasi-permanent situation of overexploitation of deep low renewable groundwater resources. This situation threats the sustainability of these resources barely rain fed under present day conditions. Besides to the availability of these resources for long term use, the ineffective use of the released volume is manifested by the important ratio of efficient irrigation to loss to evaporation and drainage runoff since the applied quantity exceeds the real water requirements of the irrigated crops [2,3]. In fact, the water quantity distributed for date palm is more than 20,000–30,000 m^3/ha [28]. However, according to a number of scientific-based estimation in different countries, the real need defining effective consumption for safe date palm production range between 12,000 to 18,000 m^3/ha [29]. This surplus has undoubtedly, various environmental impacts. It induces progressively water logging problems due to the platitude to the oasis land the proximity of Chotts depressions with regard to the insufficient drainage. The high evaporation rate enhances salt precipitation and accumulation in the cultivated land surface which leads increasingly to soil salinization and reduction of water infiltration by progressive formation of gypsum crusts [7–9,27].

3.1.2. Distribution of water for irrigation is variable and irregular

The spatial and the temporal variation of irrigation scheduling have adversely impacted on the production and on the growth of the agricultural products. In fact, if the date palm is adapted to long drought conditions, the variation on the other cultivated types such short periods of water stress can have a serious effect on crop yields if occurring during water sensitive development stages [30].

Furthermore, with regard to the irregular distribution that may exceed three months of drought and the tower-irrigation method, the cumulative irrigation duration is about continuous 15–40 h. Many ecological impacts are induced by this mismanagement. In fact, besides to water lost to evaporation, and water logging issues, the increase infiltration in the sandy loam soils reaches the new formed oasis aquifer [2,3,27]. The increase of piezometric levels in these shallow aquifers, generally characterized by poor water quality (TDS between 8 to 19 g/L) has adverse impacts on soil structure and soil fertility via a development of frequent gypsum crusts in the deep soil layers and reducing soil aeration and water infiltration. The data from soil analysis indicate that soil salinities are between 3.6–5.9 mS/cm in different investigated oasis (Fig. 2). These issues are amplified by the uncontrolled expansion of agricultural lands for private owners.

Additionally, the agricultural land is progressively mined on soil fertility, soil structure destroyed by compaction and combustion of organic material and topsoil through soil erosion. The above points-out the necessity to address water constraints together with soil fertility constraints. It also suggests that the different water management technologies which lower the risks for crop failure can function as

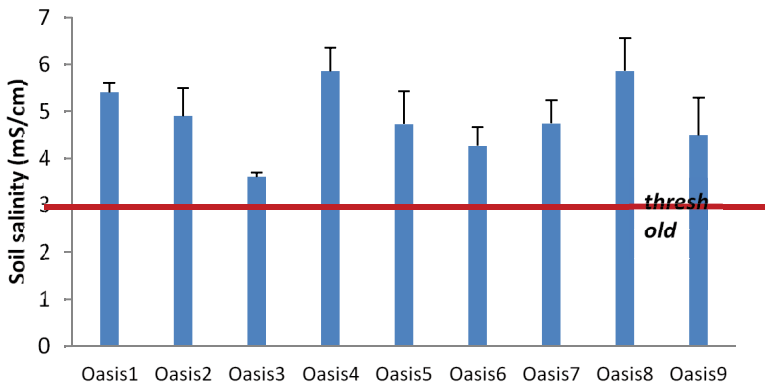

Fig. 2. Soil salinities.

an entry point for successful efforts of increasing investments in land productivity [30].

3.1.3. Leaching issues

The irregular distribution of irrigation water coupled with the old school irrigation technique and the insufficient drainage system result in continuous leaching of the oasis lands. These high mineralized waters are enriched by the trace elements concentrations relative to the used pesticides and fertilizers (triple superphosphate $Ca(H_2PO_4)_2$, potassium sulphate (SOP) and ammonium nitrate NH_4NO_3, etc).

Unfortunately, until present there is no reliable evaluation of the runoff volume released to the environment which may be used as a supplementary alternative to overcome water shortage periods. Indeed, the continuous decrease of conventional freshwater resources highlights the importance of the unconventional water resources in supporting agriculture water needs and in maintaining safe production of oasis system [31].

Additionally to the lost volume, the released runoff without preliminary treatment adversely impacts the ecological system of the region (Fig. 3). On the basis of the obtained data from drainage water analysis, the salinity of these waters varies from 12.5 to 26.8 mS/cm. This pollution has incurable effects because the salinity concentrations of soil around the drainage stations are very high (30–43 mS/cm).

3.1.4. Old school irrigation methods

The used irrigation techniques in these oases are traditional and they are based on flood/ basin irrigation via tower system. This technique has some negatives impacts on soil productivity and on resistance of the cultivated types [3,27]. It induces, a continuous water lost to evaporation and hinges on discharge of the excess of irrigation water on the Sebkhas, Chotts and (or) in other infertile lands. It creates as well new formed oasis aquifer just few meters below the surface inducing changes on soil structure and reducing water infiltration and soil aeration (Fig. 4). It enhances additionally the leaching of the different pollutants at the oasis surface leading, often to diffuse contamination of the groundwater resources fed by runoff of irrigation water [2]. This type of contamination as it is represented by multiple sources and large dispersion across the agricultural lands, seems to be difficult to manage. Thus, remediation efforts are limited to periodic physic-chemical characterization of these resources.

Fig. 3. Runoff release in the study area.

Fig. 4. Irrigation system and irrigation network in some agricultural land in the study area.

3.1.5. Irrigation water quality

The agricultural lands from oasis and greenhouses are irrigated principally with waters from deep confined and semi-confined CI and CT aquifers embodying low renewable resources under present-day conditions. The analytical data indicate that the salinity of these waters has exceeded 4–5 g/L reaching locally 20 g/L at Djemna area. These waters are classified as high mineralized saline to brackish waters with important permanent hardness ratio. These waters are unsuitable to be used in agricultural according to the commonly used quality indices namely EC > 3,000 μs/cm; SAR from 6.7 to 9.5; TH between 48 and 69; PI from 46 to 58% (Fig. 5).The continuous use of these waters induce, undoubtedly, growing issues of soil salinization, alkalization and permeability loss. However, the quasi-permanent water deficit and the frequent water shortage periods give less concern to query on the quality of water used for irrigation. In spite of the numerous works previously published indicating that these waters are unfit for agricultural activities and that the continuous irrigation with these resources of the poorly evolved soils and GYSOILS of southwestern Tunisia induce a progressive abandonment of the cultivated lands, management efforts and rehabilitation measures have partially been adopted without any effective evaluation at farm scale. Indeed, for such dynamic issues, policy responses to address water quality issues in agriculture need to be part of a policy package that encompasses water issues, soil fertility, land productivity, climate adaptation, social livelihood, economic value and a range of policy instruments institutional reforms and broader community engagement (Fig. 5).

3.1.6. Limited conventional water resources/Challenges for sustainable aquifer exploitation

In the agro-based regions of highly arid environment such as Southern Tunisia, the extreme water stress is amplified by the limited potential of the low renewable groundwater resources. Increasing exploitation of these reservoirs for decades have resulted in a huge reduction of the available resources. In fact, despite the huge stock of SASS aquifers covering more than one Million of km^2, the recent recharge of this multi-layered aquifer system reaches barley the 2.5% of the total volume of aquifers. The distribution of fresh water flows is, furthermore, irregular and unequal [27,29] while the exploitation exceeds 100% and reaches locally 200% in some localities of Kebili region. Correspondingly, the number of the pumping wells has increased from 2000 to 14000 water wells in less than five years of which more than 80% are private wells without any reliable assessment neither of their spatial implementation nor the abstracted quantity. In consequence, the water table in these aquifers has fallen by an annual average of 100 m in the last decades [8,26]. Aquifer decompression and local land subsidence issues were recorded by the local residents and scientific committee. Indeed, the "mining behavior" without resource-use balance consideration threatens the sustainability of these waters. The lack of governmental and institutional supervision network is the principal cause leading to this alarming situation of continuous reduction of agricultural productivity of these cultivated lands [3,26,29].

3.1.7. Uncontrolled use of energy

Besides to the loss of fresh water resources, the study area is characterized by uncontrolled use of different types of energy. The first is related to the heat loss from deep confined hot water of the CI aquifer. This aquifer has an average mean of temperature of 50°C that exceeds in some wells 85°C. However, the use of the traditional atmospheric cooling system permits the exploitation of these waters at appropriate temperature without conservation or recovery of the lost energy to the atmosphere (Fig. 6).

The second type is linked to the uncontrolled use of solar and wind energy for water pumping. Unfortunately, this project is one of the most important ecological scheme

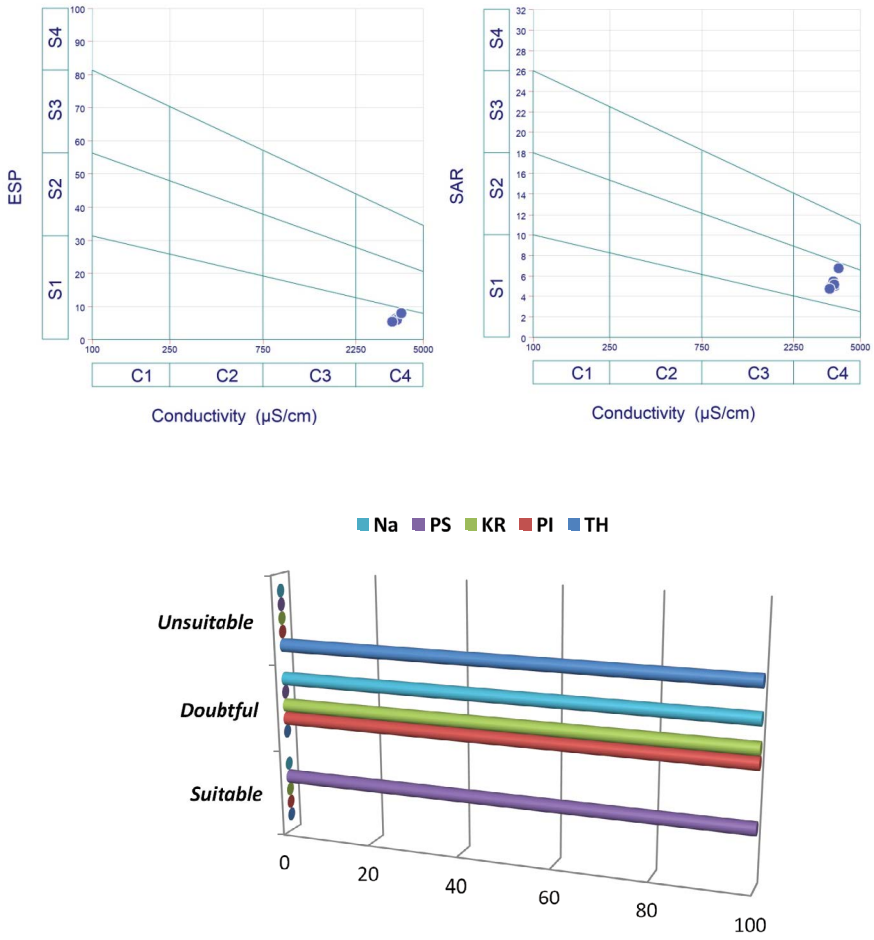

Fig. 5. Water characteristics.

Fig. 6. Use of solar energy in the study area.

in North Africa however the mismanagement and the lack of institutional and governmental supervision and systematic control has resulted in inappropriate use of these renewable energy to lead to irreversible environmental impacts of natural resources exploitation. In the quasi-total areas of the project, the instrumental implementation are relative to local residents and private owners associated with water well used for irrigation. Thus, the free use of these resources lead to uncontrolled abstraction from water wells largely above the recommended requirements

of the cultivated crops. This situation is commonly observed in the study area leading to both continuous water loss and increasing soil infertility [3].

4. Discussion

In the study area, the ecological-economic unbalance has conducted to various environmental issues that are reaching the maximum tolerance limits of the quasi total ecological systems. Indeed, the natural conditions and the physiological features of the region constrain the safe development of agriculture activities and sustainable freshwater resources. At the same time, management issues have a great part on the degradation that has been reached. In fact, according to field investigation and the analysis of the collected data human, the lack of monitoring, vulgarization, information diffusion, institutional support, and especially governmental supervision and legislative control are the main reasons on behalf all these issues. The important number of illegal water wells (twice or three times the public legal wells), the expansion of private oasis lands, the open access to different alternatives of energy without control raises the inequality accessibility between different farmers, creating unbalanced competition on the one hand and reducing the optimal long term exploitation potential of natural resources. The review of rehabilitation measures indicates that there is quite a set of scattered development efforts on water management, but seemingly little research on the viability of the systems within the context of framing system. The Baselienn study for management has to be conducted on farm addressing different scales and address the system related issues above with regard to the equitable, efficient and sustainable use of different environment resources (Table 1 and Figs. 7 and 8).

Among the principal factors and measures of primary importance to be adopted in the study area, water quality and water productivity or water use efficiency. Thus, to get a fruitful natural resources management for sustainable development, a careful understanding of the principal key factors governing these major parameters is required as giving by the following points;

- Water quality used for irrigation should never be an isolated effort within a farming system. It should instead rather be seen as a catalyst to improvement a modernization of production systems. Indeed, to control the main entry point is essential for reducing risks for abandonment of oasis, to evaluate the uncertain degree of potential investment for unconventional water resources and more updated irrigation technique. The management of these resources requires increased emphasis on site specific manageable techniques precisely adapted to each location. Accepted approach towards the formulation of policies for development and natural resources management for mitigating land use and its impacts on water and soil resources. These policies must necessity be species and site-location specific.
- The opportunities of increasing efficiency of water use in agriculture, especially for date palm with special focus on the reuse of the available non-conventional resources for more reasonable management of groundwater resources using more effective irrigation system such as micro-irrigation which still limited under the palm trees in Tunisian oases. It requires, in addition, field experiences for the evaluation of the impacts of water quality from unconventional resources on the development of date palm and on crop yield (nutritive value).

The above points-out the necessity to address water constraints together with soil fertility constraints. The different water management technologies lowering the risks for crop failure can be used as an entry point for successful efforts of increasing investments in land productivity. This requires a rehabilitation of managing policies on real adapted responses to access the best available science-based evidence and operate in an open and transparent manner to regain confidence of local farmers which is of paramount importance to create a framework for a coherent and a valuable work

Table 1
Water and soil resources characterization in the study area

Ecological factors	Water resources			
	Overexploitation	Water quality	Pollution	Surface water
Oasis of Kebili	6.73% exploitation of shallow aquifer	TDS > 19 g/L	Petroleum contamination	Non-perennial
	164.96% exploitation of CT aquifer	>4 g/L	Nitrate contamination	
	218.38% exploitation of CI aquifer	>5 g/L		
Oasis of Tozeur	85.65% exploitation of shallow aquifer	>8 g/L	Nitrate contamination	Non-perennial
	87.30% exploitation of CT aquifer	>4 g/L	Fluoride contamination	
Ecological factors	Soil resources			
	Soil salinization		Soil alkalization	
Oasis of Kebili	Observed in the most parts of the region		High risks in the oasis lands	
	Increasing risks in other localities		Severe restriction for the greenhouses	
Oasis of Tozeur	Observed in El Hamma region		High risks in the cultivated lands	
	Increasing risks in the most parts of the region			

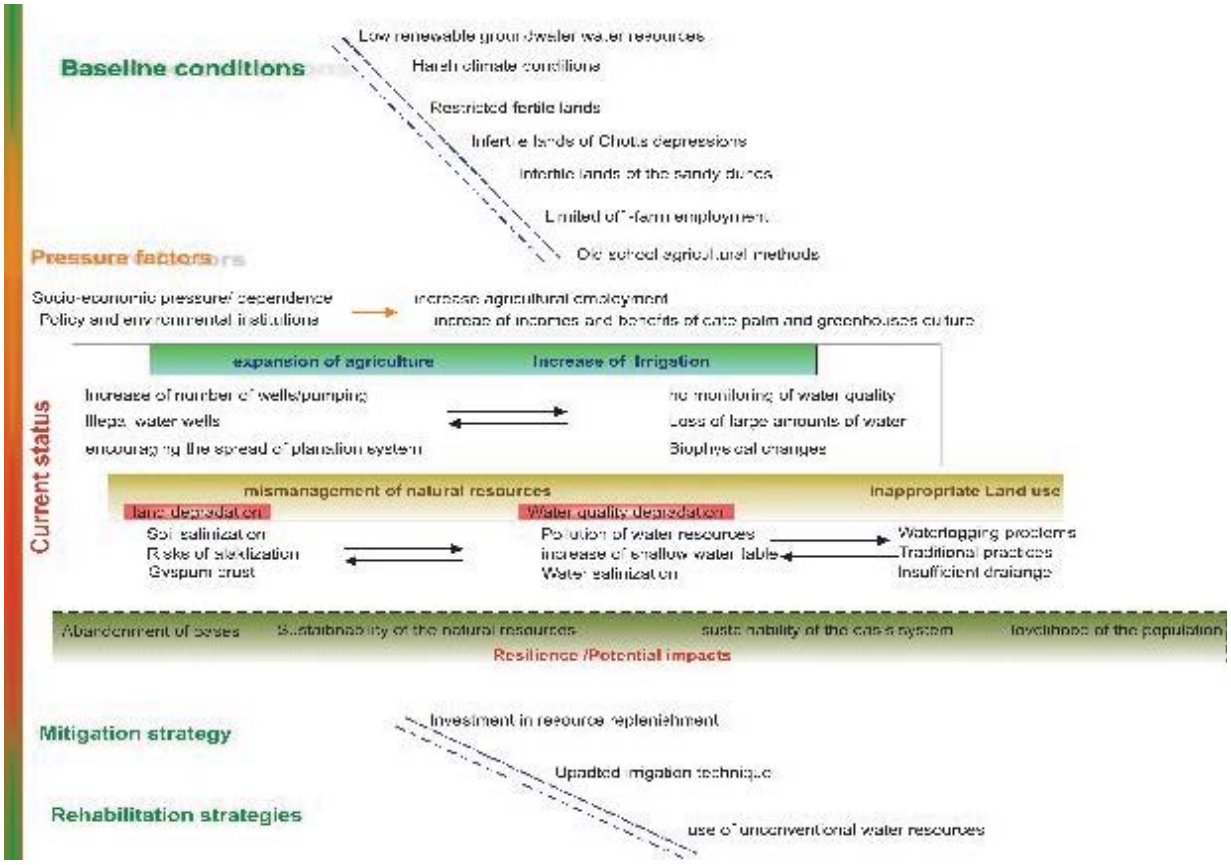

Fig. 7. Evolution of environmental features of the study area.

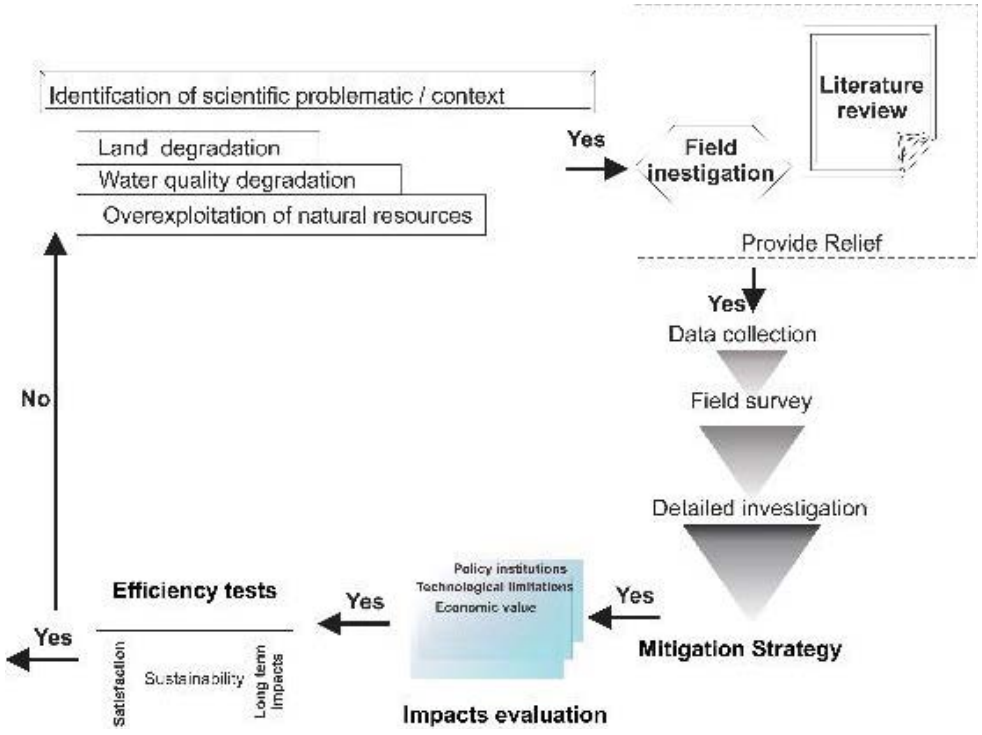

Fig. 8. Rehabilitation process.

of sharing responsibilities. Thus, to grantee the sustainability of integrated land and water management with respect to water multi-functionality, it is imperative to understand the linkage between economic production models, ecologic-environmental management, social framework for strategic management and decision-making model. The agricultural land is progressively mined on soil fertility, soil structure destroyed by compaction and combustion of organic material and topsoil through soil erosion.

5. Conclusion

The review of the different environmental features of Southern Tunisia highlights that the economic security and the ecological conservation are continuously threatened by high risks of oasis abandonment and loss of productivity. Given the difficulty to seek other means of living, the rehabilitation of these sites is recommended and the evaluation of different alternatives for securing land productivity is required.

The various decision made by the different partners have raised natural resources allocation without efficient participatory strategies. Thus, the observed issues should be overcome via controlled individual behavior of local farmers. The adoption of their indigenous knowledge is essential to have more fruitful promising rehabilitation strategies. Indeed, their participation in management process will reconstruct the links between different decision makers and give more reliable information diffusion, the key factor for participative remediation approach.

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