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Eucalyptus sp. as biodrainage system in an arid region: A case study from the Souf oasis (south Algeria)

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Abstract

Arid environments are generally characterized by water scarcity, but some anthropogenic activities or extreme weather conditions can lead to inverse results at the local or regional scales, necessitating a drainage system. This paper describes the application of biodrainage systems in the Souf oasis (Algerian Sahara) as an example of arid environments. The bad management of water resources in the Souf oasis led to rising shallow water levels that threatened the agricultural sector and urban agglomeration; so, a system of bio drainage based on *Eucalyptus camaldulensis* was used to resolve and correct this perturbation. The adopted bio drainage system effectively contributed to decreasing shallow water levels with other benefits such as protecting soil from saliniation and ameliorating life quality. The paper recommends that water availability for agricultural activities be considered when using biodrainage systems in arid regions with the valorisation of treated wastewater.

Keywords: *Eucalyptus camaldulensis*, arid environments, biodrainage, waterlogging, Souf oasis, Algeria

Introduction

Arid regions are characterized by lower humidity, precipitation scarcity, higher evapotranspiration and temperatures, a low level of soil organic matter, and a poverty of vegetation cover (Monger *et al.* 2005; Tchakerian 2015). Arid lands cover approximately 41% of the global land surface and are expanding as a result of global warming (Goudie 2009; Arriagada *et al.* 2018). Moreover, arid lands are home to more than 38% of the worldwide population (Shunlin *et al.* 2013; Xue *et al.* 2015). Arid land ecosystems play an important role in global biophysical processes by maintaining the balance of atmospheric constituents and reflecting and absorbing solar radiation (Gaur & Squires 2018).

Groundwater, especially shallow water is the only source of water available for various needs in most arid regions (Khezzani & Bouchemal 2018a), because it is easy to use. Furthermore, it is susceptible to pollution, and its levels are unstable. According to Al-Zubari (2017), the agriculture quota of global water consumption can reach about 85%.

The water table can rise or fall according to the various anthropogenic activities, the season of the year

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and the amount of precipitation that occurs (Zahid *et al.* 2010). Although most arid regions are experiencing a drop in water tables (Prinz & Singh 2000), anthropogenic activities can lead to perturbations in the hydrological cycle and cause waterlogging in some areas at the local or regional levels. In addition, the interaction of saline groundwater with higher soil layers damages crop species (Engel *et al.* 2005).

Drainage is vital for waterlogged areas, and many techniques can attain it. According to Singh & Lal (2018), traditional engineering drainage technologies such as vertical or subsurface drainage can resolve the problem, but they are expensive and produce large amounts of effluent, which is difficult to dispose of. Many recent studies confirm that plants can be an alternative drainage tool, which has recently attracted interest in environmental management (Jena *et al.* 2017). This method is called biodrainage.

Biodrainage is the process of using bioenergy to remove surplus soil water by deep-rooted, fast-growing trees through evapotranspiration (Singh & Lal 2018). This method is less costly and more environmentally friendly. In addition to its role in combating waterlogging, trees used in biodrainage systems can reduce atmospheric pollution (Jena *et al.* 2017). Trees in biodrainage systems play an important role in the psychological and physical comfort of people. It also improves the climate, the city‘s aesthetics, recreational opportunities, environmental protection, biodiversity, food production, and raw materials for some industries (Ignatieva *et al.* 2011; Horváthová *et al.* 2021; Schwaab *et al.* 2021).

Many tree species are suitable for biodrainage systems, such as *Casuarina*, *Syzigium*, *Prosopis*, *Leucaena*, *Populus, Acacia*, *Dalbergia* and *Eucalyptus* (Singh & Lal 2018). Although waterlogging is a common phenomenon in rainy regions and rarely occurs in arid areas, it did happen in the Souf oasis (Saharan Algeria). This paper highlights applying a biodrainage system in the Souf oasis, using *Eucalyptus camaldulensis* to resolve the rising level of shallow water and soil salinization problems.

Location and general characteristics of Souf oasis

Souf oasis is situated in the South-Eastern part of Algeria and belongs to El-Oued province. This oasis extends over 11738.4 km² (22.8%) (Figure 1) (Khezzani & Bouchemal 2016). The total population of this oasis was about 624000 (94.5%) inhabitants in 2018, with a heterogeneous value of population density amounted to be 53.15 people per km². Life in this oasis is based on irrigated agriculture activity (Khezzani & Bouchemal 2018a). In the past, this activity has been characterized by a subsistence nature, but now it has developed to become commercial (Khezzani *et al.* 2019).

The climate of the study area is hyper-arid, characterized by a hot and dry summer and a mild winter. Temperatures can drop to a near-freezing point in the winter and can reach 45 °C during the summer, with an annual rate of 26 °C. The monthly averages of relative humidity do not exceed 30% during the summer and may reach up to 65% during the winter (Khezzani *et al.* 2021). The rainfall is low, sporadic, and oscillatory, with an annual total rarely exceeding 70 mm. The evaporation is characterized by high values exceeding 2200 mm (Khezzani *et al.* 2016). Winds are usually mild, but in spring and autumn, they become violent (Khezzani & Bouchemal 2017). Souf oasis is characterized by

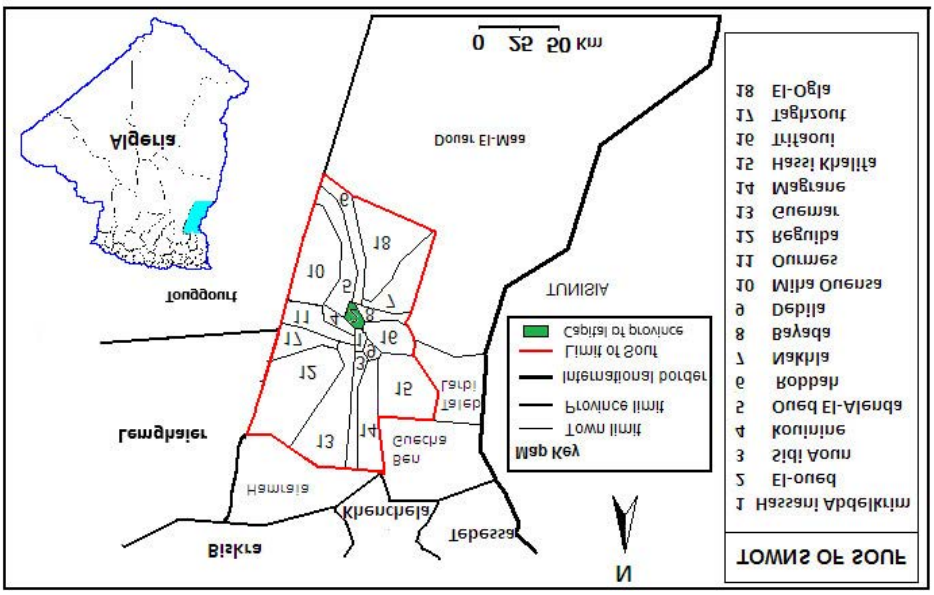

Figure 1. Study area location

sandy soil that is very poor in organic matter (Bouselsal & Ouarekh 2021).

Despite the drought features that characterize the oasis, it sleeps on significant fossil water reserves. This groundwater exists within three layers that vary in depth and chemical properties.

The first groundwater layer is called a phreatic aquifer (P.A.), characterized by a high salinity ranging between 2 and 10 g/l (Pulido-Bosch *et al*., 2018). The phreatic aquifer depth is between 1 and 60 m and used for agriculture only (Khezzani, 2018).

The second groundwater layer is called the Terminal Complex Aquifer (C.T.). Its depth varies between 400 and 600 m, and its thickness is typically about 400 m. The CT aquifer is used principally for urban and drinking purposes and irrigation in some limited regions (Khezzani 2018); furthermore, it is characterized by a salinity ranging from 2 to 4 g/l (Pulido-Bosch *et al*. 2018).

The third and last aquifer is called the Intercalary Continental (CI); it occurs at a depth of between 1800 and 2200 m and has a thickness of between 200 and 400 m (Guendouz *et al*., 2006). The CI is characterized by a temperature that exceeds 70 °C and a salinity ranging from 2 to 3 g/l. The CI aquifer is used only for urban and drinking purposes (Khezzani 2018).

Phreatic water level perturbation

In the last three decades of the previous century, the Souf oasis suffered from water disturbances that affected mainly the phreatic aquifer. These imbalances resulted in the rise of water levels both in urban and agricultural areas. Consequently, waterlogging threatened the urban fabric and traditional buildings (Figure 2), where many parts of the Souf cities have become uninhabitable, and hundreds of families have lost their homes (Côte 2006). Local authorities have stopped granting building permits in or near flooded areas (Khezzani 2007). Moreover, the waterlogging phenomenon contributed to the spread of some epidemic diseases among the local population, such as cutaneous leishmaniasis (Khezzani & Bouchemal 2017), typhoid fever (Khezzani & Bouchemal 2016), and dysentery (Khezzani 2018).

In the agricultural issue, the Souf oasis has lost a large part of its world agricultural heritage. This problem led to the flooding of hundreds of Ghouts (Figure 3), which caused the death of thousands of palm trees (Remini 2006, Khezzani & Bouchemal 2018b). As a result, hundreds of farmers lost their agricultural lands, which were flooded. Kadri & Chaouche (2018) reported that of 9700 Ghouts in the region, only 2355 Ghouts remain. On the other hand, many areas were affected by salinization (Figure 4) (Khezzani & Bouchemal 2018b, Pulido-Bosch *et al.* 2018). Unfortunately, all the measures taken by local authorities at that time were ultimately unable to solve the problem (Kadri & Chaouche 2018).

Figure 2. An urban area affected by waterlogging

The green belt project and its consequences in Souf oasis

After extensive studies carried out by several national and foreign studies offices, the authorities decided to implement a sewage system. However, the latter will not be ready in the short term (Khezzani 2007). Therefore, as an urgent solution, the authorities considered adopting a biological drainage system to reduce the water table level, especially in severely damaged areas like Chott, Sidi Mestour and Nezla neighbourhoods. This afforestation process was accomplished under a green belt project (Kadri & Chaouche 2018; Khezzani 2018).

This project is based on forest trees characterized by rapid growth, adaptation to the local conditions, and their ability to absorb significant quantities of water. After consultations with specialists in this field, the choice was made on *Eucalyptus* sp. because most studies confirm that many of *Eucalyptus* sp. are tolerant of soil and water salinity (Lopes *et al.* 2012; de Souza *et al.* 2015; Shariat & Assareh 2016) and heat stress (Gauthier *et al.* 2014; Teskey *et al.* 2015). Also, besides its tolerance to waterlogging (Argus *et al.* 2015), it is suitable for drought conditions (Saadaoui *et al.* 2017; Mateus *et al.* 2021). Furthermore, Côte (2006) indicates that adult *Eucalyptus* sp. can absorb between 200 and 500 liters of water per day. Moreover, a tree canopy can lower groundwater tables by 1–2 meters in 3–5 years under optimal conditions (Singh & Lal 2018).

The project started in 2003 in the Sidi Mestour neighborhoods, the most damaged area by flooding. Later, it expanded in the vicinity of the university and the Chott region in 2004 and 2005. Inside the cities, especially those threatened by waterlogging, the directorate of the forests and the directorate of the environment have planted *Eucalyptus camaldulensis* next to main roads (Figure 5), inside residential neighborhoods, and within green spaces. Furthermore, *Eucalyptus camaldulensis* were planted in large areas outside the cities and near the agricultural regions. The seedlings were not produced locally but were brought from the northern provinces, which differ in climate and soil from the conditions prevailing in the study area.

The forestation density in the open areas ranged between 200 and 400 trees/ha (Khezzani 2007). Until 2019, the result of the green belt project was more than 165000 trees of *Eucalyptus camaldulensis* planted on an area of 385 hectares both outside and inside cities. Currently, the Directorate of Forests and the Directorate of Environment are still using *Eucalyptus camaldulensis* on a large scale in various afforestation campaigns.

The *Eucalyptus* genus is an exotic in the Souf oasis, but it has proved to have a great ability to grow and live in waterlogged and salinized soil. After 15 years, the adopted biodrainage system effectively depletes the shallow water level (Khezzani 2018). A study by Khezzani & Bouchemal (2018b) reported that the water table in damaged areas has decreased by 1 to 2 meters. Also, the oasis recorded a significant decrease in leishmaniosis incidence (Khezzani & Bouchemal 2017), water-borne diseases such as typhoid fever (Khezzani & Bouchemal 2016), and dysentery (Khezzani 2018).

After the groundwater level decreased, many farmers regained their agricultural lands, and the local authorities also allowed the construction of buildings in areas that were previously forbidden.

In addition to its role in the waterlogging combat, the green project has presented many socioeconomic, biological, and ecological benefits. The Souf oasis cities

Figure 3. An agricultural area affected by waterlogging (Ghout system)

Figure 4. An agricultural soil affected by salinisation in waterlogging area

have become more suitable for life than before. *Eucalyptus camaldulensis* planted within the urban fabric contributed to cooling the summer temperature and contributed to pollution combat by absorbing thousands of tons of carbon dioxide. Furthermore, *Eucalyptus camaldulensis* planted in the surroundings of cities have contributed to creating a space for sports, leisure, and recreation. In the context of biodiversity, *Eucalyptus* trees have become the habitat of many bird species such as *Streptopelia* sp.

At the international level, *Eucalyptus* genus have successfully combated waterlogging in many regions worldwide, including the Haryana region of northwest India. A biodrainage system based on *Eucalyptus tereticornis* lowered the water table by 0.85 meters in 3 years in waterlogged fields. These plantations sequestered 15.5 tons of carbon per hectare and generated 46.6 tons per hectare of fresh biomass with a benefit-cost ratio of 3.5. Furthermore, lowering the water table and associated soil improvement by *Eucalyptus* plantations increased the wheat grain yield by 3.4 (Ram *et al.* 2011).

The question that arises is, what will be the fate of these *Eucalyptus* trees after the water level has returned to its normal state? Also, what is the future of the groundwater level in the presence of this type of trees, especially in agricultural areas?

According to Ma *et al.* (2020), the roots of the *Eucalyptus* sp. continue to grow and penetrate the soil layers to search for groundwater. As a result, the trees will continue exploiting the groundwater and reducing it to critical levels, making it difficult for farmers to use it. It is expected that the study area will not suffer from the problem of water inundation in the future, which is in line with the expectations of the study by Khezzani &

Figure 5. *Eucalyptus camaldulensis* forestation outside cities

Bouchemal (2018b). This matter is due to the expansion of agricultural activity, which consumes more than 85% of the available water resources, in addition to its dependence on the surface layer mainly (Khezzani 2018).

No tree can grow and develop without irrigation in the Souf oasis. Although the *Eucalyptus* genus contains species tolerant to drought such as *E. camaldulensis, E. grandis* and *E. urophylla* (Saadaoui *et al.* 2017); they cannot withstand the severe or sudden drought that can occur in the future.

The first option that the authorities can take is to get rid of these trees to protect the groundwater from depletion. This may achieve the desired purpose, but in return, it will have adverse effects on the soil, biodiversity, urban agglomeration, and climate. As for the second option, if the local authorities decide to keep these trees because of their many benefits, the surface water layer will suffer from depletion. Thus, the matter will negatively affect the agricultural sector, which is the basis of the economy in the oasis. The difficulty of preferring one of the two options is due to the overlap between the urban and agricultural fields that characterize the Souf oasis.

The solution that reconciles the two previous options is to keep the *Eucalyptus* trees and monitor the level of shallow water. Then, when needed, the trees are periodically irrigated with treated wastewater to avoid exposure to severe drought. According to Khezzani (2018), the oasis owns 4 wastewater purification plants, producing more than 9 million cubic meters of water annually. This treated wastewater is discarded into Chott Halloufa without being used. The study by Khezzani & Bouchemal (2018a) also presented several methods for exploiting this alternative water source.

In the same context, this research recommends thinking about the possibility of introducing the *Eucalyptus* sp. crop for economic purposes (wood and oil) by investing the treated wastewater in irrigation. Much research, such as Moges (2010), indicates that *Eucalyptus* sp. can produce economically profitable biomass relative to the amount of water it absorbs compared to other crops.

More actions are needed. Establishing a local nursery to produce *Eucalyptus* seedlings will help select the species most adapted to the region's conditions. On the other hand, plant breeding programs must be adopted to improve the adaptation and resistance of plants to environmental stresses, especially salinity, heat, and drought. Nevertheless, the success of *Eucalyptus* cultivation in the Souf oasis opens new horizons for the rehabilitation of dry areas and reduces the likelihood of desertification.

Conclusion and recommendations

Water scarcity is the dominant feature in arid regions, while the waterlogging phenomenon is considered a limited problem at spatial and temporal levels that need a drainage system. Biodrainage is an environmentally friendly drainage technique with many socioeconomic, biological, and ecological benefits with its primary role in waterlogging combat. The biodrainage system based on *Eucalyptus camaldulensis* have effectively combated waterlogging that threatened the agriculture sector and cities in the Souf oasis.

The availability of water resources and their use mode must be considered in bio drainage systems establishment, especially in areas with a high potential for agricultural production. Therefore, the study recommends considering using the treated wastewater in irrigating trees in public places as the first step to preserving the gains achieved. Furthermore, the availability of treated wastewater as an alternative water source opens the way for introducing the *Eucalyptus* crop and investment in the production of oils and wood.

Conflict of Interests:

The authors declare no conflicts of interest related to this paper.

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