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ADDRESSING DESERTIFICATION IN ALGERIA: ETIOLOGIES, NATIONAL POLICIES, AND ACCOMPLISHMENTS

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Abstract
Desertification, affects 36.62% of non-desert land in Algeria, stands as a critical environmental challenge demanding thorough analysis and strategic intervention. This study offered a nuanced exploration of the multifaceted dynamics of desertification, scrutinizing its varied causes, ecological repercussions, and governmental countermeasures. Drawing on extensive research, the article synthesizes insights from previously overlooked factors such as colonialism, wildfires, socio-economic shifts, and the evolving climate landscape. Since 1962, Algeria has committed to mitigate desertification through strategic programs into national development plans, intricately woven into the fabric of national development plans. Noteworthy among these initiatives is the vegetation barrier project, conceived to erect a formidable vegetation barrier against the relentless advance of encroaching deserts. The legal and institutional frameworks, coupled with meticulous planning under the National Spatial Development Plan (SNAT 2025), underscore Algeria's proactive stance. Despite commendable achievements in afforestation, watershed protection, and socio-economic development, persistent challenges underscore the need for continued collaboration, adaptive strategies, and an unwavering commitment to mitigating the profound impacts of desertification on Algeria's diverse ecosystems and communities.

Keywords: Desertification, Algeria, Land degradation, Afforestation, Green Dam, National Programs

1. Introduction

Drylands, which include arid, semi-arid, and dry sub-humid regions, cover nearly half of the Earth's surface, these regions are usually characterized by the ratio of annual precipitation (P) to annual potential evapotranspiration (PET), the relationship between the annual precipitation (P) and the annual potential evapotranspiration (PET), expressed as P/PET and often less than 0.65, furthermore is referred to as the aridity index (AI) (Li et al., 2019; H. Wang et al., 2023; L. Wang et al., 2012), Based on the UNEP classification, drylands are classified into four primary subtypes based on the

aridity index (AI): hyper arid regions (AI < 0.05), arid regions (0.05 ≤ AI < 0.2), semiarid regions (0.2 ≤ AI < 0.5), and dry sub humid areas (0.5 ≤ AI < 0.65) (S. Feng & Fu, 2013; Lead et al., 2005), globally, Drylands span over a various climatic regions, such as temperate grasslands and tropical deserts, such as temperate grasslands and tropical deserts, all characterized by a persistent moisture deficit and high evaporative demand (N. J. Middleton & Sternberg, 2013).

These areas are particularly vulnerable to desertification, which is a form of land degradation caused by both climatic changes and human activities (Q. Feng et al., 2015; Verón et al., 2006). Desertification leads to a significant decline in biodiversity and agricultural productivity, which has serious impacts on ecosystems and human livelihoods (D'Odorico et al., 2013). Globally, desertification is a major challenge, affecting over two-thirds of the world's countries, a fifth of the world's population, and a quarter of the earth's land area (Behnke & Mortimore, 2016). Desertification is expanding at an alarming rate, estimated between 50,000 to 70,000 km^2 per year (Bao et al., 2017). This highlights the urgent need for sustainable land management and global cooperation to combat this threat to human survival and sustainable development.

In Africa, drylands cover 1,959 million hectares, representing 66% of the continent (Cervigni & Morris, 2016; FAO, 2020). One-third of this land consists of hyper-arid deserts, covering 672 million hectares, and is largely uninhabited, apart from a few small oases. The remaining two-thirds, amounting to 1287 million hectares, consist of arid, semi-arid, and subhumid regions home to about 400 million people, accounting for two-thirds of the total African population (Amiraslani & Dragovich, 2011; Boudjemline & Semar, 2018; Darkoh, 1998). Among the African nations, Algeria - hailed as the largest African country with a total surface area of 2,381,741 km^2, is one of the countries where desertification remains a critical problem. Notably, 87% of the total area is classified as a hyper desert, with limited oases, while 11% consists of steppe areas (~20 million hectares) and pre-Saharan areas (~12 million hectares), and the remaining 2% is littoral (Ali, 2009; Benmessaud et al., 2010a; Mihi et al., 2022). Furthermore, it is noteworthy that an estimated 500,000 hectares of land in Algerian high plains are currently undergoing desertification, while an incredible 7 million hectares are at immediate risk of its process to be affected (Ali, 2009; Benmessaud et al., 2010a; Djeddaoui et al., 2017; PNAE-DD, 2002).

Since 1992, the Algerian authorities have paid great attention to desertification. The government has initiated several measures to address this critical issue (Azzouzi et al., 2017, 2018). In this context, the main objective of this study is to provide an in-depth analysis of desertification in Algeria by identifying its root causes and examining the countermeasures taken by the Algerian authorities. This research explores both natural and anthropogenic causes of desertification, and critically assesses the effectiveness of Algeria's legal and institutional frameworks in addressing these challenges. In addition, the study assesses the alignment of Strategies to combat desertification with the National Spatial Development Plan 2025 (SNAT 2025), and provides insights into the environmental, economic, and social impacts of policy implementations. By analyzing concrete successes and societal benefits, the study aims to provide a comprehensive understanding of desertification in Algeria, while highlighting the effectiveness and challenges of current mitigation efforts.

2. The Recognition and Evolution of Desertification:

Historical background

Environmental degradation in arid and semi-arid regions is an ancient problem that has been shaping human civilizations for thousands of years. Archaeological evidence points to Neolithic civilizations that once lived in the Sahara, showing the long history of humans in these dry environments (Giannini et al., 2008a; Liu et al., 2008; Verstraete, 1986).

The historical dynamic of desertification in North Africa has been strongly affected by long-term climatic variation, these changes are attributed to Milankovitch cycles, which describe variations in Earth's orbital parameters, including eccentricity, obliquity, and precession, leading to cyclical changes in the distribution of solar radiation, thereby influencing climatic patterns on both regional and global scales over tens of thousands of years (Giannini et al., 2008b), these cycles have historically determined the shifts between humid and arid conditions in the Sahara, directly affecting the dynamics and severity of desertification in the region, (Kröpelin et al., 2008) Alongside to these gradual processes, Significant and rapid environmental changes, such as the 5.9-kiloyear and 4.2-kiloyear events played a pivotal role in shaping North Africa's environmental history, (Demenocal et al., 2000) Around 5900 years ago, the 5.9-kiloyear event marked a pivotal transition in regional climatic patterns, (Cullen et al., 2000) This event initiated the termination of the African Humid Period, resulting in widespread aridification and the expansion of desert landscapes, Similarly, the 4.2-kiloyear event associated with severe drought and societal disruptions in multiple regions, intensified arid conditions across the Sahara and adjacent areas, Understanding these natural, long-term drivers is essential for differentiating between climatic and anthropogenic factors in current desertification.

Following this long history of natural environmental change, the concept of "desertification" as a distinct environmental problem began to emerge in scientific discourse. Over time, the understanding of desertification evolved—from its early conceptualization to its recognition as a major global environmental issue—providing valuable insights that have shaped the development of modern mitigation strategies (Verón et al., 2006)

Early Conceptualization:

André Aubréville introduced the concept of desertification for the first time in 1949, by botanist and forester André Aubréville in a seminal work titled "Climats, Forêts et Désertification de l'Afrique Tropicale," (Bao et al., 2017; Salamani et al., 2022), Aubréville's research highlighted how deforestation and unstable agricultural practices damaged African forests, transforming farmland into desert-like conditions (Mainguet1994). His findings represented a turning point in recognizing human influence on environmental degradation. Presenting desertification as an environmental problem for the first time, Aubréville emphasized in his view of desertification that human actions such as land management played a key role in this phenomenon by desertification was clearly presented as an environmental problem for the first time (Aubréville, 1949; Dregne, 1986; Gangneron et al., 2022)

Early Recognition and the Term "Desertification

The term "desertification" was originally used by French naturalist and forester Louis Lavauden in 1927 to characterize soil degradation in dry locations (Louis Lavauden, 1927), but Aubréville popularized it. However, the word only gained scientific traction after Aubréville used it. In his research, (Behnke & Mortimore, 2016; MEA, 2005) Aubréville pointed out the significance of soil erosion and human-induced factors like deforestation and fire in increasing the

degradation of productive land into desert-like conditions. According to his research in West Africa, where savanna and forests were becoming more and more mixed due to human activity, even with the significance of Aubréville's early contributions, the idea was mainly limited to a group of Ecologists, Foresters, and Botanists at that time (Aubréville, 1949).

Expanding Understanding: 1950s–1960s

Desertification started to become more recognized and well-known in academic circles After Aubréville popularized the term (Glantz & Orlovsky, 1984), throughout his studies in the 1950s, Jean Tricart enhanced the understanding of desertification by demonstrating the significance that salinization and wind erosion played in the land degradation of West African soil. His research broadened the definition of desertification to include both human and climatic influences. During this period, however, desertification remained a specialized topic, attracting little attention outside specific geographical studies (Tricart, 1954).

Global Recognition in the 1970s: The Dust Bowl and the Sahel Drought

During the 1970s, desertification gained global attention, especially after two major environmental crises: the Dust Bowl in the American Midwest during the 1930s (Kassas, 1995)and the Sahel drought (1968 to 1974) (Govaerts & Lattanzio, 2008; Thomas, 1997). During the Dust Bowl, poor agricultural practices combined with drought caused massive dust storms that destroyed crops and displaced communities (D'Odorico et al., 2013). In the same way, the Sahel drought resulted in large areas of grasslands becoming barren, resulting in widespread famine and migration. This crisis adversely affected grazing lands and water resources, making drylands susceptible to both human activity and extreme climatic conditions (Behnke & Mortimore, 2016; Le Houérou, 2009).

In response to the drought in the Sahel, the United Nations Conference on Desertification (UNCOD) was convened in Nairobi in 1977 (UNEP, 1999a). It brought together international organizations, scientists, and decision-makers to address desertification globally. The Action Plan to Combat Desertification was created due to the meeting, opening the door for global collaboration in preventing and controlling desertification. This event marked the beginning of a new phase in the history of desertification as it raised international awareness of the extent of desertification and the urgent need for coordinated action (UNEP, 1999a; UNESC, 2007).

Evolving Scientific Understanding: 1980s–1990s

Desertification evolved in the 1980s and 1990s, and researchers recognized that it is a multifactorial process influenced by natural and anthropogenic factors (Sivakumar, 2007). Additionally, unsustainable land use practices such as deforestation, overgrazing, and improper irrigation have been found to significantly accelerate desertification (Dregne, 1986). To raise awareness, UNEP published the Desertification Control Bulletin to disseminate information on best practices for land rehabilitation and reforestation. Because of these efforts, a more comprehensive understanding of desertification emerged as a result of the interaction between environmental and socioeconomic factors (Reynolds et al., 2007).

The establishment of UNCCD 1994

In 1994, in response to the call of the United Nations Conference on Environment and Development (UNCED) in 1992, the UNCCD became the first international legal agreement with international effect to specifically focus on desertification through an approach that is connected to environmental and development concerns as well as sustainable land management in order to fight desertification (Behnke &

Mortimore, 2016; Kannan Ambalam, 2014; Le Houérou, 2009). The UNCCD has received widespread support since its inception, with 197 countries and the European Union committing to it (Amiraslani & Dragovich, 2011).

In addition, the United Nations has established an international multilateral environmental regulatory framework to combat desertification, which includes relevant implementing measures, such as national policies, laws, institutional regulatory frameworks, and practices of sovereign states and territories (Richard S. Odingo, 1990). To promote a fairer, and more sustainable future, in line with the UN Agenda 2030, especially, to achieve the UN Sustainable Development Goals (UN SDGs) (Carpentier & Braun, 2020; Hák et al., 2016).

Linking Desertification with Climate Change: Early 2000s

In the early 2000s, awareness of desertification and its connection to other environmental problems, including climate change, grew. This period marked a significant advance in understanding how these two global challenges are interconnected and how they impact sustainable development (Lonergan, 2005; UNEP, 1999b).

The UNCCD began to incorporate climate change considerations as a crucial part of its framework for action (Giannini et al., 2008a). Climate change considerations have been included as an integral part of the UNCCD. The group recognized that efforts to curb desertification could have major impacts on both climate change adaptation and climate change mitigation plans (Bao et al., 2017). Concerning guidelines for sustainable land management and the restoration of degraded areas, and community-based approaches to enhance resilience against climate impacts (UNESC, 2007), the UNCCD particularly emphasized the importance of sustainable land management techniques. It was also suggested that these interventions could increase the capacity of terrestrial carbon sequestration, which would reduce the concentration of greenhouse gases in the atmosphere (Darkoh, 1998).

The UNCCD encourages research and knowledge exchanges and sharing between dryland and non-dryland countries in order to address the effects of climate change on desertification (Kannan Ambalam, 2014; Zakri et al., 2005). The goal was to promote scientific studies that investigated the dynamic between land degradation and climate variability, as well as the best practices for sustainable land use.

3. Overview of Algeria: Location, Climate, and Natural Features

Geographically, Algeria is located in the northern part of the African continent, between latitudes 28.0339° N and 1.6596° N. The country is bordered by the Mediterranean Sea to the north, and borders with Morocco to the west, Mauritania and Mali to the southwest, and Niger to the southeast, Libya in the east, and Tunisia in the northeast. Measuring 1,200 km from east to west and 2,000 km from north to south, Algeria covers significant portion of the Sahara (Ali, 2009; Saad et al., 2011). According to the United Nations, 43.8 million people lived there in 2020 and according to the worldmeter (www.Worldometers.info), this number is expected to increase to 60.9 million people by 2050.

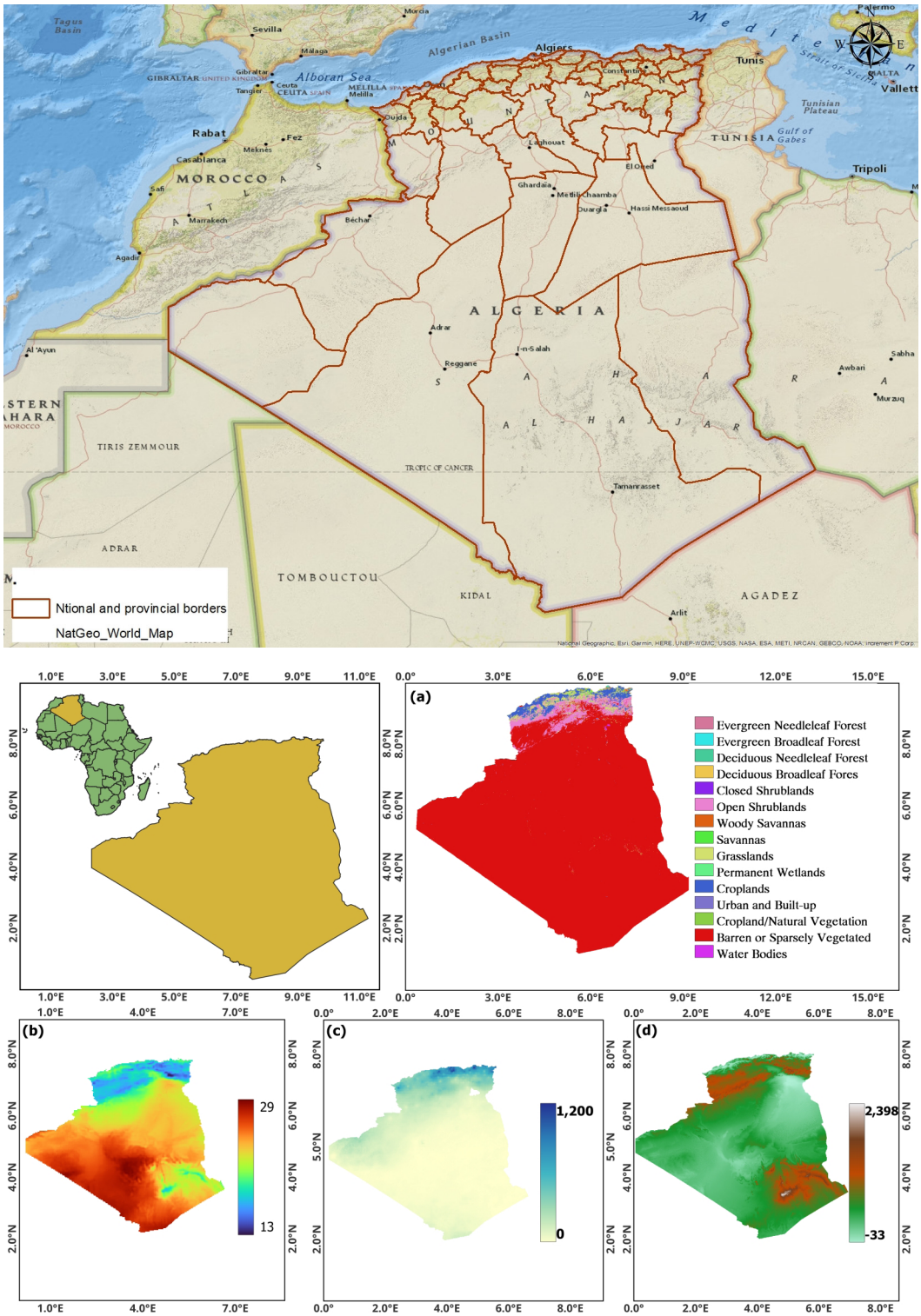

Fig. 1. Geographical Context and Environmental Variables of Algeria: a) Land Cover in Algeria, b) Spatial Distribution of annual Temperature in Algeria, c) Spatial Distribution of annual Precipitation in Algeria, d) Elevation Distribution.

4. State of desertification in Algeria:

In Algeria, desertification is one of the most pressing environmental issues that requires immediate attention and intervention. The land classified as vulnerable to desertification accounts for 36.62% of Algerian non-desert area (Tahar & Boureboune, 2009) (Table 1), indicating that a large portion of the country is at risk of desertification. This highlights the urgent need for immediate measures and steps to combat desertification and mitigate its negative consequences. A close behind are areas of moderate sensitivity, accounting for 26.60% of the total area, and susceptible areas, accounting for 16% of the total area, requiring immediate intervention to counteract this phenomenon in these areas.

In Algeria, water erosion threatens nearly 10 million hectares of land in Algeria, with soil losses estimated at approximately 120 million tons per year—an amount equivalent to the annual degradation of about 40,000 hectares of arable land—and results in the displacement of approximately 16.6 million cubic meters of material through landslides. In particular, the plateaus, which cover over 20 million hectares, represent a serious threat of desertification. (Ali, 2009; Mostefaoui, 2017). In addition, according to the 2004 annual report of the Ministry of Regional Planning and Environment, 12 million hectares are vulnerable to water erosion, resulting in significant soil loss and siltation of dams.

5. The causes of desertification in Algeria

Desertification is caused by multiple factors, which changed over time and vary location. Since Algeria is a large country with verse climates, desertification varies from region to region depending on climate and severity of human activities (MEA, 2005; M. K. Seely, 1998; M. Seely & Wöhl, 2004). Recent climate change has intensified dust storms in Algeria, driven by rising temperatures, altered precipitation patterns, and stronger winds (N. Middleton et al., 2019). The Sahara Desert, including Algeria, is a major contributor to global mineral dust emissions, accounting for 50–70% of the total (Ginoux et al., 2012). Increased droughts and land degradation, exacerbated by climate change, have heightened dust mobilization in North Africa (Kok et al., 2023). Changes in atmospheric circulation, such as reduced wintertime surge activity, have facilitated the long-range transport of Saharan dust, with particles reaching as far as Scandinavia and Finland (Varga et al., 2023). A 2023 study documented 86 dust events in Finland between 1980–2022, with 59 originating from the Sahara, highlighting the far-reaching impacts of North African dust storms (Varga et al., 2023). These events are increasingly linked to Arctic amplification and meridional atmospheric patterns (Francis et al., 2019). In addition, a notable example of this phenomenon is observed in Spain and the Canary Islands,

Table 1. Categories of land vulnerability to desertification in Algeria according to the Algerian General Directorate of Forests and the National Centre for Space Technologies

Category	Area (ha)	%
Desertified	487.902	3.53
Very sensitive to desertification	2.215.035	16.03
Sensitive to desertification	5.061.388	36.62
Medium sensitivity	3.677.035	26.60
Low sensitivity to desertification	2.379.170	17.21
total	13.820.530	100%

Source: Author-created based on (SNAT, 2008).

where intense dust storms, locally known as calima events, are frequent due to their proximity to Africa (Muhs et al., 2021), These events not only impact air quality but also contribute to significant environmental and health challenges (O'Loingsigh et al., 2014). Such phenomena underscore the interconnectedness of regional and global climates. Dust storms pose serious health risks, including respiratory and cardiovascular issues, alongside economic losses in agriculture and aviation (Shao et al., 2011).

These impacts call for targeted strategies to address desertification and mitigate dust storm effects in Algeria, Spain, the Canary Islands, and beyond (Kok et al., 2023), while climate change has significantly amplified natural drivers of desertification such as dust storms, it is equally crucial to recognize the historical and ongoing anthropogenic pressures that have profoundly shaped land degradation in Algeria.

In the Tell and coastal regions of Algeria "French companies" carried out extensive exploitation of local forests during the French occupation resulting in the near total destruction of the forest. The French "Genie Militaire" systematically felled 300,000 m3 of wood between 1840 and 1848. In addition, an annual production of 153,000 m3 of charcoal was recorded. In the initial phases of colonization, it is estimated that a significant 1 million hectares of forests were lost between 1870 and 1940 (Sivak, 2013; Zaimeche, 1994). Particularly noteworthy are the effects of the Second World War, during which wood production alone increased to 1.5 million m3. At the same time, firewood production was more than 7 million m3, while charcoal production was 6 million m3. This extensive exploitation of Algerian forests reveals the profound environmental impact of colonial activities in the region (Boudy P, 1948; Zaimeche, 1994), furthermore fires are one of the most important factors leading to land degradation and, ultimately, desertification. (Arezki Djema & Mahand Messaoudene, 2009) Showed in their study that the region was severely affected in the period 1980-1990, with the total of area 380,588.38 ha in 1980 and 521,503.38 ha in 1990 of burned forests, while the total of burnt forest reached 1,490,032.19 ha between 1963 and 2007. Another cause of land degradation in this region of the country is logging for fuel, industrial purpose, and construction work. Furthermore, the use of forests as permanent pastures for livestock exposes forest to illegal deforestation, leading to land degradation (David D. Briske et al., 2011; Fenu et al., 2022; Minea et al., 2022; Sanjari et al., 2009). Algeria experienced a significant loss of 192,000 hectares of tree cover, between 2001 and 2021, a decline of 16% in 2021 alone, the country lost 20.5 hectares, contributing to land degradation, erosion, reduced agricultural productivity, and increased climate change, given the role of trees in storing carbon dioxide and moderating global temperatures. Finally, the vertical cultivation method on the slopes and the use of high-tech machinery and mechanization to break up the soil's surface which promotes erosion by rain and wind, are also causes of soil degradation.

The Algerian steppes, which occupy a key position between the Tell Atlas and the Sahara Atlas, cover an area of approximately 20 million hectares and form the largest rangeland in North Africa (Hirche et al., 2011b). The region experience large variations in rainfall amounts, ranging from 200 to 600 mm, and has experienced a significant decrease in annual rainfall and sometimes several consecutive years of drought (Belaroui et al., 2014a; Boudiaf et al., 2021; Mihi et al., 2022; Zegrar et al., 2015). These changes have resulted in increased evaporation and reduced soil moisture, making it difficult for vegetation to grow and thrive, making the environment vulnerable and increasing sensitivity to desertification.

In the Algerian steppes, home to over 6 million people herding livestock, nomadic transhumance was traditionally practiced to maintain ecological balance. However, socio-economic changes, such as

mechanization of the agriculture, have led to the decline of this practice, and contributed to overgrazing as pastoralists become sedentary. This shift has led to large livestock, caused environmental problems such as a decline in native vegetation, soil erosion, and loss of biodiversity, overgrazing of Livestock has also depleted the soil, and reduced agricultural productivity, particularly in high plains areas. These changes increase the risk of desertification, and pose long-term threats to the environment (Bencherif et al., 2021; Benhizia et al., 2024; Henri-Noël Le Houérou, 1992; Koch et al., 2008; Mostefaoui, 2017; Tahar & Boureboune, 2009; Wafa et al., 2019)

Regarding the Sahara, which covers much of the country, studies found that it expanded by 10% between 1920 and 2013 (ONS). This expansion was largely due to reduced rainfall and increasing and recurring periods of severe drought. In addition, wind plays an important role in exacerbating desertification by increasing the severity of sandstorms and dust storms in the region, and leading to the permanent disappearance of vegetation cover hundreds of kilometers away (MEA, 2005; UNEP, 1999a). Other factors contribute to the degradation of oases, such as salinization and the use of wastewater use, which have threatened the productivity of date palms and have damaged the environment and wildlife. This has made the Sahara an even more hostile environment for life.

6. Algeria's National Program to Combat Desertification: An Overview of Efforts and Strategies

The Algerian government continually committed to mitigate desertification in the country's northern regions, as the Ministry of Agriculture and Rural Development demonstrates (Zerrouki et al., 2021). Programs such as the Popular Workshops for Reforestation (CPR), which have been existed since 1962, the Tertiary Plan (1967–1969), and the Later Plans (1970–1977) highlight a consistent attempt to address the complex aspects of desertification. These initiatives aimed to build the necessary infrastructure, employ people in rural areas, and involve people in reforestation. These plans included tree nurseries, community engagement, and the Green Dam initiative, with a focus on afforestation and reforestation. In particular in the first and second five-year plans (1980–1989), special development programs emphasized the importance of the natural environment in preventing desertification and gave priority to large scale afforestation. (Ali, 2009; Benhizia et al., 2021a; Wafa et al., 2019).

Algeria has used vegetation barriers, exemplified by the Green Dam project, to combat desertification in the steppe areas surrounding the Sahara. The Green Dam (Barrage Vert), Launched in the 1970s, originally aimed to create a 1,500 km-long and 20 km-wide vegetation barrier (spanning approximately 3 million hectares) to prevent the progression of ergs and extensive areas of mobile dunes, using primarily drought-resistant species like Aleppo pine (Pinus halepensis) and esparto grass (Stipa tenacissima). Despite the challenges including monoculture vulnerabilities, limited community engagement, and water scarcity and limited successes, the remains of the barrier, made primarily of Aleppo pine trees, still survive today. The project shares conceptual parallels with the pan-African Great Green Wall (GGW) initiative, though it predates the GGW by decades and maintains a stronger focus on ecological restoration rather than the GGW's integrated socioeconomic approach. In 1987, the government formulated the National Plan to Combat Desertification, an extension of the vegetation barrier project, and intensified its operational activities. This shift incorporated more sustainable practices based on lessons from earlier implementation. Furthermore, the creation of the High Prefecture for the Development of the Steppes in 1987 represents a broader initiative renewal and holistic development of the Algerian steppes, aligning with emerging international frameworks for dryland restoration.

(Abdelkrim et al., 2013; Azzouzi et al., 2018; Belaroui et al., 2014a; Benhizia et al., 2021a; Djeddaoui et al., 2017; Mostefaoui, 2017; Wafa et al., 2019).

After 1990, Algeria intensified its efforts to combat desertification in response to growing challenges and global attention. Aligned with the United Nations Convention to Combat Desertification, these initiatives, integrated into broader development frameworks (Arnous et al., 2009), focused on the national program to combat desertification. A multidimensional approach, initiated in 1994, aimed to upgrade and improve forest resources, develop forest resources, expand watersheds, revitalize forestry activities, promote forest resources, and address unemployment in desertified regions (Royal et al., 2013; Wafa et al., 2019). Over two decades (2000-2020), the national afforestation program has successfully reforested 1,245,900 hectares, reflecting a sustained commitment to improve the country's forest cover within broader national development programs.

Since 2000, Algerian government programs have taken into account the principles of sustainable development, as shown by the national environmental strategy for 2001-2010 (Wafa et al., 2019). This commitment was further consolidated with the passage of the Environmental Protection and Sustainable Development act in 2001, which supplemented the Environmental Protection act of 1983. The government's commitment to environmental protection and sustainable practices was underlined by formulation of a national action plan for environmental and sustainable development (2001-2004), which emphasized population awareness and participation in combating desertification. Algeria also introduced two national plans for agricultural and rural development in 2000 and 2002, which included strategies such as land assessment, reforestation, protection of steppes and oases, creation of specialized employment in forestry, participatory approaches to agricultural development, and promotion of livestock farming include stabilization of rural communities.

6.1 Legal Framework to Combat Desertification: Policies, Laws and Strategies

Algeria has created a comprehensive legal framework that includes all state laws and regulations. This framework covers various regulations on land use, water resources management, and promoting sustainable agricultural practices. The main goal of these laws is to protect natural resources, curb soil erosion, and promote sustainable land use. In addition, the legal framework incorporates provisions for reforestation in affected areas, to ensure the effective implementation of projects and programs to combat desertification. Several laws have been enacted to conserve natural resources and wealth, with the following laws having particular importance:

- Ordinance N °: 75-43 of June 17, 1975, which contains the law on grazing, which focuses particularly in article 6 on the rational use and protection of lands subject to erosion and desertification.
- February 5, 1983, Law N °: 80-83 concerning environmental protection.
- July 17, 1983, Law N °:17-83 relating to the water law.
- June 23, 1984, Law N °:12-84 relating to the general forest regime, which relates to the rational use and protection of lands subject to erosion and desertification.
- January 27, 1987, Law N °: 87-03 relating to spatial planning.
- Ministerial decree of March 26, 1997, specifying the imposition of a grazing tax in areas dedicated to the protection of forests and areas of pastoral agriculture.
- December 12, 2001, Law N °: 01-20 relating to the planning and sustainable development of the territory, particularly its article 20.
- • June 23, 2004, Law N °: 04-03 relating to protecting mountain areas within the sustainable development framework.

- August 4, 2005, Law N °: 12-05 relating to water, amended and supplemented.
- May 13, 2007, Law N °: 06-07 relating to green spaces' management, protection, and development.

Institutional Framework for Combating Desertification:

Algeria ratified the International Convention to Combat Desertification on May 22, 1996, and established two national agencies to monitor and implement programs to combat desertification. As a result of desertification, Algeria has had to rely on these two organizations:

1. Supreme Council for Environment and Sustainable Development 1994: It is a national institution chaired by the Prime Minister and includes several ministries. In addition, its mission is to ensure the integration of the national action program into national development policy.
2. National Coordinating Authority 1998: is headed by the Directorate General of Forests and comprising several specialized bodies, including:

- General Directorate of Forests.
- The General Directorate of the Environment.
- High province for the development of the steppe.
- The National Institute of Maps and Remote Sensing.
- The National Meteorological Office.
- Scientific and technical research center for arid zones.
- The National Center for Space Technologies.
- The National Office of Studies and Rural Development.
- The National Forestry Research Center.
- The National Agency for Nature Conservation.

Additionally, national companies are working to sensitize and integrate the population in the process of combating desertification, including the following organizations:

- The Association for the Protection of the Steppes.
- The Association for the Promotion of Rural Development.

Programs to combat desertification

Table 2. Algerian program to combat desertification after the independence.

the period	The program and the type of operation
1962-1967	Population workshops on reforestation (Reforestation in areas with high unemployment rates)
1967-1969	The tertiary level (Planting trees in degraded areas to restore vegetation cover)
1970-1973	The first quadrennial plan (Combating desertification through productive reforestation)
1974-1977	The second quadrennial plan (Developing and strengthening the first quadrilateral program)
Different periods	Special programs (Activities aimed at raising awareness, providing information, and reforestation)
1980-1984	The first five-year program (Developing a watershed and reforestation)
1985-1989	The second five-year plan (The use of a wide variety of plant species in reforestation)

1971-1990	Green Dam (Located in the extreme north of the Sahara, covering an area of 1500 km by 20 km on average, the purpose of this vegetation barrier was to stop the progression of the ERG (area of mobile dunes in the Sahara)).
Since 1987	National Plan to Combat Desertification (Enhancing and expanding Green Dam operations based on an agro-forestry and pastoral approach)
1987	Establishment of a High Prefecture for Steppe Development (Enhancing land management and vegetation cover of the steppes through integrated development)
Since 1994	Major Works (Developing and maintaining forest areas, expanding Green Dams, protecting watersheds, and valorizing forest products)
Since 2000	National plan for agricultural development (Land valorizing, steppe, and oases development, and job creation in the afforestation sector).
2000-2020	National afforestation program (About 1900245 ha of forests were planted, including 333260 ha for desertification control and 562000 ha for watershed protection).
2002	National Plan for Agri-Rural Development (Implement a participatory approach to the development of agriculture and livestock while stabilizing the rural population).
2001-2004	Sustainable Development and Environment National Plan (Coordination and integration of environmental protection and environmental rehabilitation)

7. Algerian program to combat desertification according to the National Spatial Development Plan 2025 (Schéma National d'Aménagement du Territoire SNAT 2025):

SNAT 2025 covers many sectors and areas, including urban planning, infrastructure development, environmental conservation, and socio-economic development. The aims is to achieve a balanced and sustainable spatial distribution of population, economic activities, and infrastructure while protecting natural resources and improving the quality of life of Algerian citizens (Saidi et al., 2023); The formulation of the National Spatial Development Plan 2025 is of great importance at the national level. This initiative has been the focus point since 2000, specifically emphasizing the development of a comprehensive National Soil Conservation and Desertification Control Plan (PNAE-DD, 2002). To achieve this, an in-depth study examined the complex relationship between natural resource productivity, population displacement, and poverty. The main goal of this plan is to secure and improve soil resources through integrated land-use planning, including soil conservation measures. A crucial element is creation of an agricultural land classification map that describes in detail the status of agricultural and steppe land, including ownership and usage rights. In addition, a strong legal framework has been created to involve local communities, stakeholders, farmers, and breeders in natural capital conservation initiatives. This framework also supports the controlled continuation of opening state domains to concessions, thereby promoting sustainable development practices.

Increasing agricultural productivity in Algeria requires a comprehensive land development program with aim of upgrading 600,000 hectares by 2010 and 1,000,000 hectares by 2025 (SNAT, 2008a). Alongside mitigate desertification, the measures also address sand encroachment, land salinization, and rising waters in the lower Sahara. Specific guidelines target vulnerabilities in different areas, such as

mountains, steppes, and protected areas. The development of coastal regions will respect laws protecting coastal areas, particularly those subject to degradation. Protective measures aim to preserve ecological integrity, cultural heritage, and tourism value. Proactive approaches extend to sensitive areas, and emphasize sustainable management and protection. For mountains and forests, combating desertification includes preserving and restoring these regions through comprehensive watershed development and erosion control initiatives.

The national objective for 2025 aims to extend Algeria's forests to 1,250,000 ha, contributing to ecological balance, resource conservation, and desertification mitigation. The "green dam" revitalization within the National Plan to Combat Desertification involves a strategic plan, including accurate mapping and specific reforestation targets covering 3 million hectares. Community engagement, awareness campaigns, and a holistic approach addressing deforestation causes are recommended. Legal constraints on land ownership, effective monitoring, and water resource considerations are crucial. Expanding forestry activities to include suitable plant species supports the sustainability of the "green dam" initiative.

The steppe region, characterized by arid and semi-arid grasslands, is subject to various factors contribute to land degradation, including overgrazing, soil erosion, and inadequate land management practices. These processes have resulted in the loss of vegetation cover, a decline in soil fertility, and increased vulnerability to desertification. This region in Algeria has been a key of focus in efforts to combat desertification and restore degraded lands. SNAT 2025 intervention in this region covers all areas that have experienced land degradation, and is estimated a cover approximately 7 million hectares; The High Commission for Development of the Steppe (HCDS) has made concerted efforts to restore degraded lands in the steppe region. Through targeted restoration measures, such as reforestation, soil conservation measures, and sustainable

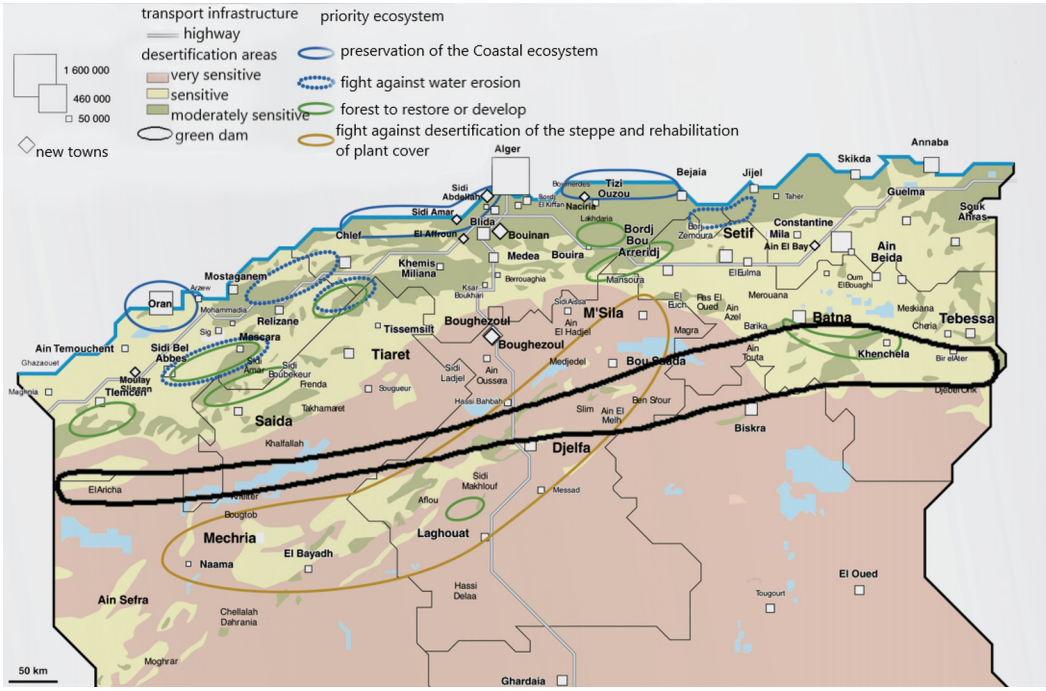

Fig. 2. Algerian program to combat desertification according to the national land-use plan (SNAT 2025)

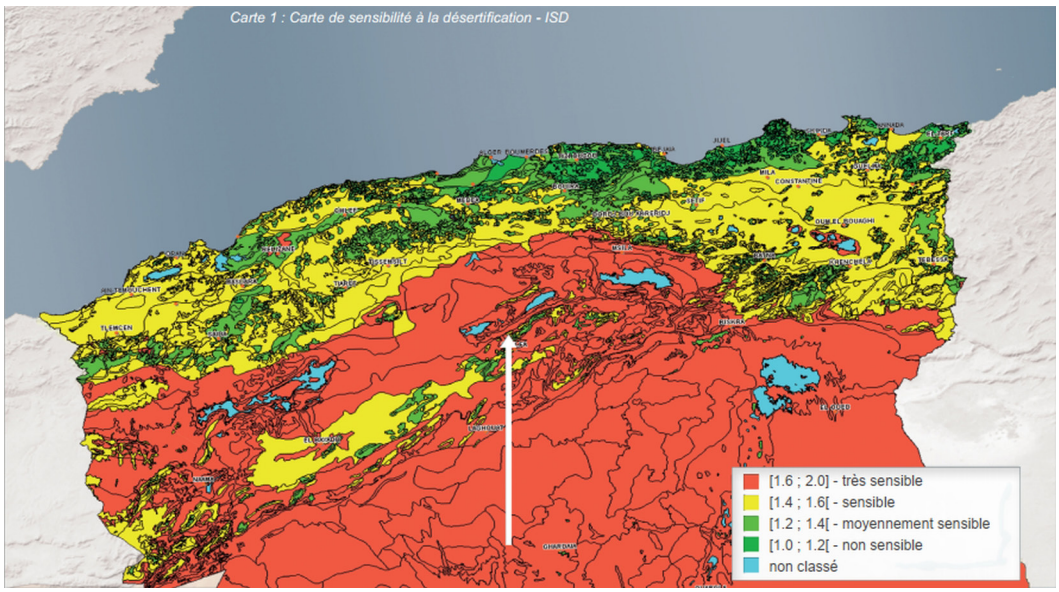

Fig. 3. Map of Sensitivity to desertification according to the National Spatial Development Plan (SNAT 2025)

land management practices, the HCDS has successfully protected approximately 3 million hectares of degraded land. Furthermore, the restoration of degraded lands in the steppe region contributes to the conservation of biodiversity, preservation of ecosystem services, and mitigation of climate change impacts. It helps protect and restore important wildlife habitats and supports the region's overall ecological balance.

Overall, the Algerian National Spatial Planning Scheme SNAT 2025 has yielded significant benefits in desertification mitigation, sustainable development, conservation, community engagement, infrastructure development, and resilient urbanization. These outcomes contribute to the overall well-being and long-term prosperity of Algeria and its people.

8. Achievement and Benefits of Algerian Policy and Programs in Combating Desertification

Algeria has made significant strides in mitigating the impacts of desertification by implementing comprehensive policies and initiatives. These efforts have resulted in significant accomplishments and led to several benefits for the country's ecosystems, communities, and sustainable development. This section highlights some key achievements and benefits of Algerian policy and initiatives in combatting desertification (Le Roux & Bouazid, 2009). In the initial years following Algeria's independence, projects aimed at mitigating desertification were implemented without adequate technical studies on the fundamental aspects of project execution. These initiatives primarily focused on afforestation works and basic infrastructure, neglecting the social dimension of the problem (Ali, 2009; Belaroui et al., 2014b; Le Roux & Bouazid, 2009). Technical methods were employed to address the issue, and this period enabled the identification of various deficiencies and mistakes that impeded the progress of numerous comprehensive development operations undertaken in the affected areas, between 1962 and 1980 approximately 4.1 million ha of forests have been planted, out of which 1.3 million ha are productive forests (Safriel, 2020), the most prevalent tree species in these forests is the Aleppo pine, which occupies a significant

area of 880,000 ha primarily in semi-arid regions, oak and cork trees, on the other hand, are mainly found in the northern parts of the country and cover an estimated area of 229,000 ha, insufficient results were achieved during this period due to the absence of technical studies prior to the reforestation programs (Benalia, 2009), resulting in monoculture activities and disregard for the social factors of the population in affected areas, human factors, alongside drought, are significant contributors to land degradation, but after 1976, an integrated approach has been developed to agricultural and pastoral forestry within the framework of the vegetation barrier and an attempt to introduce the social dimension within these projects and operations (Ali, 2009; Belaroui et al., 2014b; Benalia, 2009).

In the post-1990 era, due to the intensification of desertification and growing global concern over the issue, Algeria has initiated various national programs and plans to combat it, these plans have been integrated into development plans, with the country's primary efforts focused on this framework (Merdas et al., 2017), serving as a complement to its national program for desertification control, Approximately 2.5 million ha of forests have been established through various reforestation programs, including 75,000 ha of cork and oak forests, 250,000 ha for the production of forest products, 562,000 ha for the purpose of soil and mountain slopes protection, 333,260 ha for combating desertification, and 25,640 ha for reforestation of parks and gardens and Create job opportunities for approximately 509,460 individuals within a 20-year period (SNAT, 2008b), in addition Constructing 2360 km of roads to alleviate rural isolation, the purpose were to expand forest resources and improve land quality and increase wood production by managing existing forests furthermore establish windbreaks to enhance agricultural and pastoral production and preserve land and protect slopes and stabilize sand dunes to prevent sand encroachment.

The efforts to combat desertification in Algeria have been integrated into development plans and strategies to preserve the environment and improve rural residents' living conditions. Implementing various initiatives and policies, such as afforestation, soil protection, and land management, has led to significant achievements in mitigating desertification and restoring degraded lands. The inclusion of the social dimension in these efforts has also provided employment opportunities and improved the well-being of rural communities.

Algeria's recent reforestation policy has changed, reflecting a strategic shift toward adaptive, evidence-based land restoration strategies, The National Reforestation Plan (NRP), which was launched in 2000, and aimed to cover 1.2 million hectares over two decades, integrating afforestation, soil conservation, and community employment. (Merdas et al., 2017), nevertheless, these early implementation phases were characterized by notable deficiencies, particularly exemplified by the degradation of Stipa tenacissima grasslands due to mismatched top-down interventions (Sliman & Aidoucf, 2004), This ecological degradation, highlighted the need for ecologically appropriate restoration strategies, Contemporary programs such as the Green Dam rehabilitation project now prioritize mixed-species plantations, which demonstrate marked resilience against invasive insects (notably Thaumetopoea pityocampa) reducing infestation rates by 40–60% in Djelfa's semi-arid zones (Hezil et al., 2024), This aligns with global findings on biodiversity-mediated pest resistance (Barsoum et al., 2016; Eigenbrode & Adhikari, 2023; Setiawan et al., 2017), recent research findings significantly enhance these restoration initiatives. Research by (Liiv et al., 2025) demonstrated 70% seedling survival rates in Djelfa through the application of decomposable moisture-retention matrices, while the multi-species stands established within the Green Dam program (comprising Pinus halepensis, Pistacia atlantica, and Ceratonia siliqua) have demonstrated measurable improvements

in carbon capture capabilities and localized climatic stabilization (Benhizia et al., 2021b; Stanturf et al., 2014), Critically, participatory frameworks now engage local communities in composite production and monitoring, addressing past socio-ecological disconnects (Hezil et al., 2024), these progressive developments exemplify Algeria's transition toward integrated restoration frameworks that effectively harmonize policy instruments, scientific advancements, and community-based environmental managment in combating desertification challenges, however, there is still a long way to go in the fight against desertification, and continuous efforts and monitoring are necessary to maintain the achieved progress and address the ongoing challenges.

9. Conclusion

This study underscores the urgent challenge of desertification in Algeria, which affects over 36.62% of its non-desert land. Despite significant government initiatives since 1962, including the vegetation barrier project and integration into national development plans, although there were some challenges in the early years, such as the lack of technical studies and the focus on monoculture activities, the government's integrated approach to mitigate desertification has shown positive results in recent years, Algeria continues to encounter substantial obstacles, such as inadequate collaboration among stakeholders and insufficient funding. Ongoing issues, including land degradation and the impacts of climate change,

To effectively combat desertification, Algeria must enhance collaboration among government agencies, local communities, and international organizations. Key areas for future efforts include improving research and monitoring systems to provide data-driven insights and ensure adaptive management, as well as fostering active community participation to develop culturally relevant and socially inclusive solutions. Additionally, aligning desertification strategies with broader environmental policies will create more cohesive and efficient approaches.

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Conflicts of Interest

The authors declare no conflict of interest.

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