Chapter

Desertification in Agricultural Lands: Approaches to Mitigation

Mehdi Rastgoo and Alireza Hasanfard

Abstract

Urban expansion and industrial development destroy agricultural lands, pastures, and forests, and reduce the ecological and biological potential of lands, known as desertification. Diminished land potential due to one or a combination of processes such as erosion, destruction of water resources, destruction of vegetation, and swamping, by climate and human factors, is called desertification. Among these, human factors have a vital role in the emergence of this phenomenon. Excessive human economic activity upsets the ecological balance of arid and semi-arid regions, leading to adverse environmental changes. With the expansion of deserts in some parts of the world, food production and water resources are declining, resulting in environmental migration. Due to the limited capacity of urban areas to provide facilities and services, these migrations will cause severe socioeconomic problems. In general, climatic and human factors are among the fundamental causes of desertification in the world. Preventing improper agricultural practices that lead to salinity and widespread soil degradation requires well-planned and strengthened awareness programs and development of information and care systems for areas exposed to desertification and drought, while also addressing the economic and social dimensions in these ecosystems.

Keywords: climate, desert, ecological balance, soil degradation

1. Introduction

Desertification is at the forefront of the environmental crises currently facing the international community. In sensitive and fragile desert-adapted ecosystems, degradation processes can easily be converted into an irreversible trend. Desertification reduces access to ecosystem services, increases food insecurity and poverty, and affects communities' well-being [1]. Desertification is land degradation or the impoverishment of arid, semi-arid (drylands), and some subhumid ecosystems, resulting from many factors including human activities and climatic change. The assessment of global scale desertification vulnerability to climate change and human activity is important to help decision-makers formulate the best strategies for land rehabilitation and combat global desertification in sensitive areas [2]. The range and intensity of desertification have increased in some dryland areas over the past several decades [3].

Drought and unreliable and variable rains are recurrent problems. Even without climate change, drylands face a daunting array of threats including population pressure, social changes (e.g. settlement of traditionally nomadic peoples), and exploitive agricultural and grazing practices that increase deforestation, soil erosion,

salinization, and water depletion. Many political and institutional problems have conspired to degrade 20% of the world's drylands, including 22% of Asia's and 25% of Africa's susceptible drylands [4].

Regions like Africa are particularly vulnerable to desertification since two-thirds of the continent is made up of either deserts or drylands, while 73% of its agricultural drylands are already degraded. More than two-thirds of its population is composed of subsistence farmers, and, therefore, the impact of land degradation is immediate and devastating [5].

2. Desertification processes

Desertification may occur as a result of one process or the interaction of several functions. For example, wind erosion is one of the essential desertification processes in arid regions of the world, which alone or combined with other processes leads to desertification. The main desertification processes refer to the destruction of plant resources, soil resources, soil erosion, and water erosion, which are further explored below. In addition to natural factors, policies in Greece or Europe in recent decades have been reported to contribute to intensive land cultivation, overgrazing, rural–urban migration, etc., which directly affect desertification [6].

2.1 Destruction of plant resources

Degradation of vegetation through harvesting and destruction is the dominant desertification process. Ma et al. [7] cited vegetation degradation as an essential factor in southwest China's socio-economic development. The researchers also identified nutrients in the soil, especially N, P, and K, as the main factors influencing plant species composition in rocky desert areas. Vegetation conservation in Greece has been introduced as an influential factor in reducing water and wind erosion [6]. Vegetation cover and vegetation composition are the most common characteristics of many terrestrial ecosystems. These characteristics are associated with many ecosystem services, including biodiversity, soil and water conservation, food production, and fiber. It is also common to use these two indicators to assess land degradation and rehabilitation and rehabilitation project success. Deforestation contributes to about 17% of annual human greenhouse gas (GHG) emissions [8]. Humans resort to deforestation to meet their wood and energy needs. Deforestation for fuelwood is much more significant in developing countries with high populations and less access to commercial energy sources. Forests are also being destroyed to provide more land for agriculture [9]. Desertification risk scenarios in northeastern Brazil predict that 75% of forest areas will decline from 2010 to 2040. In this scenario, most forest areas will be replaced by agricultural lands [1]. Therefore, lands with more suitable vegetation are more resistant to degradation. In contrast, poor vegetation areas are fragile and accelerate desertification over time due to adverse environmental factors.

2.2 Destruction of soil resources

Land degradation in recent years has become a primary global concern due to increased waste disposal and demand for food production. Soil flexibility is limited, and soil degradation can never be easily reversed. In this century, the focus of land degradation has been on soil erosion, since forests, grasslands, and wetlands have been destroyed for crop production.

Severe land use without proper soil management, especially in fragile ecosystems, can accelerate desertification [10]. Human activities or climate change negatively affecting vegetation can lead to irreversible soil degradation in semi-arid regions [11]. Soil degradation in the semi-arid region of northeastern Brazil is driven by a limited set of variables, the most important of which are climatic, economic, and population growth variables. These factors lead to the expansion of agricultural lands and overgrazing, which increase the rate of deforestation [12].

Soil degradation processes:

2.2.1 Physical destruction

These refer to drastic changes in the soil's physical properties, including reduced permeability and porosity, reduced stability of the soil structure, and loosening and compaction of the soil [13]. Root zone compaction is the main form of physical degradation in arable lands and pastures, reducing soil fertility and reducing the amount of soil organic matter. Low structural stability of compacted soils leads to high vulnerability to mechanical stresses from agricultural operations. Therefore, reducing soil permeability, increasing runoff, increasing erosion, reducing soil aeration, and reducing biomass production are side effects of soil compaction and tuber formation that should be considered an indicator to assess the intensity of desertification.

2.2.2 Chemical degradation

A change in the soil's chemical properties in such a way that it interferes with nutrient uptake is called soil chemical degradation. Soil salinization, soil acidity imbalance, soil leaching, and ultimately reduced soil fertility are the most critical consequences of chemical soil degradation. Chemical degradation of soil can also occur due to increased concentrations of some toxic components such as aluminum.

2.2.3 Soil biodegradation

Microorganisms in agricultural soils play a crucial role in soil fertility. The reduction of soil organic matter and living microorganisms in soil is called biodegradation. Humus is an essential soil substance that increases soil porosity, soil stability, soil water holding capacity, and micronutrients. Organic matter depletion is the first state of biodegradation that leads to changes in other soil properties. In arid regions, depletion of soil organic matter leads to a decrease in soil moisture-holding capacity, a reduction in crops, and an increase in soil erosion [14]. Land-use change affects the physical, chemical, and biological properties of the soil. The conversion of pastures into agricultural lands in some areas of Iran has reduced the soil quality and increased soil degradation. It has been reported that the transformation of ranges to agricultural fields in three regions in Isfahan province has reduced soil organic matter by about 26% in agricultural lands, which is probably due to poor vegetation density (**Figure 1**) [15].

2.3 Soil and water erosion

In the last century, the significant destruction of land has been through soil erosion, as the areas of forests, grasslands, and wetlands have been removed for crop production. Soil erosion is one of the essential desertification processes during which soil particles are separated, transported, and deposited. Moreover, the soil decays and its organic matter decreases in the process of erosion. Humans obtain more than 99.7% of their food (calories) from land and less than 0.3% from the

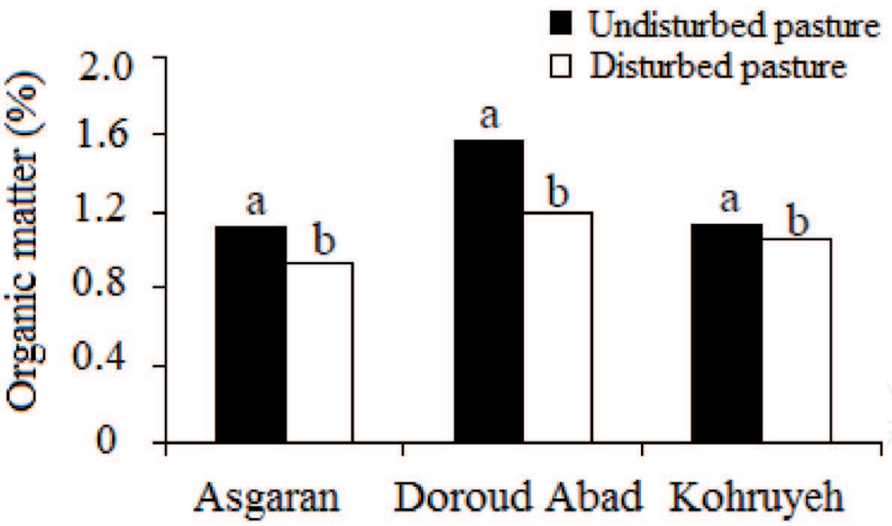


Figure 1.
Percentage of soil organic matter in the lands of three regions. The same letters for the regions indicate no statistical difference at the 5% level with the LSD test [15].

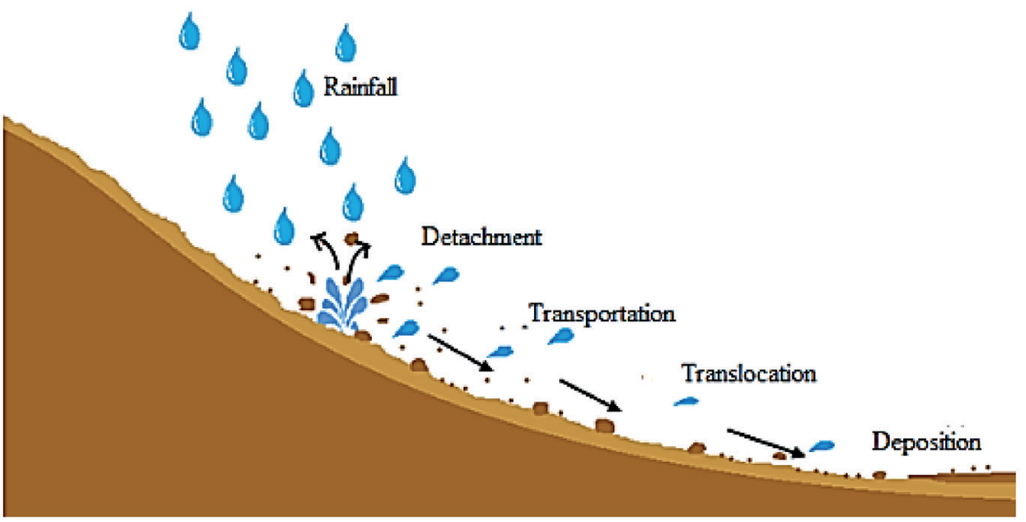


Figure 2.
Erosion stages by water [17].

oceans and other aquatic ecosystems. About 10 Mha of crops are lost each year due to soil erosion, thus reducing the amount of arable land available for food production [16]. Water erosion means the removal, transport, and deposition of soil particles by rain, runoff, and gravity **Figure 2** [18] shows the mechanism of water erosion. Rain erosion is one of the most critical water erosion types, which occurs more widely than other types. As rainfall occurs, the raindrops onto the soil surface and makes the first contact with the soil [19]. The loosening of soil particles or the detachment process takes place when soil particles disengage as the rain touches down on the soil. Afterward, soil particles are transported by rolling, splashing, or dragging and translocate to another place. Finally, soil particles are deposited at some other place at a lower elevation [17].

3. Factors affecting desertification

The process of land degradation in arid areas is called desertification, which affects the land capacity to provide ecosystem services, such as food production or biodiversity

hosting, to name a few. It is stimulated by both human activity and climate and depends on the specific context. More than 1 billion people in about 100 countries face some of the risks associated with the effects of desertification [20]. The risk of desertification can increase in parts of the world that may become arid due to climate change.

According to the United Nations (UN), about 2.1 billion people worldwide (25–30%) living in arid and semi-arid regions [21] are among the poorest people. Approximately 70% of rainfed areas are located in Africa and Asia (**Figure 3**) [3]. Asia, followed by Africa and South America, have the largest populations in arid regions [23]. The global population growth rates are very high, especially in dry areas. The rapid population growth increases the pressure on land and natural resources that have already been oppressed and leads to poverty by degrading land and increasing desertification [24].

Parivar et al. [25] comparisons of open, green, and impervious surface areas (ha) in Yazd, Iran for 1991 and 2018 (**Figure 4**). The continuum, impermeable levels (built area) increased strongly during the period under study. From 1991 to 2018, there was an 80% decrease in open space, 63% decrease in green space, and a 90% increase in built-up area. In this way, population growth and urban development reduce green space, which leads to desertification.

Numerous factors affect the intensification and advancement of desertification, which can be classified into two categories, anthropogenic and climatic factors.

3.1 Anthropogenic factors

Human factors play an intensifying role in the development of desertification in arid and semi-arid ecosystems. These factors have a significant contribution to the process of land degradation. The annual plants are destroyed and the soil dries out when rainfall is low, thereby providing water and wind erosion and forming deserts and desertification globally. Some researchers have identified humans as a significant cause of desertification [4]. The shares of human factors and natural elements involved in desertification were 87 and 13%, respectively [26]. Changes in the use and destruction of forests and pastures, overgrazing, salinization of water and soil resources, burning of crop residues, improper use of groundwater, irregular

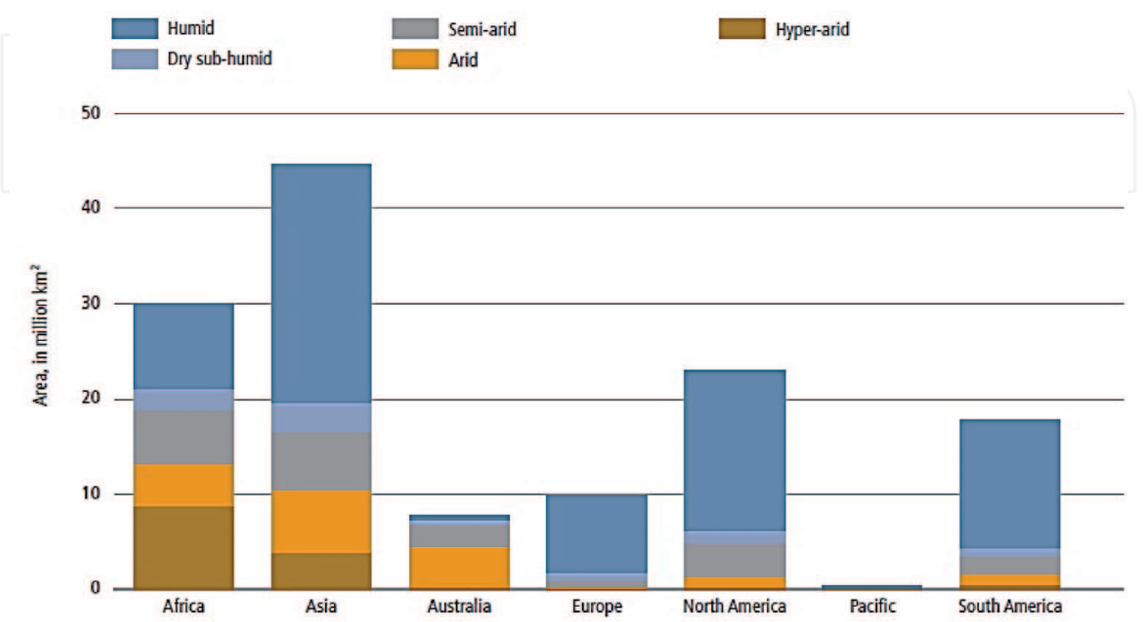


Figure 3.
Dryland categories across geographical areas (continents and Pacific region). Data: TerraClimate precipitation and potential evapotranspiration (1980–2015) [22].

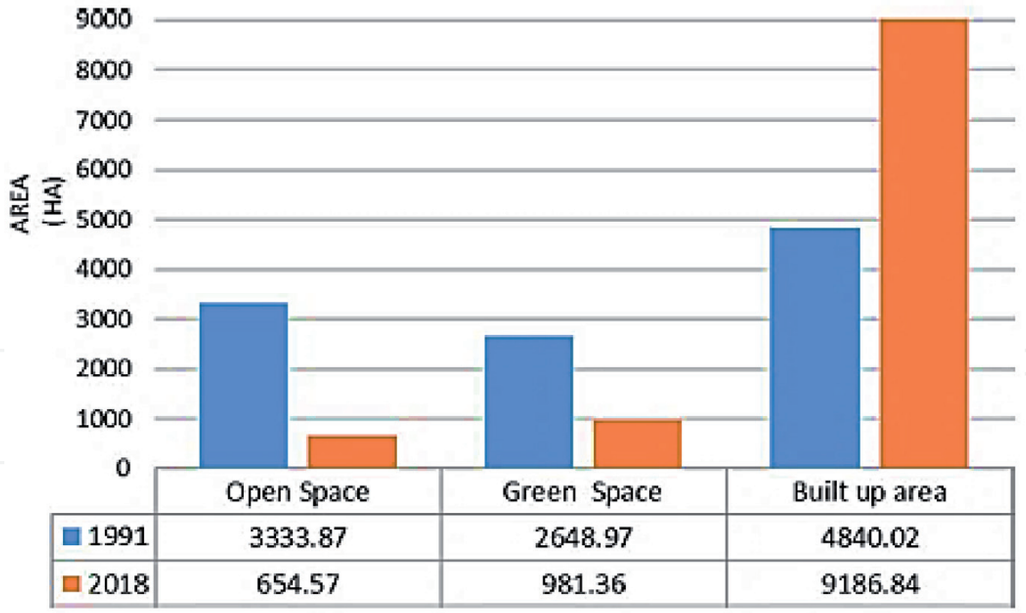


Figure 4.
Land areas (ha) in Yazd categorized as open, green, and built-up space (1991–2018) [25].

plowing, and failure to observe proper crop rotation in agriculture, fire, sediment settlement, development of urban areas, and industrial activities are among the most important factors influencing desertification by humans. Deserts are divided into two general categories—natural deserts of environmental origin and human deserts. Natural deserts are commonly found in arid and hyper-arid regions of the world, and humans have a minor role in their formation, making bare natural landscapes without vegetation. In addition to arid and hyper-arid regions, human deserts can be seen in other climatic zones, including semi-arid to humid regions.

3.2 Climatic factors

Climate change can further increase the risk of desertification for those regions of the world that may change into drylands for climatic reasons. Because arid areas are used for various purposes, such as agriculture, grazing, and gathering wood for fuel, the multiple activities performed in them can exacerbate the problem of desertification and bring about lasting changes in rainfed ecosystems. In this regard, drought, irregularity in rainfall, topographic factors, and radiation angle are the most critical environmental factors affecting desertification.

Although the effects of climate change can be seen in all activities, its impact on agricultural production seems to be more pronounced; annual damage from the adverse impacts of climate change due to rising temperatures, long periods of drought and desertification has been reported to be far greater than other activities affected by this change. For example, climate change has directly reduced crop productivity by reducing crop yields [27]. Barren ecosystems have low and variable rainfall, so climate change and other factors that lead to prolonged drought can rapidly reduce these ecosystems biological productivity. These changes may be temporary and last only one season, or they may last for years and decades [3].

4. The role of agriculture in desertification

One of the most important causes of desertification, especially in arid and semi-arid regions of the world, is improper activities in agriculture. Dense and

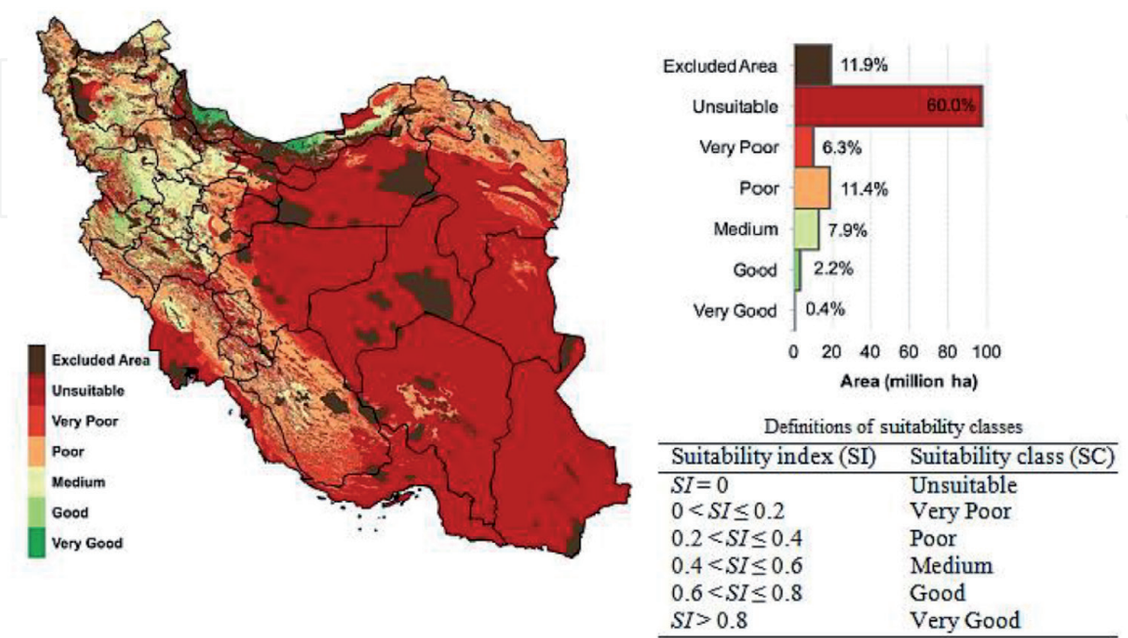
improper cultivation of crops reduce soil structure stability and lead to soil degradation and erosion [28]. When the soil's pressure increases due to agricultural operations and land clearing, soil fertility decreases, resulting in soil degradation and erosion.

Irrigation systems have developed over time as an agricultural technique in arid areas with low rainfall. If irrigation methods are misapplied, water loss and lowering of groundwater aquifers will lead to salinization and alkalinization of lands. Therefore, one of the most critical factors in desertification in agriculture is improper irrigation, which will ultimately lead to the destructive effects of drought, the phenomenon of soil and water salinization due to improper management of agricultural land [28]. Salinity is caused by improper irrigation in soils of arid and semi-arid regions. The leading cause of salinity and alkalinity in some parts of the world is the entry of low-quality water. Improper irrigation and lack of proper drainage raise the groundwater level and form a surface saline aquifer. With soil degradation, vegetation decreases and the soil is exposed to water and wind erosion, and its fertility is severely reduced. Therefore, knowing the main reasons for the salinization of soil and water in the world's regions and proper management of such lands can help reduce the process of desertification.

Changes in the soil's chemical composition with the use of fertilizers or chemical pesticides lead to changes in the soil's physical condition, which increases soil erosion. On the other hand, nitrogen released from chemical fertilizers and its mixing with groundwater lead to pollution of groundwater resources, which is recognized as a severe problem in some parts of the world [29].

Effects of fire on vegetation cover change and expedite the process of desertification by humans is proven. The severity of the fire damage depends on the conditions of the area. In arid lands, severe fires lead to the extinction of plant, animal, and soil species, which in some cases alter ecosystems and contribute to intensified desertification. Frequent burning of straw and crop residues and reducing land fertility are also influential factors in desertification.

There is an important concern about the conversion of agricultural land to barren desert, exacerbated by desertification in countries such as Iran.



Definitions of suitability classes

Suitability index (SI)	Suitability class (SC)
$SI = 0$	Unsuitable
$0 < SI \leq 0.2$	Very Poor
$0.2 < SI \leq 0.4$	Poor
$0.4 < SI \leq 0.6$	Medium
$0.6 < SI \leq 0.8$	Good
$SI > 0.8$	Very Good

Figure 5.
Classification of Iran's land suitability for agriculture based on soil properties, terrain, and climate conditions [30].

Accordingly, desertification is one of the most important factors in Iran, which has been exacerbated by drought. The result of drought and desertification is a reduction in Iran's land suitable for agriculture. Mesgaran et al. [30] classified Iran's land suitability for cropping as (million ha): very good 0.4% (0.6), good 2.2% (3.6), medium 7.9% (12.8), poor 11.4% (18.5), very poor 6.3% (10.2), unsuitable 60.0% (97.4), and excluded areas 11.9% (19.3) (**Figure 5**). Hence, reducing suitable land for agriculture means reducing food production, which threatens food security.

5. Desertification and food security

The most critical role of the agricultural sector is to ensure sustainable food security. So food security is, by definition, a situation where everyone has access to adequate, healthy, and nutritious food [31]. Therefore, desertification can be considered one of the most important factors limiting agricultural product production and, ultimately, the challenge of food security. According to **Figure 6**, if the population grows at a fixed exponential rate, the amount of food required will increase exponentially. But Malthus held that the output of food could increase only by a constant amount each period. Given these two different growth processes, food requirements would eventually catch up with food production. The population hits the subsistence level of food production at the Malthusian trap, shown here at point T [32].

Drought stress in arid and semi-arid regions such as Iran has posed a serious challenge to sustainable production to provide food for the growing population. Concerns about the vulnerability of agricultural production become more pronounced when there is a proper understanding of the impact of climate change. If desertification leads to degradation and degradation of water, soil, and vegetation resources as three factors of survival in vulnerable ecosystems, food security will face serious problems. Thelma [33] reported that desertification has exacerbated the problem of food security in eleven states in northern Nigeria and its effect is very glaring on the agricultural sector.

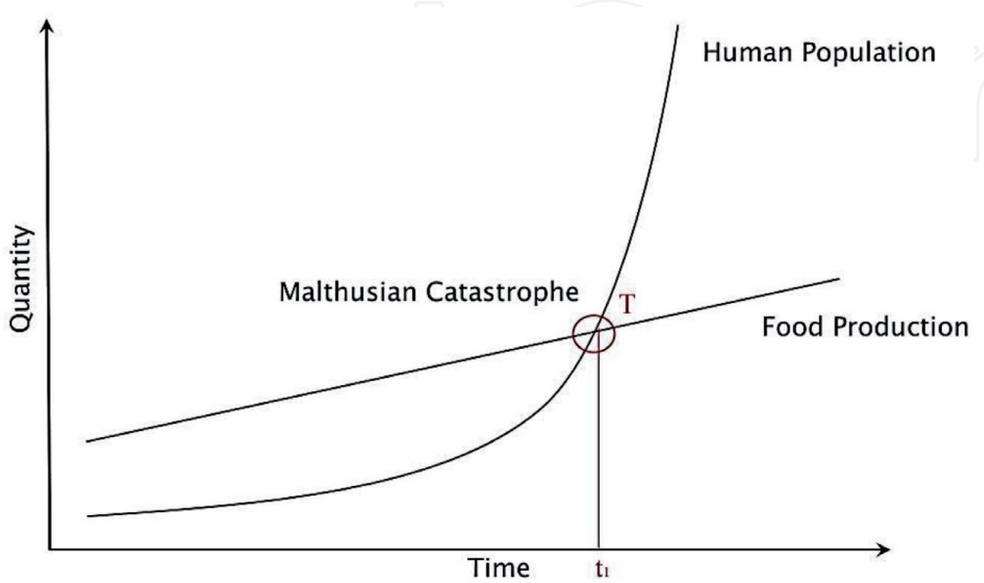


Figure 6.
The Malthusian growth model [32].

6. Strategies to combat desertification

In 1977, at the United Nations Conference on Desertification (UNCOD) in Nairobi, Kenya, representatives, and delegates first contemplated desertification's worldwide effects. The conference explored the causes and contributing factors and also possible local and regional solutions to the phenomenon. Also, the delegates considered the varied consequences of desertification, such as crop failures or decreased yields in rain-fed farmland, the loss of perennial plant cover and thus loss of forage for livestock, reduced woody biomass, and therefore scarcity of fuelwood and building materials, a decrease in potable water stocks from reductions in surface water and groundwater flow, increased dune intrusion onto croplands and settlements, increased flooding due to rising sedimentation in rivers and lakes, and amplified air and water pollution from dust and sedimentation [34].

Non-desertification means preventing desertification of areas exposed to desertification due to destructive human actions, not destroying existing natural deserts. Climate, as the two main climatic factors that have many changes and fluctuations, plays an essential role in forming arid and desert areas. Since arid and semi-arid regions occupy a large part of the world area, identifying the potentials in these areas and discovering resources to provide management solutions to take advantage of existing potentials and prevent desertification from Is of particular importance [3].

The priority in combating this phenomenon is to prevent the destruction of lands that have not yet been destroyed or where the descent rate is low. In contrast, for the conquered lands, remedial plans should be considered. According to international experts, including the following in the medium and long-term goals can significantly improve desert management activities.

- Strengthen awareness and development of information and care systems for areas exposed to desertification and drought, including the economic and social dimensions of these ecosystems

- Development of comprehensive desertification plans and their inclusion in national development plans and programs and national environmental plans.

- Combating land degradation through soil conservation, afforestation, and reforestation.

- Develop comprehensive compensation and mobilization programs to combat drought, including self-help arrangements for drought-prone areas and programs for environmental refugees.

- Develop coordinated development programs to eradicate poverty and improve living standards in areas prone to desertification.

- Encourage and improve the level of public cooperation and environmental education with a focus on desertification control and drought management

7. Conclusion

Because rainfed environments are used for a variety of human purposes (such as agriculture, livestock grazing, and timber collection), the various activities

performed in them can exacerbate desertification problems and bring about lasting changes in rainfed ecosystems. Desertification is a phenomenon that occurs as a result of natural or human factors. In recent decades, Desertification has intensified with the loss of fertile lands, destruction of pastures and agricultural lands, salinization and erosion of lands, and quantitative and qualitative reduction of surface and groundwater. This phenomenon poses a serious threat to most of the world's ecosystems, mainly arid and semi-arid regions.

In recent years, due to the overexploitation of natural resources, this process has become more intense and severe, and comprehensive management is needed to deal with it. Implementing and implementing projects appropriate to this challenge and benefiting from successful practical programs in the world can effectively reduce the desertification process, especially in arid and semi-arid regions. In general, correct knowledge and assessment of the state of the world's deserts will help manage these areas.

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