Prepublished copy

Nature Environment & Pollution Technology

This is a peer-reviewed prepublished version of the paper

A Review of Environmental Monitoring for Land Desertification Using Geospatial Analysis and Remote Sensing

Ghaidaa Sabah Yousef [1*], Hayder Dibs[2], and Ahmed Samir Naje[3]

1) Water Resources Management Engineering Department, College of Engineering, Al-Qasim Green University, Babylon, 51013, Iraq;
2) Water Resources Management Engineering Department, College of Engineering, Al-Qasim Green University, Babylon, 51013, Iraq;
3) Water Resources Management Engineering Department, College of Engineering, Al-Qasim Green University, Babylon, 51013, Iraq;
Corresponding Author: Ghaidaa Sabah Yousef Ghaida.m106416@wrec.uoqasim.edu.iq

Abstract

Studying and evaluating desertification is essential due to its potential occurrence as a result of both natural and anthropogenic processes. Precise forecasting of forthcoming climate change perils is crucial for devising policies, action strategies, and mitigation measures at both the local and global scales. Remote sensing facilitates the examination, monitoring, and forecasting of several aspects of desertification. Throughout the years, many methodologies have been employed to investigate desertification through the utilization of Remote Sensing (RS). This study investigated the worldwide prevalence and temporal sequence of research that utilized remote sensing (RS) to investigate desertification. In addition, the study assessed the primary approaches and factors employed in the examination of desertification through the analysis of remote sensing data. The application of remote sensing (RS) in the investigation of desertification can be traced back to 1991. Between 2015 and 2020, an annual average of over 40 publications were published, indicating a substantial rise in the utilization and accessibility of remote sensing (RS) technology for the purpose of monitoring desertification. However, there is a significant disparity in the amount of research conducted in different fields. Asia demonstrates a substantially higher quantity of studies in contrast to America or Africa. China has conducted the highest number of research on desertification using remote sensing (RS) techniques. The Thematic Mapper (TM) sensor is the principal source of satellite data, specifically Landsat pictures. The primary techniques utilized for studying desertification are classification and monitoring of alterations. Furthermore, remote sensing methods commonly employ land cover/land use change and vegetation, together with its attributes such as the Normalised Difference Vegetation Index (NDVI), as the primary factors for studying desertification.

Key Words	Land Degradation, Remote sensing Indices, Environmental monitoring, Landsat Satellite images
DOI	https://doi.org/10.46488/NEPT.2025.v24i02.D1697 (DOI will be active only after the final publication of the paper)
Citation of the Paper	Ghaidaa Sabah Yousef, Hayder Dibs, and Ahmed Samir Naje, 2025. A Review of Environmental Monitoring for Land Desertification Using Geospatial Analysis and Remote Sensing. *Nature Environment and*

	Pollution Technology, 24(2), D1697. https://doi.org/10.46488/NEPT.2025.v24i02.D1697

1. Introduction

Desertification and land degradation exert a substantial influence on both the economy and the environment. Land degradation impacts around 1.4 billion individuals worldwide, with 74% of this population residing in impoverished conditions. In addition, the simultaneous occurrence of drought and desertification is causing a yearly decrease of 12 million hectares of cultivable land (United Nation 2015; Dibs et al., 2023; Al-Janabi et al., 2024). Land degradation is the decline in the productivity of land, both in terms of its biological and economic output. This leads to the deterioration of the physical, ecological, and economic qualities of the soil, as well as the permanent loss of natural vegetation (United Nations 1994; Bakr et al. 2012; Dibs et al. 2014; Van & Jetten 2015).

Since 1970, there has been a growing political and international attention towards arid, semi-arid, and sub-humid areas. This is mostly due to their significant contribution to both food production and the social advancement of communities. This issue has been extensively studied (Li et al. 2016; Becerril-Pi˜na et al. 2016; Liu et al. 2018; Zhao et al. 2018; Kadhim et al., 2022). Desertification is the process of land deterioration in ecosystems that are dry, semi-arid, and sub-humid. Desertification is the process by which a place undergoes a transformation into a desert or experiences the formation of desert-like conditions (Verstraete, 1986; Dibs et al., 2020; Dibs et al., 2021a and 2021b; Hashim et al., 2021). Nevertheless, in 1977, the United Nations published the initial all-encompassing explanation of the concept, which accounted for the economic consequences of this occurrence. Desertification refers to the gradual reduction or complete destruction of a land's capacity to sustain life, which can ultimately result in the formation of desert-like environments (United Nations, 1977). In 1994, the definition of desertification was broadened to encompass the deterioration of land in arid, semi-arid, and dry sub-humid areas caused by both human actions and changes in climate. This notion currently encompasses the impact of human actions on climate change, in addition to the economic consequences.

The information originates from the United Nations in 1994. Since its official endorsement, this concept has been extensively utilized in numerous international research on desertification. Consequently, it has offered numerous and versatile approaches for measuring, analyzing, and simulating desertification (Li et al., 2006; Cui et al., 2011; Bakr et al., 2012; Lamchin et al., 2016; Xu et al., 2016; Becerril-Pi ña et al., 2016; Liu et al., 2018; Zhao et al., 2018; Dibs et al., 2022a and 2022b; Hashim et al., 2022; Dibs & Al-Ansari, 2023). In this study, desertification is defined as the deterioration of land in arid, semi-arid, and dry sub-humid regions due to human activities and climate changes, ultimately resulting in desert-like conditions.

Desertification is widely acknowledged by the worldwide community as a major worry because of its diverse detrimental impacts on the environment, including dust storms, silting, soil salinization, and degradation (United Nations, 2015). In addition, desertification can result in notable socio-economic issues, including limited availability of food, poverty, and health implications such as malnutrition and respiratory diseases (Xiao et al., 2006; United Nations, 2015). Desertification is an irreversible phenomenon influenced by natural elements such as temperature, precipitation, and the decrease in vegetation cover. It is also impacted by human activities like alterations in land use and land cover, industrialization, and urbanization (Stringer, 2008; Santini et al., 2010; De Pina Tavares et al., 2015; Xu et al., 2016). Desertification is a significant obstacle to achieving sustainable development in arid, semi-arid, and moderately humid regions, leading to environmental and socioeconomic issues (Wang et al., 2006; Helld´en &Tottrup, 2008; Li et al., 2016; Dibs et al., 2023a and 2023b; Dibs et al., 2023c). Desertification was incorporated into the Sustainable Development Goals outlined in the 2030 Agenda for Sustainable Development in order to address its possible effects on the economy, ecology, and society. The main objective of Sustainable Development Goal 15 is to safeguard, repair, and encourage the sustainable utilization of land-based ecosystems, proficiently administer forests, prevent desertification, and cease and reverse the deterioration of land and loss of biodiversity(United Nations 2015). According to future climate change projections, desertification will increase globally due to changes in temperature, precipitation, carbon sequestration, and atmospheric carbon dioxide levels. Sustainable Development Goal 15.3 aims to rehabilitate land and soil that have undergone degradation due to desertification, drought, and floods. The primary objective is to attain a state of balance by 2030, when restoration activities effectively offset the adverse impacts of land degradation. Addressing desertification is essential for reducing global poverty and mitigating the negative impacts on biodiversity and climate change resulting from human activities.

The changes will be caused by variations in rainfall, a higher frequency of droughts, and the continuation of dry conditions (D'Odorico et al., 2013; Al-Bakri et al., 2016; Mutti et al., 2020).

Desertification and land degradation exert a substantial influence on both the economy and the environment. Land degradation impacts around 1.4 billion individuals worldwide, with 74% of this population residing in impoverished conditions. In addition, the simultaneous occurrence of drought and desertification is causing a yearly decrease of 12 million hectares of cultivable land (United Nations, 2015). Land degradation is the decline in the productivity of land, both in terms of its biological and economic output. This leads to the deterioration of the physical, ecological, and economic qualities of the soil, as well as the permanent loss of natural vegetation (United Nations, 1994; Bakr et al., 2012; Dibs et al., 2020; Palacios et al.,1999).

since 1970, there has been a growing political and international attention towards arid, semi-arid, and sub-humid areas. This is mostly due to their significant contribution to both food production and the social advancement of communities. This issue has been extensively studied (Li et al., 2016; Becerril-Pi˜na et al., 2016; Liu et al., 2018; Zhao et al., 2018). Desertification is the process of land deterioration in ecosystems that are dry, semi-arid, and sub-humid. Desertification is the process by which a place undergoes a transformation into a desert or experiences the formation of desert-like conditions (Verstraete, 1986; Dibs et al., 2020; Dibs et al., 2021a and 2021b; Hashim et al., 2021). Nevertheless, in 1977, the United Nations published the initial all-encompassing explanation of the concept, which accounted for the economic consequences of this occurrence. Desertification refers to the gradual reduction or complete destruction of a land's capacity to sustain life, which can ultimately result in the formation of desert-like environments (United Nations, 1977). In 1994, the definition of desertification was broadened to encompass the deterioration of land in arid, semi-arid, and dry sub-humid areas caused by both human actions and changes in climate. This notion currently encompasses the impact of human actions on climate change, in addition to the economic consequences.

The information originates from the United Nations in 1994. Since its official endorsement, this concept has been extensively utilized in numerous international research on desertification. Consequently, it has offered numerous and versatile approaches for measuring, analyzing, and simulating desertification (Li et al., 2006; Cui et al., 2011; Bakr et al., 2012; Lamchin et al., 2016; Xu et al., 2016; Becerril-Pi ña et al., 2016; Liu et al., 2018; Zhao et al., 2018; Dibs et al., 2022a and 2022b; Hashim et al., 2022; Dibs & Al-Ansari, 2023). In this study, desertification is defined as the deterioration of land in arid, semi-arid, and dry sub-humid regions due to human activities and climate changes, ultimately resulting in desert-like conditions.

Desertification is widely acknowledged by the worldwide community as a major worry because of its diverse detrimental impacts on the environment, including dust storms, silting, soil salinization, and degradation (United Nations, 2015). In addition, desertification can result in notable socio-economic issues, including limited availability of food, poverty, and health implications such as malnutrition and respiratory diseases (Xiao et al., 2006; United Nations, 2015). Desertification is an irreversible phenomenon influenced by natural elements such as temperature, precipitation, and the decrease in vegetation cover. It is also impacted by human activities like alterations in land use and land cover, industrialization, and urbanization (Stringer, 2008; Santini et al., 2010; De Pina Tavares et al., 2015; Xu et al., 2016). Desertification is a significant obstacle to achieving sustainable development in arid, semi-arid, and moderately humid regions, leading to environmental and socioeconomic issues (Wang et al., 2006; Helld´en and Tottrup, 2008; Li et al., 2016; Dibs et al., 2023a and 2023b; Dibs et al., 2023c). Desertification was incorporated into the Sustainable Development Goals outlined in the 2030 Agenda for Sustainable Development in order to address its possible effects on the economy, ecology, and society. The main objective of Sustainable Development Goal 15 is to safeguard, repair, and encourage the sustainable utilization of land-based ecosystems, proficiently administer forests, prevent desertification, and cease and reverse the deterioration of land and loss of biodiversity (United Nations, 2015). According to future climate change projections, desertification will increase globally due to changes in temperature, precipitation, carbon sequestration, and atmospheric carbon dioxide levels. Sustainable Development Goal 15.3 aims to rehabilitate land and soil that have undergone degradation due to desertification, drought, and floods. The primary objective is to attain a state of balance by 2030, when restoration activities effectively offset the adverse impacts of land degradation. Addressing desertification is essential for reducing global poverty and mitigating the negative impacts on biodiversity and climate change resulting from human activities.

The changes will be caused by variations in rainfall, a higher frequency of droughts, and the continuation of dry conditions (D'Odorico et al., 2013; Al-Bakri et al., 2016; Mutti et al., 2020). The forecast of future desertification trends primarily focuses on natural and human-induced elements, such as temperature, precipitation, wind, and vegetation covers/types, as these are the main causes of desertification. It is widely agreed upon that increasing temperatures and less rainfall would exacerbate the frequency, intensity, and duration of droughts. Climate change forecasts indicate that desertification would increase globally due to changes in temperature, precipitation, carbon storage, and atmospheric carbon dioxide levels. These changes will arise due to variations in precipitation, heightened frequency of droughts, and prolonged periods of aridity. (D'Odorico et al., 2013; Al-Bakri et al., 2016; Mutti et al., 2020; Sameer and Hamid, 2023).

Currently, the application of remote sensing images in combination with deep learning methods has led to numerous advantageous findings in the field of desert research. However, there is a need for a broader integration of these approaches. To address this problem, we have conducted a

Thorough overview and detailed examination for comparison. Figure 1 depicts the exact structural framework. Prior to initiating the inquiry, it was crucial to select a remote sensing dataset specifically for the desert and perform necessary data processing. After completing these first tasks, it was crucial to first examine and classify both mobile and non mobile deserts, in light of the occurrence of desertification. Therefore, it was necessary to monitor the desertification occurring in mobile deserts. In order to provide a more accurate understanding of desertification conditions, further categorization and monitoring of the morphological changes in mobile deserts were carried out. This review critically analyzes and summarizes the research procedures utilized in different disciplines, aiming to provide a thorough evaluation of the present state of research and explore prospective directions for future investigations.

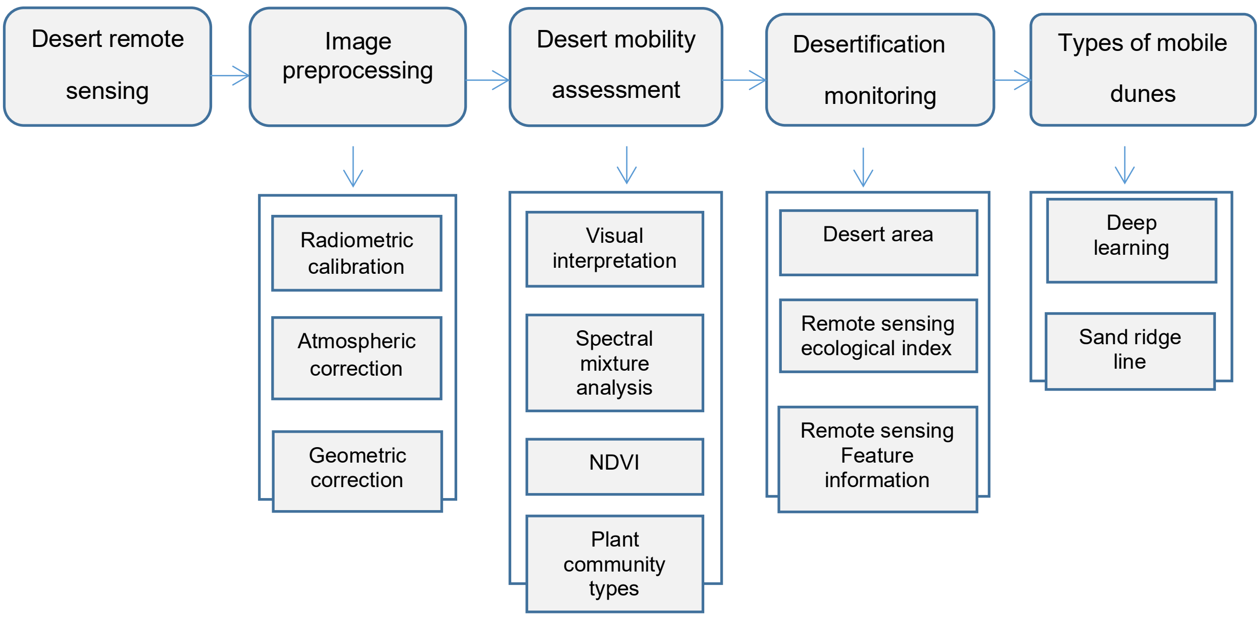

Figure 1. Framework of desertification monitoring.

2. Desertification Detection

Therefore, it is crucial to differentiate between the occurrence of desertification and other phenomena such as climate change, desiccation, unpredictability, and drought, and swiftly highlight their interconnectedness. Drought is a natural event characterized by a transitory period of significantly reduced rainfall compared to the usual observed levels (UNCCD, 1994 : Darkoh, 1996). Typically, current biological and social techniques are sufficient for managing temporary deficits in rainfall(Darkoh, 1996). Wilhite and Glantz (1985) categorize and analyze several forms of drought, such as meteorological, agricultural, hydrological, and socioeconomic drought.

Desiccation is the term used to describe long periods of less rainfall that can endure for several decades and have a significant impact on ecological and socioeconomic patterns. Resolving this issue requires a blend of efforts from both domestic and foreign sources. Desertification is not directly caused by drought or desiccation alone. However, if humans mismanage land, the consequences of these processes can be amplified, resulting in desertification in dry locations (Hulme and Kelly 1993, Darkoh 1996). Whereas climate change refers to long-term changes in climatic patterns, climate variability refers to transient variations in the climate. The modifications may result from either natural occurrences or human initiatives (Kelly & Hulme 1993, Darkoh 1996) According to Glantz and Orlovsky (1983), changes can occur in any or all of the atmospheric factors, such as precipitation, temperature, wind speed and direction, and evaporation.

Different forms of this kind could lead to changes in ecosystems, which in turn can impact human activities related to the utilization of these ecosystems. Climatic change is the concept that there are gradual modifications in the usual weather patterns, which are mostly accountable for desertification. These changes arise organically within the climate systems (IPCC, 2007). The intricate relationships and reciprocal connections between desertification and climate change are intricate. According to the Intergovernmental Panel on Climate Change (IPCC) in 2007 and the Millennium Ecosystem Assessment (MA) in 2005, desertification causes soil and plant depletion, which in turn fuels global climate change.

Research has established that if desertification is not controlled, it might lead to significant emissions of the greenhouse gas CO_2 into the atmosphere. Consequently, this would have substantial detrimental effects on the entire climate system. Global climate change is thought to exacerbate desertification by amplifying evapotranspiration and perhaps diminishing precipitation in arid regions. The West African Sahel region has clearly shown a tendency of rising hyperaridity, as reported by (Glantz & Orlovsky 1983 ; Kelly & Hulme 1993) .Land desiccation is an irreversible natural phenomenon that is beyond human intervention.

Furthermore, a number of investigations by researchers like (Darkoh 1996). Reed and Stringer (2015), and others have clearly shown that climate change is a real phenomenon that is greatly influencing the occurrence of desertification and land degradation in Africa. Our understanding of the relationship between climate change and desertification in diverse socio-ecological zones, as well as their potential interconnections in various circumstances, is currently limited. Clearly, they are reciprocally exerting an influence on one other and resulting in detrimental outcomes for the existing ecosystems.

3. Desertification Effects

The complex phenomena of desertification is the result of several interactions between environmental and human systems. The initial limitation of its analysis to biophysical environmental disciplines indicates a lack of comprehension of the complex nature of desertification. Impacts are quantifiable alterations in significant characteristics related to a particular situation (Grainger 2009). As to Grainger (2009), the human environment system undergoes a transition to a distinct state upon exceeding specific thresholds. The repercussions of any form of environmental destabilization have consistently demonstrated to be unacceptable and detrimental.

Therefore, the overall effects can be comprehended by considering the cause-and-effect relationship of the phenomenon. However, the diagnosis can be more comprehensively grasped and implemented based on the distinct area or region. The 2005 Millennium Ecosystem Assessment brought attention to the fact that desertification varies greatly in terms of its effects and extent in various places, and that it also evolves with time. The variability is determined by the degree of aridity in combination with the human impact on the ecosystems.

However, there is a notable discrepancy in our understanding and analysis of desertification and its underlying causes (MA 2005 ; FAO 1993). The impacts of desertification vary depending on the particular geographic region, country, and year, and are influenced by four distinct causes.

- Factors that lead to land degradation encompass the magnitude and scope of gravity,
- as well as the intensity of climatic conditions
- These factors include the size and variety of the population affected, as well as the amount of progress
- and advancement in the country.

Hence, when individuals experience increasing poverty and societies remain less developed, the severity of desertification's long-term consequences and the likelihood of catastrophic outcomes also escalate, particularly in the face of challenging climatic conditions. Desertification has a worldwide influence by diminishing the fertility of land and depriving individuals of vital biological resources necessary for human sustenance (Darkoh 1996, 1998). As a result, this leads to secondary socioeconomic effects such as famine and illnesses that arise from insufficient agricultural production, poverty, and restrictions on water quality and availability (UNCCD, 2013). Desertification leads to a decrease in plant growth, which in turn leads to a reduction in livestock output, overall plant biomass, and plant species diversity. Desertification is linked to the decline in biodiversity and the decrease in the number of living organisms within a specific area and timeframe(El-Karouri 1986; Mortimore 1989; Nneji 2013; Stephen 2014; Olagunjo 2015). This phenomenon is also known as the reduction in the range of living species (Senanayake, 2012). Grazing areas and pasture accessibility are significantly impacted by desertification (Okello, 2014 ;Ijah, 2014). The socio-economic consequences are wide-ranging and include the loss of social capital, an increase in household debt, and the erosion of regional traditions and ecological expertise (Fredrickson et al., 1988; Zaman 1997). One of the factors influencing the rise in migration is desertification (Ababa 2007; Abdi et al., 2013; Olagunjo 2015). The reported impact of this issue on the exploitation of natural resources has resulted in confrontations among different user groups(Abbas, 2014; Ijah, 2014; Oladipo, 2015). Desertification also affects pastoralists, a common practice in dry areas (Mortimore 1989; Stiles 1983; Tully & Shapiro 2014).

The severance of the profound connection between persons and the land results in substantial modifications in social structure, cultural legacy, and political stability (FAO 2001). Regional conflicts and the failure of weak administrations are more likely to occur as a result of the rising rates of malnutrition and water scarcity among people (UNCCD 2014).
Desertification in China leads to a significant reduction in cultivable land and a drop in the benefits provided by vegetation. Moreover, It lowers the standard of living in urban industrial zones and raises the costs of upkeep for the physical infrastructure. Notably, it results in a rise in rural poverty and migration driven by environmental factors. The destruction has intensified on a global scale. Minuscule particles carried by dust and sandstorms have already reached the western coast of America. The sandstorms are causing harmful health effects in the eastern and southern regions of China, as well as in Japan and Korea. Japan, Korea, and parts of eastern and southern China are also suffering negative health impacts from the sandstorms.

Desertification presents a substantial threat to the sustenance of millions of individuals and leads to yearly financial setbacks as a result of reduced output. As a result of mandatory relocation, farmers have been forced to migrate, leading to a growing imbalance in the demographic distribution between China's eastern and western areas. The stability of society is at danger due to the rising unemployment rate, which is fueling tensions between urban and rural populations and a rise in criminal activity (Zeng 2005).

Mexico has been greatly impacted by desertification. This issue arises when persons forsake land that has experienced degradation and relocate to locations that are less suitable for agricultural cultivation (Schwartz 1994).

The report neglects to take into account Mexico's poverty rate, which affects around two-thirds of its population, who predominantly live in poverty. The study did not consider indications of desertification consequences, such as changes in agricultural productivity and the diversity of farmed crops.
The UN report illustrates that desertification in Burkina Faso leads to a multitude of significant consequences. The factors that contribute to poverty and destitution include the following: a decline in soil fertility or its total loss; a decline in biodiversity; a loss of plant life and delicate ecosystems; an increase in climatic fluctuations; conflicts between farmers and herders; and movement of people and livestock, including transhumance and nomadism (www.org/esa/sustdev)(Kambou 2002).emphasized significant signs of the impact of desertification, including an increase in poverty rates in rural regions and alterations in migration patterns.

The United Nations should have recognized the changes in livestock size and composition as significant indicators of impact in countries with pastoralist communities and high poverty rates, as well as a decline in vegetation and fodder coverage. This would have facilitated a more methodical evaluation of the influence of desertification on pastoralism. Moreover, the effect indicators and the state indicators were combined, making it difficult to distinguish between the two (Kambou 2002). did not offer a more explicit indication of migratory tendencies. The FAO study found that the primary consequence of desertification in Somalia is the occurrence of localized conflicts among Somali clans and lineages. These conflicts arise due to disputes over the ownership and administration of newly constructed boreholes and the adjacent meadows.

The study has identified a deficiency in understanding regarding potential alterations in the species and physical characteristics of animals over a specified period of time. The Ghanaian Environmental Protection Agency (2002) identified several consequences of desertification, including decreased soil fertility and agricultural productivity, the enlargement of unproductive land, reduced vegetation cover in terms of both quality and quantity, and a decreased ability of the land to withstand natural climate variations. The socio-economic ramifications include increasing deforestation, famine, higher rates of migration, lower incomes, and a rise in poverty. As a national report, it is anticipated to offer a thorough comprehension of the phenomenon. Specifically addressing the impacts on livestock in the study would have been more thorough, given the sizeable population of 1.25 million cattle, 2.5 million goats and 2.4 million sheep in Ghana's savannah. Moreover, the concept of plant cover decline as a pivotal indicator of desertification was unclear and did not offer any indication of a definite timeframe.

Furthermore, the study encountered difficulty in accurately assessing the influence of fluctuations in agricultural production on individuals' means of subsistence and the subsequent repercussions (Abdi et al., 2013). desertification is the main catalyst for the migration of rural inhabitants to urban areas in Sudan.
The association between political and social instability and land degradation is significant, as demonstrated by the civil disturbance in Southern Sudan, resulting in a significant influx of people migrating to Kenya. The examination also uncovered a decline in vegetation and the extinction of important species. The decrease in rainfall leads to the well-acknowledged phenomenon of vegetation deterioration, soil erosion, and reduced agricultural output and livestock production, accompanied by an increase in migration. The migration indices and crop output loss, which are important indicators of severe outcomes, lack sufficient information. In order to gather more comprehensive data from the local residents, the study may have utilized survey approaches.

The Ethiopian Highlands currently suffer from 14 million hectares of severely damaged soil. Within the next 20 years, it is predicted that the highlands' per capita income will drop by 30% if this pattern of soil deterioration continues (Tamirie 2000). The study determined that the present condition of the land is inadequate for sustaining plant life, resulting in a decrease in organic matter. As a result of degradation, Ethiopians have become increasingly vulnerable to drought. Regretfully, the study was unable to obtain more precise data—particularly about agricultural output and the extent of migration—by combining its contextual assessment, field observation, questionnaire, and interview (Jones 2006).

According to a case study on poverty and governance in Namibia, the economy was significantly impacted by desertification. In their 2011 study, Seely and Klintenberg examined desertification in Central Namibia and found that the primary causes of the effects of desertification were soil erosion, deforestation, deterioration of arable land, degradation of rangelands, and degradation of woodlands.

Applying a cautious approach, experts have calculated that the annual economic loss in central Namibia is at a minimum of US$10 million. The main expenses identified were the reduced accessibility of construction materials and firewood, exacerbated by the time required to collect them or the cost of purchasing them from the market as replacements.

Both the 2006 study undertaken by Jones and the 2011 study carried out (Jones 2006 ; Seely & Klintenberg). demonstrated a tendency to emphasize the economic aspects of desertification, indicating bias. As a result, there was a lack of data collection from individuals who are most impacted by desertification, potentially leading to a more thorough comprehension of the situation. According to research by Klintenberg and Seely (2004), 70% of Namibians are dependent on subsistence farming. Unfortunately, the study lacked any empirical evidence about the influence of desertification on crop productivity.
Undertook a research in Namibia to evaluate the economic consequences of desertification in the region. The majority of Namibians live in communal areas where they depend on the land for their nourishment and financial gain from cattle, but the study also revealed that desertification has complex effects on the time and labor required for fuelwood and fencing, as well as the food security of families. The phenomenon of desertification in commercial districts exhibited a wide range of characteristics and resulted in various consequences. Specifically, the proliferation of shrubs was discovered to have a detrimental effect on the accessibility of grazing lands, resulting in a decrease in the animal population and subsequent loss in sales (Quan et.al ,1994).

The study undertook an economic evaluation of the impact of desertification on the livelihoods of individuals in Namibia. Nevertheless, it overlooked the fact that immigration and migration are commonplace and may have an effect on remittances sent home and, in turn, the economy. For the over a million Nigerians who live on the edge of the floodplain and depend on the marsh for their livelihoods as farmers, cattle herders, and fisherman, Emeka (2013) claims that there have been serious socioeconomic repercussions(Emeka 2013). The reduction in fish productivity in Nigeria's rivers, lakes, swamps, and flood plains provides more evidence of the detrimental effects of drought and desertification in the Sahel and Sudan regions (Palacios & Ustin 1998 ; Ajayi 1996) . The total production from all fresh water sources had an annual drop of approximately 54% between 1980 and 1985.

The research undertaken by Emeka (2013) and Nwafor (1982) has not adequately investigated crucial indicators of the consequences, such as the pervasive conflict between farmers and livestock owners in Northern Nigeria, namely in the Frontline states (Ajayi 1996).

Study does not provide information on whether the drop in yield was specifically caused by the crops that were cultivated (Thelma 2015).
Desertification in Northern Nigeria poses a significant economic hazard. The main consequences of desertification in the region are the detrimental impacts on both food security and employment.
The study additionally revealed that the majority of conflicts in the area stem from environmental factors. The primary source of conflict develops between agriculturalists and pastoralists. Nevertheless, the study did not investigate the impact of agricultural cultivation on desertification, resulting in a significant lack of knowledge in this area. The Nigerian government claims that desertification has worsened the food situation in the region, leading to a decrease in the food security index. Drought leads to significant economic upheaval. The significant decline in the Gross Domestic Product (GDP) by 18.4 percent in 1971-1972 and 7.3 percent in 1972-1973 can be attributed to the presence of drought.
Moreover, it was thought to be the primary reason of the food price index's sudden spike and the decline in non-oil exports that followed. Migration resulting from aridity or drought occasionally results in the fragmentation of families, since males frequently abandon females and offspring in order to seek employment in urban areas (FMEnv 2001). Pastoralism is an essential component of peoples' livelihoods and a key indicator of the effects of desertification, but its effects on it are little understood. An alarming pattern has arisen among these nations, indicating that developing countries are nearing a crucial juncture.
The consequences of desertification in Burkina Faso, Sudan, Nigeria, Ghana, and other countries have become a major source of social discontent and insecurity. The nations have seen widespread poverty, conflicts arising from the exploitation of natural resources, and a significant increase in urban migration due to desertification. The desertification in China can be attributed to the magnitude and variety of its population.

4. Desertification Control Measures

Addressing desertification and land degradation in affected countries is crucial for attaining sustainable development (UNCCD 2006). Concern over the growing extent and effects of desertification around the world led to the official approval of the United Nations Convention to Combat Desertification in Paris in 1994. By the year 2000, more than 172 governments have signed the convention (UNCCD 2006). On May 19, 2014, Southern Sudan became the 195th member to join the Convention. The primary goal of the Convention is to tackle desertification and alleviate the negative consequences of drought in Africa. The recommended approach is to implement customized control measures that consider the unique circumstances of each country (UNCCD, 2006). In addition, the UNCCD proposed the implementation of measures such as:

1. Enforcing strategies to avoid and diminish the deterioration of land, including the rehabilitation of land that has already been degraded.
2. Raising awareness and educating people who are affected by land degradation.
3. Improving the social environment through the elimination of poverty and the enhancement of health and educational conditions. fostering knowledge sharing on sustainability, and emphasizing the significance of natural resources.

4. Revitalizing the traditional wisdom of indigenous cultures.

The development of community conservation zones in Benin employed a participatory strategy to save the biodiversity of coastal wetlands (www.worldbank.org). Presently, about 150 communities are actively engaged in the process and possess the capacity to efficiently harness the biological diversity of marine resources in a manner that ensures long-term sustainability. These communities also benefit from environmentally conscious corporate activity. The endeavor has successfully alleviated the poverty of the individuals residing in the vicinity of the river, who were previously compelled to deplete and deplete the natural resources more people are realizing how important it is to protect mangroves, coastal areas, and forests in order to ensure that future generations can continue to live .Previous projects supported by the World Bank have specifically targeted sub-watersheds in the lowland regions of Burkina Faso. These programs have demonstrated the ability of communities to improve the efficiency of rural resources. By adopting sustainable practices that prioritize the preservation of biological and agricultural diversity, as well as the restoration of soil and water resources, the people of Burkina Faso have effectively achieved economic growth while also promoting environmental well-being. The SILEM Project introduced the concept of biodiversity in a productive setting within the Sahel region. The program facilitated and accelerated the creation of community connections to guarantee the enduring conservation of natural resources at the local watershed level.

This was achieved through the implementation of incentives, the establishment of an investment structure that is in line with the nation's objectives, and the recognition and enhancement of individual and collective skills. Approximately 160 towns received allocated funds to support the execution of several initiatives pertaining to the management of natural resources. Natural resource preservation, livestock and fishery management, forestry management techniques, reforestation, soil and agriculture techniques, and water conservation technologies were among the activities (UNCCD 2013). One important aspect of the problem that none of the World Bank's studies addressed was the need to raise public awareness of desertification. The Rehabilitation of Arid Environments (RAE) is a recognized nonprofit organization that is widely praised for its efforts in advancing rural development in Kenya.

RAE is based in Baringo County, in the semiarid and dry lowlands of the Rift Valley in Kenya. The Royal Academy of Engineering (RAE) has been actively involved in this industry for over three decades. In the early years of RAE's operations, growing problems with soil erosion, loss of plant diversity, and other factors rendered about 70% of Baringo County's land unusable. The terrain was severely degraded, and there was a significant prevalence of instability and ethnic tensions due to insufficient resources. The incidence of poverty has reached concerning proportions, with rates as high as 90 percent in several regions, and there has been a pervasive absence of sufficient access to food. Lake Baringo, the main source of freshwater in the area, was heavily contaminated with sediment. The RAE implemented a comprehensive strategy to restore the damaged areas by involving the community and incorporating traditional knowledge. RAE initiated the restoration of the original savannah grass ecosystem by reintroducing native grass species that had vanished as a result of excessive grazing. The Royal Academy of Engineering (RAE) has reached a consensus on a standardized approach for overseeing the reseeded districts.

The settled residents employed fences, whilst the nomadic herders engaged in communal grazing. Income-generating endeavors including hay baling, collecting and selling grass seed, apiculture, field rentals, milk sales, thatching grass harvesting, and firewood collection strengthen these tactics. A research undertaken by the United Nations Development Program (UNDP) in 2013 focused on analyzing strategies to enhance the empowerment of local communities. The study focused primarily on improving people's means of supporting themselves, conducting initiatives to reduce the impact of drought, and utilizing the capabilities of traditional knowledge. The initiative presently provides direct benefits to over 20,000 individuals, while an additional 380,000 to 550,000 people benefit indirectly from it (UNCCD 2013). Although there are still certain project management difficulties that have not been handled, the natural grass and tree species that were previously not present in the area are now thriving. The soil's physical features, including its nutritional composition and water absorption capacity, have shown improvement.

Community organizations have witnessed a decrease in poverty rates and an enhancement in food security. Both males and females studying and assessing desertification is crucial because it can arise from both natural and human-induced causes. Accurate prediction of impending climate change threats is essential for developing policies, plans of action, and mitigation techniques on a local and global level. Remote sensing enables the analysis, surveillance, and prediction of several elements of desertification. Throughout the years, many methodologies have been employed to investigate desertification through the utilization of Remote Sensing (RS). This study investigated the worldwide prevalence and temporal sequence of research that utilized remote sensing (RS) to investigate desertification. Furthermore, the study evaluated the main methodologies and variables used in the investigation of desertification by analyzing remote sensing data. The first use of remote sensing (RS) for desertification research dates back to 1991. Between 2015 and 2020, an annual average of over 40 publications were published, indicating a substantial rise in the utilization and accessibility of remote sensing (RS) technology for the purpose of monitoring desertification. However, there is a significant disparity in the amount of research conducted in different fields. Asia demonstrates a substantially higher quantity of studies in contrast to America or Africa. China is the country that has used remote sensing (RS) techniques to perform the most study on desertification. The Thematic Mapper (TM) sensor is the primary provider of satellite data, particularly Landsat images. The main methodologies employed for investigating desertification are categorization and surveillance of changes. Additionally, vegetation and its characteristics, such as the Normalized Difference Vegetation Index (NDVI), are frequently used in conjunction with remote sensing techniques to research desertification. This is relevant in the most arid regions of Ethiopia that are currently experiencing extended periods of severe drought or a consistent decrease in moisture levels. Disregarding variations in climate, ecology, economy, culture, and human activity, the terracing programs implemented in different regions may prove to be unsuccessful, as policies and practices that are successful in one area may not necessarily work well in another. In the highlands of Ethiopia, Tamirie (2000) conducted a study that discovered various methods for managing desertification in the region. The techniques encompass the implementation of physical and biological conservation measures, the establishment of a catastrophe preventative and preparedness strategy, and the creation of an environmental protection agency.

The study focused exclusively on desertification in the Ethiopian highlands, however it did not provide any analysis on the efficacy of institutional frameworks in addressing this issue. Moreover, the socio-economic tactics used in the highlands were not examined in the study (Darkoh 2000). The indigenous people of Mid-Boteti have evolved a number of strategies to endure in their harsh environment, which is marked by recurrent droughts. The practice of utilizing the periodic increase in river flow in a region that is mostly dry is referred to as "flood recession cultivation." Additional adaptations are implementing mixed cropping techniques, strategically relocating animals based on water availability, substituting cattle with goats in times of drought, and integrating non-agricultural and agricultural activities to mitigate risk.

The 2004 study conducted by Klintenberg and Seely focused on the monitoring of land deterioration in Namibia and proposed several solutions to combat desertification (Klintenberg & Seely2004) . hese activities entail raising awareness about the causes and consequences of land degradation, while also working together with local communities and scientists to build the National Monitoring System (Jones 2006). found that the establishment of the Programme to Combat Desertification (NAPCOD) was part of Namibia's institutional framework. Through pilot projects in certain areas, NAPCOD worked with rural stakeholders to evaluate land use, agricultural techniques, and alternative ways of living.The World Wildlife Fund (WWF), Namibia's Ministry of Environment and Tourism, and USAID are all providing financial support for the LIFE project, which seeks to help Namibia implement community-based resource management. The project centers around three primary domains: augmenting the natural resource foundation, establishing indigenous institutions, and fostering the development of enterprises rooted in natural resources. Consequently, it combines the preservation of biodiversity, democratic principles, governance, and enterprise development into a single cohesive endeavor.

The study, although thorough in analyzing the overall response of the institution, does not discuss the precise method for evaluating the efficiency of control measures. This relates to a lack of knowledge about the integration of the local population into the system, particularly with regard to biophysical control techniques. The study did not provide any empirical evidence from a survey that demonstrated the local population's reactions to desertification.

Tanzania implemented control measures by creating government-operated tree seedling nurseries around the country. The nurseries sent a diverse range of young trees to villages with the intention of planting them (Darkoh 1982, 1987).

A thorough education campaign regarding the dangers of desertification and the importance of afforestation was launched in a number of regions. The government created physical and regional land use plans as part of a comprehensive national strategy on land and human settlement. Furthermore, the government aimed to decrease the utilization of fuel wood by promoting the adoption of alternative energy sources such as coal, natural gas, solar, and wind power. Furthermore, the prioritization involved implementing ways to combat soil erosion and overgrazing, promoting public engagement, providing training for environmental law enforcement, and advancing research. To effectively address desertification, the control strategies used combined bio-physical and socio-economic measures. The study has presented a multitude of prospects for additional investigation into desertification in Tanzania.

The National Action Programme to Combat Desertification was formulated in 1999, and a regulatory structure for Environmental Management in Tanzania was also established. Muyungi's 2007 research revealed a significant level of government engagement in environmental matters and the sustainable management of resources in Tanzania following the Rio Conference in 1997. The National Environmental Action Plan, which conducts a comprehensive assessment at the national level and establishes a framework for integrating environmental considerations into government decision-making, has made significant advancements.

5. Remote Sensing for Desertification

Remote sensing (RS) is beneficial for evaluating the primary indicators of desertification due to its ability to encompass extensive regions (El-Hassan 2004; Sun et al., 2005). Monitoring and mapping desertification is the most effective technique for managing and stopping the progression of desertification. Remote sensing methods have been used to identify and characterize sand dunes and their shifting patterns throughout time, as well as to monitor and evaluate changes in land degradation(Collado et al., 2002; Lam et al., 2010). Satellites have supplied data for worldwide surveillance during the last twenty years, which is crucial for enhancing our comprehension of desertification (Collado et al., 2002; Pellikka et al., 2005; Yanli et al., 2012). Desertification, a persistent issue, is seeing a yearly growth rate of 25%. Consequently, multiple investigations have been carried out utilizing remote sensing techniques to detect these activities on a worldwide scale (Collado et al., 2002; El-Hassan, 2004; Sun et al., 2005; Shalaby & Tateishi, 2007; Fang et al., 2008). Remote sensing (RS) technology offers numerous benefits, including time efficiency, wide coverage (unattainable by ground-based methods for large areas or regions), rapid data acquisition, and The capacity to enable continuous monitoring of land covering and land utilization over an extended period (Wu et al., 2002; Shalaby & Tateishi, 2007). The techniques listed provide different levels of imaging resolution; they are categorized as high (SPOT, IKONOS, QuickBird, GeoEye-1, Worldview-1, WorldView-2) and low (NOAA-AVHRR), medium (Landsat TM, Landsat MSS, IRS-I, ISS-II). Landsat imagery is frequently used to depict the impact of desertification on both humans and the environment. The extensive availability and easy accessibility of these pictures is primarily responsible for this problem (Wu et al., 2002; El-Hassan, 2004; Sun et al., 2005; Leona & Sommer 2000 ; Yang et al., 2007). Improved resolution in imaging enables the detection of more complex details, resulting in increased precision and more detailed image analysis.

Data from remote sensing can be fed into a geographic information system (GIS) to enable further analysis and cross-referencing with data collected from various locations or eras. By intentionally selecting the suitable band or bands according to specified factors like soil, water, or vegetation, and integrating GIS with remotely sensed data, one can acquire useful information about the attributes of land cover changes. This method is especially valuable for examining extensive regions and comprehending the spatial arrangement of various alterations in land surface (Abbas & Khan, 2007; Shalaby & Tateishi 2007).

Data from remote sensing and GIS techniques are becoming more and more important for information extraction and analysis related to a variety of topics, including the mapping of urban land use, the measurement of drifting sand areas, the study of ecosystem dynamics, and the monitoring of geological risks like global warming (Ali & Bayoumi, 2004; Sun et al., 2005; Kapetsky & Aguilar-Manjarrez, 2007).

The utilization of remote sensing data in the examination of desertification has experienced a substantial rise in recent years. Between 2000 and 2010, an average of 10 publications were published that made use of remote sensing data. However, since 2015, this number has dramatically increased to about 40 articles per year. These findings suggest a rise in the utilization of remote sensing methods and their accessibility for monitoring desertification (Fig. 2). The map in Fig. 3, reflects arid areas where remote sensing has been used to study desertification. Nevertheless, there is a noticeable geographical variation. One can observe a disparity, for instance, in the quantity of research conducted on desertification in Asia as opposed to the research on desertification in America or Africa. In Africa, there are 45 papers on desertification studies that utilize remote sensing, while in America there are 35. In contrast, Asia has a far higher number of articles, with 245 focusing on desertification and remote sensing.

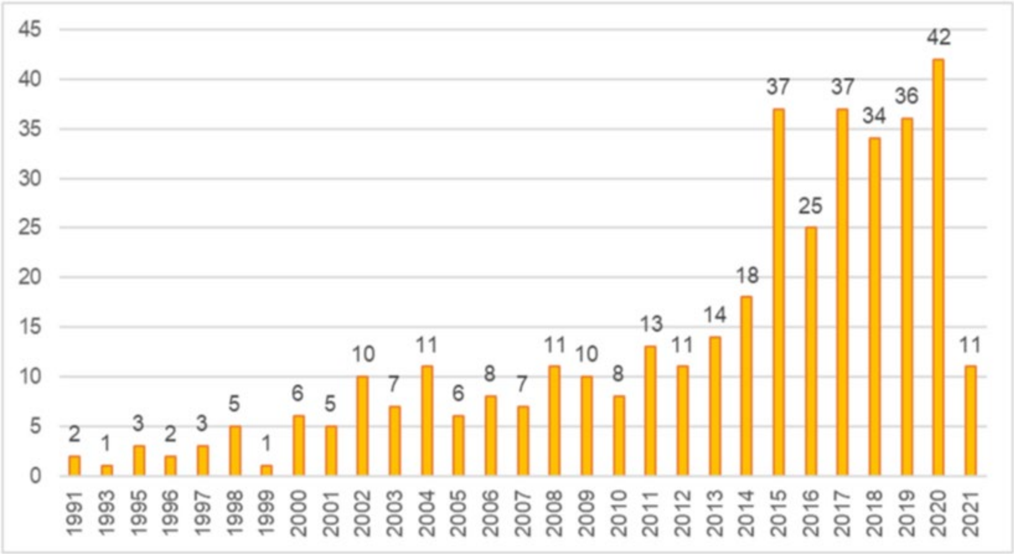

Fig. 2. Timeline of the use of remote sensing to study desertification (Daniela et al.,2022).

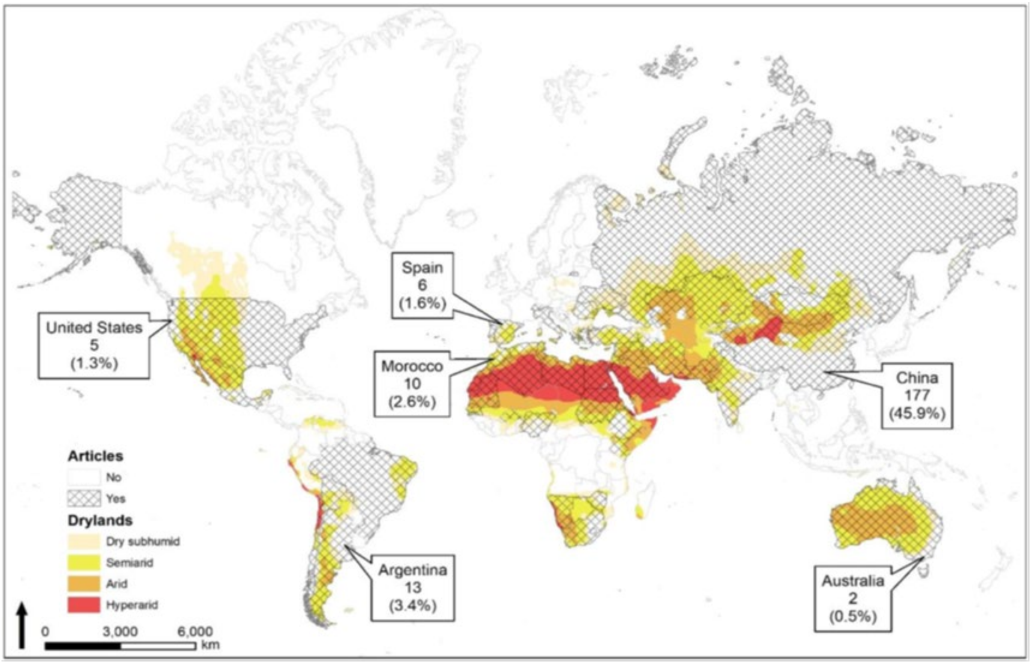

Figure 3. displays the countries and regions that have conducted research publications on desertification utilizing remote sensing (Daniela et al.,2022).

6. Remote Sensing Techniques

Researchers have employed the usage of (Bayarjargal et al., 2006; Murad & Saiful, 2011). To identify and assess meteorological drought. The NOAA-AVHRR sensor is frequently employed for the investigation of drought. Integrating reflectance bands—the Normalized Difference Vegetation Index (NDVI)—and thermal bands—the Land Surface Temperature (LST)—is necessary for the data acquisition process. The application of this sensor has been extensively used in the domain of drought study, as evidenced (Karnieli & Dall'Olmo 2003). Other often used drought-related indicators include the Vegetation Condition Index (VCI), Global Vegetation Index (GVI), Integrated or Standardized NDVI, and NDVI anomaly for identifying and tracking drought-affected areas.

Many different methods have been used to evaluate and analyze the desertification process using remote sensing data. Classification and change detection are the most used methods in recent years, as shown in the figure.4

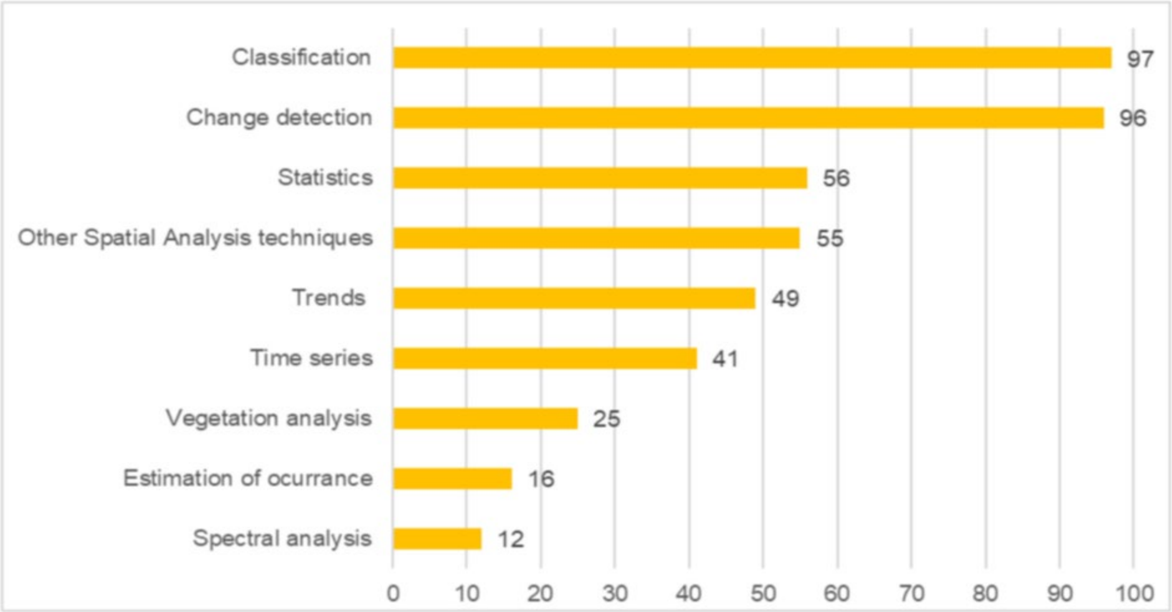

Fig. 4. Most used methods for the study of desertification using remote sensing over the past 35 years(Daniela et al.,2022).

7. Challenges Associated with Remote Sensing

Remote sensing technology employs automated devices, such as satellites, to acquire and send visual data (Hay et al., 2000). Prior to utilizing remotely sensed imagery, such as satellite imagery, for the assessment of a particular matter or concern, it is imperative to perform corrective processing, including atmospheric correction and picture alignment, as well as to conduct comprehensive data analysis (Jha 2010). It is crucial to merge remotely sensed data with supplementary data, ensuring that both sources are precisely aligned and integrated (Levin 2009). Accurate and trustworthy data is essential for effectively applying the results of inventory analysis, environmental monitoring, and high-quality thematic mapping (Adjei 2009). Precision is essential in order to facilitate policy reform and build vital management frameworks that are important for regulating desertification processes (Kelly & Thomas 2012).

Presently, relying solely on satellite pictures is insufficient for making a dependable conclusion. Therefore, it is crucial to utilize qualitative methodologies (Mesev 2007). Every imaging sensor has specific limitations in its capacity to recognize situations, including thematic, temporal, and other forms of interpretation (Chen 1995). Remote sensing is suggested as a method for obtaining timely, current, and somewhat accurate information to support the sustainable and efficient management of vegetation (Kasawani et al., 2010).

8. Desertification Key Indictors

Remote sensing is a useful tool for detecting, monitoring, and mapping many important indicators of desertification processes in areas that are impacted. To analyze different environmental scenarios, researchers frequently use indicators including land use, soil , erosion, urbanization and drought.

Land Cover/Land Use: Satellite data has demonstrated its utility in the examination of vegetation, encompassing the analysis of its composition and land utilization. The expansion of agricultural areas has the capacity to negatively affect water reserves and quality, as well as the chemical and physical characteristics of soil (Karnieli & DallOlmo 2003; Collado et al., 2002; El-Hassan, 2004; Shalaby et al., 2004; Al Harbi, 2010).

Remote sensing methods are used to monitor changes in agricultural land use, which makes it easier to monitor the processes of desertification in semi-arid and arid regions. Land use and agricultural land are good indicators because they can be easily identified in satellite imagery. By examining the color composites, one can find variations in the topsoil and vegetation distribution composition.

Remote sensing techniques enable the evaluation of changes in vegetation and the estimation of desertification processes (Ali & Bayoumi, 2004). Several research studies have investigated changes in land cover and land use in arid and dry regions of Africa (Palmer & van Rooyen, 1998), China (Wu et al., 2002), Sudan (Ali & Bayoumi, 2004), Egypt (Shalaby et al., 2004; Shalaby & Tateishi, 2007), and Saudi Arabia (Al Harbi, 2010) in connection with land degradation and desertification. The increase in agricultural land is strongly linked to the decrease in areas of natural vegetation (Al-Balooshi, 2003; Shalaby & Tateishi, 2007; Al Harbi, 2010).

Inadequate land management techniques, such as overgrazing, excessive irrigation, mining, and deforestation for residential purposes, can inflict substantial damage to the land and exacerbate the process of desertification. Remote sensing technology can help identify these challenges. The research conducted in Argentina (Collado et al., 2002), North China (Fang et al., 2008), Saudi Arabia (Weiss et al., 2001; Al Harbi, 2010), and the Sahel (Hein & Ridder, 2006) Utilized satellite imagery obtained from Landsat-2, Landsat TM, NOAA-AVHRR, Landsat TM5, and SPOT. Remote sensing data has been used to examine changes in vegetation coverage, patterns, and condition in desertification research, by utilizing the normalized differential vegetation index (NDVI) (Chen & Zhu, 2001).

An increasing amount of data indicates that using the Red-Edge spectral band can improve the sensitivity and accuracy of plant study, especially in areas with little flora, including semi-arid and dry regions (Jha 2010 ; Kundu & Dutta, 2011; Yanli et al., 2012). It is essential to detect decreases in proportion to the initial level in order to evaluate the severity of drought and estimate the process of desertification (Weier & Herring, 2012). Satellite imaging can be utilized to observe the deterioration of ecosystems by quantifying rain-use efficiency (RUE), a commonly employed measure for assessing the condition of plant cover[115] (Hein and Ridder, 2006) decrease in RUE signifies a reduced capacity of the flora to transform water and nutrients into biomass (Hein & Ridder, 2006; Verón et al., 2006). The following loss in plant cover results in reduced nutrient accessibility and increased runoff due to soil compaction. Hein and De Ridder (Hein & Ridder, 2006) observed that prior research on remote sensing (RS) and radiation use efficiency (RUE) failed to take into account the impact of annual rainfall fluctuations on RUE. Remote sensing methods are unable to substitute the necessity for data obtained directly from the ground. The utilization of remote sensing and supplementary data in agricultural research is mutually beneficialPrompt and efficient results can help farmers create comprehensive and ongoing management plans through strategic planning and decision-making (Hill et al., 2006).

Soil: Remote sensing imaging has been utilized to analyze soil properties in research on desertification (Ustin et al.,2004; Ben-Dor et al., 2009). Climate fluctuations render fragile soils susceptible to erosion and subsequent desertification (Dragan et al., 2005; Rangza et al., 2008). The processes accountable for the augmentation and reduction in the quantities of crucial constituents in soil can lead to soil degradation and, consequently, desertification. The application of the Grain Size Index (GSI) of topsoil in mapping soil degradation has the potential to be a valuable tool for assessing land degradation and desertification processes by identifying variations. Hill 51 found several regions in China that contain a significant amount of high-quality sand (Xiao et al., 2005; Rangza et al., 2008). Utilized the GSI index to ascertain the origin of sand/dust storms in Mongolia. In order to guarantee the effectiveness of the GSI index, it is crucial to employ images captured prior to the emergence of short-lived plants in the spring (Hill 2000 ; Xiao et al., 2005).

Soil salinity: Soil salinity poses a significant challenge to agricultural progress in arid and semi-arid areas, leading to soil sterility and consequent land degradation and desertification (Salazar 2007; Al-Balooshi 2003). The primary factor leading to desertification along the Albatinah coast of Oman is soil salinity. Furthermore, the soil composition in the region has greatly contributed to the acceleration of desertification (Al-Balooshi 2003). Remote sensing techniques are a useful method for identifying and charting soil salinity (Al-Balooshi 2003; Al-Khaier 2003; Al-Mulla 2010). Using salinity indicators including the Soil Salinity Index (SSI), Brightness Index (BI), and Soil and Sodicity Index (SSSI), Abbas and Khan (2007) employed multi-temporal IRS-1B LISS-II pictures to detect salinity in degraded land.

Evaluating soil salinity has shown to be challenging in semi-arid and arid regions characterized by little vegetation and low soil moisture levels. Vegetation cover and vegetation health are commonly used as alternative indicators for assessing soil salinity in low to medium resolution multispectral pictures, such as Modis and Landsat imaging.

Erosion: Desertification leads to a decrease in vegetation and an increase in soil erosion. The phenomena occurs because the exposed soil is vulnerable to erosion caused by the combined effects of wind and water (RomeroDiaz 1999; Shalaby & Tateishi, 2007). Soil erosion is a geological phenomenon in which material is gradually eroded from the Earth's surface by processes such as weathering, dissolution, abrasion, corrosion, and transportation. Contemporary methods employ satellite data acquired via remote sensing to precisely monitor plant cover and arid terrain, facilitating the identification of erosional processes and the extent of desertification (Chen et al., 2004).

Human activities, such as agricultural practices and deforestation motivated by economic interests, significantly contribute to erosion in semi-arid and dry regions like China and the Middle East (Dregne, 1986). Remote sensing is essential for observing the dynamic phenomena of wind erosion. The yearly fluctuations in wind generate forces that contribute to the dynamic displacement of sand dunes in China, as a component of the wind erosion process (Sun et al., 2005).

Urbanization: Irreversible desertification refers to the phenomenon of urban expansion encroaching into and permanently transforming desert areas (Shalaby et al., 2004). Urbanization, driven by economic and population growth, is causing agriculture to spread into environmentally vulnerable regions, resulting in desertification (Shalaby et al., 2004; Shalaby & Tateishi, 2007). The exponential growth of the human population results in a significant strain on resources, including groundwater reserves, as well as home food and water supplies. This stressor ultimately results in significant environmental deterioration (El-Hassan, 2004;Leona & sommer 2000 ; Moseley& Jermé, 2010).

Remote sensing techniques are employed to categorize land use and urban development for the purpose of assessing the effects of urban expansion and desertification (Pellikka et al., 2005; Makarau et al., 2011; Yanli et al., 2012). Researchers observed a significant rise in erosion-prone areas over a 15-year period by utilizing SPOT and Landsat data. The primary cause of this land degradation was determined to be urban growth (Pellikka et al., 2005; Yanli et al., 2012, Shalaby et al.2004). The expansion of metropolitan areas in Egypt results in the loss of 20,000 hectares of extremely fertile agricultural land per year, intensifying the strain on susceptible regions.

Drought: Drought is a prolonged period of inadequate rainfall in a specific area, leading to the degradation of land and contributing to the advancement of desertification (Jupp et al., 1998; ElHassan, 2004). Satellite remote sensing is capable of efficiently monitoring and tracking the presence of moisture, the kind of land cover, and the condition of plants over extensive areas and over extended periods of time. Remote sensing is a highly efficient method for monitoring and evaluating the extent of plant stress, which can serve as an indicator of drought. It allows us to evaluate the reaction of regions to drought on a large scale (Jupp et al., 1998).

9. Desertification Indices

Vegetation indices are mainly used to accurately detect desertification, evaluate plant development and stress, measure vegetation cover, land cover, and biomass production by utilizing multispectral satellite data (Kumar et al., 2010). Fluctuations in the vegetation index can be used as indications of the ongoing processes of land degradation and desertification. The Normalised Difference Vegetation Index (NDVI) is frequently employed for identifying vegetation coverage and evaluating the state of vegetation (Chen, 1995; Weier & Herring, 2012; Yanli et al., 2012) . Time series analysis of NDVI enables the construction of a benchmark that represents the typical productivity of plants in a certain region. Low NDVI levels indicate a minimal disparity between the red and NIR signals, indicating that the plant is under stress and has restricted photosynthetic activity. The utilization of land plant cover as an indicator for desertification was prohibited (Shafie et al. 2012). The NDVI measure is susceptible to multiple factors, including the magnitude of vegetation coverage, moisture levels in plants and soil, plant distress, and photosynthetic activity. Semi-arid and arid regions typically have a higher proportion of exposed ground and visible rock compared to temperate or tropical environments.

The soil-adjusted vegetation indices, namely SAVI, SAVI1, and SAVI2, include a correction factor to account for soil brightness, as proposed by Huete in 1988. This correction factor is applied to minimize the influence of background sensitivity in the study, as highlighted by Chen in 1995. In their work, Kundu and Dutta (2011) utilized NDVI time trend and long-term rainfall data to illustrate the gradual process of desertification in the Rajasthan region. This event was attributed to a complex interplay between anthropogenic and climatic factors (Shafie et al. 2012). Found that the Weighted Difference Vegetation Index (WDVI) produced more precise maps of the Iranian study area than TSAVI2, MSAVI1, and NDVI, as per their analysis. While these other indexes demonstrated good performance, they were not as precise.

10. conclusion

Desertification is a highly debated topic in numerous countries and on the international stage. The use of remote sensing data to investigate desertification began in 1986 and has since expanded to 48 nations, with China being the most studied. Research findings indicate that over 42% of the studies concentrate solely on one country, potentially distorting the global understanding of the desertification process and its dynamics. The main methods utilized for researching desertification via remote sensing are change detection and categorization. Vegetation and its related characteristics, such as NDVI, land cover, and phenology, are the primary factors commonly used in this specific context.

The main purpose of employing remote sensing in the investigation of desertification was found to be the analysis and evaluation of the desertification process. Surprisingly, there have been few studies that have used remote sensing data to predict and reproduce future changes in desertification. Given the expected exacerbation of desertification due to climate change, it is imperative for future study to prioritize this objective. The predominant focus of research has primarily been on analyzing specific elements when studying instances of desertification. Depending solely on a single criterion to determine the frequency of desertification may lead to an insufficient comprehension of the desertification phenomenon.
Therefore, it is advisable to do research that integrates several variables. The existing methodologies and tactics employed to examine desertification are also applied to scrutinize other interconnected topics, such as land degradation. This is leading to a lack of understanding of the methods for investigating desertification and its dynamics.

Declaration of competing interest: The authors declare no conflict of interest.

Acknowledgements: We would like to acknowledge the insightful contributions of the Editor and anonymous reviewers

11. References:

Al-Janabi, A. M. S., Dibs, H., Sammen, S. S., Yusuf, B., Ikram, R. M. A., Alzuhairy, S. H., & Kisi, O. (2024). Comparison Analysis of Seepage Through Homogenous Embankment Dams Using Physical, Mathematical and Numerical Models. Arabian Journal for Science and Engineering, 1-10.

Ababa, A. (2007), “Africa Review Report on Drought and Desertification”, Fifth Meeting of the Africa Committee on Sustainable Development. Regional Implementation Meeting for CSD, Vol. 16, pp. 8-14.

Abbas, A. and Khan, S. 2007. Using remote sensing techniques for appraisal of irrigated soil salinity. In Oxley, L. and Kulasiri, D. (eds). International Congress on Modelling and Simulation (MODSIM). Christchurch, Modelling and Simulation Society of Australia and New Zealand, New Zealand, pp. 2632-2638.

Abbas, I.M. (2014), “No Retreat No Surrender Conflict on Survival Between Fulani Pastoralist and Farmers in Northern Nigeria”, European Scientific Journal, Vol. 8 No.1, pp. 331-346.

Abdi, O.A., Glover, E.K. and Luukkanen, O. (2013), “Causes and Impacts of Land Degradation and Desertification: Case study of the Sudan”, International Journal of Agriculture and Forestry, Vol 3 No. 2, pp. 40-51

Adjei, S. 2009. Assessing desertification in the upper east regionof Ghana using remote sensing (RS) and geographic information system (GIS). Retrieved 12 May 2012 from wansec.org/sites/default/files/wansec_ph.d._thesis_proposal_final.pdf.

Ajayi, S.S. (1996), "Fish and Wildlife" in Federal Environmental Protection Agency (FEPA). Nigerian Biodiversity: Strategy and Action Plan First Draft. Abuja, the Presidency.

Al-Bakri, J.T., Brown, L., Gedalof, Z., Berg, A., Nickling, W., Khresat, S., Salahat, M., Saoub, H., 2016. Modelling desertification risk in the north-west of Jordan using geospatial and remote sensing techniques. Geomatics, Nat. Hazards Risk 7 (2), 531–549. https://doi.org/10.1080/19475705.2014.945102.

Al-Balooshi, A. C. 2003. Desertification in Al- Batinah Plain in Sultanate of Oman. Unpublished doctoral dissertation, University of Jordan, Amman, Jordan, pp. 30-60 (in Arabic).

Al-Harbi, K. 2010. Monitoring of agricultural area trend in Tabuk region– Saudi Arabia using Landsat TM and SPOT data. The Egyptian Journal of Remote Sensing and Space Sciences 13:37-42.

Ali, M. M. and Bayoumi, A. A. M. S. 2004. Assessment and mapping of desertification in Western Sudan using remote sensing techniques and GIS. International Conference on Water Resources and Arid Environment, Riyadh, Saudi Arabia 5-8 December 2004, pp.1-16.

Al-Khaier, F. 2003. Soil Salinity Detection Using Satellite Remote Sensing. International Institute for Geo-information Science and Earth Observation, Enschede, 70 p.

Al-Mulla, Y. A. 2010. Salinity mapping in Oman using remote sensing tools: status and trends. In Ahmed, M., Al-Rawahy, S.A. and Hussain, N. (eds). A Monograph on Management of Salt-affected Soils and Water for Sustainable Agriculture. Sultan Qaboos University, Oman, pp. 17-24

Bakr, N., Weindorf, D.C., Bahnassy, M.H., El-Badawi, M.M., 2012. Multi-temporal assessment of land sensitivity to desertification in a fragile agro-ecosystem: environmental indicators. Ecol. Indicat. 15 (1), 271–280. https://doi.org/10.1016/j.ecolind.2011.09.034.

Bayarjargal, Y., Karnieli, A., Bayasgalan, M., Khudulmur, S., Gandush, C. and Tucker, C. J. 2006. A comparative study of NOAA–AVHRR derived drought indices using change vector analysis. Remote Sens. Environ. 105:9-22

Becerril-Pi˜na, R., Díaz-Delgado, C., Mastachi-Loza, C.A., Gonz´alez-Sosa, E., 2016.Integration of remote sensing techniques for monitoring desertification in Mexico. Hum. Ecol. Risk Assess. 22 (6), 1323–1340. https://doi.org/10.1080/10807039.2016.1169914.

Ben-Dor, E., Chabrillat, S., Demattê, J. A. M., Taylor, G. R., Hill, J., Whiting, M. L. and Sommer, S. 2009. Using imaging spectroscopy to study soil properties. Remote Sens. Environ. 113:38-55.

Ben-Dor, E., Chabrillat, S., Demattê, J. A. M., Taylor, G. R., Hill, J., Whiting, M. L. and Sommer, S. 2009. Using imaging spectroscopy to study soil properties. Remote Sens. Environ. 113:38-55.

Chen, J. M. 1995. Evaluation of vegetation indices and a modified simple ratio for boreal applications. Can. J. Remote Sens. 22:229-242.

Chen, Y., Takara, K., Cluckie, I. D. and De Smedt, H. F. (eds) 2004. GIS and Remote Sensing in Hydrology, Water Resources and Environment. IAHS Press, Oxfordshire, pp. 207-392.

Chen, Z. Q. and Zhu, Z. D. 2001. Development of land desertification in Bashang area in the past 20 years. J. Geogr. Sci. 11(4):433-437.

Collado, A., Chuviecow, E. and Camarasaw, A. 2002. Satellite remote sensing analysis to monitor desertification processes in the crop- rangeland boundary of Argentina. J. Arid. Environ. 52:121-133.

Cui, G., Lee, W.K., Kwak, D.A., Choi, S., Park, T., Lee, J., 2011. Desertification monitoring by LANDSAT TM satellite imagery. For. Sci. Technol. 7 (3), 110–116.https://doi.org/10.1080/21580103.2011.594607.

D'Odorico, P., Bhattachan, A., Davis, K.F., Ravi, S., Runyan, C.W., 2013. Global desertification: drivers and feedbacks. Adv. Water Resour. 51, 326–344. https://doi.org/10.1016/j.advwatres.2012.01.013.

Dibs, H., Mansor, S., Ahmad, N., & Al-Ansari, N. (2023). Robust Radiometric Normalization of the Near Equatorial Satellite Images Using Feature Extraction and Remote Sensing Analysis. Engineering, 15, 75-89.

Daniela R . M. , Jadunandan D. , Booker O.2022 . The use of remote sensing for desertification studies: A review . School of Geography and Environmental Science, University of Southampton, Southampton, SO17 1BJ, United Kingdom.

Darkoh M.B.K. (1998), "The Nature, Causes and consequences of Desertification. The Dry Lands of Africa", Land and Development, Vol. 9, pp. 1-20.

Darkoh M.B.K. (2000), "Desertification in Botswana", RALA Report No 200.Agricultural Research Institut.Keld nabolt, Reykjavik, Iceland.

Darkoh, M.B.K. (1982), "Desertification in Tanzania", Geographical Association. Geography, Vol. 67 No.4.

Darkoh, M.B.K. (1987), "Combating desertification in the arid and semi-arid lands of Tanzania", Journal of Arid Environments, Vol. 12, pp. 87-99.

Darkoh, M.B.K. (1996), "Desertification: its human costs", Forum for Applied Research & Policy, Vol.11 No. 3, pp. 12-17.

De Pina Tavares, J., Baptista, I., Ferreira, A.J.D., Amiotte-Suchet, P., Coelho, C., Gomes, S., Amoros, R., Dos Reis, E.A., Mendes, A.F., Costa, L., Bentub, J., Varela, L., 2015. Assessment and mapping the sensitive areas to desertification in an insular Sahelian mountain region case study of the Ribeira Seca Watershed, Santiago Island, Cabo Verde. Catena 128, 214–223. https://doi.org/10.1016/j.catena.2014.10.005.

Dibs, H. and Al-Ansari, N., 2023. Integrating highly spatial satellite image for 3d buildings modelling using geospatial algorithms and architecture environment. Engineering, 15(4), pp.220-233.

Dibs, H. and Mansor, S., 2014, October. Mapping rubber tree growth by spectral angle mapper spectral-based and pixel-based classification using SPOT-5 image. In Proceedings of 35th Asian Conference on Remote Sensing (ACRS), Nay Pyi Taw (pp. 27-31).

Dibs, H., Al-Ansari, N. and Laue, J., 2023b. Analysis of Remotely Sensed Imagery and Architecture Environment for Modelling 3D Detailed Buildings Using Geospatial Techniques. Engineering, 15(05), pp.328-341.

Dibs, H., Hasab, H.A., Jaber, H.S. and Al-Ansari, N., 2022b. Automatic feature extraction and matching modelling for highly noise near-equatorial satellite images. Innovative Infrastructure Solutions, 7(1), p.2.

Dibs, H., Hasab, H.A., Mahmoud, A.S. and Al-Ansari, N., 2021b. Fusion methods and multi-classifiers to improve land cover estimation using remote sensing analysis. Geotechnical and Geological Engineering, 39(8), pp.5825-5842.

Dibs, H., Hasab, H.A., Mezaal, M.R. and Al-Ansari, N., 2021a. Comparative analysis of integrating and combining thermal TIRS and OLI data to superior change Detection using Geospatial Techniques.

Dibs, H., Jaber, H.S. and Al-Ansari, N., 2023c. Multi-fusion algorithms for detecting land surface pattern changes using multi-high spatial resolution images and remote sensing analysis. Emerging Science Journal, 7(4), pp.1215-1231.

Dibs, H., Mansor, S., Ahmad, N. and Al-Ansari, N., 2022a. Geometric correction analysis of highly distortion of near equatorial satellite images using remote sensing and digital image processingtechniques. Engineering, 14(01), pp.1-8.

Dibs, H., Mansor, S., Ahmad, N. and Al-Ansari, N., 2023a. Robust Radiometric Normalization of the near Equatorial Satellite Images Using Feature Extraction and Remote Sensing Analysis. Engineering, 15(2), pp.75-89.

Dibs, H., Mansor, S., Ahmad, N., Pradhan, B. and Al-Ansari, N., 2020. Automatic Fast and Robust Technique to Refine Extracted SIFT Key Points for Remote Sensing Images. Journal of Civil Engineering and Architecture, 14(6), pp.339-350.

Dibs, H., Mansor, S., Ahmadb, N. and Al-Ansari, N., 2020. Simulate New Near Equatorial Satellite System by a Novel Multi-Fields and Purposes Remote Sensing Goniometer. Engineering, 12, 325-346.

Dragan, M. T., Sahsuvaroglu, I. G. and Feoli, E. 2005. Application and validation of a desertification risk index using data for Lebanon. Management of Environmental Quality: An International Journal 16(4): 309-326.

Dregne, H. E. 1986. Desertification of arid lands. In El-Baz, F. and Hassan, M. H. A. (eds). Physics of Desertification. Martinus Nijhoff Publishers, Dordrecht, pp. 4-34.

El-Hassan, I. M. 2004. Desertification monitoring using remote sensing technology. International Conference on Water Resources and Arid Environment 2004. King Saud University, Riyadh, pp. 1-15.

El-Karouri, M.O.H. (1986), "Impact of desertification on Land Productivity", in Farouk E.and Hassan, M.H. (Eds), A Physics of Desertification, Dordrecht, The Netherlands: Martinus Nijhoff Publishers, pp. 52-59.

Emeka,E.E. (2013), "Drought and Desertification as they affect the Nigerian Environment", Journal of Environmental Management and Safety, Vol. 4 No 1, pp. 45-54.

Fang, L., Bai, Z., Wei, S., Yanfen, H., Zongming, W., Kaishan, S. and Zhiming, L. 2008. Sandy desertification change and its driving forces in western Jilin Province, North China. Environ. Monit. Assess. 136:379-390.

FAO (1993), "Sustainable development of drylands and combating desertification", Corporate Document Repository.

FAO (2001), "Food insecurity-When People live with Hunger and Fear Starvation"-UN Food and Agricultural Organization, Rome.

FMEnv (2001), "National Action Programme to Combat Desertification", The federal Ministry of Environment, Nigeria.

Fredricson E., Havstard K.M. and Hyder, R. (1998), "Perspective on desertification. South-Eastern United States", J. Arid Environment, Vol. 39, pp. 191-207.

Glantz, M.H. and Orlovsky, N.S. (1983), "Desertification: A review of the Concept", Desertification Control Bulletin, Vol. 9, pp. 15-22.

Grainger, A. (2009), "Developing a Baseline Survey for Monitoring Biophysical and Socio-Economic Trends in Desertification, Land Degradation and Drought", Consultancy Report for the UNCCD.

Hashim, F., Dibs, H. and Jaber, H.S., 2021, July. Applying Support Vector Machine Algorithm on Multispectral Remotely sensed satellite image for Geospatial Analysis. In Journal of Physics: Conference Series (Vol. 1963, No. 1, p. 012110). IOP Publishing.

Hashim, F., Dibs, H. and Jaber, H.S., 2022. Adopting gram-schmidt and brovey methods for estimating land use and land cover using remote sensing and satellite images. Nature Environment and Pollution Technology, 21(2), pp.867-881.

Hay, S. I., Randolph, S. E. and Rogers, D. J. 2000. Remote Sensing and Geographical Information Systems in Epidemiology. Vol. 47 of Advances in Parasitology. Academic Press, London, 357 p.

Hein, L. and Ridder, D. E. 2006. Desertification in the Sahel: A reinterpretation. Global Change Biol. 12:751-758.

Helld´en, U., Tottrup, C., 2008. Regional desertification: a global synthesis. Global Planet. Change 64 (3–4), 169–176. https://doi.org/10.1016/j.gloplacha.2008.10.006.

Hill, J. 2000. Assessment of semi-arid lands: Monitoring dryland ecosystems through remote sensing. In Meyers, R. A. (ed.). Encyclopedia of Analytical Chemistry – Instrumentation and Applications. John Wiley & Sons, Chichester, pp. 8769-8794.

Hill, J., Jarmer, T., Udelhoven, T. and Stellmes, M. 2006. Remote sensing and geomatics applications for desertification and land degradation monitoring and assessment. In Escadafal, R. and Paracchini, M.L. (eds).

Geometrics for Land and Water Management: Achievement and Challenges in the Euromed Context. International Workshop, Joint Research Centre, Italy, 23-25 June 2004, pp. 15-22.

Hulme, M. and Kelly, M. (1993), “Exploring links between desertification and climate change”, Environment, Vol. 35 No. 6, pp. 39-45.

Ijah, A. (2014), Conflicts between Fulani Herders and Farmers in Central and Southern Nigeria: Discourse on proposed establishment of grazing routes and reserves. An International Journal of Arts and Humanities Vol.3. No.9 pp 66-84.

IPCC (2007), “Climate Change 2007: Impact and Vulnerability”, Contribution of Working 192 Group 11 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Appendix 1-Glossary, 872.

Jha, M. K. 2010. Natural and Anthropogenic Disasters: Vulnerability, Preparedness and Mitigation. Springer, London, pp. 355-384.

Jones T.B. (2006), "Case Study on Successful South African NRM Initiatives and their Impact on Poverty and Governance. Country Study: Namibia”, United States Agency for International Development

Jupp, D. L. B., Guoliang, T., McVicar, T. R., Yi, Q. and Fuqin, L. 1998. Soil Moisture and Drought Monitoring Using Remote Sensing I: Theoretical Background and Methods. EOC Report 1998.1. CSIRO, Canberra, 96 p.

Kadhim, N., Ismael, N. T., & Kadhim, N. M. (2022). Urban landscape fragmentation as an indicator of urban expansion using sentinel-2 imageries. Civil Engineering Journal, 8(9), 1799-1814.

Kambou, J.B. (2002), “Burkina Faso: Sahel Integrated Lowland Ecosystem Management Phase 1”, Ministry of Environment and Water. Burkina Faso.

Kapetsky, J. M. and Aguilar-Manjarrez, J. 2007. Geographic Information Systems, Remote Sensing and Mapping for the Development and Management of Marine Aquaculture. Food and Agriculture Organization of the United Nations, Rome, pp. 30-65.

Karnieli, A. and Dall’Olmo, G. 2003. Remote-sensing monitoring of desertification, phenology, and droughts. Management of Environmental Quality: An International Journal 14(1):22-38.

Kasawani, I., Norsaliza, U. and Hasmadi, S. 2010. Analysis of spectral vegetation indices related to soil-line for mapping mangrove forests usingKelly, M. and Hulme, M. (1993), “Desertification and Climatic Change”, Trempo 8, pp. 1-7

Kelly, M. and Hulme, M. (1993), “Desertification and Climatic Change”, Trempo 8, pp. 1-7.

Kelly, R. L. and Thomas, D. H. 2012. Archaeology. Cengage Learning, London, pp. 67-75.

Klintenberg, P. and Seely, M. (2004), “Land Degradation Monitoring in Namibia: A First Approximation”, @www.environment-namibia.net/’.

Kumar, P., Rani, M., Pandey, P., Majumdar, A. and Nathawat, M. 2010.Monitoring of deforestation and forest degradation using remote sensing and GIS: A case study of Ranchi in Jharkhand (India). Report and Opinion 2(4):14-20.

Kundu, A. and Dutta, D. 2011. Monitoring desertification risk through climate change and human interference using remote sensing and GIS techniques. International Journal of Geomatics and Geosciences 2(1):21-33.

Lam, D., Remmel, T. and Drezner, T. 2010. Tracking desertification in California using remote sensing: A sand dune encroachment approach. Remote Sens. 3:1-13.

Lamchin, M., Lee, J.Y., Lee, W.K., Lee, E.J., Kim, M., Lim, C.H., Choi, H.A., Kim, S.R., 2016. Assessment of land cover change and desertification using remote sensing technology in a local region of Mongolia. Adv. Space Res. 57 (1), 64–77. https://doi. org/10.1016/j.asr.2015.10.006.

Leone, A.P. and Sommer, S., 2000. Multivariate analysis of laboratory spectra for the assessment of soil development and soil degradation in the southern Apennines (Italy). Remote Sensing of Environment, 72(3), pp.346-359.

Levin, S. A. 2009. The Princeton Guide to Ecology. Princeton University Press, New York, pp. 82-86.

Li, S., Zheng, Y., Luo, P., Wang, X., Li, H. and Lin, P. 2007. Desertification in Western Hainan Island, China. Land Degrad. Develop. 18:473-485.

Li,Q., Zhang, C., Shen, Y., Jia, W., Li, J., 2016. Quantitative assessment of the relative roles of climate change and human activities in desertification processes on the Qinghai-Tibet Plateau based on net primary productivity. Catena 147, 789–796. https://doi.org/10.1016/j.catena.2016.09.005.

Liu, Q., Liu, G., Huang, C., 2018. Monitoring desertification processes in Mongolian plateau using MODIS tasseled cap transformation and TGSI time series. J. Arid Land10 (1), 12–26. https://doi.org/10.1007/s40333-017-0109-0.

MA (2005), Ecosystems and Human Well-being Desertification Synthesis, World Resource Institute, Washington DC.

Makarau, A., Palubinskas, G. and Reinartz, P. 2011. Multi-sensor data fusion for urban area classification. In Stilla, U., Gamba, P., Juergens, C. and Maktav, D. (eds). Joint Urban Remote Sensing Event (JURSE). Munich, Germany, pp. 21-24.

Mesev, V. 2007. Integration of GIS and Remote Sensing. John Wiley and Sons, London, pp. 17-55.

Mortimore, M. (1989), Adapting to Drought. Farmers, Famines and Desertification in West Africa, Cambridge University Press.

Moseley, W. G. and Jermé, E. S. 2010. Desertification. In Warf, B. (ed.). Encyclopedia of Geography. Sage Publications Inc., Thousand Oaks, 1:715-719

Murad, H. and Saiful, A. 2011. Drought assessment using remote sensing and GIS in North-West region of Bangladesh. 3rd International Conference on Water and Flood Management, (ICWFM), p. 27.

Mutti, P.R., Lucio, P.S., Dubreuil, V., Bezerra, B.G., 2020. NDVI time series stochastic models for the forecast of vegetation dynamics over desertification hotspots. Int. J. Rem. Sens. 41 (7), 2759–2788. https://doi.org/10.1080/01431161.2019.1697008.

Nneji, L.M. (2013), "A Review of the Effects of Desertification on Food security", Report and Opinion, Vol. 5 No. 10, pp. 27-33.

Okello. A.L., Majekodumi, A.O., Molala, A., Welburn, S.C. and Smith, J. (2014), "Identifying motivators for State-Pastoral dialogue: Exploring the relationship between livestock services, self-organization and conflict in Nigeria's Pastoralist Fulani", Pastoralism, Vol. 4 No.12, pp. 1.

Olagunju, T.E. (2015), "Drought, Desertification and the Nigerian Environment: A review", Journal of Ecology and Natural Environment, Vol 7, pp. 196-209.

Palacios-Orueta, A. and Ustin, S.L., 1998. Remote sensing of soil properties in the Santa Monica Mountains I. Spectral analysis. Remote sensing of Environment, 65(2), pp.170-183.

Palacios-Orueta, A., Pinzon, J.E., Ustin, S.L. and Roberts, D.A., 1999. Remote sensing of soils in the Santa Monica Mountains: II. Hierarchical foreground and background analysis. Remote Sensing of Environment, 68(2), pp.138-151.

Palmer, A. R. and van Rooyen, A. F. 1998. Detecting vegetation change in the southern Kalahari using Landsat TM data. J. Arid. Environ. 39:143-153.

Pellikka, P. K. E, Clark, B. J.F , Sirviö, T. and Masalin, K., 2005. Environmental change monitoring applying satellite and airborne remote sensing data in the Taita Hills, Kenya. Remote Sensing and Geoinformation

Processing in the Assessment and Monitoring of Land Degradation and Desertification. Trier, Germany, pp. 223-232.

Quan, J., Borton, D. and Conroy, C. (1994), "A Preliminary Assessment of Desertification in Namibia", A Report Prepared for the Directorate of Environmental Affairs (Ministry of Environment and Tourism). Ministry of Tourism, Water and Rural Development and Desert Ecological Research Unit of Namibia.

Rangza, K., Sulaimani, B., Sarsangi, A. R. and Abshirini, A. 2008. Change detection, mineralogy, desertification mapping in east and northeast of Ahvaz City, sw Iran using combination of remote sensing methods, GIS and ESAs model. Global Journal of Environmental Research 2(1):42-52.

RomeroDiaz, A., Cammeraat, L. H., Vacca, A. and Kosmas, C. 1999. Soil erosion at three experimental sites in the Mediterranean. Earth Surf. Process. Landforms 24(13):1243-1256.

Sameer, M. K., & Hamid, A. M. (2023). Remote Sensing and GIS Techniques in Monitoring Land Use Land Cover Change. International Journal of Sustainable Construction Engineering and Technology, 14(1), 13-20.

Salazar, L. A. 2007. Integrating remote sensing, geographic information system and modeling for estimating crop yield. ProQuest, New York, pp.140- 145.

Santini, M., Caccamo, G., Laurenti, A., Noce, S., Valentini, R., 2010. A multi-component GIS framework for desertification risk assessment by an integrated index. Appl. Geogr. 30 (3), 394–415. https://doi.org/10.1016/j.apgeog.2009.11.003.

Schwartz, M.L. and Notini, J. (1994), "Desertification and Migration. Mexico and the United States", Research paper, US Commission on Immigration Reform.

Seely, M. and Klintenberg, P. (2011), "Case Study Desertification: Central Namibia. Silviculture in the Trophics", Tropical Forestry 8, Springer-verlag Berlin Heidelberg.

Seely, M. and Klintenberg, P. (2011), "Case Study Desertification: Central Namibia. Silviculture in the Trophics", Tropical Forestry 8, Springer-verlag Berlin Heidelberg.

Senanayake, R. (2012), Desertification and Biodiversity. Ground Views Journalism for Citizens.

Shafie, H., Hosseini, S. M. and Amiri, I. 2012. RS-based assessment of vegetation cover changes in Sistan Plain. International Journal of Forest, Soil and Erosion 2(2):97-100.

Shalaby, A. and Tateishi, R. 2007. Remote sensing and GIS for mapping and monitoring land cover and land-use changes in the Northwestern coastal zone of Egypt. Appl. Geogr. 27(1):28-41.

Shalaby, A., Aboel Ghar, M. and Ryutaro, T. 2004. Desertification impact assessment in Egypt using low resolution satellite data and GIS. Int. J. Environ. Stud. 61(4):375-383.

Stephen, D. (2014), "Land Degradation and Agriculture in the Sahel of Africa. Causes, Impacts and Recommendations", Journal of Agricultural Science and Applications (J.Agric.Sci.Appl.,), Vol 3 No.3, pp. 67-73.

Stiles, D.N. (1983), "Desertification and Pastoral Development in Northern Kenya. Commission on Nomadic Peoples", Nomadic Peoples Vol.13 pp 1-14.

Stringer, L.C., 2008. Reviewing the international year of deserts and desertification 2006: what contribution towards combating global desertification and implementing the united Nations Convention to combat desertification? J. Arid Environ. 72 (11), 2065–2074. https://doi.org/10.1016/j.jaridenv.2008.06.010.

Sun, D., Dawson, R., Li, H. and Li, B. 2005. Modeling desertification change in Minqin County, China. Environ. Monit. Assess. 108:169- 188.

Tamirie, H. (2000), "Desertification in Ethiopian Highlands", RALA Report No. 200.

Thelma, M.N. (2015), "Desertification in Northern Nigeria: Causes and implication for National food security. Peak", Journal of social sciences and Humanities. Vol.3 No.2. pp. 22-31

Tully, T.G. and Shapiro, E. (2014), “Analysis of Kenyan Livestock Market and Feasibility Study of Livestock Business”, Masters project submitted in partial fulfilment for the Master of Environmental Management in the School of the Environment of Duke University.

UNCCD (2006), Implementing the United Nations Convention to Combat Desertification in Africa. Ten African Experiences, Secretariat of the United Nations Convention to Combat Desertification, Bonn, Germany.

UNCCD (2014), Desertification. The Invisible Frontline. Secretariat of the United Nations Convention to Combat Desertification, Bonn, Germany.

UNCCD, (2013), A Stronger UNCCD for a LAND Degradation Neutal World. Secretariat of the United Nations Convention to Combat Desertification, Bonn, Germany.

UNEP (1994), Intergovernmental Negotiating Committee for the elaboration of an International Convention to Combat Desertification in those Countries Experiencing Serious Drought and /or Desertification, particularly in Africa. Final Text of the Convention.

United Nations, 1977. Report of the United Nations Conference on Desertification.Nairobi, vol. 29. August – 9 September. A/CONF.74/36.

United Nations, 1977. Report of the United Nations Conference on Desertification. Nairobi, vol. 29. August – 9 September. A/CONF.74/36.

United Nations, 1994. United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought And/or Desertification particularly in Africa.

United Nations, 2015. Transforming Our World: the 2030 Agenda for Sustainable Development, 70/1. A/RES/.

Ustin SL, Roberts DA, Gamon JA, Asner GP, Green RO. Using imaging spectroscopy to study ecosystem processes and properties. BioScience. 2004 Jun 1;54(6):523-34.

Van den Elsen, E., Jetten, V., 2015. Combatting desertification using a multidisciplinary approach. Catena 128, 211–213. https://doi.org/10.1016/j.catena.2014.10.001.

Verón, S. R., Paruelo, J. M. and Oesterheld, M. 2006. Assessing Journal of Food, Agriculture & Environment, Vol.11 (2), April 2013 797 desertification. J. Arid. Environ. 66(4)751-763.

Verstraete, 1986. Verstreate M.M. (1986), “Defining Desertification. A Review”, Climatic Change, Vol. 9 pp.5-18

Wang, X., Chen, F., Dong, Z., 2006. The relative role of climatic and human factors in desertification in semiarid China. Global Environ. Change 16 (1), 48–57. https://doi.org/10.1016/j.gloenvcha.2005.06.006.

Weier, J. and Herring, D. n.d. Measuring Vegetation (NDVI and EVI). Nasa Earth Observatory. Retrieved 18 May 2012 from http:// earthobservatory.nasa.gov/Library/MeasuringVegetation/measuring_ vegetation_3.html.

Weiss, E., Marsh, S. E. and Pfirman, E. S. 2001. Application of NOAA- AVHRR NDVI time-series data to assess changes in Saudi Arabia’s rangelands. Int. J. Remote Sens. 22(6):1005-1027.

Wu, B. and Ci, L. J. 2002. Landscape change and desertification development in the Mu Us Sandland, Northern China. J. Arid. Environ. 50(3):429-444.

Xiao, J., Shen, Y., Tateishi, R., Bayaer, W., 2006. Development of topsoil grain size index for monitoring desertification in arid land using remote sensing. Int. J. Rem. Sens. 27(12), 2411–2422. https://doi.org/10.1080/01431160600554363.

Xiao, J., Shen,Y. and Tateishi, R. 2005. Mapping soil degradation by topsoil grain size using MODIS data. Retrieved 16 April 2012 from http://crs.itb.ac.id/media/Jurnal/Refs/Critical_Review/Referensi/03_LainLain/p003_Jieyingxiao_paper.pdf.

Xu, D., Song, A., Tong, H., Ren, H., Hu, Y., Shao, Q., 2016. A spatial system dynamic model for regional desertification simulation - a case study of Ordos, China. Environ. Model. Software 83, 179–192. https://doi.org/10.1016/j.envsoft.2016.05.017.

Yang, X., Ding, Z., Fan, X. and Zhou, Z. 2007. Processes and mechanisms of desertification in northern China during the last 30 years, with a special reference to the Hunshandake Sandy Land, eastern Inner Mongolia. Catena 71(1):2-12.

Yanli, Y., Jabbar, M. T. and Zhou, J. 2012. Study of environmental change detection using remote sensing and GIS application: A case study of Northern Shaanxi Province, China. Pol. J. Environ. Stud. 21(3):783-790.

Zaman, S. (1997), "Effects of rainfall and grazing on vegetation yield and cover of two arid Rangelands in Kuwait". Environ. Cons, Vol. 24, pp. 344-350.

Zeng, L. (2005), "Gobi Desertification", ICE Case Studies, Gobi.

Zhao, Y., Wang, X., Novillo, C.J., Arrogante-Funes, P., V´azquez-Jim´enez, R., Maestre, F.T., 2018. Albedo estimated from remote sensing correlates with ecosystem multifunctionality in global drylands. J. Arid Environ. 157 (9), 116–123. https://doi.org/10.1016/j.jaridenv.2018.05.010.