

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

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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 to monitor 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.

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INTRODUCTION

Desertification and land degradation significantly impact both the economy and the environment. Land degradation affects approximately 1.4 billion people globally, with 74% of them living in impoverished conditions. The combined effects of drought and desertification result in an annual loss of 12 million hectares of cultivable land (United Nations 2015, Dibs et al. 2023a, Al-Janabi et al. 2024). Land degradation reduces land productivity in both biological and economic terms, leading to the deterioration of soil quality and permanent loss of natural vegetation (United Nations 1994, Bakr et al. 2012, Dibs et al. 2020, Palacios et al. 1999, Dibs & Mansor 2014, Van & Jetten 2015).

Since the 1970s, there has been increasing political and international attention toward arid, semi-arid, and sub-humid regions due to their crucial role in food production and social development. Extensive research has been conducted on this issue (Li et al. 2016, Becerril-Piña et al. 2016, Liu et al. 2018, Zhao et al. 2018, Kadhim et al. 2022). Desertification refers to land degradation in dry ecosystems, leading to desert-like conditions (Verstraete 1986, Dibs et al. 2020, Dibs et al. 2021a, 2021b, Hashim et al. 2021). The United Nations (1977) provided the first comprehensive



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definition, emphasizing its economic consequences. This definition was expanded in 1994 to include land degradation caused by human activities and climate change, highlighting its socio-economic and ecological impacts.

The concept of desertification has since been widely used in international research, offering diverse methodologies for measuring, analyzing, and modeling its progression (Li et al. 2007, Cui et al. 2011, Bakr et al. 2012, Lamchin et al. 2016, Xu et al. 2016, Becerril-Piña et al. 2016, Liu et al. 2018, Zhao et al. 2018, Dibs et al. 2022a, 2022b, Hashim et al. 2022, Dibs & Al-Ansari 2023). Desertification is recognized globally as a major environmental concern due to its adverse effects, including dust storms, soil salinization, and biodiversity loss (United Nations 2015). It also has severe socioeconomic consequences, such as food scarcity, poverty, and health issues like malnutrition and respiratory diseases (Xiao et al. 2006, United Nations 2015).

The phenomenon is influenced by natural factors like temperature, precipitation, and vegetation loss, as well as human activities such as deforestation, urbanization, and land-use changes (Stringer 2008, Santini et al. 2010, De Pina

Tavares et al. 2015, Xu et al. 2016). Desertification poses a significant barrier to sustainable development in affected regions, necessitating urgent mitigation strategies (Wang et al. 2006, Helldén & Tottrup 2008, Dibs et al. 2023a, 2023b, 2023c). Recognizing its far-reaching consequences, the United Nations incorporated desertification into the Sustainable Development Goals (SDGs), particularly Goal 15, which aims to combat land degradation and promote ecosystem restoration (United Nations 2015).

Climate change projections indicate an increase in desertification due to shifts in temperature, precipitation patterns, and atmospheric carbon dioxide levels. These changes will exacerbate droughts and prolonged dry conditions, further intensifying land degradation (D'Odorico et al. 2013, Al-Bakri et al. 2016, Mutti et al. 2020, Sameer & Hamid 2023). SDG 15.3 emphasizes restoring degraded land and achieving land degradation neutrality by 2030, underscoring the necessity of addressing desertification to reduce poverty and mitigate climate change impacts.

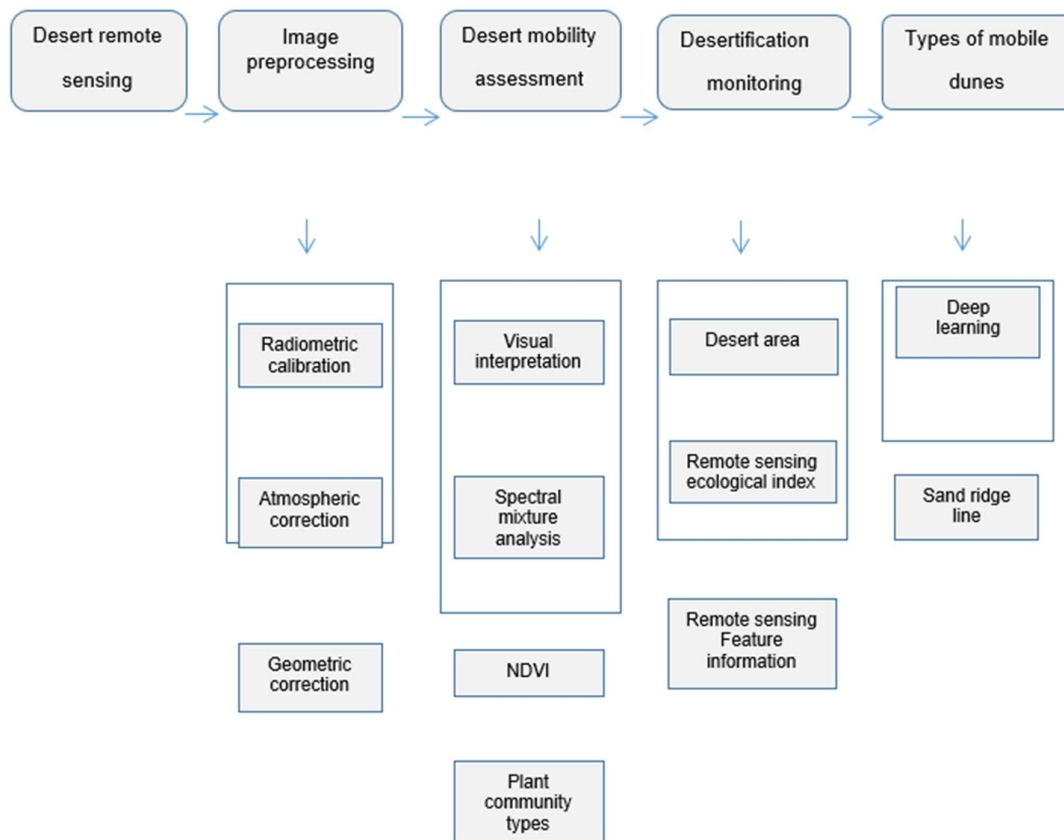


Fig. 1: The framework of desertification monitoring.

Advancements in remote sensing and deep learning techniques have enhanced desertification monitoring and assessment. However, further integration of these technologies is needed for improved accuracy and predictive capabilities. The application of remote sensing data and machine learning has provided valuable insights into desertification trends, yet additional interdisciplinary efforts are required for robust, scalable solutions. This study provides a comprehensive analysis of existing research methodologies, highlighting current trends and future directions in desertification research. Fig. 1 depicts the exact structural framework. Before initiating the inquiry, it was crucial to select a remote sensing dataset specifically for desert analysis and perform necessary data processing. This included examining and classifying mobile and non-mobile deserts, monitoring desertification in mobile deserts, and further categorizing morphological changes to improve understanding of desertification dynamics.

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 & 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 & 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 & 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 CO₂ 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, several 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. They are reciprocally exerting an influence on one other and resulting in detrimental outcomes for the existing ecosystems.

DESERTIFICATION EFFECTS

The complex phenomenon 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 the 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 et al. 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 (Fredricson 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 in 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 & Notini 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 potential alterations in the species and physical characteristics of animals over a specified period. 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. 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 (Tamir 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. Seely & Klintenberg (2011) 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.

Jones (2006) and Seely & Klintenberg (2011) 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 & 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 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 fishermen, Emeka (2013) claimed 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). The 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 for 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.

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 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. 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 to monitor 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 studies 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, Tamir (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 of 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 many strategies to endure 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.

Klintonberg & Seely (2004) focused on the monitoring of land deterioration in Namibia and proposed several solutions to combat desertification (Klintonberg & Seely 2004). Hence 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 to plant them (Darkoh 1982, 1987).

A thorough education campaign regarding the dangers of desertification and the importance of afforestation was launched in many 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.

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

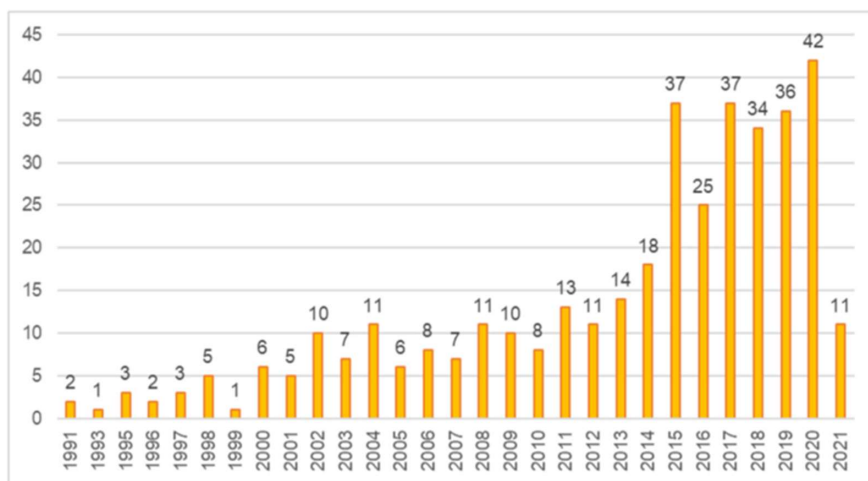


Fig. 2: Timeline of the use of remote sensing to study desertification (Daniela et al.2022).

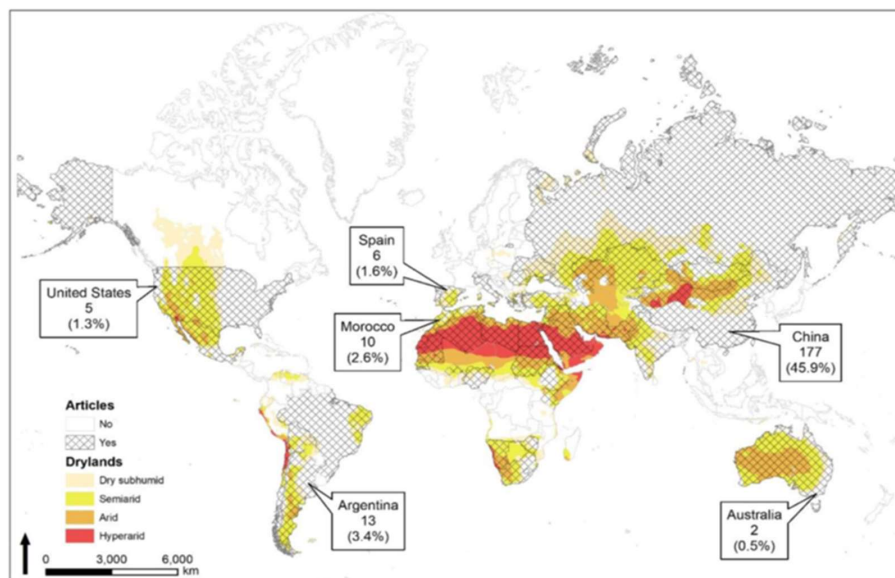


Fig. 3: displays the countries and regions that have conducted research publications on desertification utilizing remote sensing (Daniela et al. 2022).

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 are 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.

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

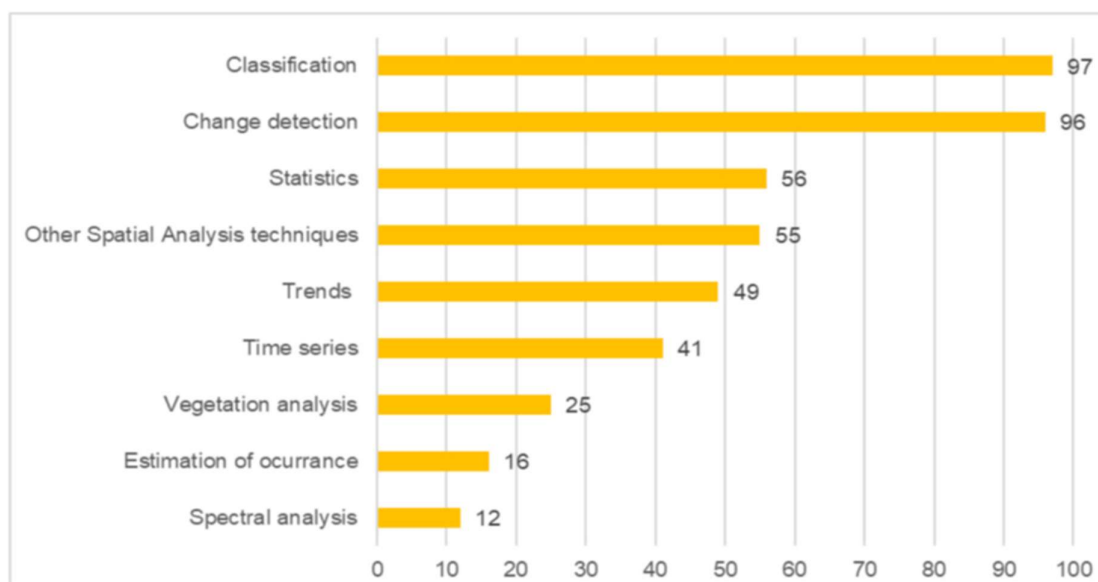


Fig. 4: Most used methods for the study of desertification using remote sensing over the past 35 years (Daniela et al. 2022).

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 Fig. 4.

Challenges Associated With Remote Sensing

Remote sensing technology employs automated devices, such as satellites, to acquire and send visual data (Hay et al. 2000). Before 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 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).

DESERTIFICATION KEY INDICATORS

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 can negatively affect water reserves and quality, as well as the chemical and physical characteristics of soil (Karnieli & Dall’Olmo 2003, Collado et al. 2002, El-Hassan, 2004, Shalaby et al. 2004, Mohammed et al. 2022, Hassan et al. 2020, Ali et al. 2020, Naje et al. 2020, 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 & Ci. 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 conditions 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 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 & 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 (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 beneficial, 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. To guarantee the effectiveness of the GSI index, it is crucial to employ images captured before 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 & 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 phenomenon 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 to assess 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 15 years 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, El-Hassan, 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 extended periods. 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).

DESERTIFICATION INDICES

Vegetation indices are mainly used to accurately detect desertification, evaluate plant development and stress, and 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 of 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 (1988). This correction factor is applied to minimize the influence of background sensitivity in the study, as highlighted by Chen (1995). In their work, Kundu & Dutta (2011) utilized NDVI time trends 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.

CONCLUSIONS

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, future studies must 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.

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