Mapping of the *Prosopis-Juliflora* (Mesquite) invasion and its effects on pastoralist livelihoods in the Red Sea State, Sudan – a remote sensing approach

UNIVERSITY OF BERGEN

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Master's thesis in environmental geography, University of Bergen

Institute of Geography, August 2022

Acknowledgment

First and foremost, I thank God and praise him who gave me the strength and patience to complete this research.

I would like to thank the family of the Institute of Geography at the University of Bergen for allowing me to learn and practice work in the field of GIS and remote sensing.

I would like to extend my sincere thanks to my supervisor, Professor Dr**. Gidske Leknæs Andersen** for accepting my research in her scientific field, particularly in the field of remote sensing, for her scientific supervision, advice, and personal guidance, and his unlimited support throughout the research period. I appreciate her knowledge and her open mind, and it is not an exaggeration to say, this research without her could not see the light.

My sincere thanks and very special appreciation to my husband **Ahmed Ali Ibrahim** for his unlimited support and cooperation.

I would like to express my deepest gratitude to my loving children, **Asif** and **Yamin**, who made our lives wonderful and from whom we derive the continuity of life.

I would like to thank my colleague, Mohamed Talib at Red Sea University, for his help and support.

Finally, I am very grateful, and I thank my Greatest Mother and Father who passed away, thanks to their prayers which were for me a certain good and supportive good, to achieve success, who have always wished me.

Contents

Abstract

Land cover management policies and land use changes are among the risks facing pastoral lands in eastern Sudan. Land use/land cover (LULC) changes play a major role in the study of global change. LULC and human/natural modifications have largely resulted in deforestation, biodiversity loss, global warming, and an increase in natural disaster-flooding.

This thesis's investigates vegetation change with a focus on the expansion of Prosopis-Juliflora (Mesquite) and its impact on pastoralist livelihoods in Red Sea State in Sudan. The current study was conducted in three areas of Red Sea State (Sinkat and Jubayt, Ashat, and Salum). Remote sensing and Geographical Information systems (GIS) were used to monitor and map changes in land cover and land use (LULC). Multi-temporal Landsat satellite data from 1984-2020 (1984,1990,1995,2000,2005,2010,2015 and 2020) were used to identify LULC change and study the dynamics of change, the effects of the expansion of the P. juliflora on the livelihoods of pastoralists in the Red Sea region (Sudan), and the identification of possible adaptations therein were studied using interviews. Socioeconomic data were correlated with remote sensing data to analyze the causes and effects of change in LULC and land degradation.

The study found that the high NDVI values in the Sinkat area were clustered in the water drainage areas, with peaks in 2000 and 2015. In Salum and Ashat, high NDVI values were concentrated in the plains (pastoral land). The highest values of NDVI were recorded in the Salum in the period between 1990 to 2000 and 2015. In Ashat, the highest values were also recorded in 2000 and 2015. In general, the values decreased in the period between 2005 to 2010 and increased in 2015, maybe because of the fluctuations in the precipitation rate. *P. juliflora* can adapt and survive in marginal and even highly degraded lands because its roots extend so deep that they reach permanent soil moisture and/or aquifers. *P. juliflora* is a rapidly spreading invasive species that reduce ecosystem services by displacing local biodiversity. This found differences in views between the beneficiaries, including farmers, herders, and charcoal traders. Farmers believe that *P. juliflora* is invading their lands, while herders in the study area see it as a source of fodder for their animals and shade during the hot dry season, and it provides timber for building homes. The farmers, shepherds, and charcoal traders agreed that *P. juliflora* is a valuable source of fuel and charcoal makers also of income, due to high-quality charcoal. The study emphasized that some invasive species are useful and important because they create good livelihood opportunities, but on the other hand increase vulnerability within local social ecosystems.

Abstrakt

Retningslinjer for forvaltning av arealdekke og endringer i arealbruk er blant de bestemmende faktorene for risikoen som pastorale land står overfor i det østlige Sudan. Denne studien undersøker vegetasjonsendring med fokus på utvidelsen av Porosopis-Juliflora (Mesquite), og dens innvirkning på pastoralists levebrød i Rødehavsstaten i Sudan. Den nåværende studien ble utført i tre områder av Rødehavsstaten (Sinkat og Jubayt, Ashat og Salum). Studien tar sikte på å vurdere vegetasjonsendring og vurdering av utvidelsen av P. juliflora og dens innvirkning på levebrødet til gjetere i Rødehavsstaten i Sudan. Fjernmåling og geografisk informasjonssystem (GIS) ble brukt for å overvåke og kartlegge endringer i arealdekke og arealbruk (LULC). Multi-temporale Landsat-satellittdata fra 1984-2020 (1984,1990,1995,2000,2005,2010,2015 og 2020) ble brukt til å identifisere LULC-endring og studere endringsdynamikk, effekten av utvidelsen av P. juliflora på levebrødet til pastoralister i Rødehavsregionen (Sudan) og identifiseringen av mulige tilpasninger der ble studert ved hjelp av intervjuer. Sosioøkonomiske data ble korrelert med fjernmålingsdata for å analysere årsakene og virkningene av endring i LULC og landforringelse.

Studien fant at de høye NDVI-verdiene i Sinkat-området var samlet i vannavløpsområdene, med topper i 2000 og 2015. I Salum og Ashat var høye NDVI-verdier konsentrert i slettene (pastoralt land). De høyeste verdiene av NDVI ble registrert i Salum i perioden mellom 1990 til 2000, og i 2015. I Ashat ble de høyeste verdiene også registrert i 2000 og 2015. Generelt gikk verdiene ned i perioden mellom 2005 og 2010 og økte i 2015, kanskje på grunn av svingningene i nedbørsraten.

P. juliflora kan tilpasse seg og overleve i marginale og til og med svært nedbrente landområder fordi røttene strekker seg så dypt at de når permanent jordfuktighet og/eller akviferer. P. juliflora er en raskt spredende invasiv art som reduserer økosystemtjenester ved å fortrenge lokalt biologisk mangfold. Dette fant forskjeller i synspunkter mellom mottakerne, inkludert bønder, gjetere og trekullhandlere. Bønder tror at P. juliflora invaderer landene deres, mens gjetere i studieområdet ser det som en kilde til fôr til dyrene og skygge i den varme tørre årstiden, og den gir tømmer til boligbygging. Bøndene, gjeterne og trekullhandlerne var enige om at P. juliflora er en verdifull inntektskilde for drivstoff- og trekullprodusenter også på grunn av trekull av høy kvalitet. Studien la vekt på at noen invasive arter er nyttige og viktige fordi de skaper gode levemuligheter, men på den annen side øker sårbarheten innenfor lokale sosiale økosysteme

Chapter One

Background

1.1 Introduction

Major changes in land use and climate during recent decades have initiated changes in vegetation cover(Johnson & Miyanishi, 2008). Land use/land cover (LULC) changes play a major role in the study of global change. LULC and human/natural modifications have largely resulted in deforestation, biodiversity loss, global warming, and an increase in natural disaster-flooding (Mas et al., 2004).LULC change directly impacts biotic diversity worldwide, contributes to climate change, is the primary source of soil degradation, and alters ecosystem services and thereby, affecting the ability of biological systems to support human needs. Such changes also determine, in part, the vulnerability of places and people to climatic, economic, or socio-political perturbations (Lambin & Geist, 2008).

Remote sensing is an effective tool for monitoring land cover and environmental changes. Land-use changes can be assessed through various approaches, such as image interpretation, spectral indices, or classification, that can be combined in two or multiple timesteps to detect changes in LULC. Investigating temporal and spatial changes that have occurred dependent on socio-economic and biophysical processes through a multidisciplinary approach to address land degradation and desertification (Rindfuss, Walsh, Turner, Fox, & Mishra, 2004). Advance in remote sensing has emerged through the availability of new sensors and technologies, including solar-induce chlorophyll sensor (SIF) and thermal infrared (TIR) sensors capable of this unprecedented frequency for spatiotemporal observations.

Hudak and Brockett,2009 emphasized that remotely sensed data are useful for quantification and monitoring of changing vegetation responses to driving forces in a semi-arid ecosystem, such as precipitation, fire, and grazing (A. Hudak & Brockett, 2004)). Landsat is a valuable source as it has 30m of data back to the 80s. Timeseries can give a better picture of the development than only combining two images. It is essential to consider and keep pace with the rapidly evolving and changing ecosystem through remote sensing technologies.

The vegetation in Eastern Sudan is part of the Sahel zone, which represents a macro gradient from the Sahara Desert to dry tropical Acacia forests in the south. This zone has gone through various changes in the last century, and many studies have related the changes to anthropogenic factors (Ayyad, 2003). In contrast to the drought periods during the 1970s and 1980s, the Sahel zone is moister now and, in many parts, the vegetation is regenerating. Major changes in land use and climate during recent decades have initiated changes in vegetation succession (Johnson & Miyanishi, 2008; Kardol & Wardle, 2010).

The biological invasion has been defined as the movement of a species outside its natural range due to anthropogenic factors or a natural process (Kollmann, 2007a). It deals with characteristics such as the absence of natural enemies, availability of resources, and environmental conditions. The physical nature makes the habitat/community vulnerable to invasion(Kollmann, 2007; Van Kleunen, Dawson, Schlaepfer, Jeschke, & Fischer, 2010). In the seventies, *P. juliflora* was introduced in Sudan as a program to combat desert encroachment in the form of reserves and belts with the aim of combatting desertification and protecting the area from dunes. *P. juliflora* was through afforestation, considered to be the first line of defense against environmental degradation in many arid regions of the world, However, there was a lack of knowledge about it is invasive properties. Since then, *P. juliflora* has found its way into fertile agricultural lands, irrigation canals, and natural ecosystems and has become a threat to the future of agricultural and pastoral activity in many areas. Nevertheless, *P.juliflora* has some economic benefits, such as providing erosion control, shade, fuelwood, building materials, and pods for animal and human consumption in arid and semi-arid regions (Mbaabu et al., 2019). Therefore, Mesquite has played role in the livelihood of the population in the study area, due to its importance as a source of animal and human food and as a reliable source of fuel.

The study will be able to help in knowing the extent to which the pastoral community has adapted to and accepted *P. juliflora* and its impact on their livelihoods. Further, it aims to identify and evaluate changes in the vegetation cover in the study area, by analyzing, monitoring, and mapping land use and land cover (LU / LC).

1.2 Specific objective

This study focuses on the assessment of vegetation change and the assessment of the expansion of *P. juliflora* and its impact on the livelihoods of herders in Red Sea State in Sudan. The current study was conducted in three areas of Red Sea State (**Sinkat and Jubayt, Ashat, Salum**), using remote sensing and QGIS programmer. using descriptive and quantitative analytical approaches, the interpretation of satellite images (Landsat 5 TM, Landsat 7, ETM, and Landsat 8,) and mapping of NDVI, the study aims to find the answer to the question: Is the expansion of *P. juliflora* species one of the determinants of the deterioration of vegetation cover, and is it possible to adapt to changes under the balance system? In addition, to identify the adaptation that occurred in the pastoral community in the study area. The broad objective of this study is to map and assess the LULC change and degradation in light of this background, the following objectives were formulated

1) Mapping and monitoring land use and land cover processes (LU/LC) for drought and land degradation in different decades (1984,1990,1995,2000,2005,2010,2015 and 2020).
2) To identify LULC change and to examine the change dynamics at different spatial and temporal to the mapping of vegetation cover change relate vegetation change to *P. juliflora* expansion.
3) impact of the expansion of the *P juliflora* on the livelihood of pastoralists in the Red Sea state (Sudan), to identify the possible adaptations in the livelihood.
4) based on the finding (1-3) discuss appropriate conservation measures to enhance land productivity and sustainable development.

1.3 The research questions

1) Is the expansion of P. *juliflora* species one of the determinants of the deterioration of vegetation cover, and is it possible to adapt to changes under the balance system?

2) What measures are appropriate to conserve and promote land productivity and sustainable development?

Chapter Two

Literature review

3.1 Introduction:

Land cover is the physical appearance of the surface which gives information about the distribution of vegetation cover, water, soil, and other physical structures of land. On the other hand, land use indicates land utilized by humans for their needs (Rawat & Kumar, 2015).

Land cover change means changing the certain continuous characteristics of the land, such as soil properties and vegetation type over a landscape. Land use is resulting from environmental change due to human activities (Patel, Verma, & Shankar Singh, 2019).

Vegetation cover changes have been attracting increasing attention from environmentalists and socio-economists. Such changes have been occurring rapidly and involving large areas, especially in developing countries and their influence on environmental conditions may be as serious as the effect of climate change. The change in vegetation changes the radiative and non-radiative properties of the surface. The outcome of the competing biophysical processes of the Earth's surface energy balance varies in space and time which can lead to warming or cooling depending on the specific vegetation change and the nature of the climate (Gregory, Andrew, Lydia, Roberta, & Harris, 2004). Sometimes a change in the natural environment leads to a decrease in the total biomass available to humans and animals. The reasons behind these changes are the process of climate change or activities caused by manmade.

The important issue is what type of practices have a significant negative impact on vegetation cover. Deforestation and reforestation with invasive plants is a major problem facing ecosystems.

Biological invasion is the movement of a species outside its natural range because of anthropogenic factors or a natural process (Kollmann, 2007). However, most biological invasions are man-made. Invasive species have become a common focus of ecologists, natural resource managers, and biological conservationists due to their rapid spread, the threat to biodiversity, and damage to ecosystems (Kandwal, Jeganathan, Tolpekin, & Kushwaha, 2009). The spread of invasive species has led to the homogenization of plant and animal life in the world, changing species composition and community structure and changing biogeochemical cycles. It is also recognized as one of the major drivers of global biodiversity loss and species extinction (Huang & Asner, 2009).

Land degradation and desertification are some of the world's greatest environmental challenges in the light of a rapidly growing world population and increasing demand for food, fiber, and biomass energy. Land degradation is an important ecological and environmental problem facing the world. Land degradation leads to a loss of available grassland resources, a decrease in biological production, and the deterioration of the environment (Fu, Li, Hou, Bi, & Zhang, 2017). Land degradation can also be described as a reduction in the provision of ecosystem services. Ecosystem services are the benefits provided to human society by natural ecosystems, or more broadly put, the ecosystem processes by which human life is maintained (Charles & Dukes).

Landscape provision services, e.g., in the form of wood, food, etc., and cultural services, such as recreation, are supported by regulating services, such as the carbon cycle, and also by supporting services, such as nutrient cycling (Leemans & De Groot, 2003) Many invasive species cause consecutive effects in communities and affect biotic and abiotic components of ecosystems (Crooks, 2002). Almost all ecosystem services can be negatively affected by invasive species, although there are positive effects. This usually results in the impact on multiple ecosystem services. *Prosopis juliflora* was introduced in Sudan as a program to combat the encroachment of the desert in the seventies in the form of reserves and belts to combat desertification to contribute to the protection of the area from dunes was indicated invasive of *P juliflora* is complex and often confusing. The identity of the prevalent species in Sudan is controversial (Abdel Bari, 1986). The species, when, introduced, was claimed to be *P. juliflora*, however, it was, later, identified by Wunder,1966 as *P. chilensis* (Wunder, 1966). This identity, confirmed by (Abdel Bari, 1986), was refuted by (Elfadl, 1997) and (ABD ELBASIT et al., 2012). who ascertained the species as *P. juliflora.* The tree is a copious seed producer. In South Africa, over six hundred thousand seeds were reported to be produced per tree per annum (Zimmermann, 1991).

This type of plant has economic benefits, such as providing erosion control, shade, fuelwood, building materials, and pods for animal and human consumption in arid and semi-arid regions. It is also considered one of the plants with a high ability to compete with natural plants and spread. The mechanism by which Prosopis is spreading and the rate of spread constitute the main problem in agricultural and pasture lands (Elsidig, Abdelsalam, & Abdelmagid, 1998). *P. juliflora* has invaded both natural and artificially managed habitats, including watercourses, floodplains, highways, degraded abandoned land, and irrigated areas. The weed is more of a problem within central, northern, and eastern Sudan. Mesquite infestations cover over 230,000 hectares, with the greatest degree of infestation found in eastern Sudan (Babiker, 2006).

Remote sensing has become an important tool applicable to developing and understanding the global, physical processes affecting the earth (A. T. Hudak & Wessman, 1998) Recent development in the use of satellite data is to take advantage of increasing amounts of geographical data available in conjunction with GIS to assist in interpretation (García-Mora, Mas, & Hinkley, 2012).

3.2 Land cover and land-use change

Land use refers to man's activities and the varied uses which are carried out on the earth's surface, and land cover refers to natural vegetation, water bodies, rock/soil, artificial cover, and others noticed on the land (Anonymous 1989).The change in land use is the conversion of land use due to human intervention for various purposes, such as agriculture, settlement, transportation, infrastructure, manufacturing parks, recreational uses, mining, and fishing (W. B. Meyer & Turner, 1996).

Changing the land cover can be manifested as conversion or modification. The first refers to the complete replacement of one type of cover with another. In contrast, the latter refers to a change in composition (W. B. Meyer & Turner, 1996). Land cover can change without changes in land use, due to the interference of natural factors such as scarcity of rains or drought, natural disasters, conflicts, and displacement. It is important to distinguish the difference between land cover and land use, and the information that can be ascertained from each.

The properties measured with remote sensing techniques relate to land cover, from which land use can be inferred, particularly with ancillary data or a priori knowledge. Land cover is related to the causes and consequences of land use because a change in land cover, in turn, leads to a change in land use. Land use/land cover (LULC) changes play a major role in the study of global change where LULC and human/natural modifications have largely resulted in deforestation, biodiversity loss, global warming, and an increase in natural disaster-flooding (Mas et al., 2004).

Knowledge about land use/land cover change is becoming increasingly important to overcome biodiversity loss, environmental quality degradation, agricultural and grazing land loss, and wetland destruction. Rapid population growth, rural-urban migration, the transition of rural land to urban, lack of assessment of environmental services, Poverty, ignorance of biophysical limitations, and use of environmentally incompatible technologies are the main reason behind LU/LC changes. In the mid-1970s, concerns about land use/cover surfaced in the research agenda on global environmental change for several decades with the realization that land surface processes influence climate. Land cover change modulates atmospheric surface energy exchanges, which have an impact on regional climate (Otterman, 1974).

Ecosystems are the sources and sinks of carbon; This confirmed the impact of land use/cover change on global climate across the carbon cycle (Woodwell et al., 1983). The important contribution of local evaporation to the water cycle – i.e., rainfall recycling – as a function of land cover has highlighted another important impact of land use/cover change on climate, at the local to regional scale and on biodiversity, and the capacity of biological systems to support human needs (Eltahir & Bras, 1996).

There is a set of major driving forces needed to make profound changes in land use such as climate change, natural disasters, population growth, urbanization, wars, and displacement.

With the increasing rate of population growth in Sudan, there has been an increase in the production of food crops as agriculture plays a prominent role in securing the livelihoods of the growing population. The increasing use of irrigation and mechanization has led to an increase in the demand for the use of agricultural land in Sudan, with the conversion of other types of land use and vegetation to the use of agricultural lands, such as agriculture in forested areas and the expansion of pastureland areas. There is also a growing need for more resources, through housing, food, and clothing needs.

3.3 pastoral lands

Grazing is an important subsistence system and is one of the major land uses around the world. According to the Food and Agriculture Organization (Matthews & No, 2001), grazing is a production system that contributes significantly to the economic growth of countries. It is a system based on social relations between people, their natural resources, and the livestock they possess. Pastoralism sustains and secures livelihoods in marginal lands (Krätli, Huelsebusch, Brooks, & Kaufmann, 2013). Pastures are lands where indigenous plants are often herbs or plants that resemble weeds, or shrubs, and are managed as a natural ecosystem. They include grasslands, savannas, shrubs, deserts, and meadows. Pastoral lands are estimated to cover about 25% of the Earth's surface (Liebig et al., 2006). This makes them an essential resource for maintaining environmental services and biodiversity conservation (Gregory et al., 2004). Drylands have been recognized as cultural landscapes or human-ecological systems, and both concepts recognize the importance of human influence and the cumulative long-term ecological knowledge inherent in land-use systems (G. L. Andersen et al., 2014). It has also been recognized that researchers need to consider traditional environmental knowledge (TEK) as a potentially important source of scientific information (G. L. Andersen et al., 2014). Sudan is one of the largest livestock-producing countries in Africa and the Arab World, where the livestock sector contributes to the livelihoods of at least 26 million people. The sector also contributes significantly to the national economy as reflected in Sudan's official statistics. It provides more than 60 percent of the estimated value added to the agriculture sector and is a substantially more important contributor to the GDP than crop farming, with an average of 20-22 percent in comparison with 11 percent for the crop sector as mentioned FAO (Organization, 2020).

3.4 Forest Land

Forests have immense potential to support sustainable development pathways, and the key to realizing this is reliable data and evidence. Accurate data on forest resources are needed to monitor progress toward the targets of the Sustainable Development Goals (SDG). It is also needed to monitor progress on the Global Forest Goals and Targets of the United Nations Strategic Plan for Forests 2017–2030, the nationally determined contributions of countries under the Paris Agreement on climate change as well as globally agreed biodiversity targets, including the forthcoming post-2020 global biodiversity framework (Huang & Asner, 2009). According to FAO 2020, forests play a significant role in the global carbon cycle as both carbon sources and sinks and have the potential to form a critical component in efforts to combat global climate change. Forests are not only a resource for human exploitation but also support wildlife.

Deforestation:

Deforestation includes, for example, forest areas converted to agriculture (including agroforestry, rangelands, water reservoirs, and urban areas). The term specifically excludes areas where trees have been removed, for example, due to harvesting or logging, and where the forest is expected to regenerate naturally or with the help of cultural measures in the long run. Unless this is followed by clearing the remaining recorded forests to introduce alternative land uses, the forests are usually regenerated, often to a different secondary state.

Forests have been facing encroachment by agriculture, urbanization, and unsustainable wood fuel extraction for several decades. The lack of integrated land use plans and coordination across institutions has resulted in the uncontrolled land-use changes and conversion of vast forest tracts into agricultural areas over the past 40 years. Deforestation and degradation are indicated by a reduction in canopy cover through logging, fire, wind hunting, or other events, provided canopy cover remains above 10% (Allen, Pereira, Raes, & Smith, 1998).

Afforestation:

Afforestation refers to forest planting and/or seeding in areas that previously were not classified as forests. According to (Simberloff et al., 2013) the definition of afforestation is Conversion through forest tree planting from other land uses into the forest, or the increase of canopy cover to 10%. Reforestation is the re-growth of forests after a temporary (< 10 years) condition with less than 10% canopy cover due to human-induced or natural perturbations. Afforestation is generally the creation of forest stands in a barren/deforested area, which is defined as land converted to a land-use purpose other than forests.

Between 1990 and 2005, in West Africa and the Sahel region, forest cover decreased by 1.2 million hectares per year, which is well above the continental average. The reduction in forest cover is essentially related to the conversion of forests for agriculture, logging (fuelwood and exporting raw logs), extractive operations, infrastructure development, and fires (Organization, 2020).

To restore biodiversity and ecosystem services, it is necessary to resort to afforestation of degraded areas to achieve the United Nations sustainable development goals. Many fast-growing trees have been introduced worldwide over the past few decades to restore marginal and degraded lands for ecosystem stability. Some of these introduced species have become invasive and invaded the ecosystem resulting in significant loss of biodiversity and land degradation.

3.5 Biological invasion

Biological invasion is defined as the movement of a species outside its natural range because of anthropogenic factors or a natural process (Kollmann, 2007). Biological invasions threaten biodiversity in terrestrial, freshwater, and marine ecosystems, challenging conservation efforts (Simberloff et al., 2013). Most biological invasions are man-made (Erfmeier & Bruelheide, 2009) ,(Warren Liao, 2005).

There are adverse socio-economic impacts of invasive species, which negatively affect ecosystem services and human well-being (Vilà et al., 2019). However, alien species can sometimes also have positive effects, by providing food and shelter or by securing ecosystem processes and functions, especially in ecosystems that are highly affected by cumulative human impacts and climate change (Katsanevakis et al., 2014).

That invasion and susceptibility to invasion are not mutually exclusive since there are many overlaps between invasion mechanisms (Van Kleunen et al., 2010). Species that compete with other species through any combination of invasive traits are more invasive than those that coexist with other species. On the other hand, invasiveness deals with characteristics such as the absence of natural enemies, availability of resources, and environmental conditions. The physicality makes the habitat/community vulnerable to invasion (Kollmann, 2007),(Van Kleunen et al., 2010).

Climate change is increasing the frequency and severity of extreme events that have negatively affected food security and terrestrial ecosystems and contributed to desertification and land degradation in many regions.

Changes in climatic conditions are a direct factor influencing alien species introduced into a territory. Climate changes change the population dynamics of local species, and thus, also their geographic ranges, the structure, and composition of communities, and the functioning of ecosystems (Walther et al., 2002),(Parmesan, 2006).

Climate change and biological invasions are drivers of important impacts on biodiversity and ecosystem services (Schröter et al., 2005). Global warming has enabled new opportunities for species to expand into areas where they were previously unable to survive and reproduce (Walther et al., 2007). These changes pose complex challenges to the management of biodiversity as well as wild and cultivated resources and may include implications for ecosystem functioning (Jones, Lawton, & Shachak, 1997). It must be considered that dominant alien species may become acceptable, for example, the mesquite plant that dominates pastoral and agricultural lands in eastern Sudan has become a source of income for the population that has become adapted to the infestation of the mesquite trees.

The Prosopis species was introduced into the dryland for rehabilitation, especially after the prolonged drought of the Sudano-Sahelian region in the 1970s (N. M. Pasiecznik et al., 2001). The unprecedented spread of seeds by livestock, wildlife, and water has led to their spread to other areas in forests, streams, valleys, and seasonal wetlands. The *P. juliflora* tree uses deep-rooted to extract groundwater in the dry season and soil water in the wet season. When available, *P. juliflora* also exploits deeper water sources by growing rhizomes. *P. juliflora* can also persist in sites with little or no groundwater by growing long, shallow lateral roots. In addition, mesquite can control the evaporation of leaf water and survive even the driest seasons. Therefore, most of the native plants growing around the *P.juliflora* tree (Hosseini Bai, Blumfield, Reverchon, & Amini, 2015)

3.6 Desertification Land degradation

Definition of desertification is the spread of desert-like conditions of low biological productivity due to human impact under climatic variations(Helldén, 1991),(Reynolds & Smith, 2002). (Houghton et al., 2001), Defined desertification as land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities.

According to UNCCD (Desertification, 1999), The term desertification has been defined by the United Nations Convention to Combat Desertification(1999) as "land degradation in arid, semi-arid and dry sub-humid areas through natural processes as well as human activities".

Desertification is the process by which productive land turns into a desert and occurs mainly in drylands (Middleton & Thomas, 1997),(Pravalie, 2016),(Zeng et al., 2000). Desertification reduces food production and other ecosystem goods and services for at least 40% of the world's land area, home to about two billion people, 90% of whom live in developing countries (Adeel et al., 2005).

The natural factors are largely associated with climate variability especially droughts, while some human activities in the drylands are the major cause, especially in Africa. UNCCD defines the terms (desertification, land degradation, etc.), which were negotiated and approved during the negotiation of the dispositions of the UNCCD. According to article 1 point (f), the definition of land degradation is as follows:

"Reduction or loss, in arid, semi-arid and dry sub-humid areas, of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as:

(i) Soil erosion caused by wind and/or water.

(ii) Deterioration of the physical, chemical, biological, or economic properties of soil.

(iii) Long-term loss of natural vegetation"

Prăvălie (2021) mentions that “Is no simple or agreed-upon definition or measurement of land degradation, land degradation manifests itself through deforestation, biodiversity loss, soil erosion, soil infertility, siltation, sedimentation, flooding, and climate variability increase the occurrence of droughts and floods, while human activities such as over-cultivation, waterlogging, salinization, overgrazing, urbanization, deforestation, and land pollution all contribute to land degradation” ((Prăvălie, 2021).

IPCC defined Land degradation (1999) as “degraded of land caused by direct or indirect human-induced processes including anthropogenic climate change, expressed as long-term reduction or loss of at least one of the following: biological productivity, ecological integrity, or value to humans”. This definition applies to a forest and non-forest land: forest degradation is land degradation that occurs in forest land. Soil degradation refers to a subset of land degradation processes that directly affect the soil (Shukla et al., 2019).

related to UNCCD (2016) Land degradation is defined as “a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems” (Cowie et al., 2018).Sustainable Development Goal 15.3 (SDG 15.3) proposes to achieve a world with zero net land degradation, termed Land Degradation Neutrality (LDN), by 2030. SDG 15.3 is an important target of the SDGs related to land and ecosystem preservation and biodiversity conservation(Prăvălie, Patriche, & Bandoc, 2017).

Land degradation and desertification are among the most serious environmental problems facing the world today. The degradation is the result of the complex interrelationships between biophysical, social, and economic issues that affect many people and their lands, especially in the tropics and developing countries. Drylands face enormous threats including demographic pressure and social changes such as migration, settlement of traditionally nomadic peoples, and tribal conflicts, as well as unregulated agricultural and pastoral practices that fuel land exploitation and increase deforestation, soil erosion, soil salinization, and water depletion.

The term land degradation includes the degradation of soil and vegetation cover. Soil degradation refers to changes in the physical, chemical, and biological properties of soil, and the deterioration of vegetation cover refers to a decrease in the number of species and plant composition. Removal of vegetation exposes soil to wind and heavy rain erosion, exposing seedlings to erosion and often completely covering them with sand, causing serious problems in the regions of agricultural land and pastoral land.

3.7 Ecological resilience

Holling ,1973 mentioned that the characterized stability as the persistence of a system near or close to an equilibrium state. By contrast, resilience was introduced to indicate the behavior of dynamic systems far from equilibrium, by defining resilience as the amount of disturbance that a system can absorb without changing state (Holling, 1973). Ecological resilience is the ability of an ecosystem to absorb change, survive and return to normal. Also called environmental strength, an ecosystem can maintain its normal patterns of nutrient cycle and biomass production after suffering damage from an environmental disturbance. The ecosystem is quick to resilience if it is indeed characterized by the ability to reproduce abundantly within a short period and respond to damages by resisting it and recovering quickly to compensate for the deficiency in the population.

Many authors define the term resilience as the time required for a system to return to equilibrium or steady-state following a perturbation (Mittelbach, Turner, Hall, Rettig, & Osenberg, 1995),(Neubert & Caswell, 1997). Implicit in this definition is that the system exists near a single or global equilibrium condition. Hence the measure of resilience is how far the system has moved from that equilibrium (in time) and how quickly it returns.

As stated by Holling, elasticity emphasizes conditions far from any stable state, where instability can flip a system into another system of behavior—that is, to another stability domain (Holling, 1973). In this case, resilience is measured by the magnitude of disturbance that can be absorbed before the system redefines its structure by changing the variables and processes that control behavior. This has been dubbed ecological resilience in contrast to engineering resilience (Holling, 1973),(Walker, 1981). These damages and disturbances include random events such as fires, floods, storms, and insect infestation, or events resulting from human activities such as wars, deforestation, and soil destruction for oil extraction, as well as the effect of pesticides and other chemicals, in addition to the introduction of exotic plant or animal species into a specific environment. Disturbances of high magnitude and long duration can profoundly affect an entire ecosystem. If the ecosystem crosses a certain threshold, then it cannot recover.

Often human activities have a major role in undermining the ability of the ecosystem to adapt and resist. Perhaps the most prominent of these destructive activities to ecosystems is the excessive and indiscriminate exploitation of natural resources and pollution in addition to the problem of climate change. Hence, there is an urgent need to move to an advanced stage of environmental resource management, based on the principle of human respect for ecosystems. In order to enhance its resilient ecological resilience

Resilience or environmental strength has also become central to conservation and ecosystem management practices, especially as the latter has turned its attention to the importance of ecosystem services. These services include the provision of food, fuel, and natural products (for example, benefiting from the mesquite fruits after their introduction into the ecosystem to reduce sand encroachment and desertification in eastern Sudan in making animal fodder, making charcoal, and using wood stems as building materials for houses). They also include the aesthetic pleasure that humans derive from the natural world. Although many species retain their importance within ecosystem services, much of the conservation focus has shifted from individual species to the conservation of the ecosystem, especially its ability to maintain its structure and productivity.

Predicting the onset of disturbances has become an important component of ecosystem management, such as the control of certain plant species over the ecosystem and the disappearance of plant species from the ecosystem in addition to drought and desertification resulting from climate change and negative human activities on the environment. A greater focus has appeared on identifying early warning indicators, such as climate change, change in the ecosystem, and its associated impacts such as a change in the plant sector and the accompanying economic situation. These pointers may act as aids to management.

3.8 Prosopis Juliflora

Prosopis juliflora is a thorny evergreen tree that belongs to the Leguminosae family and grows under a wide range of environmental conditions, from the hot, dry tropics to the cool, humid tropics. It is growing rapidly and has the potential to develop deep root systems, sometimes exceeding 20-25 m ((Jorn, 2007). Under favorable growing conditions, it can develop into a tree with a height of 20 m and a trunk diameter of more than 1 meter (Holmgren, 2003),(Jorn, 2007). The genus consists of 44 species of which 40 are from the Americas. Of the remaining species, *Prosopis africana* is native to Africa, while *Prosopis kodziana*, *Prosopis. fractal* and *Prosopis cineraria* are native to the Middle East and Pakistan (Burkart, 1976).

Interest in mesquite reached its peak at the end of the seventies of the twentieth century as an important plant resource that has great economic and environmental returns, especially in marginal lands that suffer from scarcity of water resources and low soil fertility that is not suitable for agricultural activity. *P. Juliflora* was introduced in Sudan as a program to combat desert creeps in the 1970s in the form of reserves and belts with the aim of combat desertification to contribute to the protection of the area from the dunes. *P. juliflora* played an important role in shaping the lifestyle of the complexes The population in areas that were affected by *P. juliflora*, due to its importance as a permanent source of animal and human food and as a reliable source of fuel, especially in drought. *P. juliflora* was the first line of defense against environmental degradation in many regions of the world, by afforesting arid areas and combating desert encroachment. However, in recent times, and as a result of the absence of administrative and popular awareness and a correct understanding of the nature of this tree, the mesquite found its way to fertile agricultural lands, lands, irrigation canals Also, and natural ecosystem and became a real threat to the future of agricultural and pastoral activity in many areas. The tree flowers year-round. The fruiting period, peaks from December to June(Babiker, 2006) Mesquite leaves are unpalatable, while pods, renowned for high sugar (16%) and protein (12%) contents, are attractive to animals(Babiker, 2006). It also has economic benefits, such as providing control in erosion, shade, fuelwood, building materials, and pods for animal and human consumption in arid and semi-arid.

Botanical description

P. juliflora is a spiny evergreen tree with a medium height between 5-6 meters but sometimes it reaches twice that height. It takes many forms in its growth depending on the environmental conditions in which it grows. There are four distinct shapes (R. E. Meyer, 1971).

1) Shrub ranging in length between 5-6 meters and grows scattered in weed areas.

2) Shrub with one straight stem, ranging in length from 7-13 meters.

3) A shrub with several stems, found in mesquite forests.

4) A shrub with several stems that looks creeping and is found over dunes.

The number of stems increases in areas with abundant water and decreases in regions with little water. The diameter of the crown ranges from 4-to 6 meters (Ballal Siddig & El Houri Ahmed, 1986),(El Amin, 1988).

The branches are long, drooping, sometimes stalk-length. The leaf is compound, dark green to pale green, and has about 44-52 leaflets. At the base of each leaf, there are two thick forks of 1.5-5 cm in length (R. E. Meyer, 1971). Although the *P.juliflora* tree is hermaphrodite, all its important species were found to be self-incompatible (Simpson, 1977), which gives the *Prosopis* genus a high degree of genetic heterogeneity (Hunziker et al., 1986).

The seeds, characterized by the dormancy of the mantle, spread in the streams, and establish seed. Attracted by green foliage, goats, sheep, cows, and wildlife eat the ripe pods and release the seeds. The seeds encased in animal excreta spread to new locations over long distances. The pods are also transported by floodwater and runoff. After germination, *P. juliflora* seedlings grow vigorously. The fast-growing root system and the lack of palatability of the leaves increase the survival of the seedlings. In Sudan *P. juliflora* flower occurs between (December and June, and October and April) and the fruit production period extends for a period for 6 months, from. *P. juliflora* tree produces an average of 768.3 g of fruits per year, and in case there are 400 trees (5 x 5 m) per hectare, the annual production per hectare would be 307.2 kg. The highest annual fruit production reached 1344.8 kg/ha (Ballal Siddig & El Houri Ahmed, 1986).

Ecological features and properties for Prosopis Juliflora

P. juliflora is a very aggressive invader with the potential to outcompete and replace native vegetation and with a massive impact on water resources, nutrient cycling, successional process, and soil conservation *P. juliflora* is characterized by its tremendous ability to adapt to the environmental conditions it enters, and it tolerates drought and soil poverty. Alien trees cannot compete with them due to their fast-spreading and invasive preparation. *P. juliflora* grows in all types of soils, whether clay or sandy or between these and those. Mustafa and El Houri (1986) found that *P. juliflora* is characterized by ease and speed of growth directly from the seeds. The roots grow first and at an amazing speed, reaching about 27 cm in 14 weeks in muddy soil. In sandy areas with deep surface waters, the roots reach about 20 meters in length, so the tree remains green throughout the year. *P. juliflora* does not grow in flooded areas but tolerates seasonal floods and floods help to speed up reproduction (Mustafa & El Houri Ahmed, 1986).

Additionally, young *P. juliflora* seedlings are unattractive to the animal because they have unpalatable green leaves and sharp spines. *P. juliflora* also has a great ability to spread naturally in use and unused lands, because its seeds are spread in several ways, including ruminants (camels, goats, sheep, and cows). Prosopis trees can rapidly form dense thorny thickets that reduce biodiversity and block irrigation channels, obstruct roads, and block smaller trails completely affecting access to pasture, croplands, water sources, and fishing areas (Weber, 2017).

Positive impacts of P. juliflora on the environment

P. juliflora is a multi-purpose tree used as fuelwood, poles, sawn timber, and forage capsules. There are many other tree products including chemical extracts from wood or pods, honey from flowers, medicines from different plant parts, transpiration gums, fibers, tannins, and leaf compost.

The tree is also widely grown for soil preservation, in hedgerows, and as an urban and public comfort tree. (N. Pasiecznik, 1999). Its benefits are summarized in:

First, the environmental protection: One of the most important benefits of mesquite, for which it was introduced to Sudan and many other regions of the world, is its ability to stabilize dunes and afforestation of arid areas, and as a windbreak and combating desert encroachment. Mesquite has some characteristics that qualify it to play this role, such as its tolerance to drought, as well as the advantage of producing abundant, durable, and deep roots in a short time.

Second, the chemical and physical properties of the soil: Prosopis juliflora improves the chemical and physical properties of the soil (Ibrahim, Dutton, Powell, & Ridley, 1992). As a species of the legume family, it helps improve soil fertility in the ground beneath it by fixing atmospheric nitrogen through a symbiotic life.

Third, fuelwood and charcoal: Mesquite is characterized by an abundant production of firewood compared to other trees used for the same purpose, such as *Acacia nilotica*, Moringa oleifera, and *Acacia seyal*. A four-year mesquite acre produces about 16 cubic meters of firewood (El Amin, 1988). The sale of Prosopis juliflora wood and charcoal is an important source of income for the residents. Records of commercial production of charcoal and firewood in 1996/1997 from the Gash and Atbara rivers were 600,000 bags and 135,000 m3, respectively (Elsidig et al., 1998).

Fourth, the furniture industry: One of the uses of mesquite wood is that it is also used in the manufacture of wooden furniture because of its specifications and advantages that are rarely available in well-known wood in terms of durability, color, and soft texture, and ability. To resist climate changes, the shrinkage factor was found to be 4.7 compared to 13.6 and 15.8 for pecan and white oak, respectively, It is also known to be resistant to insects and wood rot microbes (Weldon, 1986).

Fifthly it also providing animal feed from dry fruits: *P. juliflora* fruit is produced in abundance and is unpalatable to all kinds of animals, as mentioned previously. The *P. juliflora* flowers are an important source of nectar, which turns into honey.

Sixth Food and pharmaceutical industries: Mesquite fruit can be used in some food industries such as flour, tahini, oils, and jams, as well as chemicals used in medicinal, aromatic, and tanning preparations. Tree bark is also used as a local medicine to treat crises, jaundice, skin diseases, rheumatism, and scorpion stings (Arya, Tomar, & Toky, 1994).

Negative impacts of P. juliflora on the environment

P. juliflora has created a problem on agricultural land, with some problems related to its effect on groundwater, due to it is growing rapidly and has the potential to develop root systems, sometimes exceeding 20-25m, and it causes groundwater to deplete. in addition to that, it has conquered millions of hectares in agricultural and pastoral areas in South Africa, East Africa, Australia, and the coast of Asia (N. Pasiecznik, 1999). The problem lies in its ability to outcompete local species, it has fast growth rates, and it covers large areas of land. Due to the ease of spreading seeds, it has long and flexible roots to penetrate the soil.

The dense forests of *P. juliflora* impede the movement of shepherds and livestock because of the thorns of the trees, which sometimes is difficult to eradicate these thorns. The dense forests of *P. juliflora* will be a comfortable shelter for groups of predators, such as hyenas, foxes, and Snakes that kill both livestock and humans.

Shiferaw (2004) mentions that the herders in the Afar region believe that livestock dung was the main factor in the spread of P. juliflora seed. Moreover, the animals that contributed to the spread are largely, and include cattle, goats, camels, donkeys, and sheep., The number of seeds extracted from 1 kg of litter ranged (goats, camels, and cows) ranged from 760 (goats) to 2833 (cattle). Moreover, cattle that travel about 15 km/day, as in many nomadic areas, will spread seeds of P. juliflora more than 100 km/week. infestation of Prosopis juliflora. Also, directly responsible for modifications in resource use and sponsor mobility patterns. (Shiferaw, Teketay, Nemomissa, & Assefa, 2004). infestation of Prosopis juliflora. Also, directly responsible for modifications in resource use and sponsor mobility patterns. As a result of the great loss of fertile agricultural lands and pastoral lands. *P. juliflora* has negative effects on livestock health. Cattle are often injured by Prosopis juliflora. spines. Animals also have dental problems when they are fed pods for long periods. These animals become emaciated and eventually die. The Result for Nakano (2001) indicates that the high sugar content in the seeds causes tooth decay in goats and inhibits the activity of bacterial cellulose in the rumen, which in turn leads to the formation of a compressed ball in the stomach and abdominal distension, which leads to the death of animals. (Nakano et al., 2001)

3.9 Remote sensing

Remote Sensing (RS) and Geographic Information systems (GIS) aid in identifying areas of land degradation with significant spatial information(Cheung, Walker, Myint, & Dorn, 2021). The ability of remote-sensing technology to get an overview of a large area makes it a powerful tool for studying the dynamics on the earth's surface (Higginbottom & Symeonakis, 2014). Remote sensing is a broad concept. One definition is “the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation” (Denniss, 1995).

Remote sensing refers to the collection of techniques that apply photographs and images, taken from air or from space to study features and monitor natural and man-based processes that take, place on the earth’s surface. Satellite imagery can cover large and inaccessible areas and can provide a repeatable collection of long-term land degradation indicators (Mohapatra, Pani, & Sharma, 2014). RS spectral indices show long-term features of the relationship between changes in vegetation dynamics and land use/land cover change (LULC) and provide valuable information for understanding land degradation processes(Shalaby & Tateishi, 2007),(Matin, Ghosh, & Behera, 2019). A permanent land-use change can only occur if the vegetation itself is severely degraded or the soil becomes infertile. A continued change could further influence regional climates and intensify ongoing land degradation (Lambin, Geist, & Lepers, 2003).

As the technology and its uses have developed, there has been a parallel shift in the platform, from balloons to airplanes, to today’s satellite. The first civilian satellite-carrying radiometric sensors, later known as the Landsat-1 satellite, was launched in 1972. Over the last twenty years, remote sensing has become increasingly important in the study of vegetation changes due to the increased spatial resolution of new sensors. Due to the availability of low-cost Advanced Very High-Resolution Radiometer (AVHRR)Images and the increasing availability of powerful computers, several change detection procedures have been described by giving priority to achieving accuracy in the radiometric registration of multitemporal imagery (Kwarteng & Chavez Jr, 1998). The combination of available sensors also remains an excellent opportunity for improvement, for instance, Sentinel-2 A+B has limitations in estimating evapotranspiration and water stress due to its lack of any thermal bands, and as such data fusion with other complementary sensors may generate opportunities to coordinate data with available thermal bands such as NASA's MODIS or Landsat-8 (Mokhtari et al., 2019). The ESA openly and freely provides Sentinel-2 with an improved number of multispectral bands, a more frequent revisit times, and a higher spatial resolution that should be of great interest to the agricultural community and international agricultural development researchers worldwide (Segarra, Buchaillot, Araus, & Kefauver, 2020).

Four types of resolution are checked; Spatial, temporal, Radiometric, and spectral resolution through the characteristics of the satellites most commonly used for dryland monitoring. Spatial resolution, or pixel size, is determined by the instantaneous field-of-view profile and sensor height (Lillesand, 2008). Thus, a pixel is the smallest element in an image, and any features smaller than this element are visually indistinguishable from its surroundings. The temporal resolution is determined by the type of satellite orbit, and the spectral resolution is determined by the number and width of the selected bands/channels (Lillesand, 2008).

Researchers have used many remote-sensing-derived indicators for different sensors to characterize land degradation (Vlek, Le, & Tamene, 2008) NDVI is one of the most connected long-term trends of the Normalized Difference Vegetation Index (NDVI). Indices composed of red and infrared reflectance are strongly correlated with the photosynthetically active biomass, chlorophyll abundance, and energy absorption (Compton J Tucker et al., 2005).

NDVI time series have been used to monitor changes in vegetation cover over decades. Vegetation cover is an important indicator for assessing the extent of vegetation restoration in degraded sandy grasslands (Zhang et al., 2004). NDVI (Normalized Variation Vegetation Index) is the most widely applied vegetation cover indicator due to its sensitivity to the presence, density, and condition of vegetation. NDVI serves as a means of monitoring changes in vegetation cover over time. The Standard Variation Vegetation Index (NDVI) is commonly used to map Spatio-temporal variation in vegetation (Compton J. Tucker, 1979). The time series can build a precise and objective historical perspective on the vegetation dynamics of terrestrial ecosystems with lower costs Remote sensing in a dryland ecosystem(Bai, Dent, Olsson, & Schaepman, 2008), NDVI time series use as a surrogate measure to reflect the status of global land degradation during the period and to further assist policymakers in understanding the entire biogeochemical processes indicated by terrestrial ecosystem bio- productivity (Li, Yang, & Zhang, 2021).

Remote sensing in dry land

Drylands are characterized by scarcity of water. Drylands are areas where precipitation is unbalanced by surface evaporation and plants' transpiration. Dryland CO_2 uptake is closely related to variation in both precipitation and air temperature, such that drought events have been linked to decreased ecosystem function and increases in plant mortality, highlighting the acute vulnerability of these ecosystems to drought (Bestelmeyer et al., 2015),(Scott, Biederman, Hamerlynck, & Barron-Gafford, 2015).

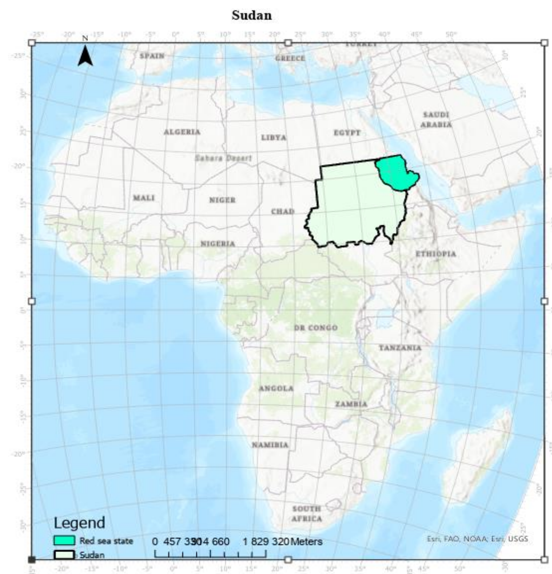
Remote sensing provides spectral data from satellites without any physical contact with the object digitally, and this digital data is converted into a visible image. It is also the best reliable source of land surface data in various contexts such as topography, biodiversity, cultural aspects of land use, etc. Remote sensing of drylands has been hampered by unique challenges, such as low signal-to-noise rates for plants, high soil background inversion, presence of photosynthetic soils, and heterogeneity High spatial from plot to regional scales, irregular growing seasons due to unpredictable monsoons, and frequent droughts (Haughton, Abramowitz, De Kauwe, & Pitman, 2018),(Zhou, Boutton, Wu, & Yang, 2017).

New and emerging developments in remote sensing hold great promise for overcoming previous challenges of dryland remote sensing through the availability of new sensors and technologies, including space-borne solar-induced chlorophyll fluorescence (SIF) and thermal infrared (TIR) sensors capable of unprecedented frequency for spatiotemporal monitoring, exciting new insights into the physiological function of plants, with opportunities to dramatically improve remote sensing- Estimates based on (GPP) This dataset provides global monthly average gross primary productivity (GPP; g carbon/m2/d). Production is determined by first computing a daily net photosynthesis value which is then composited over an 8-day interval of observations for a year. The product is a cumulative composite of GPP values based on the radiation use efficiency concept that may be used as inputs to data models for calculating terrestrial energy, carbon, water cycle processes, and biogeochemistry of vegetation (Wu et al., 2022), and (ET) the surface evapotranspiration product is the first 1 km spatial resolution ET data set for global vegetated regions at an 8-day interval The actual ET is estimated by using the canopy conductance for water vapor and CO2 exchange to scale between maximum and minimum ET under given forcing In drylands and beyond. Overcoming the limitations of current remote sensing techniques is of critical importance to constraining dryland carbon projections and water flows (William K Smith et al., 2019). Dryland ecosystems remain an area of relatively limited knowledge of Structural and functional dynamics at relatively fine spatiotemporal scales and their close association with sporadic and unpredictable water availability. and underrepresentation by long-term continuous field measurements fabricated into larger, more accessible networks (Biederman et al., 2017),(Smith et al., 2018).

Chapter Three

Study Area

This section describes the study area, it includes a general description of Red Sea State and the area of data collection in terms of field locations, population, climate, water drainage soil, and vegetation cover, in addition to the characterization of the area, which was selected for the study.



2.1 Red Sea State location

The Red Sea area falls roughly between 16° and 22° N and 34° and 36° E, the state covers about 219,000 square kilometers in the extreme northeastern part of Sudan it has a distinguished location among the states of Sudan, as it is located on the Red Sea coast with a length of 740 km. its proximity to the Red Sea as well as its special climatic conditions are completely different from the rest of Sudan. ((El Tom, 1991). The State is bounded in the west, by the Atmur Desert, the southern boundaries fringe Kassala State and the international borders with Eritrea while the northern limits fall along the borders with Egypt.

The State may broadly be divided up into four main subsystems:

1) The coastal plain: a narrow strip between 20-40 Km. wide that includes the salt marsh and a semi-desert plain east of the Red Sea Hills.
2) The Red Sea Hills: the undulating highland that lies parallel to the coastal plain and runs obliquely in a north-south axis between the Egyptian borders and the Eritrean frontier.
3) Semi-desert plain: constitute rain-shadow plains west of the hills.
4) Desert: The barren expanses that occupy the north-western part of the State, adjoining the (Amur Desert).

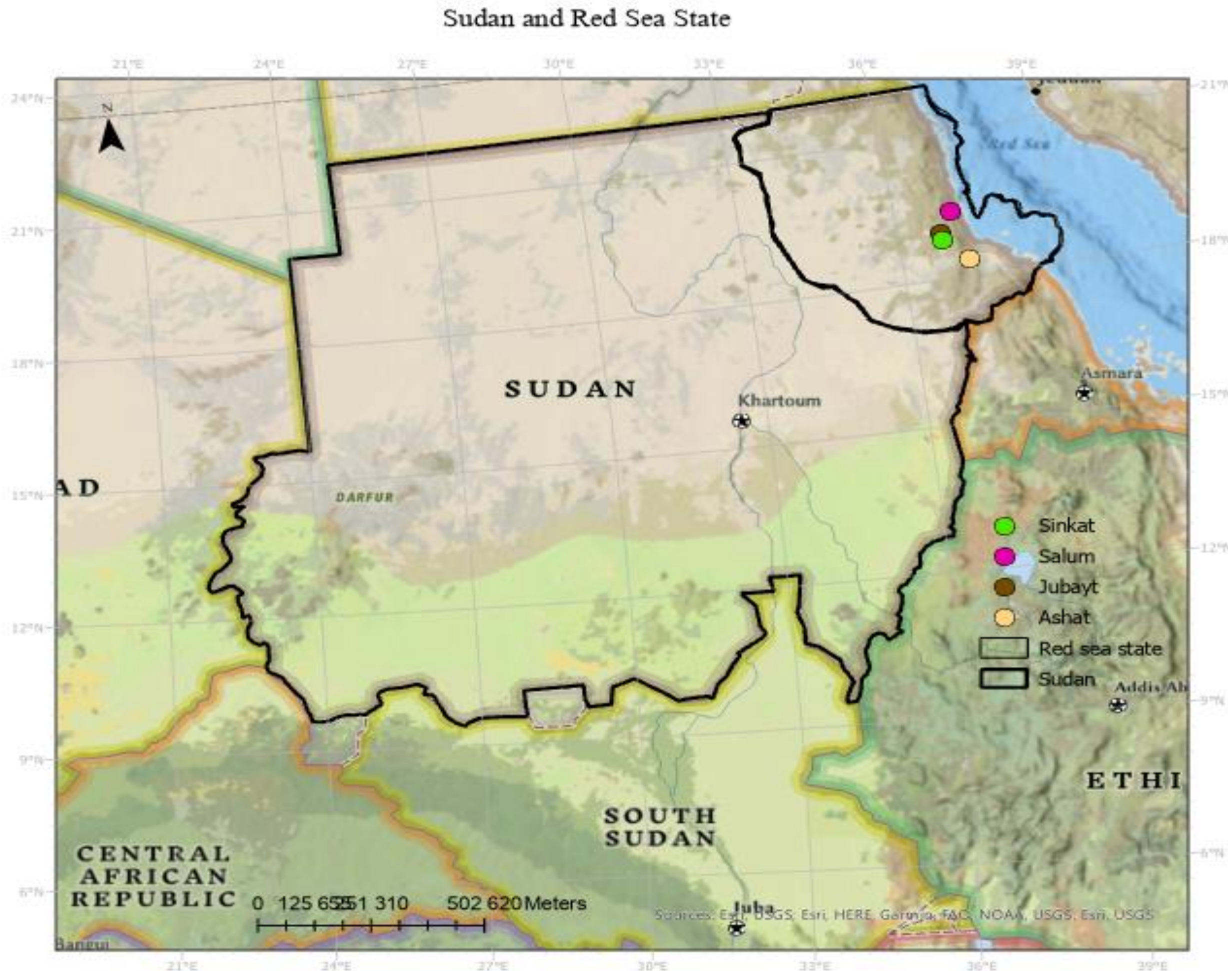


Figure (1): Map of Sudan and the Red Sea state and

2.2 Climate

The Red Sea state is a typical arid region environment characterized by higher temperature, low rainfall, high humidity, and evaporation rates. In summer and winter temperatures range between 30–47 and 20–27 °C, respectively.

The geographical location and the presence of the Red Sea as a large and somewhat adjacent water body has the Red Sea Hills as an effective physical barrier that has a clear impact on the climate of the region. Red Sea Hills (RSH) represent a climatic border; the western part of the hills receives summer rains. While the coastal area receives winter rains (November to January), caused by the NE wind passing over the Red Sea.

Humidity ranges between (42 and 76%). The wind direction at the coast is almost northerly and north-easterly throughout the year (AREA, 2008). The state has an arid climate in the northern parts and a semi-arid climate in the southern parts (Huq, Reid, & Murray, 2006). The Red Sea is directly influenced by the relatively low-pressure system in winter and the southeast monsoon in summer. The wind direction on the Sudanese Coast is almost northerly and northeasterly throughout the year. The northeastern trade winds blow during winter (November – March)) the northwestern winds (at a relatively much lower speed), locally known as "Harbor " prevail during the summer months (June – August) (Morcos, 1970).

2.3 precipitation

The precipitation, in general, is not only very limited, but also has a high coefficient of variation, and the thermal and spatial variation in precipitation is characteristic of the climate in the RSH, the annual precipitation is less than 100-200 mm (El-Tom, 1975). There are two rainy seasons in the Red Sea hills, summer rains in July-August and winter rain in October-January.

In Figure (3), the trend of rainfall in the period from 1981to 2021, there is a clear fluctuation in the percentage of precipitation, as the rainfall decreased in the period between (1981-1985), where the percentage of precipitation was recorded between (120-35 mm) in each of Sinkat, Salum and Ashat, then the percentage of precipitation increased in 1985 and reached the highest percentage of 135 mm. It decreased again until 1992 the percentage of precipitation increased, and the highest percentage reached 110 mm. Thus, there was a clear fluctuation in the percentage of precipitation in the years 1995, 2000, 2005, 2010, and 2015 where the percentage of precipitation was in Sinkat (50-120) Ashat (70-140), and Salum (50-100). In Erkweit (150-200 mm) because it is an elevated area with a climate similar to that of mountainous areas.

The RSH main water drainage system toward running in the direction of the Nile and the other runs to the red sea. The mountainous nature of the topography and the basement complex formation of the basic rocks in the region make surface runoff an important source of water in the Red Sea region, both for agriculture and for recharge of surface wells. The rocky nature of the soil, the steep slope, the nature of the precipitation in the region, and the weak vegetation cover, all contribute to the high rates of runoff in the Red Sea region. The most important khors are Odrus, Arb'at, Gowb, and Khor Arab.

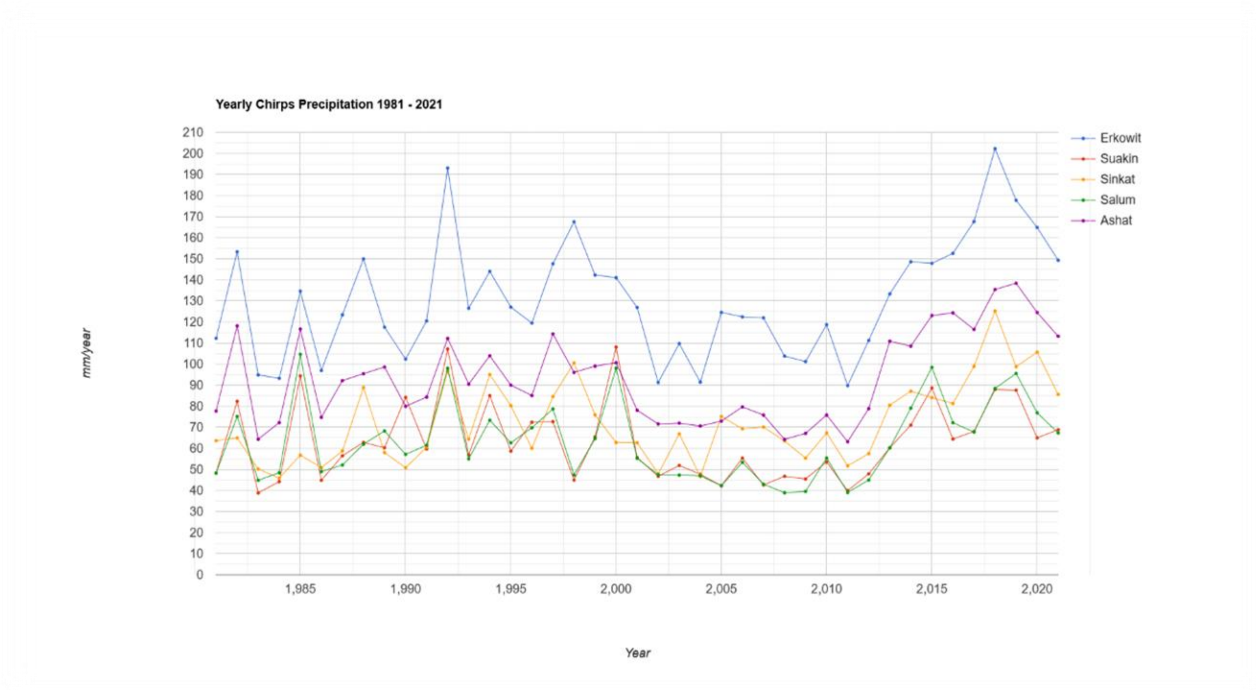


Figure 2: Yearly chirps' precipitation 1981-2020

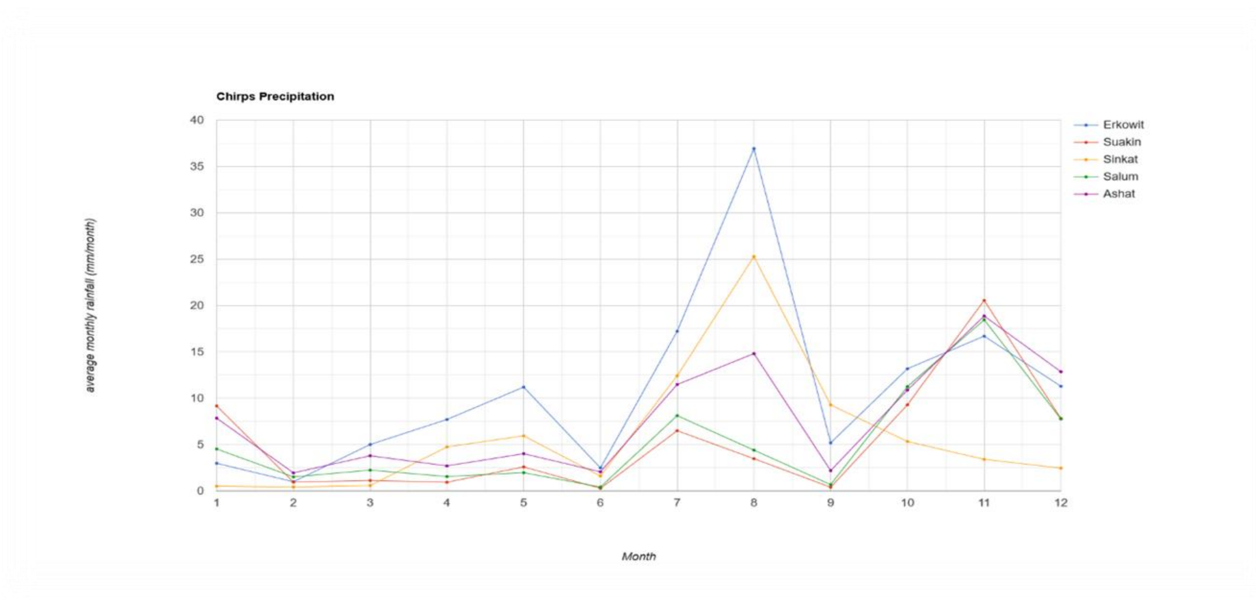


Figure 3: monthly chirps' precipitation

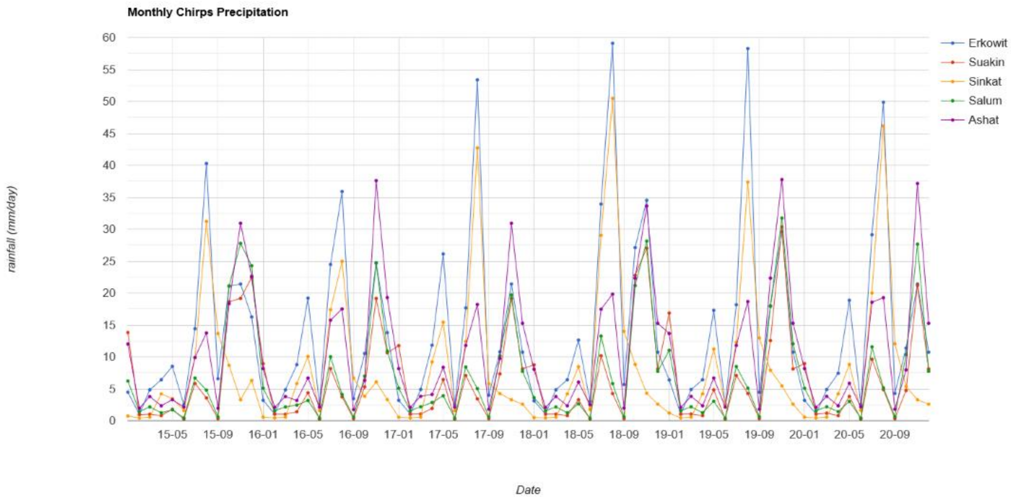


Figure 4: monthly chirps' precipitation

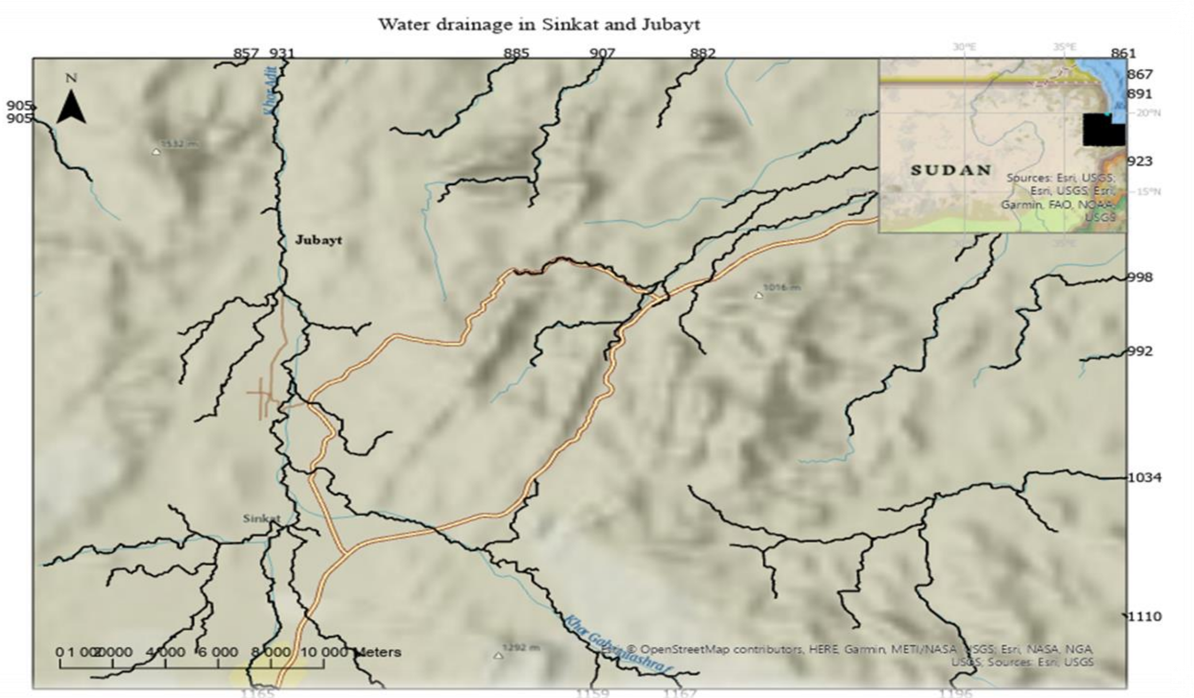


Figure 5: Mapp of water drainage in Sinkat and Jubayt

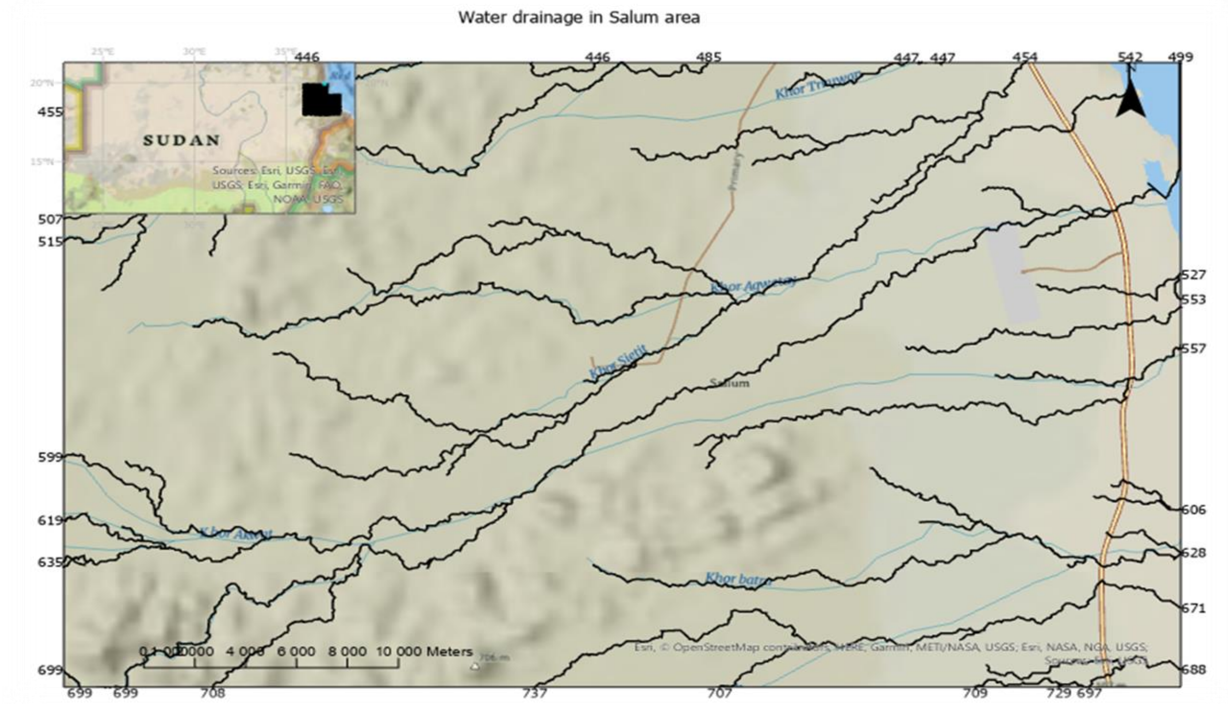


Figure 6: Mapp of water drainage in Salum

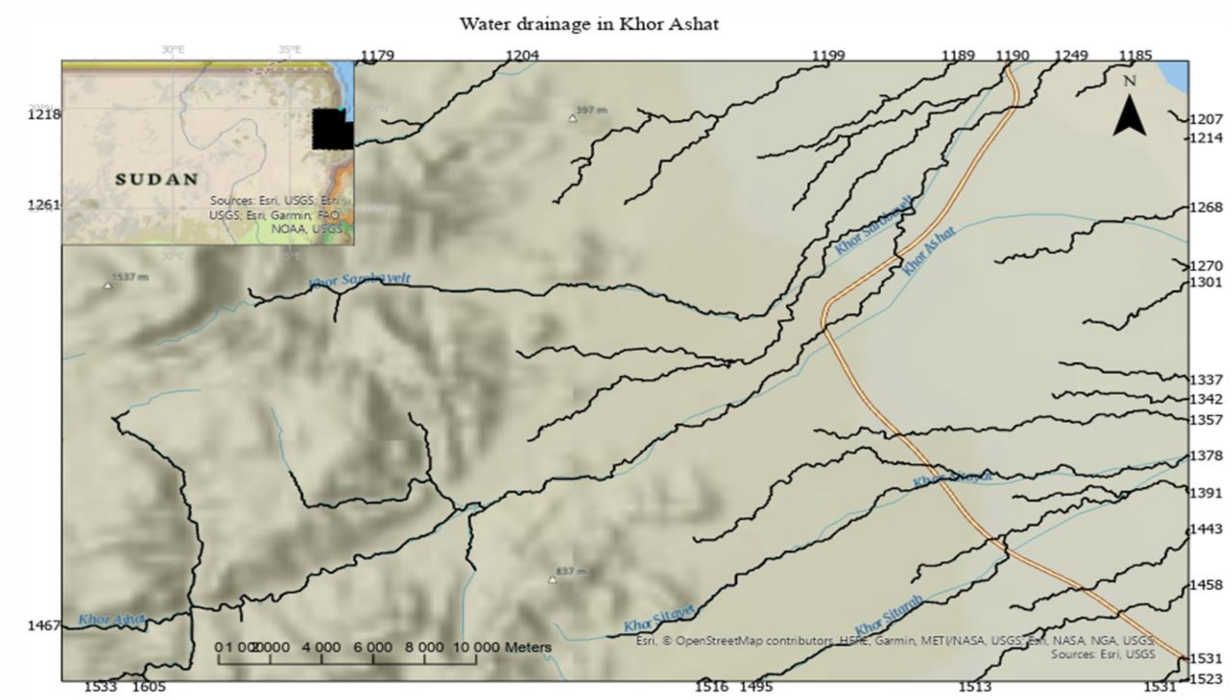


Figure 7: Mapp of water drainage in Ashat

2.4 Soils

The main soils in the area are soils found on the saline coasts, Rocky hills top, sandy soil is found in the coastal plains, and alluvial soil (Manger, 1996). These soils differ in their chemical composition due to the difference in climatic conditions, topography, and chemical and mechanical effects of temperature, water, and wind erosion.

1) Soils found on the saline coasts: It is found in salt marshes on the coast. These soils are affected by water washing in winter and sand-dune accumulation in summer. The salinity decreases with distance from the shoreline. Natural vegetation in these soils consists mainly of halophytes and salt-tolerant species grazable by goats and camels. Agricultural production in the area is very localized.

2) The rocky hill top soils: It is found on the tops of hills and slopes, and it consists of large, rugged, and broken rocks. The steep hill slopes generally contain shallow sandy and gravelly soils. In the eastern part, the soils are deep due to the accumulation of fine sands blown by the wind in the valleys and pockets amongst the hills. these areas are unsuitable for agricultural practices. and it supports poor natural vegetation, hence unsuitable for proper or intensive grazing (Bonnet & Ati, 1994).

3) Sandy soil is found in the coastal plains, but it prevails in the western plain. They vary in depth and particle size and increase in depth from the hillside to the west as dunes spread. This soil is characterized by its low fertility and is not suitable for cultivation. The natural vegetation cover is little, and the grazing capacity is relatively low.

4) Alluvial soil: It is found in the creek and basins of wadis and deltas, which are mainly composed of fine silt and sandy sediments washed by the water from the hills. The depth of this soil varies depending on the local terrain and the volume of drainage. This is the only fertile soil that is provided by seasonally rich organic matter (Manger, 1996).

2.5 Vegetation cover

Sudan is a country with a highly diverse vegetation cover and ecological zones where the rainfall varies from zero in the northern desert to more than 1,200 mm in the High Rainfall Woodland Savannah in the southwestern portion of the country. Five distinct ecological zones represent biomes with different ecological conditions and different vegetation cover, desert, semi-desert, woodland Savanah, flood region, and montane vegetation. Sudan's forests cover is about 10.3%

of its total land surface, with an estimated annual rate of deforestation of about 174,400 ha, or about 0.8% (FAO, 2015).

There are three different forms of vegetation cover in the study area, from which we can distinguish the change in vegetation cover in the Red Sea region. The vegetation is characterized by different survival strategies related to the rate of precipitation and land- use system. Types of vegetation cover in the area:

1) Ephemerals and annuals, i.e., herbs that appear at irregular intervals. When the surface moisture after rain is sufficient for germination, flowering and seed production occurs in a very short time (Krzywinski, 1996).

2) Perennial weeds and herbs that germinate when soil moisture is available and sufficient but could continue growing for more than one season, even in the dry season, the roots of this perennial weed grow so deep that they can reappear quickly with rain (Krzywinski, 1996).

3) Long-lived trees and shrubs that can survive as green biomass during successive droughts. The long roots provide sufficient water from underground resources during dry seasons and droughts. Since their speed of regeneration is slower than that of weeds, prolonged drought may prevent regeneration. These plant species are affected by different human activities and are therefore susceptible to various aspects of degradation.

The degradation is long-term and biomass loss occurs when perennial trees and shrubs are lost or removed. Short-term deterioration is controlled by the length of the drought period (*Balanites aegyptiaca, Capparis decidua, Salvadora persica, Acacia tortillis, and Prosopis chilliness).*

2.6 Population

The total population of the Red Sea Governorate is estimated at 1396110 people, according to the census (2008). The population can be categorized into rural and urban population types. The rural population can be either settlers or Bedouins and is made up of four main ethnic groups: the Beja, the Beni Amer, the Rashida, and other minor groups. The urban population is largely derived from the above groups mixed with small groups from outside the region (Oxfam & Ireland, 1990). The Beja represented the largest ethnic group in the region. They are descended from a mixture of Kushite and Arab ancestors. The Beja's group is divided by the segmented lineage model into three main subgroups or tribes: Hadendowa, Bisharin, and Atman. Each of these tribes is divided into extreme dynasties or divisions (Adats). Habits consist of small breed parts (diwabs) that make up individual families. While the Hadendowa group, the largest of the Beja subgroups, occupies most of the southern part of the region, the Bisharin is an inhabitant of the northern and northwestern parts. The Atmans occupy the area between Bisharin and Hadendowa and make up the dominant population in the rural area of Port Sudan. They are described as an offshoot of a much smaller subgroup of the Beja, the Amarar. Bani Amer is resident of South Tokar. Two-thirds of this group is registered in Eritrea. Rashaida are a Bedouin group that migrated from the north of the Arabian Peninsula during the nineteenth century. In addition to other secondary groups (Humadab, Ashraf, Kuleit).

Other ethnic groups consist mostly of West Africans (Falata) who are considered descendants of the pilgrims who passed through Sudan to Mecca in the 19th century. The urban centers are home to other groups of Sudanese and non-Sudanese. The northern Sudanese, as well as the Yemenis and Indians, dominate the better-off sector of administration and trade. Port Sudan also supports large numbers of Nuba, South Sudanese, Ethiopian and Eritrean refugees.

Historically the Beja are nomadic pastoralists, and they are by long traditions and heritage strongly attached to their homeland. They depend mainly upon their animals, and milk is the major source of their diet. They sell part of their animals to buy the small grain requirements that they normally do not grow themselves (Harrison & Jackson, 1958). During and immediately after the rainy months, they move in all directions for better animal feed. Their movement did not exceed a camel grazing range due to lack of water, and they are forced back into the badly overgrazed areas around the permanent water sources. The main animals possessed by the people are camels, followed by goats and sheep. The more water-demanding cattle are rare in the region and confined to Tokar Delta and Rural Port Sudan (around Khor Arbaat).

The recent drought of 1979 which culminated in periods of drought and famine in the region (1979-1985) radically changed the way of life of the population and the Beja in particular, mainly because the loss of animals did not leave behind enough herds. Support rural settlers or nomads. As part of survival strategies in the new extremely harsh environment (Harrison & Jackson, 1958).

Political marginalization and the lack of justice in the distribution of development led to the absence of health services and education, forcing the Beja to migrate to the city of Port Sudan, the center of the state, and leave the rural areas. The drought and the invasion of mesquite also contributed significantly to the drop in the water level if it was not easy to obtain water significantly in parts of the state, especially rural areas, and this is considered one of the main factors that contributed to pushing people out of their rural areas and abandoning them towards urban centers in the Red Sea state and all parts of Sudan (Pantuliano, 2006).

Although services are more available in the city, people complain about the fact that very few can afford to pay school fees, water, or medicine. Unemployment rates rose sharply as a result of the mechanization of the port in Port Sudan and the layoffs of many port workers, especially Beja workers who were left with very few alternatives in the market (Pantuliano, 2006). Many people live by resorting to the coal industry, especially from mesquite which is said to be a very good source of coal.

2.7 Grazing in Red Sea State

Grazing is practiced in the study area on a traditional and regional basis. Socially and customarily defined access and use rights restrict the movement of herders, which is centered around areas of the home and extends to remote and defined areas. Traditions governing usage rights are transmitted orally and by example and are practiced within the family and tribal circles (G. L. Andersen et al., 2014). The pastoral system is formed of two categories: the rural herding of animals and the recently evolved urban livestock production. In the rural herding system transhumant agro-pastoralism is also practiced in the region. In this system, the families cultivate some land and raise livestock. Some members of the household remain in their settlement areas with the milking herds, while others go off herding with the dry animals (Oxfam & Ireland, 1990), and they move with their animals on a seasonal basis long or short distances from one grazing area to another. The Rashida group moved between the Butana Plain, Western Gash, the Tokar Delta, and the coast. Hadendowa move between the south and south-western parts and the coast while the Bisharin move northwards towards Egypt and northwest to the coast. The Beni Amer movement is mainly from the southern coasts to Eritrea. The last pastoral system is the sedentary agro-pastoralism in which the livestock owner is living commonly around towns and major agricultural areas. This system is mostly restricted to the southern part of the region and is practiced by the Fellata and small groups of the Rashida, Beni Amer, and Hadendowa. The urban livestock agro-pastoral system is also practiced in the private farms around Port Sudan and Sinkat.

Pastoralists adapt to the climatic fluctuations of drylands in arid and severely arid region, and pastoralists respond to changes in the vegetation. Grasses are a valuable forage resource but are limited in time and space. On the other hand, trees are long-lived, drought-persistent, and green most of the year, thus constituting a vital resource, often aptly referred to as “multi-purpose trees” (G. Andersen, 2012). Misuse of natural resources such as overgrazing, cutting of timber biomass, frequent burning of vegetation, and expansion of rain-fed agriculture on marginal lands are among the main factors of rangeland degradation and desertification (Abu-Suwar & Darrag, 2004). Replacing original plants with food crops in fragile lands, the residential expansion inside the pastoral lands, and the accompanying human activities that negatively affect the pastures, poor land degradation, and desertification are defined as general destruction of the biological ability of the land, which ultimately leads to a desert-like state(Abd El Magid, 2007).

2.8 field locations

Fig8: Topography of Sinkat and Jubayt

The area of data collection included three locations where interviews were conducted with the residents:

1) **<u>Sinkat and Jubayt</u>** area is considered a city, and its population is semi-urban. surrounding of the area is deemed to be rural areas. Most of its residents depend on grazing, mixed agriculture, and other trades such as the coal industry. (From responses) In the sinkat and Jubayt region, it was dominated by (Acacia seyal, Balanitesa Egyptian, Capparis deciduas,

Salvadora persica, Tortilisvar, Acacia tortillas), and some annual plants. It is an effective area with a continental climate that rains in summer like the rest of Sudan, and sometimes light rains fall in winter due to its proximity to the coastal areas and in an elevated area with rich plant diversity. This prevailed until the mid-nineties (Audio recording from interviews conducted by Muhammad Talib).

2) **Salum** area is located 10 km west of Port Sudan in the Al-Qunob Awlieb locality. It is a flat area that has the dry port of Salum, which specializes in providing logistic services to the port of Port Sudan to reduce the length of the stay of goods in the ports. It is a small village, and its population is semi-urban. All sides of the area are considered rural areas. Most of its residents depend on pastoralism, mixed agriculture, and other trades such as making coal and selling dairy products. The area became a *P. juliflora* forest. due to the ease of movement of animals because it is flat land where animals play a major role in the spread of mesquite seeds in addition to the transport movement from Port Sudan to the port of Salum land. Due to the availability of water services in the region, the government-owned some farms for mixed cultivation, but due to the spread of mesquite, the population left farming and went to producing charcoal, as the financial return from the charcoal industry is greater than the return on agriculture and grazing. (From responses).

Topography of Salum area

Fig 9: Topography of Salum area

3) **Ashat** is a small village and is a rural area. Most of its residents depend on pastoralism, mixed agriculture, and other trades such as the coal industry, and it has a large livestock market. (From responses). Ashat is a pastoral market area located between Tokar and Suakin, the residents of the Ashat area practice the craft of seasonal agriculture near the Tokar Delta. *P. juliflora* moved from the Tokar Delta to Khor Ashat, and the area was dominated by Salvadora persica, which were used as a source of income for many families, and acacia species. The soft Salvadora persica (Arak trees) branches are used as a mouth cleanser. These branches are sold in the local market and also exported to Khartoum. Unorganized cutting of *Salvadora persica* and the spread of *P. juliflora* led to competition and the removal of the arak tree from the area. On the other hand, the residents of Ashat suffer from the depletion of groundwater, which they depend on for drinking because of the long roots of *P. juliflora* that reach deep into the underground water tanks. The pasture has become scarce, and the growth period of seasonal weeds has decreased It expires in a short period.

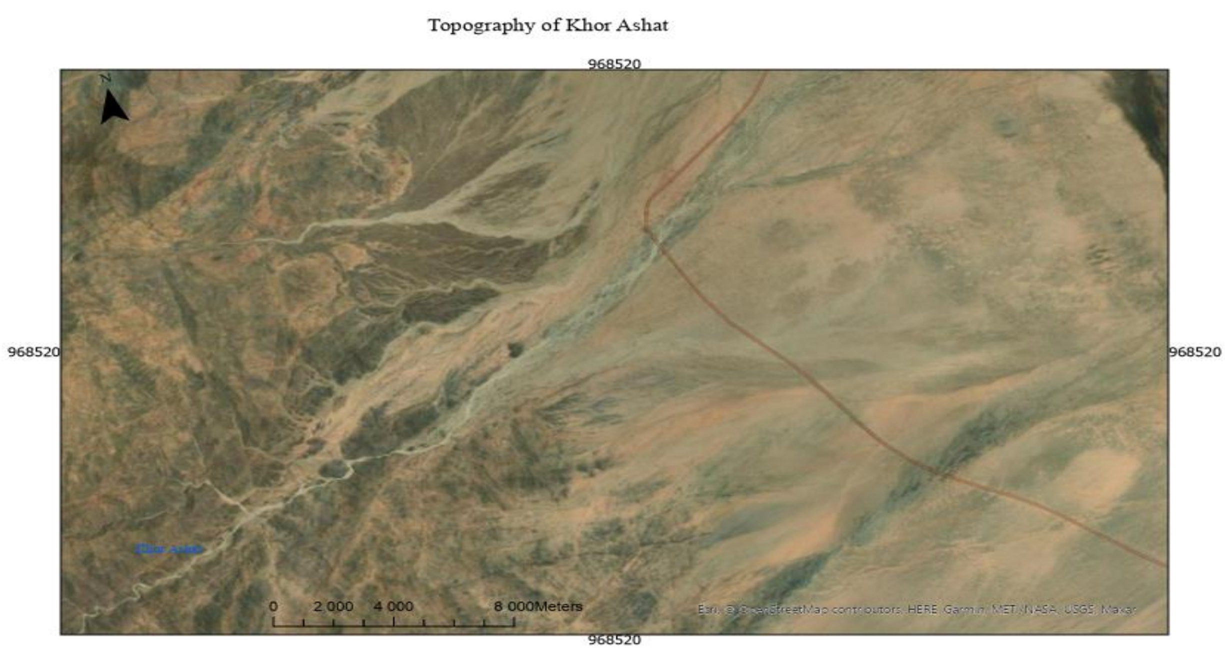


Fig 10: Topography of Khor Ashat

Figure 11: The livestock market in Ashat

Chapter Four

Materials and Methods

Satellite data selection and image Pre-Processing

4.1 Satellite data selection

Multispectral Landsat satellite data were acquired from the United States Geological Survey (USGS) for 40 years to assess patterns of LULC change in the period 1984-2020, (Table 1). The data selected to consist of thematic mapper (TM) Landsat 5 (1984,1990,1995, and 2000), Enhanced Thematic Mapper Plus (ETM+), Landsat 7 (2005 and 2010) and Operational Land Image OLI, Landsat 8 (2015 and 2020), all acquired between (April and May) representing the dry season in Sudan Google Earth was used for obtaining high spatial resolution data used to complete field data and provide an overview of a scale where trees can be id. Therefore, visual interpretation by displaying the imagery data can help in identifying the density of vegetation cover in the study area.

Table 1: Characteristics of images used in the study

	1984	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Satellite	TM	TM	TM	TM	ETM	ETM	OLI	OLI
Instrument	L_5 TM	L_5 TM	L_5 TM	L_5 TM	L_7 ETM	L_7 ETM	L_8 OLI	L_8 OLI
Date	26.04.84	11.04.90	09.04.95	22.04.2000	12.04.2005	10.04.2010	18.05.2015	13.05.2020
Path	171	171	171	171	171	171	171	171
Row	47	47	47	47	47	47	47	47
Pixel Size	30	30	30	30	30	30	30	30
Number of bands	7	7	7	7	8	8	11	11
Resolution	8 bit	8 bit	8 bit	8 bit	8 bit	8 bit	16bit	16 bit
Projection unit	Meter	Meter	Meter	Meter	Meter	Meter	Meter	Meter
Datum	WG84	WG84	WG84	WG84	WG84	WG84	WG84	WG84
UTM zone	37N	37N	37N	37N	37N	37N	37N	37N

Landsat_5:

The Landsat -5 satellite was launched in March 1984 with the sensor thematic mapper (TM). The TM has seven spectral bands: six 30-m reflective bands and one 120-m thermal band. TM bands have center wavelengths of approximately 0.49, 0.56, 0.66, 0.83, 1.67, 11.5, and 2.24 μm, respectively.

The raw and calibrated data products are quantized to 8 bits (EROS,2018). The TM sensor has been used to a great extent to establish the relationships between water quality, vegetation parameters of inland water bodies, and spectral reflections, as well as to assess and map the spatial distribution of some water quality parameters such as chlorophyll. It has been used to enable the chronicling of anthropogenic and natural change in an era when climate change has become evident (Roy et al., 2014).

Lansat_7:

The Landsat 7 ETM+ satellite sensor was launched in April 1999. Landsat 7 satellite is equipped with Enhanced Thematic Mapper Plus (ETM+) the successor of TM. Landsat 7 was designed to last for five years and can collect and transmit up to 532 images per day.

It has been used as a scan line corrector to eliminate the interline overlap or interline spacing caused by the scanning operation or orbital motion and has four color bands and one panchromatic band. (Chien et al.).

Landsat_8:

The Landsat _8 was launched in February 2013. The project is the result of a collaboration between NASA and the U.S. Geological Survey (USGS) within the Department of the Interior (Loveland & Irons, 2016). The sensor on board that Landsat 8 will use in its data collection is the Operational Land Imager or OLI which will collect imagery at a spatial resolution of 30m. OLI has 11 bands of wavelengths on the electromagnetic spectrum, and the OLI collects the light reflected from the Earth's surface from nine of these bands.

These bands on the shorter side of the wavelengths include the red bands, green bands, and visible blue. Those wavelengths on the longer side that are picked up by the OLI include the near-infrared and the shortwave infrared. (Markham, 1986).

4.2 Image Pre-Processing

A standard pretreatment process was applied to Landsat images before deriving LULC maps. This process included atmospheric correction and radiometric correction. The data was then analyzed for LULC change. Pre-processing of Landsat 8,7 and 5 images was performed in the Semi-automatic Classification Plugin (SCP) tool in Quantum GIS (ver. 3.16.12). The methodology adopted for the preparation of land use and the land cover map is described in the following sections:

In the pre-processing phase in SCP, Landsat bands were converted from **Digital Numbers (DN) to the top of Atmosphere (TOA) Reflectance** in a two-step process.

*First step, DNs were converted to radiance values using bias and gain values for the single scene.
* Second step converted the radiance to the TOA reflectance.

The SCP was also used to perform atmospheric correction using the DOS1 method (dark object subtraction 1). Landsat images were air-corrected by subtracting dark objects and thus obtaining a reflective image. This image-based procedure assumes that the darkest pixel value in each range reflects no light. Any value greater than zero is associated with atmospheric scattering and absorption. It is a relatively simple image-based method for calculating surface reflection with complete accuracy, the DOS dark-body subtraction method (Chavez, 1996). Chavez,1996 explains that “the basic assumption is that within the image some pixels are in complete shadow and their radiances received at the satellite are due to atmospheric scattering (path radiance). "This assumption is combined with the fact that very few targets on the Earth’s surface are absolute black so an assumed one-percent minimum reflectance is better than zero percent". It is an accurate, cost-effective, and easy-to-apply correction method. Thus, an image-based DOS radiometric calibration and correction method is applicable for historical data. The DOS method was effective and accurate when it is successfully applied in several Landsat studies regardless of location in cases when atmospheric measurements are unavailable (Gilmore, Saleem, & Dewan),(Yanti, Susilo, & Wicaksono, 2016), (Yepez et al., 2018).

should be mentioned here that the pixel values were compared across images for a stable/non-changing area (airstrip) and saw that values differed. Hence a further relative calibration was needed. According to (Markham & Barker, 1987) in arid regions where vegetation is low and weather conditions are stable, radiative differences between images are mostly due to sensor-induced differences and differences in ground handling (Haughton et al., 2018),(Zhou et al., 2017).

Radiometric correction calibrates the radiation or reflectance values of images acquired by optical satellite sensors. Relative radiometric correction is aimed at reducing atmospheric and other unexpected variations among multiple images by adjusting the radiometric properties of target images to match a base image (Hall, Strebel, Nickeson, & Goetz, 1991). These relative corrections allow a more accurate assessment of the characteristics of the Earth's surface and facilitate comparison between images obtained at different times.

Regression coefficients were calculated from a common area of all images in the change analysis and any clouds, and their shadows were excluded from the area to obtain the results of the necessary statistics for the final regression, i.e., means, variance, and covariance are use a line regression to find the gain offset (Rgr. Coeff).

The image of Landsat-8, 2020 was used as a reference image because it is the most recent and therefore has the highest radiometric quality. The relative radiometric correction was done through relative methods that can detect land cover changes as well as when high accuracy absolute radiometric corrections are employed (Andréfouët, Muller-Karger, Hochberg, Hu, & Carder, 2001), the relative radiometric correction was done through three models,

1) to calculate the average red band and NIR from the 2020 reference image range and the image channel to be corrected.
2) calculate the -ak and bk regression coefficients to correct for relevant ranges in all images.
3) To correct pixel value.

To normalize the dimension of the reference image the gain and offset data can be derived. The gain, ak, and offset, bk for the k th range are obtained from solving the least squares regression equation Qk. The linear least-squares regression equation and its solution for gain and offset is given in Equstion (1).

Equation 1: $Qk=\Sigma(yk-bk-akxk)\ 2 = min$

$ak = sxy/sxx$

$bk = \grave{}yk - ak\grave{}xk$

where:

y = reference image

x = subject image, i.e., the image to be corrected

sxy = covariance of x and y

sxx = variance of x

`yk = mean of the reference image

`xk = mean of the subject image

Vegetation Cover, Change Long-term trends (NDVI).

Normalized Difference Vegetation Index (NDVI) is defined as (NIR − RED)/(NIR + RED), where NIR and RED are reflectance values in the near-infrared and red wavebands, respectively (Higginbottom & Symeonakis, 2014). According to(Compton J. Tucker, 1979). Where RED and near-infrared represent respectively surface reflectance. Red is the value of visible red band and NIR is the value of the near-infrared band. Red (band 3 of Landsat TM, ETM, and band 4 of Landsat OLI) and near-infrared (band 4 of Landsat TM, ETM, and band 5 of Landsat OLI) spectrum regions.

The NDVI values are theoretically between -1 and +1, the negative valuescorresponding to surfaces other than plant covers, such as snow, water, or clouds, for which the reflectance in the red is greater than that of the near infrared. For bare soils where the reflectance is of about the same order of magnitude in the red and the near infrared, the NDVI has values close to 0. As for the flora formations, they show values of NDVI positive, generally between0.1 and 0.7 – the highest values for the densest canopies.

The NDVI is correlated with vegetation biophysical properties such as fractional cover, condition, and biomass. Plant biomass and physiological status have recently become popular in previous work in the remote sensing community. The NDVI index is used to analyze RS measurements and to assess whether the observed target contains healthy green plants by estimating the relationship between Near-infrared ratios and Red. NDVI represents the physiological activities of plants and is the most widely used vegetation index as a measure of vegetation greenness and as a proxy for ecosystem productivity(William K. Smith et al., 2019).

NDVI of all images was calculated from raster calculated, using the corrected pixel values that were gotten from radiometric correction by QGIS according to the Equation (2).

Equation 2: NDVI = (NIR – Red) / (NIR + Red).

NDVI Change (1984-2020) was calculated from raster calculated, using Equation (3).

Equation 3 = (NDVI 2020 – NDVI 1984) / (NDVI 2020 + NDVI 1984).

Time series collections provide an overview of the changes that occur over time and have proven effective in providing useful information in various fields, including environmental sciences.

(D'Urso, De Giovanni, & Massari, 2015). The change in NDVI values was shown over the entire region for the different times, by time series analysis. The process takes place in three steps.

-First step is to create the variable and dimension files.

- Second step is to create a mosaic dataset and prepare it for multidimensional construction.

- Third step is to create multidimensional information.

These steps were done in Arc GIS Pro, version 2.8.6

drainage lines DEM

The elevation data are used to build digital elevation models (DEMs) and Shuttle Radar Mission (SRTM) elevation maps with the consensus that vertical accuracy is a minimum of 16 m absolute error at 90% confidence (RMSE of 9.73 m) at the world is wide. Studies using SRTM data "as is" with no real indication of vertical uncertainties are widespread in the Earth sciences, for example in geology, geophysics, hydrological modeling, and the environment. This type of data also forms the basis for monitoring surface deformation during floods and for monitoring earthquakes and volcanoes. It is important to note that due to this high level of detail, the SRTM data is particularly used for analysis at a medium scale, i.e, less than 1:100,000, making it particularly valuable for a geography message (Śleszyński, 2012). The SRTM elevation data was used to model the drainage networks of the study areas to show the areas infested by the *P. juliflora* area. It was expanded along the bank of water drainage.

4.3. Socioeconomic Data

Data collection:

The primary data was based on a supplementary questionnaire and inventories. The inventory was based on previous sources that included satellite image data explained above this study, data were obtained through a qualitative approach, literature review, and relevant interviews. The survey uses a questionnaire covering the following categories: families of pastoralists, farmers, and artisans. Group interviews were also arranged with the participation of various community leaders.

Sampling methods:

The questionnaire was conducted by interviewing the heads of the household. Tribal chiefs, charcoal traders, pastoralists, and farmers in each village were targeted. The total sample size is 10 respondents representing different categories. From three selected study areas, namely Ashat, around Sinkat and Jybayt area, and Salum to assess vegetation cover, changes in the rate of *P. juliflora* invasion expansion, and changes that occurred in the local species in the study area. A questionnaire was prepared to evaluate the study case and obtain more accurate information to reach the objectives of the research subject.

Due to Covid19 and travel restrictions, interviews were conducted by colleagues at RSU with an interview and survey experience questionnaire divided into four sections.

Due to the small number of samples taken in the questionnaire, we had to take additional information through audio recordings of the respondents.

The questionnaire, including several questions, is found in Appendix (1). The four sections were divided to assess the case of the study and obtain more accurate information:

The first section:

Population: The objective of this section is to obtain information about the demographic structure, which contributes to making changes and adapting that were occurring in the region. In addition to the design of the construction of the houses and the materials used in their construction.

second section:

The livelihood: the objective of this section is to obtain information on the economic situation of the residents of the area, available natural resources, grazing patterns, and methods of movement of pastoral.

The third section:

Vegetation resources: The objective of this section is to obtain information regarding the vegetation cover and natural resources. the observed changes that occurred in the vegetation cover in the region during drought periods, and to obtain historical information about periods of drought. the changes of precipitation.

In addition to the livestock available in the region, and to know other crafts and other human activities.

fourth section:

Mesquite tree: The purpose of this section is to obtain information about the importance of the mesquite tree on the economic activity in the region and the benefits of the mesquite tree and its damage to the environment, population, and animals. The role of government agencies in supporting projects and helping plant control.

Obtaining additional information through audio recordings from the person who conducted the interviews with the residents of the area.

Figure 12: Interview with responded

Chapter Five

Results

5.1 Radiometric correction

Three models (cf. methods) were used to radiometrically correct the red and infrared bands in all images.

The first model calculated the mean for red bands and infrared bands using 2020 as the reference image.

In the second model, the regression coefficients, a_k, and b_k were used to correct the relevant bands in all images. The values are given in table 2.

Table 2: a_k, and b_k values for all years.

	a_k							**b_k**						
Bands / Year	1984	1990	1995	2000	2005	2010	2015	1984	1990	1995	2000	2005	2010	2015
Red	1.114	1.073	0.953	1.019	1.034	1.001	1.000	-0.039	-0.023	-0.010	-0.010	-0.090	-0.020	-0.027
NIR	1.125	1.085	0.966	1.081	1.085	1.066	1.013	-0.042	-0.012	-0.001	-0.007	-0.080	-0.022	-0.032

The third model was used to correct map and calculate radiometric correct pixel values in Figure 13: Shows, the mean and variation of pixel values in the corrected image to the reference image. As intended for the correction the values are more similar to the correction. The remaining histograms for the correction are found in Appendix (2), Fig. 13b, 13c, 13d, 13e,13f, 13g.

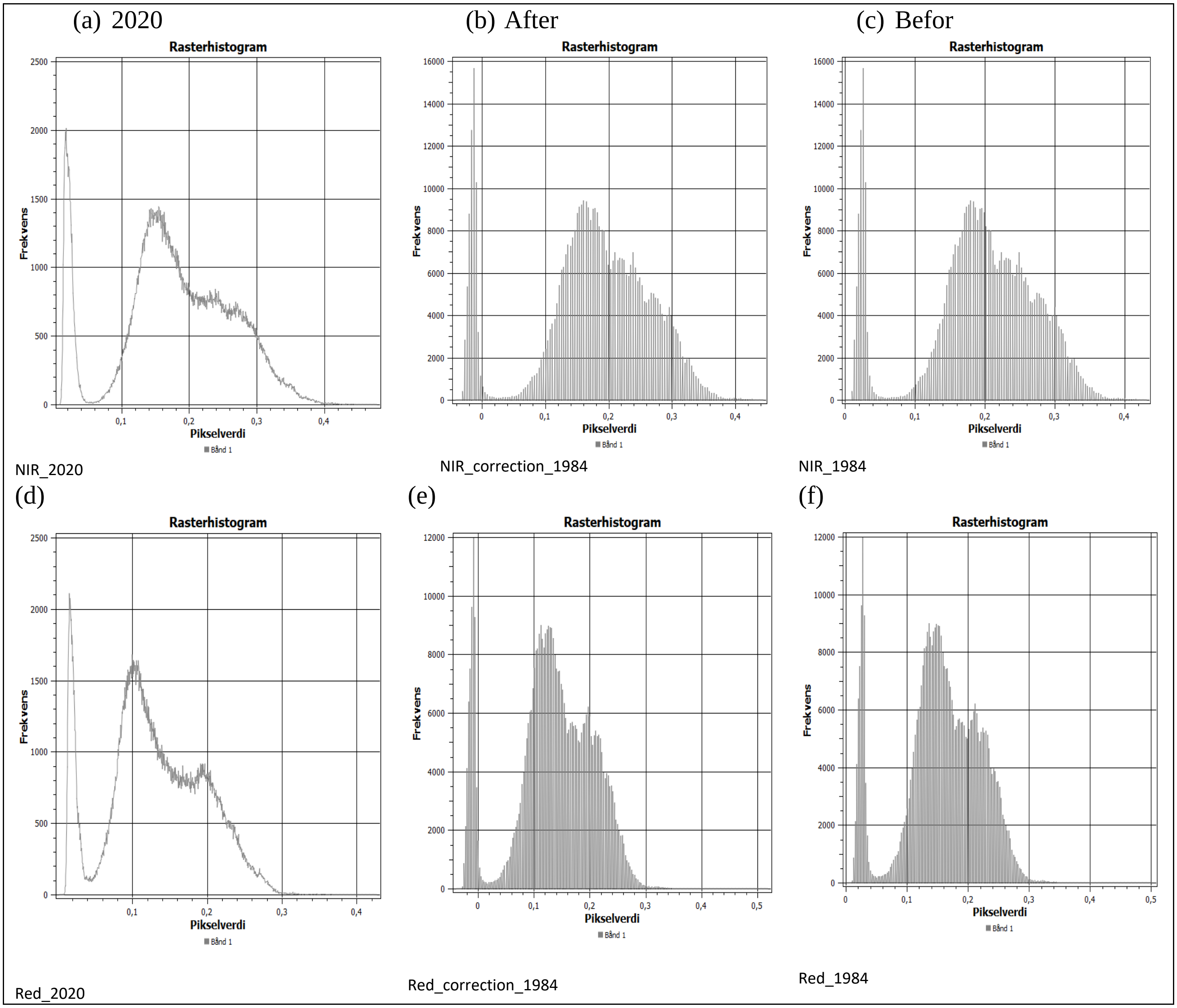


Figure 13a: Histograms for infrared (bands) upper panel (b-c) and Red upper panel (e-f) before (far right) and after (middle) correction for the corrected image (1984) compared to the reference image (left,2020).

5.2 Vegetation change

Sinkat and Jubayt

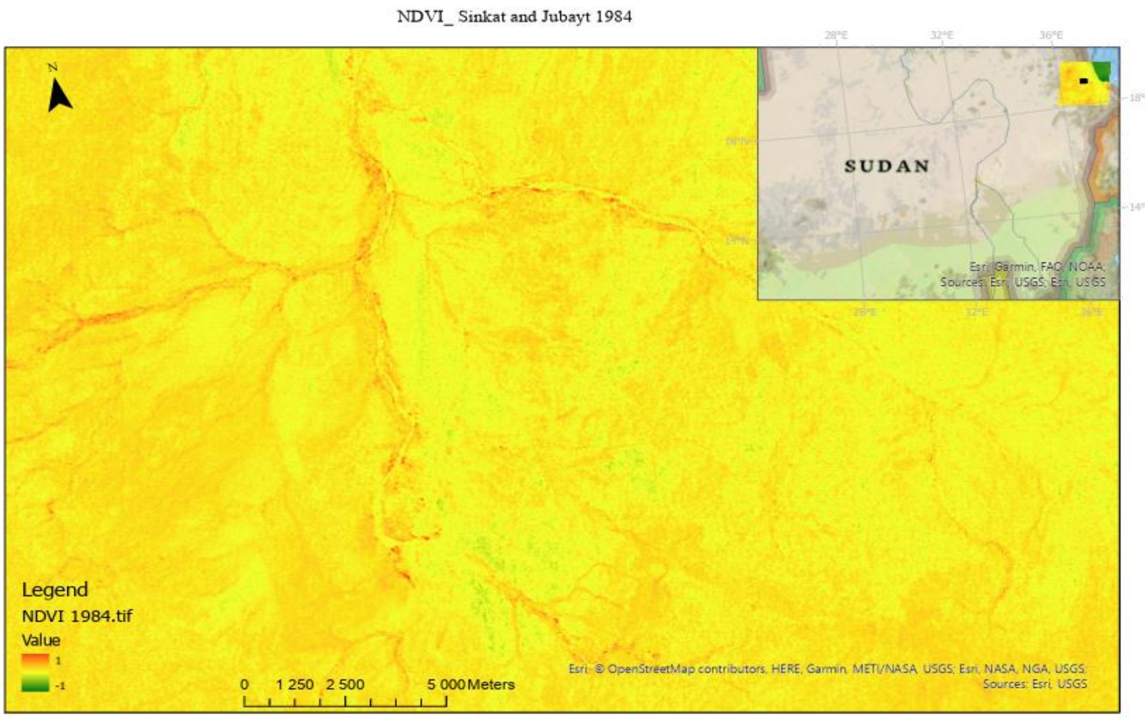
The vegetation index for 1984 shows that high values (more vegetation) are predominant in the wadies \water drainage. High positive values are in general more abundant than negative values (See Fig .14a).

NDVI-2020 shows that low values are predominant in different t parts of the region and represent negative values. the high values covered the water drainage area, it represents positive values. Maybe that is due to the expansion and spread of *P juliflora* along the draining bank where most of the annual plants disappear by the end of the autumn season. This photo was taken during the dry season (March and April) when there is little rain during this period (See Fig.14b). The maps of the remaining years (1990,1995,2000,2005,2010, and 2015) are found in Appendix (3), Fig. 14.1, 14.2,14.3,14.4,14.5, and 14.6.

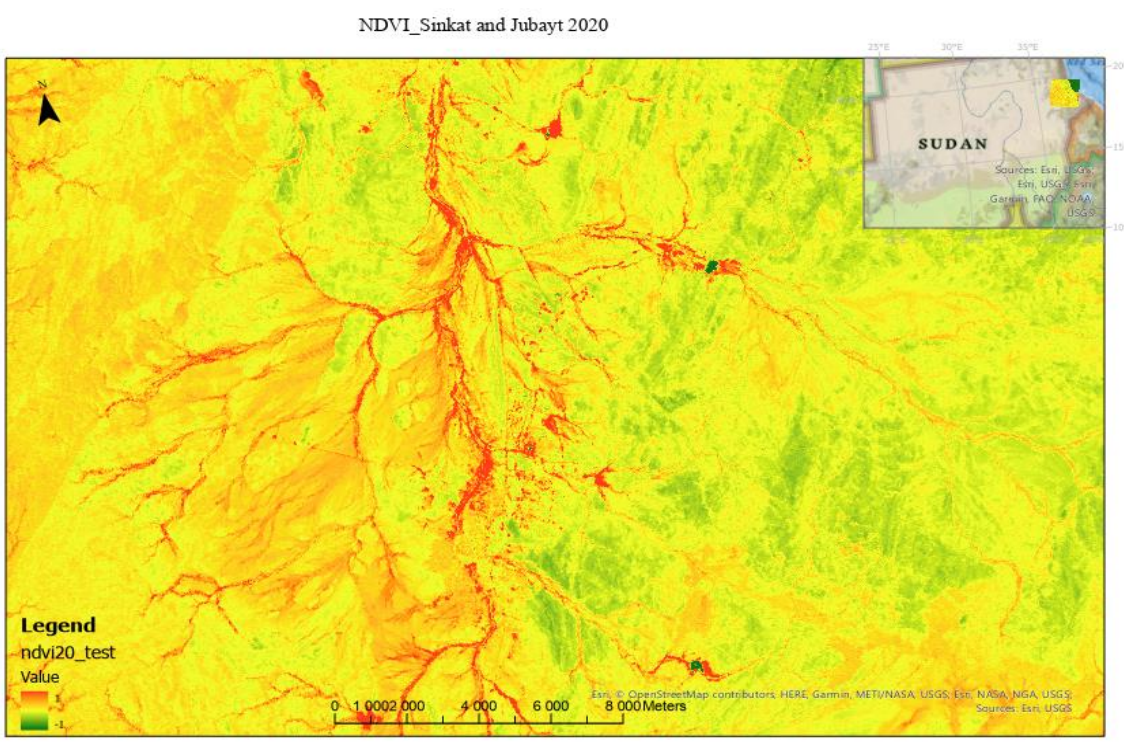
The change value in NDVI between (1984_2020), shows that the highest value of the change value was (1,28155), which is represented by the positive values, it is predominant in the wadies and water drainage. The low values cover large parts of the area, and they represent negative values (See Fig.14c).

The change in NDVI values was shown over the entire region for the different times, by time series analysis. That map shows the points selected from the study area to see the changes that have occurred over the decades. Samples were divided into three groups (location). The first group represents water drainage (A), the second group represents residential areas (B), and the third group represents transportation lines (D) in the study area (Sinkat and Jubayt), (See Fig.14d).

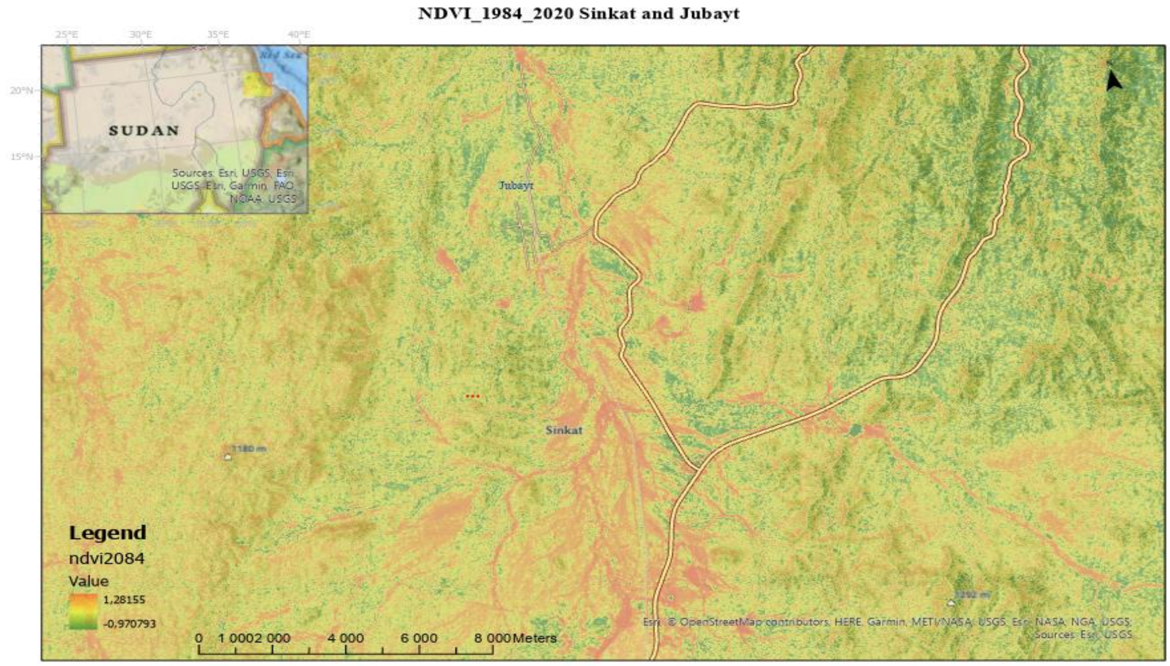
(a)


NDVI_ Sinkat and Jubayt 1984
SUDAN
Legend
NDVI 1984.tif
Value
1
-1
0 1 250 2 500 5 000 Meters
Esri, © OpenStreetMap contributors, HERE, Garmin, METI/NASA, USGS; Esri, NASA, NGA, USGS;
Sources: Esri, USGS

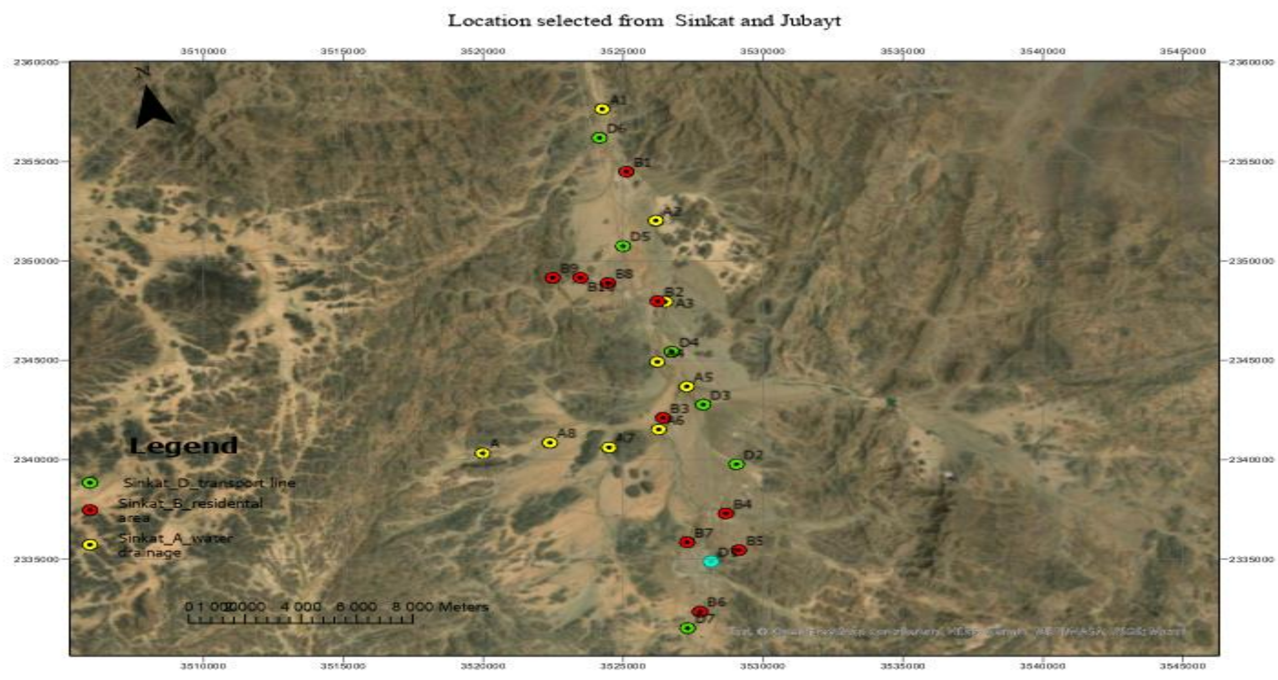
(b)


NDVI_Sinkat and Jubayt 2020
SUDAN
Legend
ndvi20_test
Value
1
-1
0 1 0002 000 4 000 6 000 8 000 Meters
Esri, © OpenStreetMap contributors, HERE, Garmin, METI/NASA, USGS; Esri, NASA, NGA, USGS;
Sources: Esri, USGS

(c)



(d)



Figur14: NDVI analysis calculated from Landsat 5-TM data for the year 1984, Landsat 8 for the year 2020, Raster calculates of change value in NDVI between (1984_2020) and Location selected from the Sinkat and Jubayt area to see the change in NDVI over the decades.

Low values of NDVI were associated with drought and desertification during the period from 1984. The results of the Spatio-temporal analysis in Sinkat and Jubayt also showed, that there was an increase in NDVI values in wadies and water drainage. where the highest value of NDVI in 1990 and 2000, was recorded in (Loc A4), (0,7). Then the values decreased in the period between 2005 to 2010 when the low values were between (0,1-0,2). There was a significant decrease in the NDVI values near the residential areas, where the NDVI low values were between (0,1-0,2), the high value was recorded in 1990 (0,8) and 2010 (0,6), and near the transportation, lines there was a significant decrease in the NDVI values were the low values was recorded in 2005 (0,1), but the high value was recorded in 2000 (0,5), which may be due to Sinkat, it is a semi-urban and administratively planned area. Near the water sources, animals graze and make charcoal is also made, according to the respondent (9,10, and 11) from Sinkat (See Fig15 a, b, and c.).

(a)

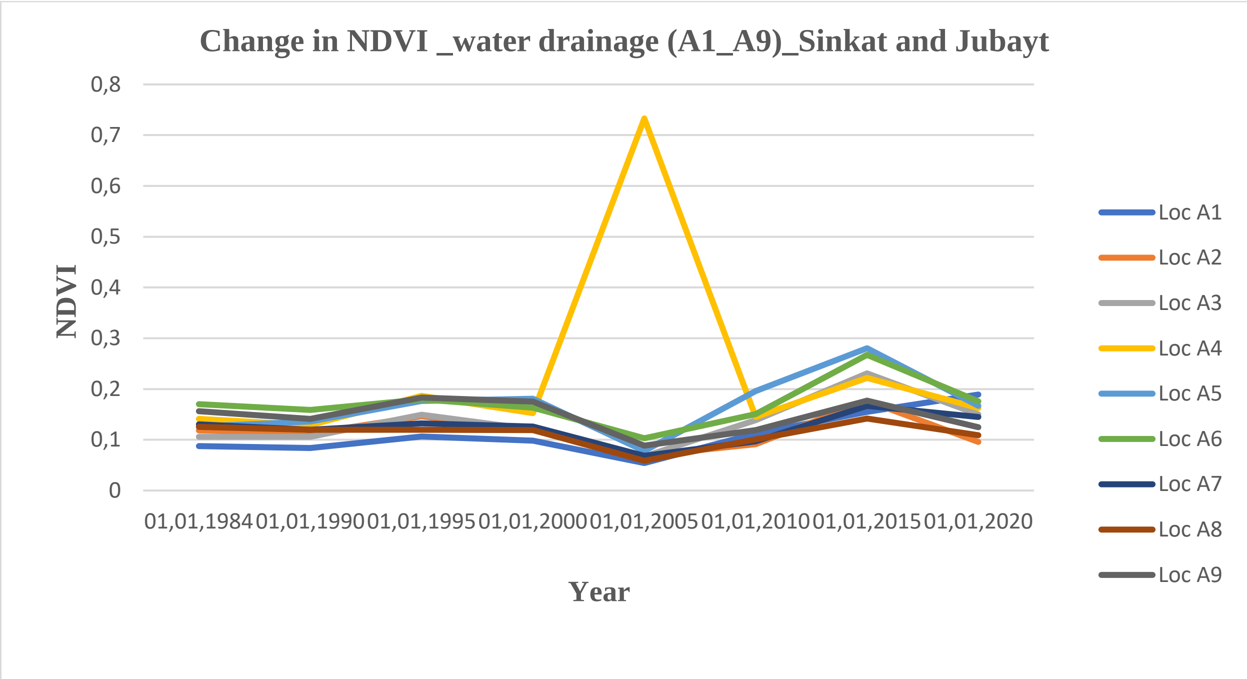


Figure 15a: Change in NDVI time series _ water drainage in Sinkat and Jubayt

(b)

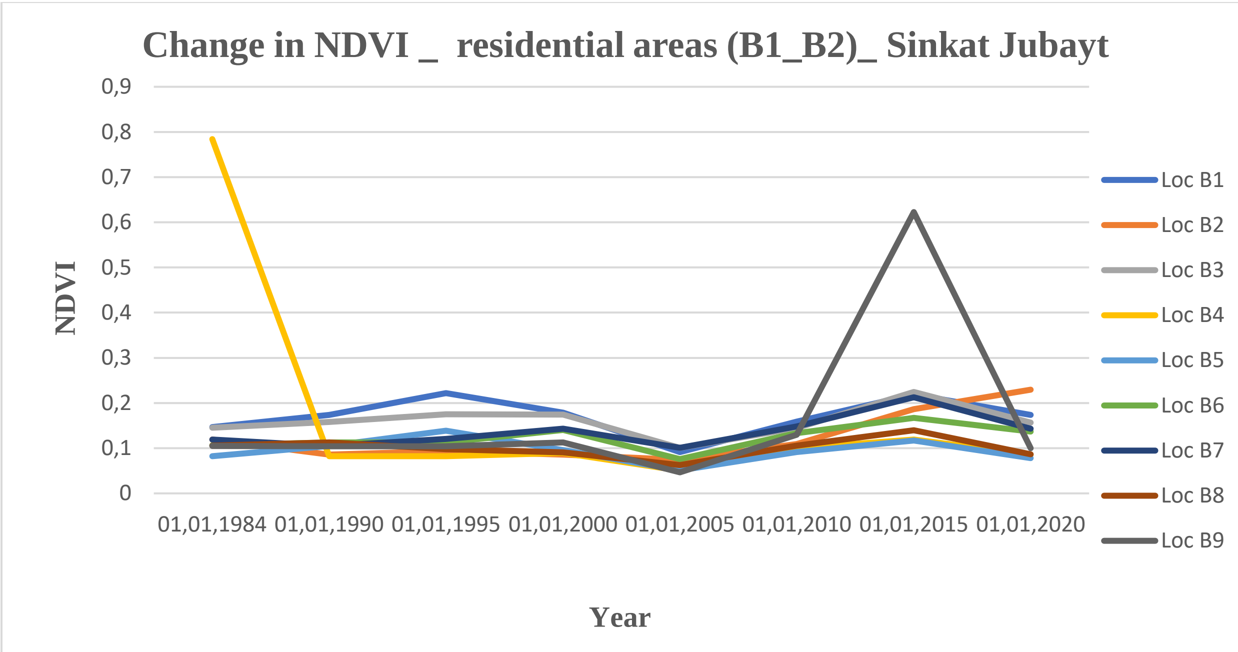


Figure 15b: Change in NDVI time series _ Residential areas in Sinkat and Jubayt

(c)

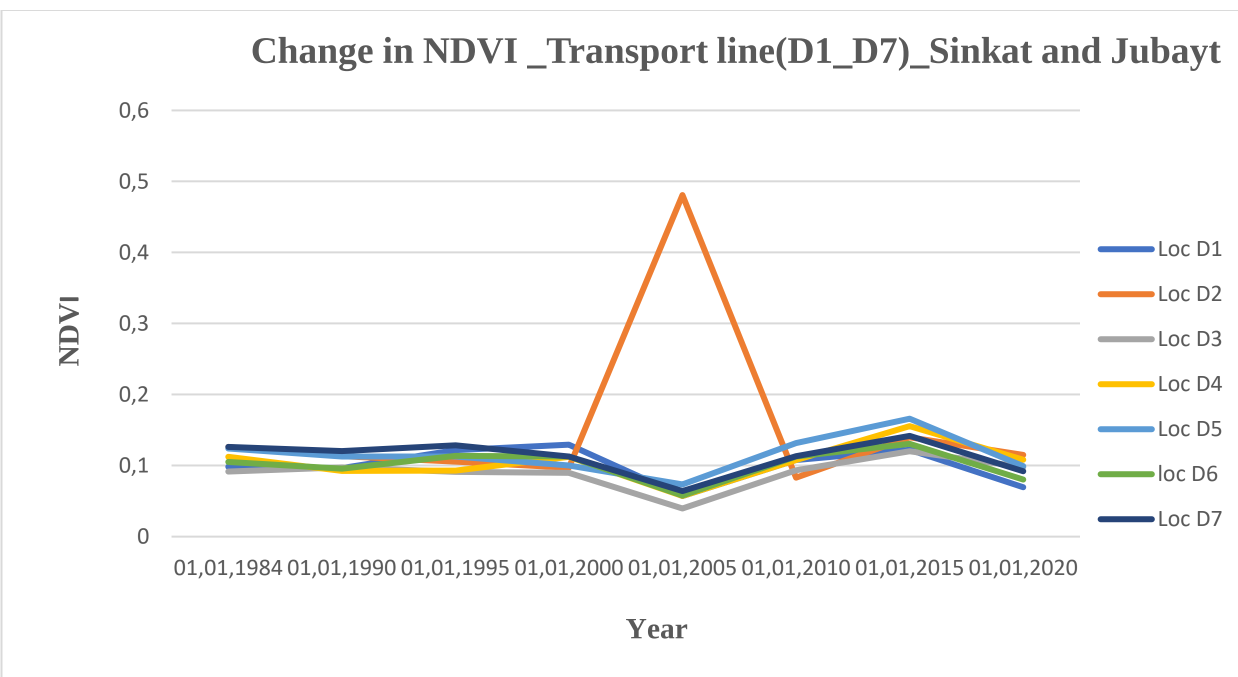


Figure 15c: Change in NDVI time series _ Transport line in Sinkat and Jubayt

Salum

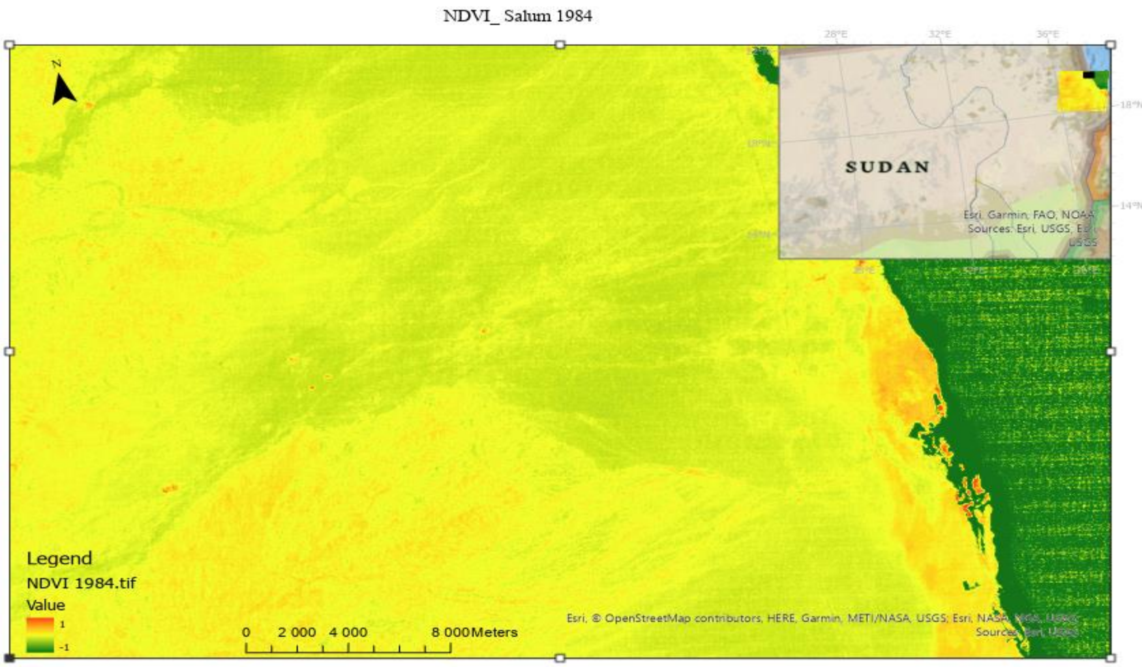
NDVI-1984 shows that low values are predominant in large parts of the Salum area, and it represents negative values. Maybe because of the association with drought and desertification in particular during the period in the 1980s see (Figure 16a).

The vegetation index of 2020 shows that high values are predominant in large parts of the Salum area it represents positive values. Perhaps the expansion and spread of P Juliflora in the region could be because of the nature of the topographical area. it is a flat area where the movement of animals is easy, and animals are one of the most important causes of the spread of mesquite seeds. This photo was taken during the dry season (March and April) when there is little rain during this period. Most annual plants disappear by the end of the autumn season See (Figure.16b). The maps of the remaining years (1990,1995,2000,2005,2010, and 2015) are found in Appendix (4), Fig:16.1, 16.2,16.3,16.4,16.5, and 16.6.

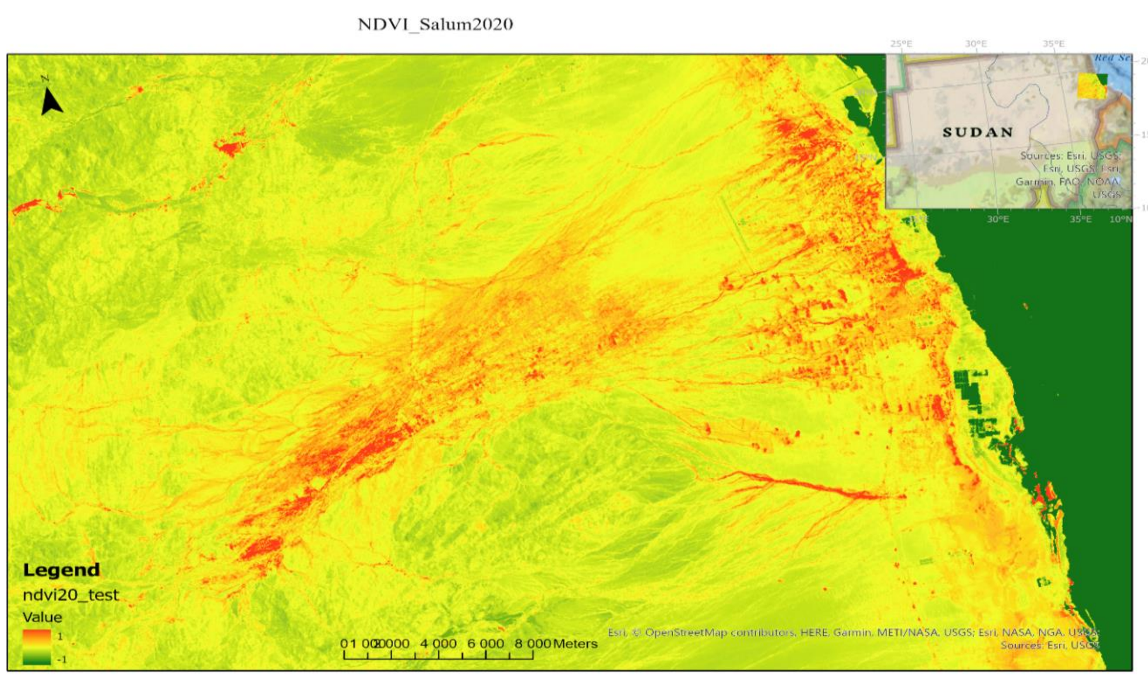
The change value in NDVI between (1984_2020), shows that all regions were predominant by the highest value of the change value was (1,28) see (Figure.16c).

The change in NDVI values was shown over the entire region for the different times, by time series analysis. That map shows the points selected from the study area to see the changes that have occurred over the decades. Samples were divided into three groups. the first group represents plain (pastoral land) (A), the second group represents Transport line (B), and the third group represents water drainage (D) see (Figure.16d).

(a)


NDVI_ Salum 1984
SUDAN
Esri, Garmin, FAO, NOAA
Legend
NDVI 1984.tif
Value
1
-1
0 2 000 4 000 8 000 Meters
Esri, © OpenStreetMap contributors, HERE, Garmin, METI/NASA, USGS

(b)


NDVI_Salum2020
SUDAN
Legend
ndvi20_test
Value
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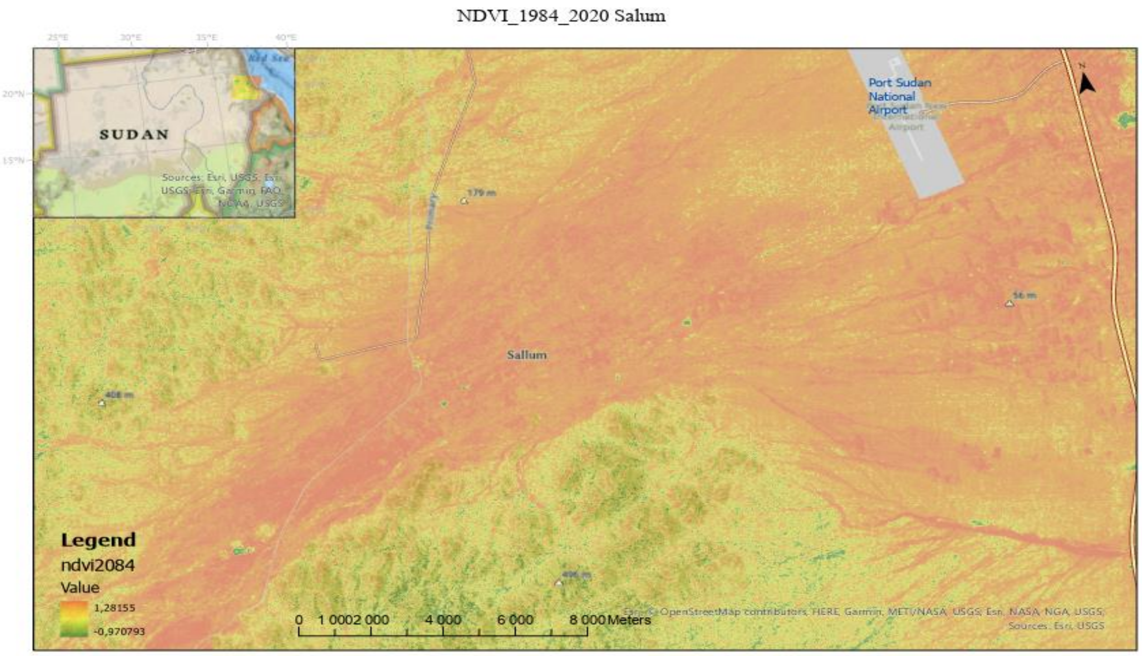
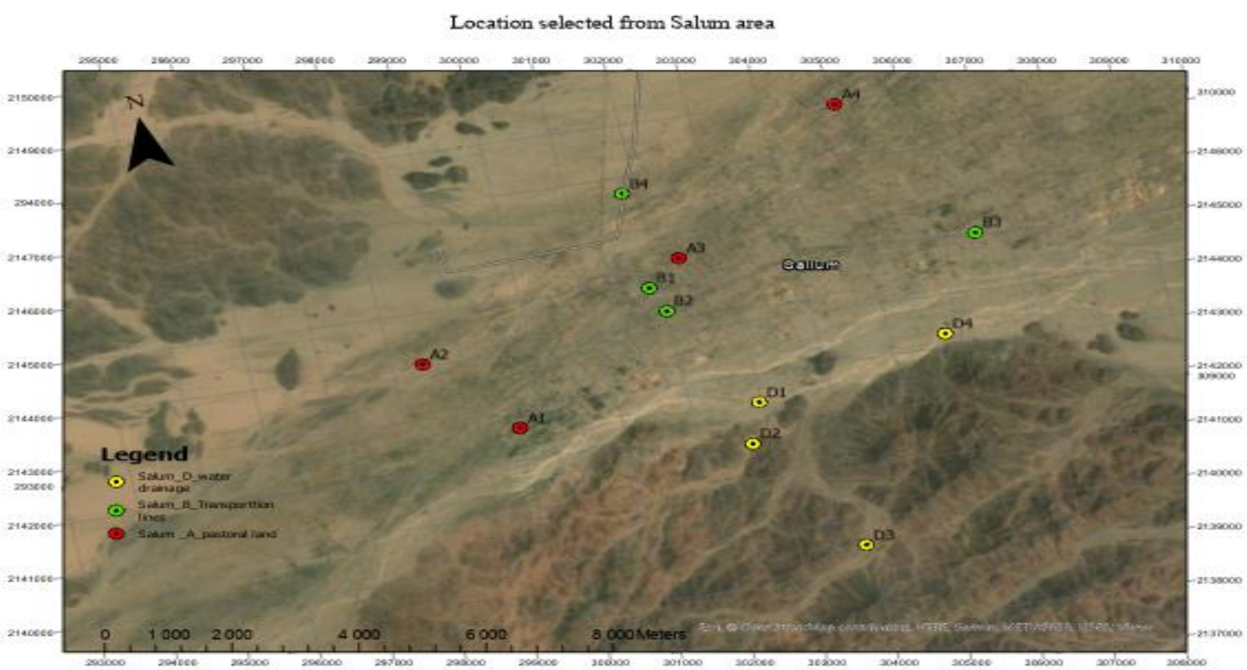
-1
01 000 2000 4 000 6 000 8 000 Meters
Esri, © OpenStreetMap contributors, HERE, Garmin, METI/NASA, USGS; Esri, NASA, NGA, USGS

(c)



(d)



Figur16a, b,c,and d : NDVI analysis calculated from Landsat 5-TM data for the year 1984, Landsat 8 for the year 2020, Raster calculates of change value in NDVI between (1984_2020) and Location selected from the Salum area to see the change in NDVI over the decades.

In the Salum area, there is an increase in NDVI values between 1985 and 2000 in pastoral land, where the highest value of NDVI was recorded in 1990 (0.8) in (Loc A4), then it decreased again between 2005 and 2010, then it was increased again to 2015 when it recorded the highest value of NDVI (0.3) in (Loc A1). In the water drainage area, the NDVI values increased in 1985 where the highest value of NDVI was recorded in 1984 (0.7) in (Loc D4), then it decreased again from 1990 to 2010, when the low values were between (0,1). The NDVI values were increased again in 2015 when the highest value of NDVI was recorded in (loc D3), (0,7). The transportation area also recorded a high value of NDVI in 1984 (0.8) in (Loc B4) and in 1990 (0,7) in (loc B3). In general, there is an increase in the values of NDVI from the year 1990 to 2000, then it decreased again from 2005 to 2010. there is an increase in 2015 where the high value was recorded (0,2) in (loc B1, B3). See (Figures17a, b, and c).

(a)

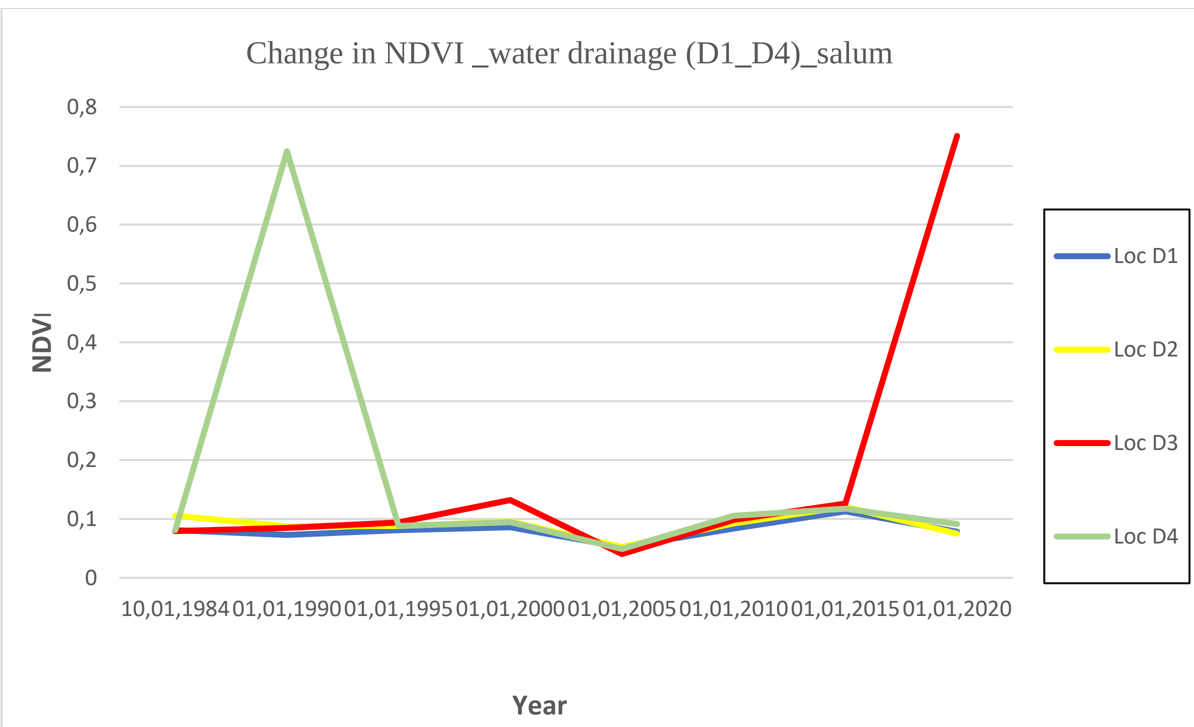


Figure 17a: Change in NDVI time series _water drainage in Salum

(b)

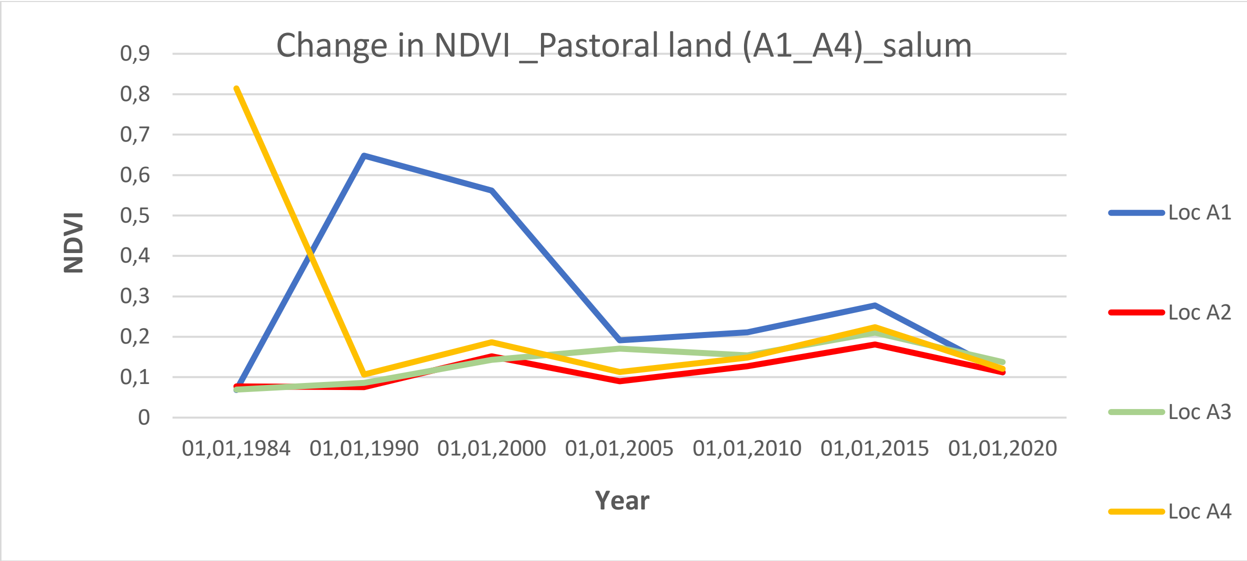


Figure 17b: Change in NDVI time series _pastoral land in Salum

(c)

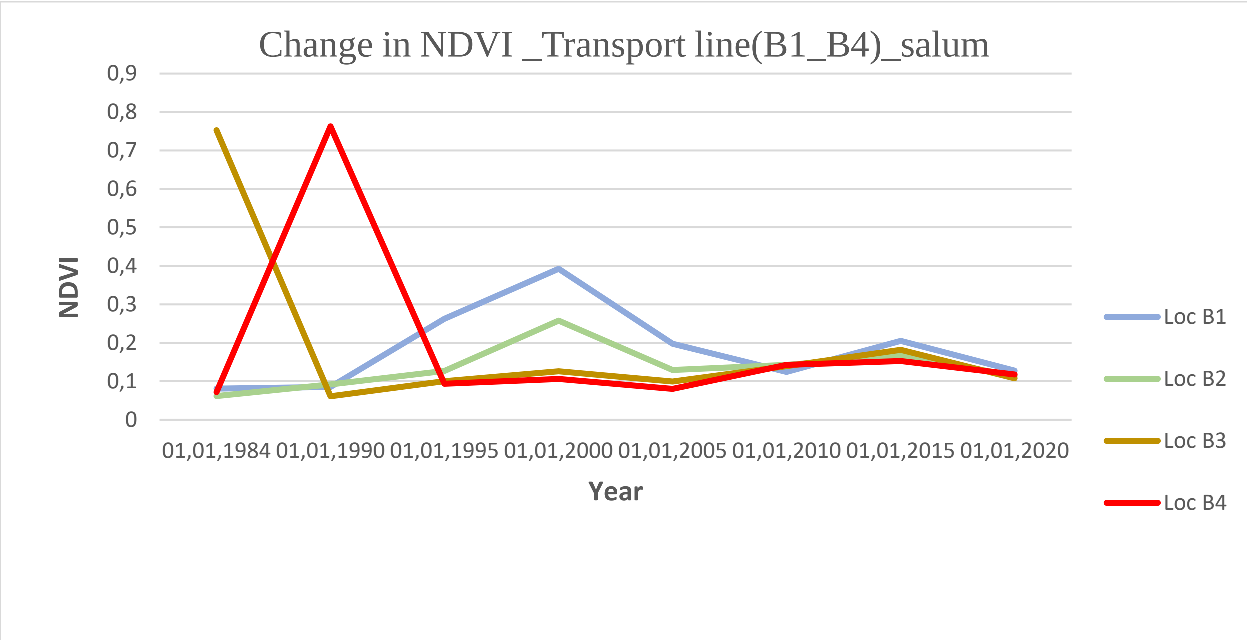


Figure 17c: Change in NDVI time series _Transport line in Salum

Ashat

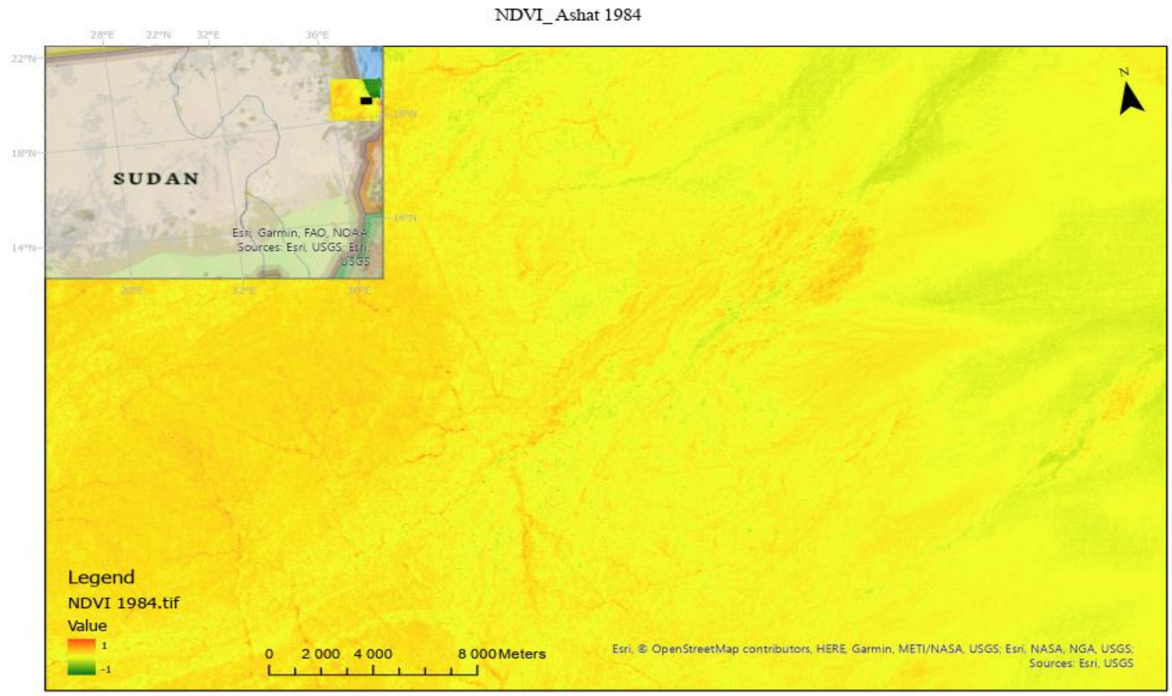
The values of the vegetation index in 1984 show that the high values represent the positive value. were predominant in Khor Ashat in the hills area representing the positive values. the lower values were found in the area near the coast, and they represent negative values see (Figure 18a).

The NDVI values of 2020 showed that high values were predominant in Khor Ashat and the small streams that flow into it. In addition, it is found in the flat plain near the coast and the Tokar Delta. The lower values of NDVI represent negative values. It is found in the mountain rocky areas see (figure 18b). The maps of remaining years (1990,1995,2000,2005,2010, and 2015) are found in Appendix (5), Fig:(18.1, 18.2,18.3,18.4,18.5, and 18.6).

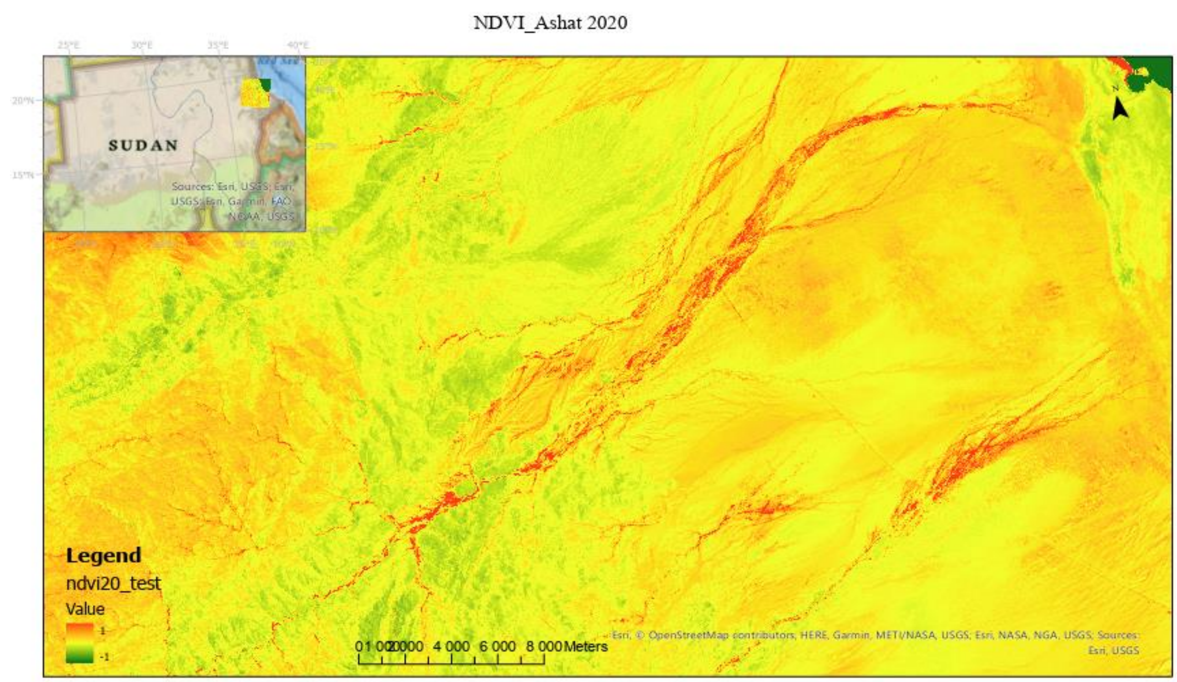
The change value in NDVI between (1984_2020), shows that the flat plain near the coast was predominant by the highest value of the change value was (1,28) and Khor area. The low values of vegetation index were predominant in the large part of the area see (Figure.18c).

The change in NDVI values was shown over the entire region for the different times, by time series analysis. That map shows the points selected from the study area to see the changes that have occurred over the decades. Samples were divided into two groups. the first group represents water drainage (A), and the second group represents plain (pastoral land) (B) see (Figure.18d). The remaining NDVI map is found in Appendix Figure (18b 18c, 18d, 18e, 18f, and 18g).

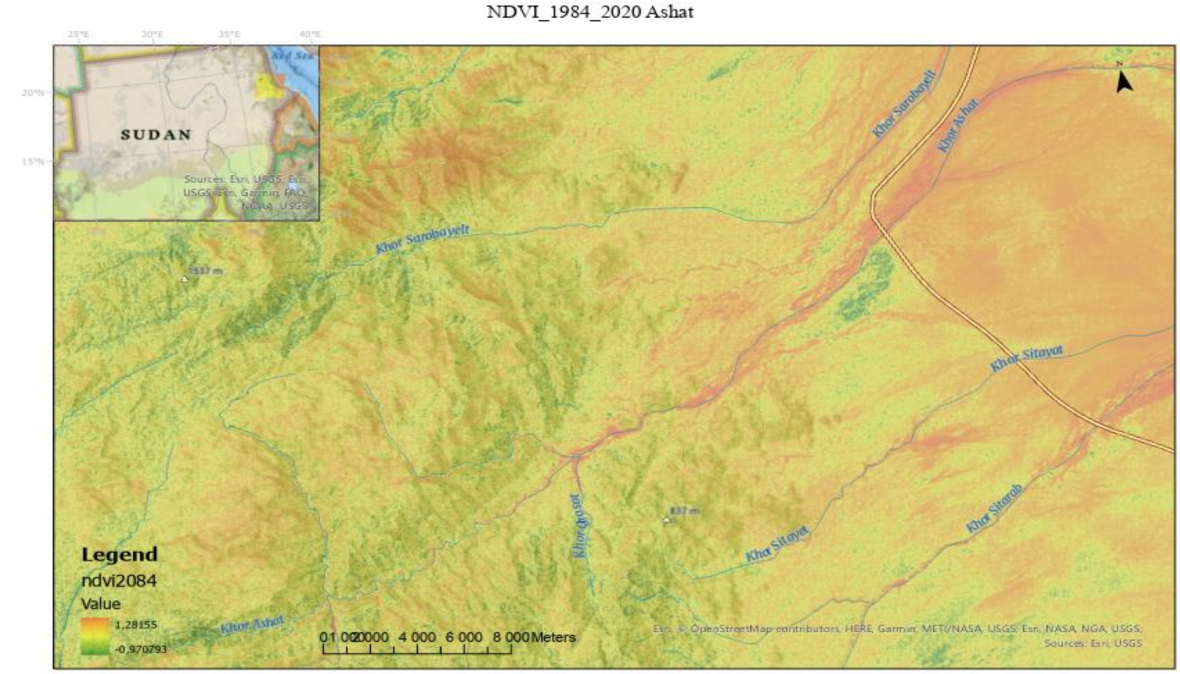
(a)


NDVI_ Ashat 1984
SUDAN
Esri, Garmin, FAO, NOAA
Sources: Esri, USGS, Esri, USGS
Legend
NDVI 1984.tif
Value
1
-1
0 2 000 4 000 8 000 Meters
Esri, © OpenStreetMap contributors, HERE, Garmin, METI/NASA, USGS, Esri, NASA, NGA, USGS, Sources: Esri, USGS

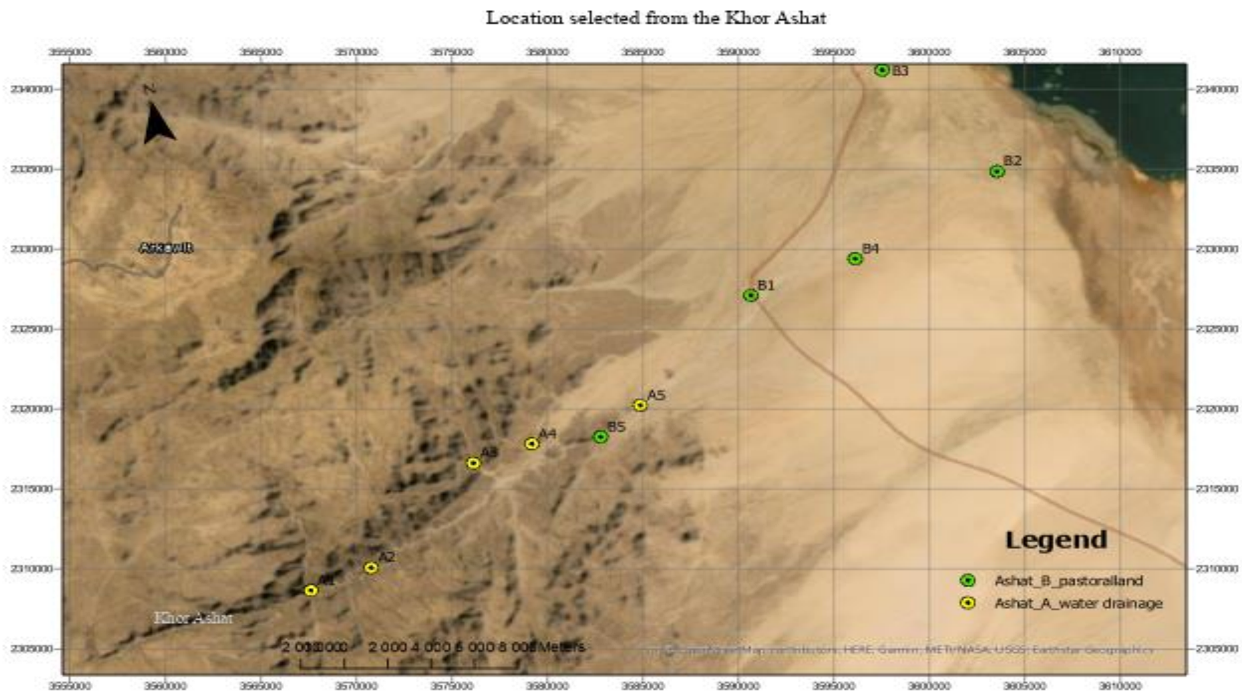
(b)


NDVI_Ashat 2020
SUDAN
Legend
ndvi20_test
Value
1
-1
Meters
Esri, © OpenStreetMap contributors, HERE, Garmin, METI/NASA, USGS, Esri, NASA, NGA, USGS, Sources: Esri, USGS

(c)



(d)



Figur18a, b,c, and d: NDVI analysis calculated from Landsat 5-TM data for the year 1984, Landsat 8 for the year 2020, Raster calculates of change value in NDVI between (1984_2020) and Location selected from the Khor Ashat area to see the change in NDVI over the decades

In Ashat area Change in the NDVI in the water drainage area increased from 1990 to 2000 were the high value of NDVI was registered (1,2) in (Loc A1), then the values decreased in the period between 2005 and 2010, then increased in 2015 where the highest NDVI value was recorded (0.3) in (Loc A2, A5. A3). The years 2010 and 2015 registered a high increase in the values of NDVI.In the pastoral lands area, there was a decrease in NDVI values from 1984 to 1995, where the values ranged between (0.1-0.15), and in 2000 the values increased, where the highest value was recorded (0.5). In general, the values decreased in the period between 2005 and 2010 and then increased in the year 2015 when the highest value was recorded (0.4). see (Figures 19 a,b, and c).

(a)

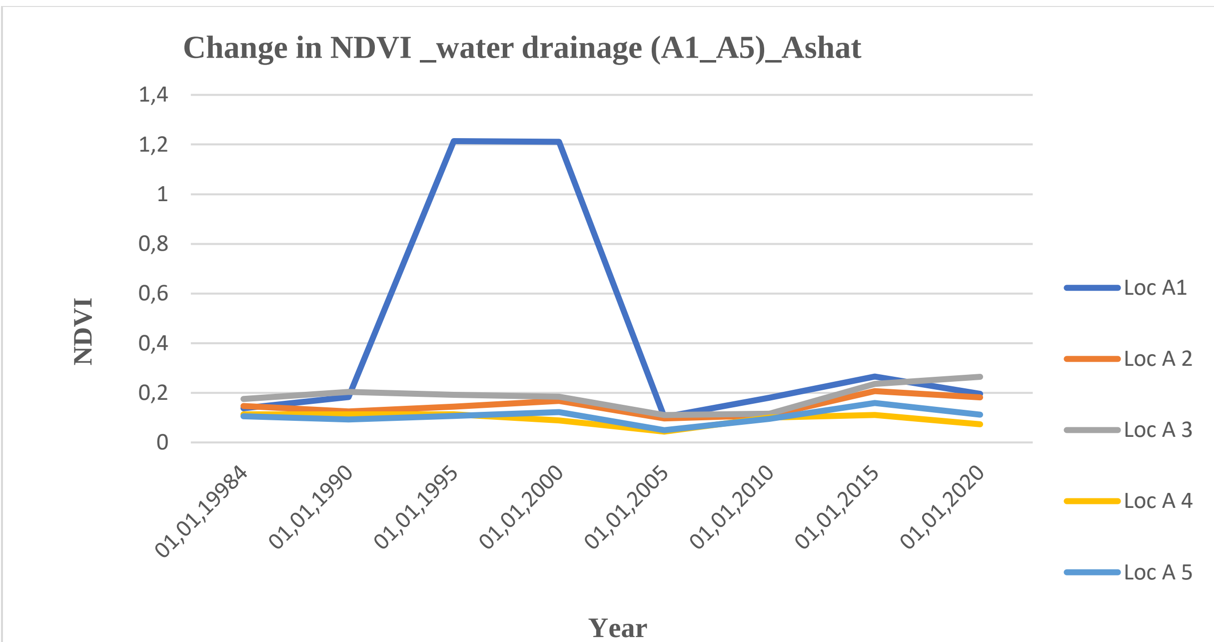


Figure 19a:Change in NDVI_water drainage in Ashat

(b)

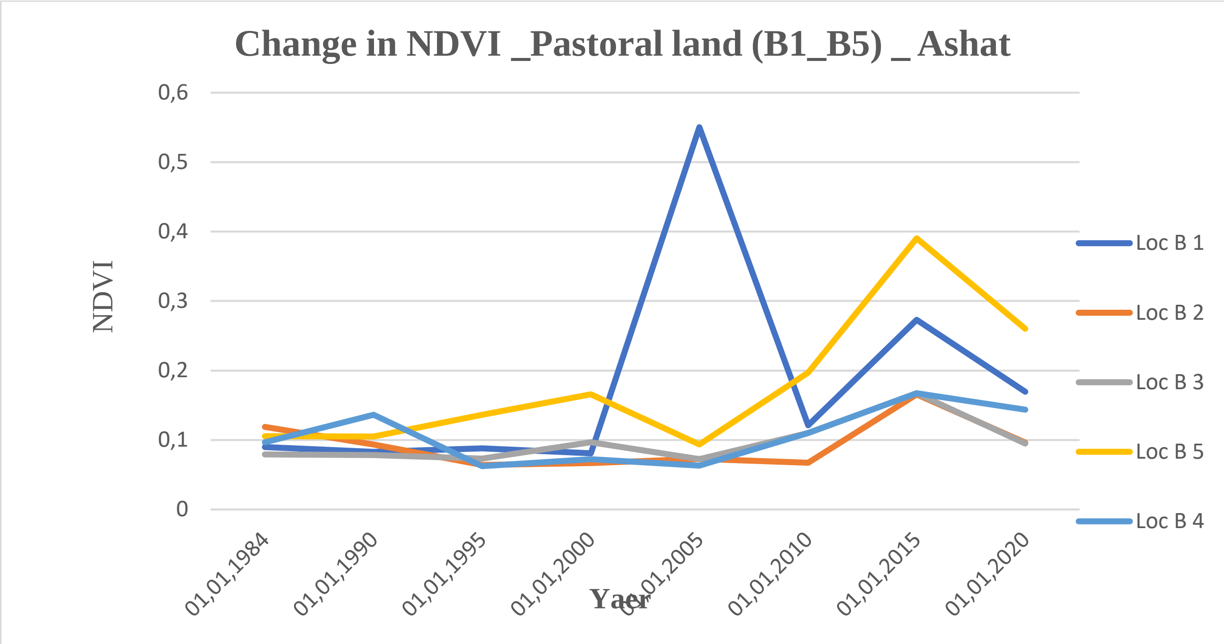


Figure 19b:Change in NDVI_pastoral land in Ashat

5.2 Socio-economic Dimension of *Prosopis juliflora*

The interview was conducted with ten notables of the tribes in the study area (Ashat, Salum, Sinkat, and Jubayt), where the population can be classified into rural people represented in the area (Salum and Ashat) and urban represented in the cities (Sinkat). The rural population can be either settlers or nomads.

Table 3: Information about Respondents.

Area	No	Age	Tribe	Occupation
Ashat	1	45	Gamilab	Charcoal maker/ merchantman
	2	40	Gamilab	Charcoal maker/ woodcutter
	3	45	Bishariab	Merchantman
	4	35	Rashaida	Driver
	5	35	Tirkway	Charcoal trader
Salum	6	60	Humadab	Charcoal maker/ herder
	7	60	Ashraf	Retired teacher
	8	50	Kuleit	Charcoal maker/ herder
Sinkat	9	45	Emerab	Herder/ merchantman/ Charcoal maker
	10	25	Emerab	Herder/ merchantman/ Charcoal maker
	11	45	Emerab	Charcoal maker/ herder

The respondents mention that the residents depend on grazing and seasonal agriculture, in addition to the craft of cutting trees and making charcoal. Charcoal production constitutes the main source of income for most of the study area - residents, in addition to selling dairy products and firewood. Most of the area's residents depend on cutting trees to build their houses,8 out of 10 respondents indicated that their homes are built of wood and sticks.

grazing is the main occupation of most of the Bedouin population. Their livestock consists of goats, sheep, camels, and some donkeys. Most of the residents of the area practice grazing, and the owners of small herds prefer stable grazing around their areas in summer (in the hills and the interior desert areas to the west of the mountains that receive summer rains and are called the Awliip, in and around the Sinkat area) and in the winter (Ashat and Salum in the coastal lands that receive winter rains and are called Gunub). The owners of large herds prefer mobile grazing. Most of the pastoralists who own small herds do not use transportation to transport their animals to graze in the fall due to the high costs of transportation and the difficulty of movement due to the intertwining of the branches of the *P. juliflora*, which hinders the movement of the pastoralism, as mentioned by respondents 2and 3 from the area of Ashat and responded 7 from the Salum area. In addition to reasons related to the number of herd animals owned by pastoralism, some have small numbers of sheep that do not need to be transported by transportation, as mentioned by respondents 8 from the Saloum area, and both respondents 9 and 10 from the Sinkat area. Respondents 9,10,11, and responded 1, said that the reasons are also due to the traditional way of grazing that pastoralism used to walk on foot.

The 9 out of 10 respondents mentioned that there were natural plants in the area, but due to climate change, reduced rainfall, and the spread and expansion of the P juliflora plant in the area led to the disappearance of these plant species from the ecosystem such as (*Acacia tortillas', Leptadenia pyrotechnical ,Aywateat mur (this is the local name of species, scientific name not recognized), Balanites aegyptiaca, Salvadora persica, and crawling trees*),Sinkat area respondents also mentioned that there were forest lands in the area between Sankat and Jubayt, but they disappeared due to the competition of the mesquite plant with the dominant plants in the area and above.

The 8 out of 10 respondents from the three regions (Ashat, Salum, and Sinkat) stated that most of the region's residents depend on wood as firewood for fuel and for building houses. All the respondents agree that there are new types of plants that have appeared in the area, such as mesquite, which is a fast-spreading plant, in addition to (Haleuk, this is the local name of species, scientific name not recognized), and (Eegab this is the local name of species, scientific name not recognized).

P juliflora is one of the plants that contributes greatly to the per capita income as it is harvested in summer. The pods of the plant and the leaves of young bushes are used as animal feed. This is considered the main reason that led to the preference of the sedentary grazing style in one area over the mobile grazing style, as indicated by 9 out of 10 participants. 7 out of 10 respondents indicated that their main occupation is making charcoal, producing charcoal from the wood of *P. juliflora*, and selling it in the market. Respondents indicated that *P juliflora* is one of the most widespread plants in the region, rapidly expanding in the region on pastoral lands, agricultural lands, water drainage and forests. In addition, the *P. juliflora* extend their long roots in the depths of the soil, causing dry wells and difficulty in reaching the water level when digging a well. It spreads quickly and grows in the form of spiny and intertwined branches that form a forest group in which brings many scorpions, snakes and other creatures that live in it. Which exposes the animals to the thorns of the P.juliflora and exposes the shepherd to the thorns, as indicated by the "Respondent No. 6 from the Salum area, which is a big problem that makes me lose sight in one of my eyes, and I was injured in different parts of my body and I was exposed to a snake bite" and they have no medicine to save people From bites of snakes and scorpions. Some residents believe that there is no need to combat and cut the *P. juliflora*, because they are a source of livelihood and livelihood for most of the population, especially the Bedouins. respondents 1, 2, and 5 of Ashat said they had no objection to *P. juliflora* cutting, "If the government is setting a framework for *P juliflora* cutting and control, it should provide us with alternative means of livelihood and animal food." Respondent 7,8 from Salum mentioned that "there is a lot of *P. juliflora* that we need to use" because it is a good source of income.

In general, according to the respondents, *P. juliflora* occupied the area and spread rapidly and the area lost many of the natural plants that were growing there. And it affected the aspects of groundwater depletion and the suffering of citizens in obtaining it. On the other hand, most of the population has become dependent on *P. juliflora* trees for the timber and charcoal industry.

Chapter six

Discussion

6.1 Discussion

This chapter represents an integrative review of the results obtained in this study on the assessment of vegetation cover change and the effect of the spread of *Prosopis juliflora* in the grazing pattern in the Red Sea State in Sudan. Overall, this study aims to investigate and assess the status of LULC and study the dynamics of change in study areas of the impact of *P Juliflora* tree expansion on the livelihoods of pastoralists in the Red Sea region (Sudan) to identify possible adaptations in livelihoods. Accordingly, the results of the study represent the analysis of image processing products, for LULC changes, analysis of vegetation indicators, and field interviews. These include spatial distributions and changes in LULC categories in different decades from 1984 to 2020. A comparison was made between vegetation maps applying both under visual methods through previous studies and interviews with local communities to determine the direction of change and transformation that occurred during the study period.

Analysis of LULC in the study area based on NDVI and St Time (Time Series)

The results obtained using NDVI in Sinkat and Jubayt showed that there was a vegetation cover that was represented by high NDVI values in 1984, although the area suffered from drought in this period, maybe because of the topography of the area, it was not much affected by drought, and it was found that there are fluctuations and a decrease in precipitation rates in the Sinkat region see (Figure 2). There was no significant change in the NDVI values during the years (1990, 1995, and 2000), perhaps due to decreased precipitation rates see (Figures 2,3, and 4). which found that the precipitation significantly affects the increased values, as the values have decreased in 2005 and 2010. See (Fig. 15a, 15b, and 15c).In 2020 the NDVI values were highly concentrated in the drainage areas, referring to Fig. 2 and Fig. (14.5 appendix), Where we cannot be certain that all plant density is *P. juliflora*, but there are annual plants It grows in the fall season but concerning the information we obtained from the respondents in the questionnaire, they indicated that there is a rapid expansion of the *P. juliflora* in the water drainage and near their residential areas, and this is attributed to the movement of shepherds from their residential areas near the water drainage areas. Although the precipitation increased slightly in 2020 when the highest precipitation was recorded at 110 mm/year. However, the satellite images were taken during the dry season (March and April) when there is little rain during this period. Therefore, the results showed that there is a decrease in the NDVI values in 2020, which confirms that the change in precipitation significantly affects the increase of the NDVI values.

In Salum area, vegetation cover was represented by low NDVI values in 1984, which indicates that this area was more affected by drought. Due to its proximity to the coast, it is a flat area that is more affected by the encroachment of dunes. Although the rate of rainfall was high from (1981-1985), the area affected by winter rain in the Awliip region near the coast. The values of NDVI continued to increase each year in 1990, 1995, and 2000, although their decrease in rainfall. This may be because the topography of the region is a flat area, and as a supportive land port to Port Sudan seaport to facilitate the process of movement and transportation of goods, in addition to being the meeting point of herders on a winter trip. It is easy to spread mesquite seeds in the availability of such factors. The values decreased in 2005 and 2010, the NDVI values are possibly affected by the decrease in precipitation rates in those years see Figures (17a, c, d). In 2020 the results showed a decrease in NDVI values, and this is because the satellite images were taken during the dry period, March-April, but after March-April, the precipitation rates increased in the region see figure (4). It is expected that the NDVI values will rise.

In the Ashat region, it was found that there was a vegetation cover with high NDVI values in 1984, although the region suffered from drought in this period, the effect of drought on it was slight due to the topography of the region and its precipitation years (1981-1985) were high, see Figures (2, 3, and 4). NDVI values decreased in 1995, 2000, and 2010 due to the variability of precipitation at all selected points. See Figure (19a, b). The high values of NDVI are related to the increase in rainfall in the Ashat region, perhaps due to Khor Ashat being a drainage area that depends largely on the amount of precipitation. The values of NDVI increased a lot in the plain areas and near the Tokar delta, where it is grown by Farmers near Tokar delta. See Appendix (5).

The change of NDVI 1984-2020 shows that in the Sinkat and Jubayt area, the high values covered the drainage area, while low values predominate in different parts of the region and represent negative values. Perhaps because of the harshness of the mountainous region, the shepherds took valleys and streams to graze their animals, and thus the density of vegetation was concentrated in this region. High values prevail in large parts of the plain area (pastoral lands) of Salum and Ashat and represent positive values. This may be due to the expansion and spread of *P juliflora* plants, as indicated by the respondents, as most of the natural annual plants disappear by the end of the autumn season, and their appearance period has become short. A previous study on the prevalence of *P. juliflora* in Africa also (Maundu, Kibet, Morimoto, Imbumi, & Adeka, 2009), indicates that an acceleration of the decline in natural grazing resources in the region as a result of the expansion of *P.juliflora*. The increase in NDVI values corresponds to the influence of the vegetation index by the greenness or dryness of plants; Especially if the vegetation is a mixture of green and dry vegetation (Compton J. Tucker, 1979). The degradation in vegetation cover occurred between 1984 and 2000 in the tree areas and this is consistent with (Alzubair, Nuri, & Ahmed, 2020). who stated that the drought period affected the Red Sea State and led to the deterioration of natural resources, especially the vegetation. This is in agreement with(Sulieman & Elagib, 2012) who indicated that the eastern Sudan region is experiencing a drastic change in LULC, which has led to a significant decrease in grazing resources, as the region witnessed a decrease in natural vegetation cover in the period between (1999-2006), and that the assessment Quantification of climate and LULC changes in Gedaref and their potential interactions have far-reaching impacts on grazing and ecosystems across eastern Sudan.

The temporal and spatiotemporal patterns detected in the case study area at all selected points revealed that NDVI values are spread mainly along the transport lines and water bodies. This is in line with findings from the Afar region of Ethiopia, where water bodies and roads have been identified as the main drivers of the Prosopis invasion (Shiferaw et al., 2019). This raises the question of to what extent, and at what rate Prosopis will also be able to dislodge the mixed vegetation on the surrounding hills and slopes, facilitated by the dispersal of Prosopis seeds by the migration of livestock.

The results of the Spatio-temporal analysis in Sinkat and Jubayt also showed an increase in the values of the NDVI index, especially in the water drainage areas during all years except for 2005 and 2010 where the values were between (0,1-0,3). There was a significant decrease in the NDVI values near the residential areas, where NDVI values were between (0,1-0,2), and near the transportation, lines were NDVI values (0,1-0,15), which may be due to Sinkat, it is a semi-urban and administratively planned area. Near the water sources, animals graze and make charcoal is also made, according to the respondent (9,10, and 11) from Sinkat.

Due to the small number of samples taken in the questionnaire, we had to take additional information through audio recording. According to the speaker's account, acacia forests of various types dominated the area until the beginning of the nineties, but they disappeared and *P. juliflora* became dominant [Audio recording from interviews conducted by Muhammad Talib] See Figures (15a, b,c). Salum also recorded the highest increase in NDVI values in pastoral areas and transport lines from 1990 to 2000, increased in 2005 through 2015, and decreased until 2020. NDVI values ranged from (0.1-0.6) in the plain area (pastoral lands) and near transport links, the lines had NDVI values between (0.1–0.7). From 1984 to 2000 there was no obvious change in the values in the drainage areas, and they decreased in 2005, this may be because the Salum area is semi-flat, a semi-rural area where it is easy to navigate. Therefore, the dispersal of *P. juliflora* seeds is rapid ease because of the movement of animals bred near houses. Where the shepherds do not force to move their animals to the top in the areas of water drainage that flow into the plain. It may also be due to the high cost of transportation and the bumpy road due to the tangle of *P. juliflora* as mentioned by the respondents of the Salum area, that limits the spread of *P. juliflora* seeds in drainage areas (see Fig. 17a, b,c).The spread of *P. juliflora* in pastoral areas and near transport lines can be attributed to the fact that the people of the area depend on grazing and charcoal production as an additional source of income for them, so the residents prefer charcoal production near transport areas where it facilitates the movement of charcoal transport in and out of the state. According to the information that we obtained later from the spoken [Audio recording from interviews conducted by Muhammad Talib], the government has given some of the people of the area farms to grow crops and graze animals for self-sufficiency, so the shepherds move within the boundaries of the grazing area and the farms and they do not move away from them, but due to the expansion of the *P.juliflora*, the residents abandoned agriculture and started producing charcoal. The Salum region is the meeting point for shepherds from different regions during the winter trip to the Awliip region. Therefore, the vegetation density maps showed an increase in vegetation cover in all regions during all years. Although 2005 and 2015 were affected by lower rainfall, it was not a major change. (See Figures 17a, b, c).

In the Ashat area, there was a fluctuation in the values between 1984 and 1995 between the low and high NDVI values in the plain area and almost similar values in the drainage area, the values decreased in 2005 and 2015 affected by the decrease in rainfall rates see Figures (19a, b).

NDVI values increased in the pastoral areas near the coast and the Tokar Delta, due to the fact that the nature of the area is a watercourse, so rainfall affects the change in NDVI values. This may be due to the movement of shepherds and farmers between Ashat and Tokar delta, as the farmers plant some crops near the Tokar delta, and it is easy to spread *P. juliflora* seeds. In addition, in Ashat there is a large market for crops and livestock. The charcoal maker prefers to produce charcoal in areas where movement is easy, and it is also easy to sell the charcoal product and crops, so the shepherds prefer to stay near the charcoal production areas, where the shepherds depend on the *P.juliflora* that grow around their areas as food for their animals.

In general, the results indicate an increase in vegetation cover in three areas of Sinkat, Ashat, and Salum in 1984, 1990, 1995, 2000, 2005, 2010, 2015, and 2020, although from 1984 to1990 the area was suffered from drought and desertification. Whereas *P. juliflora* was introduced in this period to combat drought and sand encroachment due to the drought that hit the area during this period. *P. juliflora* was not widely spread, it was small trees and herbs, and native trees were prevalent. Overall, vegetation increased to 2020, With a decrease in the native plants that used to grow in the area where 9 out of 10 respondents mentioned that there were natural plants in the area, but now *P. juliflora* is dominating the original natural area plants which have either completely disappeared, or their appearance is associated with a short growth period. As mentioned, the speaker, through the audio recording [Audio recording from interviews conducted by Muhammad Talib], said that there is a continuous decrease in the cultivated land and the disappearance of the palatable local grazing herbs, for animals. Invasive nature has led to many similar environmental impacts on many habitats in the world. Levien,1989 notes that invasive species pose another threat to biodiversity that may invade these local communities and ecosystems. In general, biological invasions cause frequent and significant prejudice against the integrity of communities and, in the long run, can lead to a decline in a particular species (Levin, 1989).

Specialized knowledge in remote sensing and the use of various techniques in satellite image classification is vital and leads to reliable results in mapping changes in LULC (William K Smith et al., 2019) indicated in their study of remote sensing of the dryland ecosystem has the potential to greatly enhance our current understanding of dryland ecosystems. On the other hand, field surveys and field verification are very important in the whole process. Studying and regularly reviewing the impacts of LULC along with socio-economic and socio-political changes facilitates the construction of a baseline database for the future.

Figure 19*:* *P. juliflora* in Khor Ashat

Figure 20: *P. juliflora* in Sinkat

Figure 21: *P. juliflora in* Salum

Ecological effect of *P. juliflora*

The continued expansion of *P. juliflora* has already caused adverse effects on biodiversity, ecosystem services, and the economy. *P. juliflora* has a strong prevalence in many drylands, reducing agricultural and pastoral productivity and threatening local biodiversity. The decline in the natural vegetation in the area may be due to climate change, reduced rainfall, and the spread and expansion of *P juliflora*. The expansion of *P juliflora* led to disappearing nation plant species such as (*Acacia tortillas', Leptadenia pyrotechnical, Aywateat mur (this is the local name of species, scientific name not recognized), Balanites aegyptiaca, Salvadora persica, and crawling trees*) according to the respondents mentioned. In the Sinkat region, forested lands disappeared between Sinkat and Jubayt, probably because of *P. juliflora's* competition with the plants prevalent in the region. All the respondents agree that there are new types of plants that have appeared in the area, such as *P. juliflora*, which is a fast-spreading plant, in addition (Haleuk, this is the local name of species, scientific name not recognized), and (Eegab this is the local name of species, scientific name not recognized). Respondents indicated that *P. juliflora* is one of the most prevalent plants in the region, as it expands rapidly in the region on agricultural lands, waterways, forests, and pastures.

Several studies have indicated the rapid spread of mesquite and its competition with the natural vegetation cover (Shiferaw et al., 2019; Sintayehu, Dalle, & Bobasa, 2020) and (Ilukor, Rettberg, Treydte, & Birner, 2016) *P. juliflora* has been identified as a threat to biodiversity and ecosystems were *P. juliflora* invaded strongly grassland in many parts of Ethiopia, South Africa, Kenya, Sudan, and Somalia. These plants replaced the more nutritious pastoral plants, reducing the overall biodiversity of these areas, Reducing the carrying capacity of pastures, increasing the spread of crop pests, and causing health problems (damaging eyes and hooves) for both domestic and wild animals, eventually leading to death.

Its staggered and intertwined branches also prevent sunlight from reaching the vegetation under the canopy, negatively affecting the local biodiversity. This is in agreement with the study (El-Keblawy & Al-Rawai, 2005) where the growth of *P. juliflora* shrubs, as well as exotic eucalyptus shrubs, in the UAE forests led to a significant decrease in species diversity and abundance of secondary species, compared to native plants *P. cineraria* and *Acacia arabica*.

It also hinders the movement of grazing during summer and winter trips in the study area, as mentioned by the respondent. Perhaps because *P. juliflora* impedes the movement of herders. Pastoralists prefer stable grazing within their areas and rely on *P. juliflora* as food for their animals. This is also due to the high costs of transportation, as indicated by the respondents in all areas of the study. Some of them have few animal herds, so they do not prefer to move. On the other hand, the charcoal industry controls its stability, as shepherds prefer to stay near the charcoal production areas and supervise it and benefit from the mesquite trees that grow around their areas to feed their animals.

The Study of Dzikity,2013 conducted in South Africa revealed Prosopis species have been highly water-consuming, and that the invasive Prosopis tree species' hybrids significantly impact groundwater levels due to the very deep taproots (Dzikiti et al., 2013) . The deep roots of *P. juliflora* led to the problem of water depletion in the area. The depletion of groundwater in the Ashat area has made it difficult to reach the groundwater range when digging an artesian well and disappear of seasonal water springs that form at the mouth of the Khor near the coast [Audio recording from interviews conducted by Muhammad Talib]. and this consistent with (Le Maitre, Gush, & Dzikiti, 2015) *P.juliflora* affects both surface runoff, groundwater recharge, and evaporation losses.

This is consistent with a study Zerga,2015 on the expansion of *P. juliflora* in the Afar region of Ethiopia, where the *P.juliflora* affected the depletion of groundwater in the region. He also indicated that the expansion of the mesquite plant in the grazing areas and livestock paths was one of the most common inconveniences imposed by the invasive plant on the pastoral community, as well as the overgrazing of the remaining pastures. Resources exacerbated the problem of water depletion in the Ethiopian Afar region (Zerga, 2015). However, the depletion of surface and groundwater led to the loss of flood waters for irrigation and agricultural expansion in proportion to the population increase and the annual reduction of the cultivated area. This may be due to *P. juliflora* unusually long roots, which allow it to reach constantly saturated water tanks. This is consistent with a study (ABD ELBASIT et al., 2012) reporting that *P. Juliflora* has two mechanisms that allow it to survive under harsh and dry conditions: fungi and drought resistance. These two mechanisms support the musket during prolonged drought conditions and allow it to compete successfully with its natural native species.

In addition, *P. juliflora's* deep roots help it live well in moisture-stressed ecosystems, and it spread and expands greatly across streams and valleys. The study found that the increase in NDVI values was higher in the water drainage regions of the three regions. This is in agreement with (Sintayehu et al., 2020) in a study on the expansion of *P.juliflora* in the Afar region of Ethiopia.

(Eckert et al., 2020) showed that the invasion of *P. juliflora* in East Africa is still at an early stage and that it is likely to expand its current geographical range significantly if left unchecked. Invasive species such as *P. juliflora* can tolerate wider ecological ranges or adapt to new environmental conditions. The current status and potential future increases in the distribution and abundance of *P. juliflora* require risk assessments when introducing plant species aimed at improving local livelihoods. species considered to be high risk should not be introduced.

In the study area coordinated, and large-scale management interventions based on the principles of sustainable environmental development are required to solve the problem of the spread of *P.*

juliflora. Moreover, remote sensing techniques can be used to support the early detection of invasive species and their potential environment, and can be used to control through the spread plans Managing the spread of *P.juliflora,* and it is negative effects can be controlled by utilization method, and replacing it with natural plants and trees of economic value. The method of utilization control through utilization to control the spread of *P.juliflora*. This is consistent with (Jema & Abdu, 2013) that mentioned, the utilization method is currently practiced in severely affected developing countries such as Ethiopia, Kenya, and South Africa. The utilization methods include converting P. juliflora land to irrigated farms, charcoal production, and production of seed flour for agricultural herders.

In the study area, they use P. juliflora firewood in their homes, but it is not preferred because it is quickly exposed to pests and insects, as mentioned by the interviewees through the audio recording [Audio recording from interviews conducted by Muhammad Talib].

The management of P. juliflora trees for firewood production can be profitable in the study area in addition to the production of charcoal and the utilization of *P. juliflora* wood in the production of compressed wood panels to achieve new incomes by exploiting invasive species. That is consistent with (Sato, 2013), who that mentioned People in developing countries have made new incomes by exploiting invasive *P. juliflora* trees. Rural households in developing countries have increased their average income by planting and managing *P. juliflora* trees for wood energy (Sato, 2013).

In Ashat area, farmers grow crops near Tokar Delta and in Salum, the government has owned mixed farming farms, as we mentioned before in this study. Farmers can plant near watercourses where irrigation water is available. Farmers replace *P. juliflora* with crops for their self-sufficiency. It is also possible to organize the charcoal industry process and introduce modern methods for the manufacture of charcoal.

Effect of *P. juliflora* on the Local Livelihood

The invasion of *P. juliflora* negatively affects the livelihood of the local population as reported by the previous study. Yousif, 2008, mentioned that indicated that the spread of *P.juliflora* in the city of Qutina and surrounding areas in central Sudan had a great impact on agricultural projects where spread *P.juliflora* in fertile agricultural lands(Yousif, 2008), Also in the Toker Delta in eastern Sudan, the *P.juliflora* invaded valuable agricultural lands and sometimes grew into impenetrable forests causing huge problems for farmers and agricultural managers (Alredaisy, 2013). Similarly, in the New Wadi Halfa scheme in eastern Sudan *P.juliflora* invaded agricultural land (Mai, 2008). This is consistent with the study (Zerga, 2015) on the expansion of the mesquite in the Afar region of Ethiopia. In addition, the interviews that were conducted with the local community in the study area confirmed it.

It also causes water depletion, obstruction of natural plant regeneration, and deterioration of arable areas and crops. According to the respondents in the three areas, the depletion of surface water and groundwater led to the loss of water used for irrigation and agriculture, and this, in turn, led to the annual reduction of the cultivated area and natural pastures. According to (a sound recording from interviews conducted by Muhammad Talib), the pasture plants were scarce, and the period of seasonal plant growth decreased and ended in a short period. Which makes the shepherds rely on the mesquite plant to feed their animals besides relying on the charcoal industry and the woodcutting craft to leave the craft of agriculture because it is a source of bad income and finding alternative jobs opportunities.

Figure 22: *P.juliflora* fruits are collected and used as animal feed

In Kenya, for example (Mwangi & Swallow, 2005), the *P.juliflora* trees invaded the Baringo region and were concentrated in low-lying areas, waterways, and swamps that form pastures and agricultural lands in the dry season. People in Ngambo and Lopwe, the two primary cultivation sites, are calling for its eradication because its undesirable properties far outweigh the desirable ones. According to these communities, their basic living options are agriculture, and livestock farming is threatened by the uncontrolled expansion of invasive alien species. This is consistent with the opinion of the residents in the Ashat area and through the information, we have obtained from the interviews with the residents, most of them believe that it is necessary to combat Mesquite trees until the ecosystem recovers and the original natural trees reappear.

Some invasive species can often worsen livelihoods, as stated by (Chambers & Conway, 1992), (Scoones, 1998), a range of negative impacts, costs, or ecosystem damage may occur as a result of invasive species, which reduced human well-being. Livelihoods are often more vulnerable despite the loss of livelihood assets and outcomes. These negative impacts of poor livelihoods are represented in (the loss of biodiversity and change of plant community structure, loss of natural capital, grazing, livestock production, lack of land available for agriculture, loss of impacts on human mobility, and access to land and health and safety issues).

P. juliflora created a conflict environment among the beneficiaries including farmers, herders, and charcoal traders. Farmers believe P. juliflora is an invasion and colonization of their lands, while herders in Sinkat area see it as a source of fodder for their animals and provide shade during the hot dry season, providing woods to build homes, and charcoal traders consider *P. juliflora* to be a source of cash income and provide the fuel is rural poor because of its excellent coal. This is consistent with (Mehari, 2015) study showing the inhabitants of the Afar region. Although P. juliflora is generally considered a harmful shrub, it provided some abundant paid benefits to the herders. In all villages, mesquite was used as a source of fodder, and firewood, for fencing houses, and for setting up barns as well.

The residents used *P. juliflora* wood to build houses, and it is used not in terms of quality of wood but in terms of the profusion of *P. juliflora* wood in the area.

Figure 23: Wood of P. *juliflora* use to build a home

On the other hand, some invasive alien species can provide new resources that constitute additional sources of income, which can change and improve livelihood strategies, through job creation, which can reduce the overall vulnerability of an individual or community and increase resilience. According to [an audio recording from the interviews conducted by Muhammad Talib], *P. juliflora* is spread everywhere and near residential areas where shepherds prefer to settle near water sources, which makes them prefer stable grazing in one area rather than mobile grazing, and no transportation costs. In addition, the traditional grazing method used by the pastoralist, who moved with their animals on foot, exposes the pastoralists and the animals to the risk of infection with this thorn. Therefore, the grazing pattern in the three regions changed to stable grazing may be because the herders and charcoal makers prefer to stay near the place of charcoal production and rely on *P. juliflora* that grow near their areas as fodder for their animals as previously mentioned. Perhaps because settling in one area is not financially costly in terms of the cost of transportation and in terms of the effort that the shepherd puts in when traveling. This is similar to what happened in the Ethiopian Afar region (Mehari, 2015), where the intertwined mesquite trees obstructed the path of the shepherds, which aggravated the problems of overgrazing due to grazing in one area. In general, the results of the interviews showed that the craft of cutting wood and the produced charcoal became the second craft for the residents of the state after the source of income from work in Port Sudan and handicrafts. The value of product income from charcoal production is greater than income from herding or farming. So, the herders and farmers took the charcoal industry as a craft and an alternative source of income for farming and grazing. Therefore, the awareness of pastoralists must be raised by training them in modern and efficient means and methods of mesquite cutting and modern methods of charcoal production and building cooperation between institutions and stakeholder groups. *P. juliflora* can be a very valuable resource for drylands as it can provide employment opportunities for the population and a very valuable source of commercial products and livelihoods in dry lands where they produce the highest quality coal. Therefore, the principle of sustainable environmental development must be adopted and applied when developing plans for future projects. India's experience in developing mesquite trees is considered scientific to collect, process, and market different products from different parts of *P. juliflora* to create job opportunities for poor rural people. within the controlling *P.juliflora* by utilizations methods that were provided by Gujarat Forest Development Corporation and Gujarat Agricultural University (Tewari, Harsh, Harris, & Cadoret, 2001).

6.2 Recommendation

1) Remote sensing techniques and geographic information systems have the potential to greatly enhance the current understanding of dryland ecosystems, and to create a comprehensive database of land uses to set and develop comprehensive development plans in the region.

2) Provide risk assessments when introducing species aimed at improving local livelihoods. Species considered to be a high risk should not be introduced in certain contexts and alternatives should be sought.

3) Create coordinated and management plans based on the principle of sustainable development to solve the problem of the spread of *P. juliflora* by using the utilization methods to reduce the spread of *P.julilflora,* transforming the lands in which *P. juliflora* spreads into irrigated farms in agricultural areas, and replacing *P.juliflora* with natural plants trees of economic value, and able to withstand the climatic conditions in the region and reduce desertification and stop the movement of sand dunes in pastoral areas.

4) Ban animal grazing in areas not affected by mesquite so that mesquite seeds do not spread again through animal manure.

5) Structuring administrative and institutional systems and building adaptive capacity to address the negative impacts of invasive alien species on livelihoods. This includes improving education and raising awareness by training farmers, herders, and charcoal traders on modern methods of *P. juliflora* cutting and modern methods of charcoal production and building cooperation between institutions and stakeholder groups, to get the most out of the benefits of *P. juliflora*.

6) Should have adopted the principles of sustainable environmental development and applied them when setting development plans for future projects. the implementation of laws and legislation by monitoring local authorities and relevant authorities.

Conclusion

P. juliflora can adapt and survive in marginal and even highly degraded lands because its roots extend so deep that they reach aquifers. It is a rapidly spreading plant that reduces ecosystem services and removes local biodiversity. Some invasive species are useful and important because they create good livelihood opportunities, but on the other hands they increase vulnerability within social and ecological systems. Environmental changes over time are accompanied by social and livelihood changes, so it is necessary to build adaptive capacities to make the most of the positive impacts of invasive species and on the other hand, address the negative impacts of invasive alien species on livelihoods.

Appendix

Appendix (1) A questionnaire

A questionnaire form to study the effects of the expansion of the mesquite tree on the pastoralists' livelihood in the Red Sea Region

Case study are ………………. Date: …………………….

The name of village /town

1.**Population**

1.Name……………………. Type: Male ………...Female ……………

2.Relationship to family …………

3.The age ………. The tribe ………. Social status: middle

4.Number of family members: 1) male ………. 2)female ………

5.Type of housing:1) Rent ………. 2) private property……………….

5.Type of construction:1) Tent ……... 2) Green Bricks ……… 3) Roca's and Piedras 4) Wood and sticks ………. 5)Straw

6.The type of fuel: 1) Wood ……… 2) Charcoal ………. 3) Other ……….

2.**The livelihood**

1.The main occupation: …………………………

2.How long have you been doing this work? ……………………….

3.Have you a job before it? …………………..

4.Have you another job? ………………………….

5.what is this job? …………………………..

6.Have your farmland? 1)Within a government project …………………………2) Land owned by the tribe ……………………….

7.What crops do you grow? ……………………

8.Have you own a herd of livestock? 1)Goats ……2) Sheep………. 3)Camels……….

9.What is the type of grazing used? 1)Mobile grazing………. 2)Stable grazing …..

10.Where did the pastoral go in the winter season? ………………….

11.Where did the pastoral go in the summer season? …………………….

12.What is the source of the family's income? ………………………………….

13.Do you face difficulty transporting livestock to pastoral lands? ………………………..

14.What are the reasons of difficulty transporting livestock? …………………….

3.**Vegetation resources**

1.Are there natural plants in the area? …………………….

2.What are the prevailing types?..........................

3.What are the prevailing types of herbs in the region? ……………………

4.What are the most important herbs for pastorale? ……………………………..

5.Are there forests in the area? 1)Yes……… 2)No………. 3)There are very little forest ………….. 4)It is removed ………………..

6.Are there natural plants that have disappeared from the area? ……………….

7.Mention natural plants that disappeared from the area? ……………………..

8.Are there natural plants that appeared in the area? …………….

9.Mention natural plants that appeared from the area?...................

10.Did you notice a change in the amount of rain? ……………

11.How would you describe this change? 1)An increase in the period of precipitation …………… 2)A decrease in the period of precipitation ……………... 3) steady ………….

12.What is the effect of this change? 1)Lack of water …………. 2)Crop failure…………...3)Animal death ……………….. 4)Lack of productivity ……………………. 5)All previous effects ……………...

4.Mesquite tree

1.What do you think about the Mesquite tree? 1)Very good …………. 2)Good ……

3)Harmful plant ……………. 4)I do not know ………………….

2.What is your positive view of the mesquite tree? ……………………..

3.What is your negative view of the Mesquite tree? …………………….

4.Is the region exposed to dust storms? ………………………….

5.Fixing sand encroachment by mesquit tree 1) Very good.……….. 2)Good …………

3)Harmful plant …………………. 4)I do not know ………………

5.Where is this species found within the area that you live? 1)On own land ………

2)On community land ……………3) On agricultural projects ………………

6.What are the most important products you harvest from this species?

7.What aspect of your needs does it supply? …………………….

8.When do you harvest? …………………………………….

9.How much of products? ………………………...

10.Are there other ways that people might generate a livelihood through Prosopis? …………………………..

11.What constraints do you face in the harvest of products from this species? ….

12.What constraints do you face in the sale of products from this species?......

13.Would you be interested in learning new/different ways of using this species?
14.Why?....................

15.What are the most serious problems you are facing with this species today?................

16.What were the most serious problems you faced with this species 15 years ago? ……………………..

17.Does eating fodder made from the fruits of mesquite cause harm to the animal?.................

18.What are the diseases resulting from eating mesquite feed animals? 1)Swelling of the animal's abdomen ……………………….2) Damaged teeth of the animal ……………… 3)Other ……………………………….

Appendix (2) Histograms for infrared and red bands Figure: 12 (b,c,d,e,f,and g)

(b)

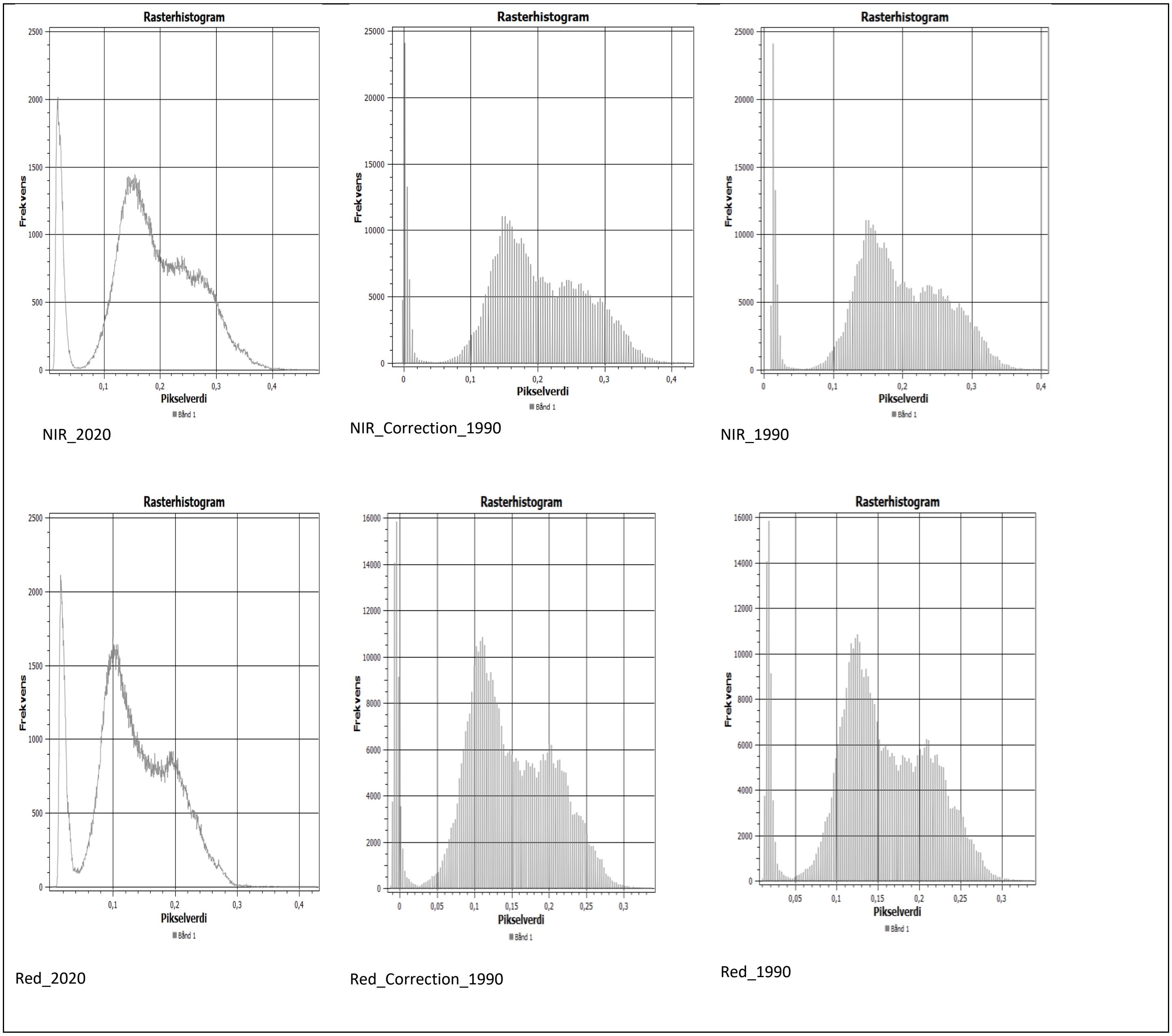


Figure 12**b**: Histograms for infrared (bands) upper panel (b-c) and Red upper panel (e-f) before (far right) and after (middle) correction for the corrected image (1990) compared to the reference image (left,2020).

(c)

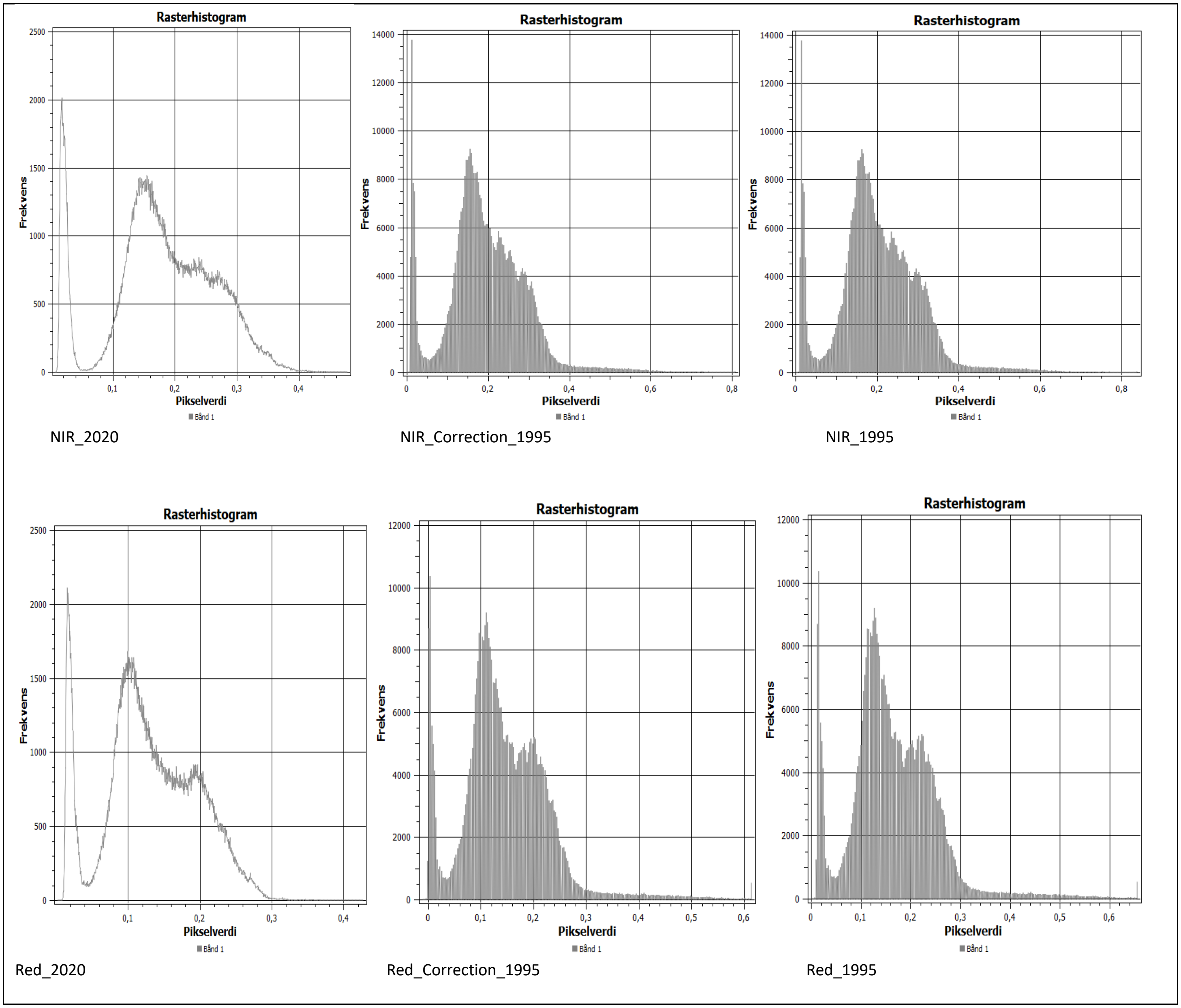


Figure 12**c**: Histograms for infrared (bands) upper panel (b-c) and Red upper panel (e-f) before (far right) and after (middle) correction for the corrected image (1995) compared to the reference image (left,2020).

(d)

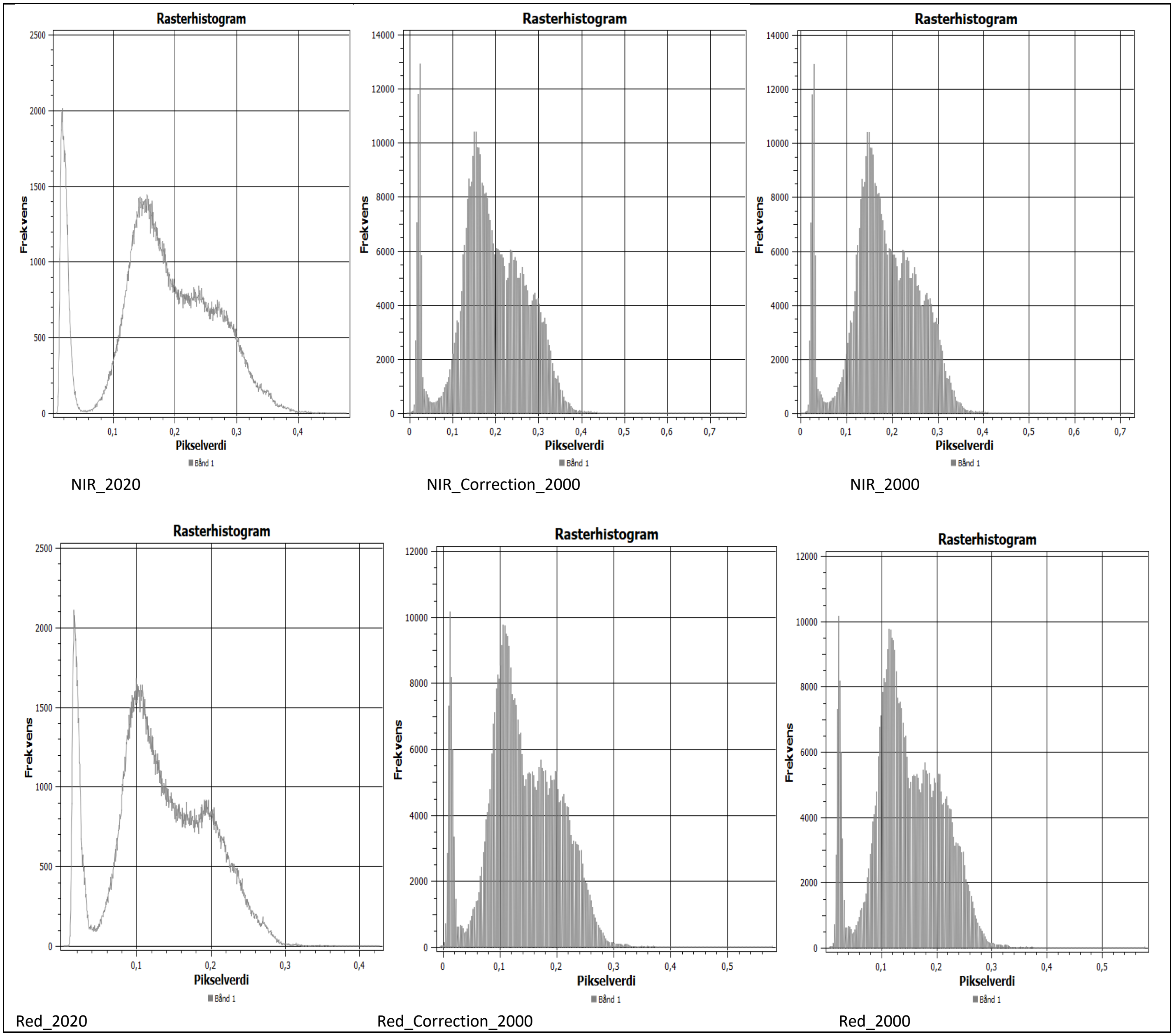


Figure 12**d**: Histograms for infrared (bands) upper panel (b-c) and Red upper panel (e-f) before (far right) and after (middle) correction for the corrected image (2000) compared to the reference image (left,2020).

(e)

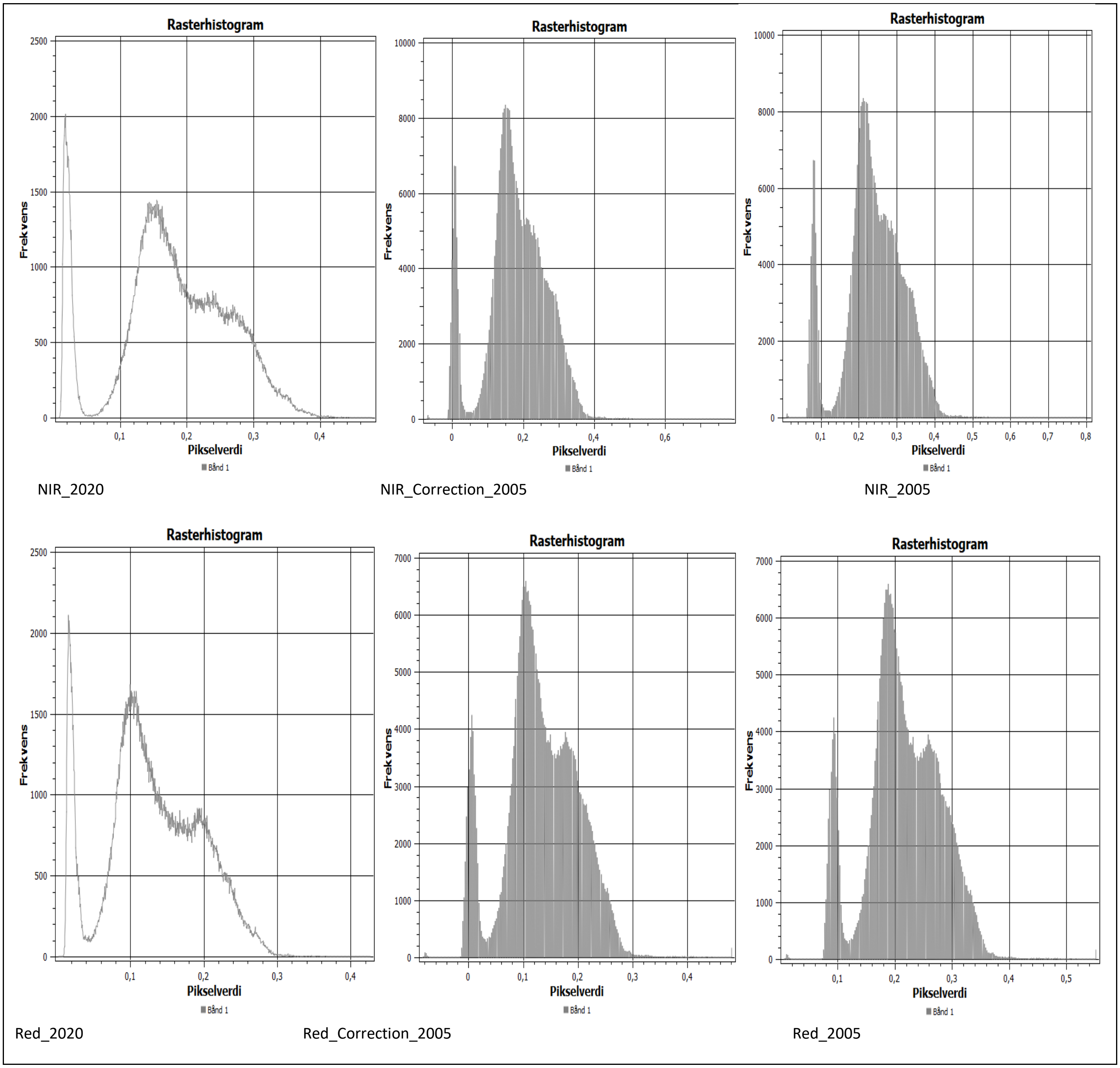


Figure 12**e**: Histograms for infrared (bands) upper panel (b-c) and Red upper panel (e-f) before (far right) and after (middle) correction for the corrected image (2005) compared to the reference image (left,2020).

(f)

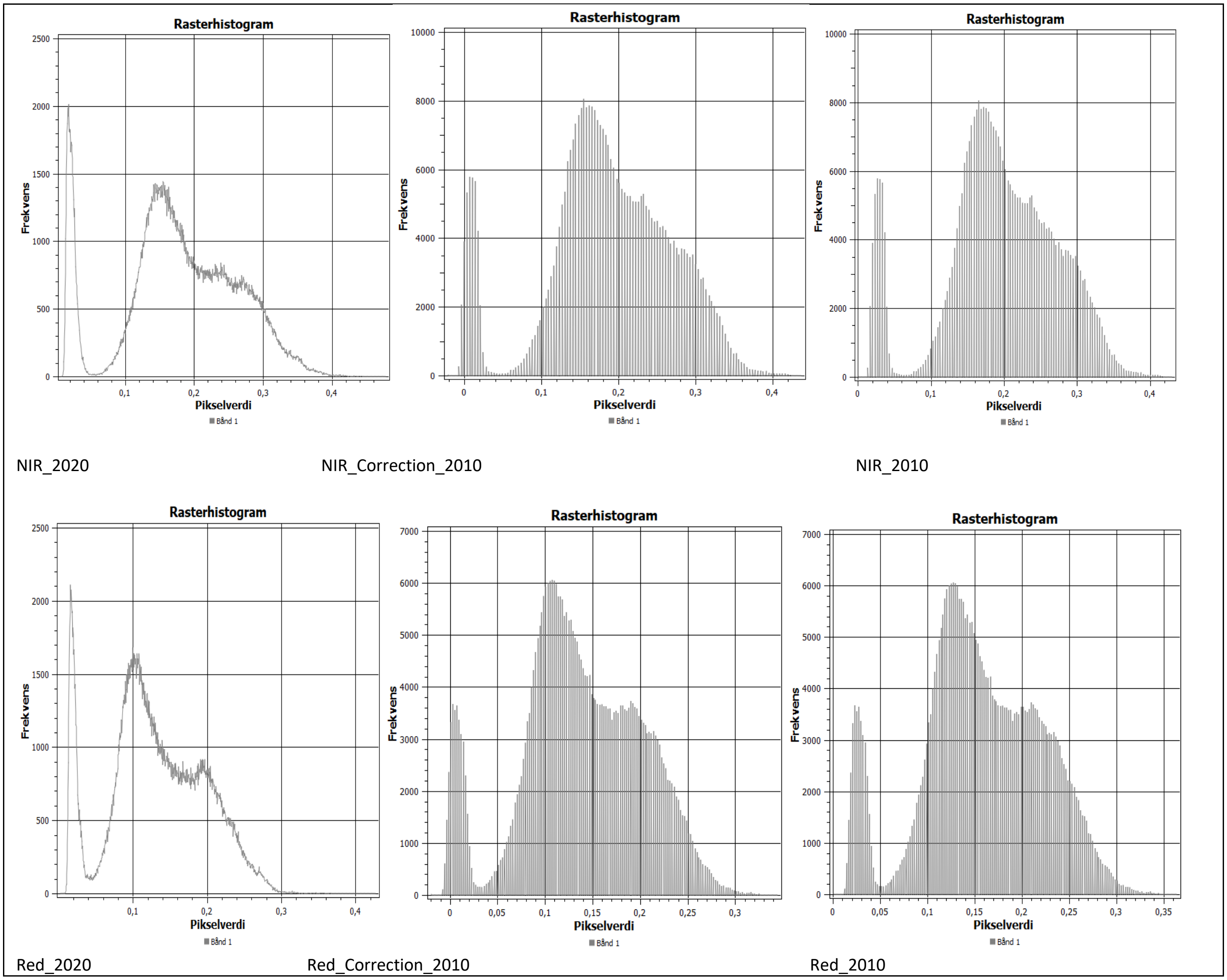


Figure 12**f**: Histograms for infrared (bands) upper panel (b-c) and Red upper panel (e-f) before (far right) and after (middle) correction for the corrected image (2010) compared to the reference image (left,2020).

(g)

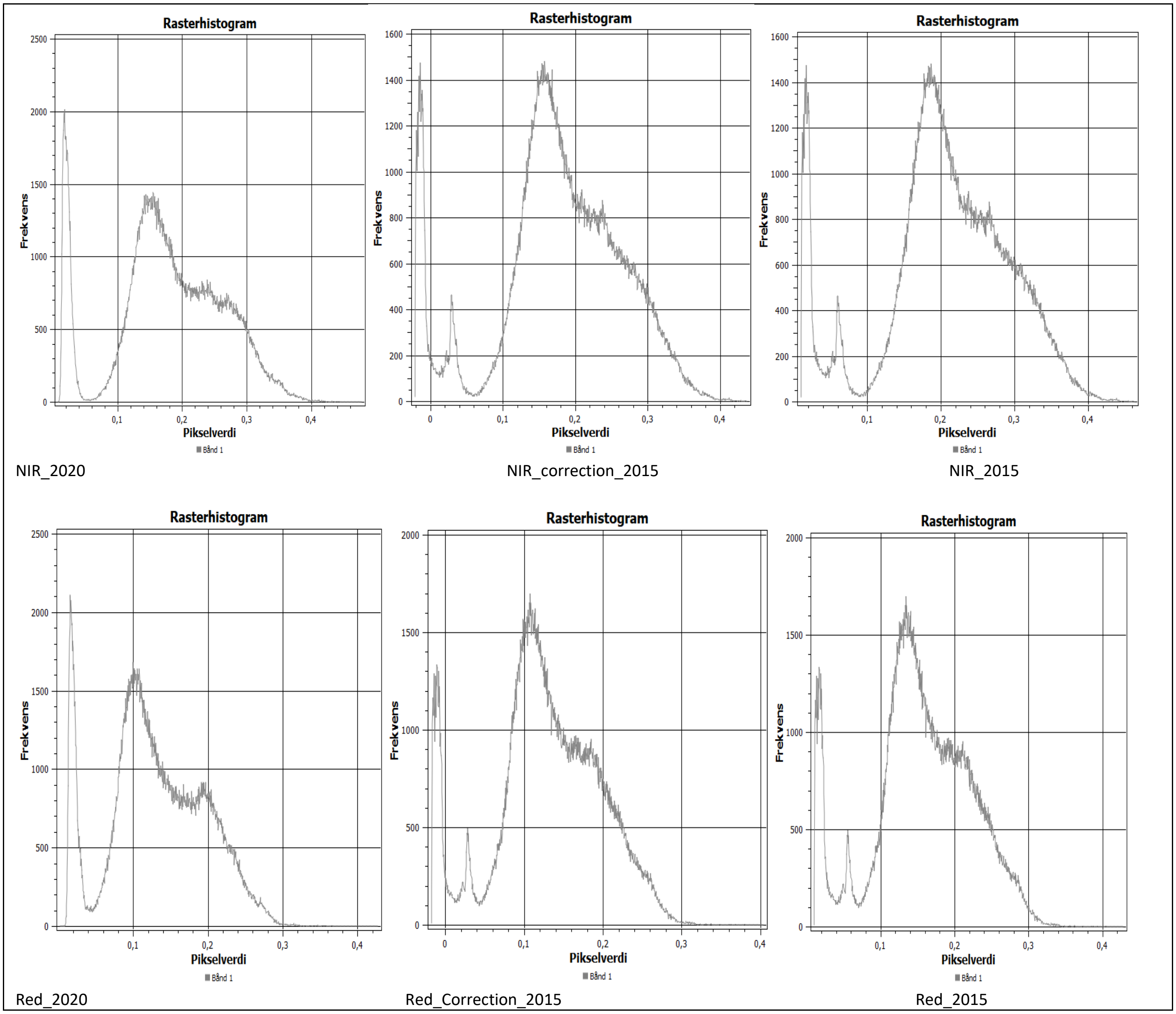


Figure 12**g**: Histograms for infrared (bands) upper panel (b-c) and Red upper panel (e-f) before (far right) and after (middle) correction for the corrected image (2015) compared to the reference image (left,2020).

Appendix (3) NDVI _Sinkat and Jubayt Figure 13: (1,2,3,4,5,and6)

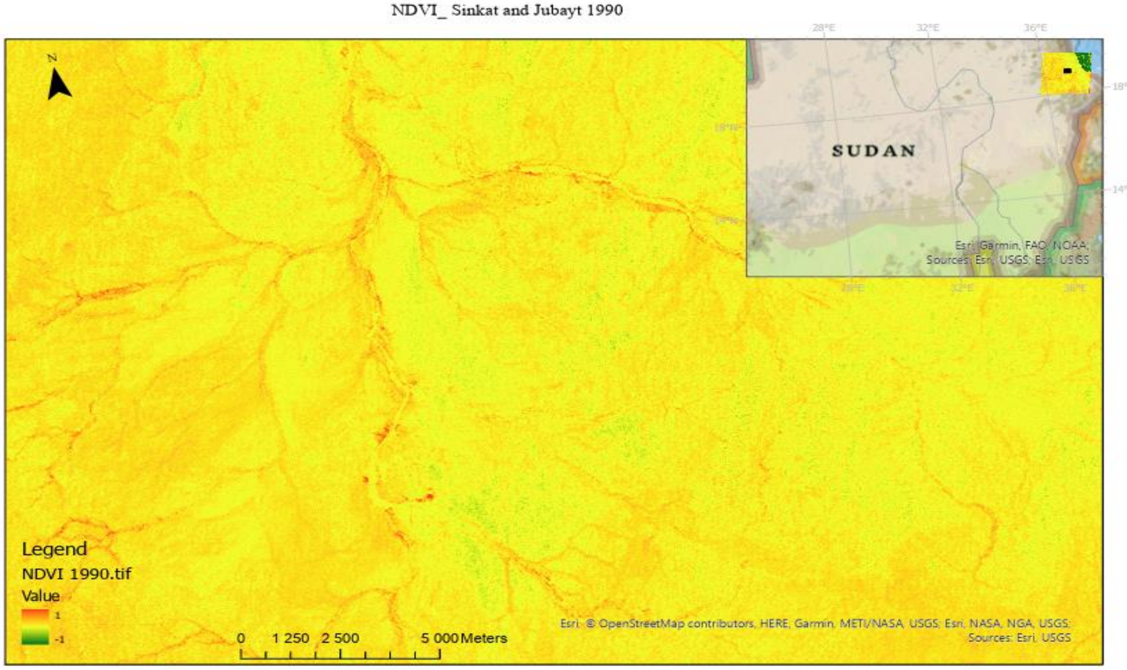


Fig 13.1: NDVI Map _1990 (Sinkat and Jubyt)

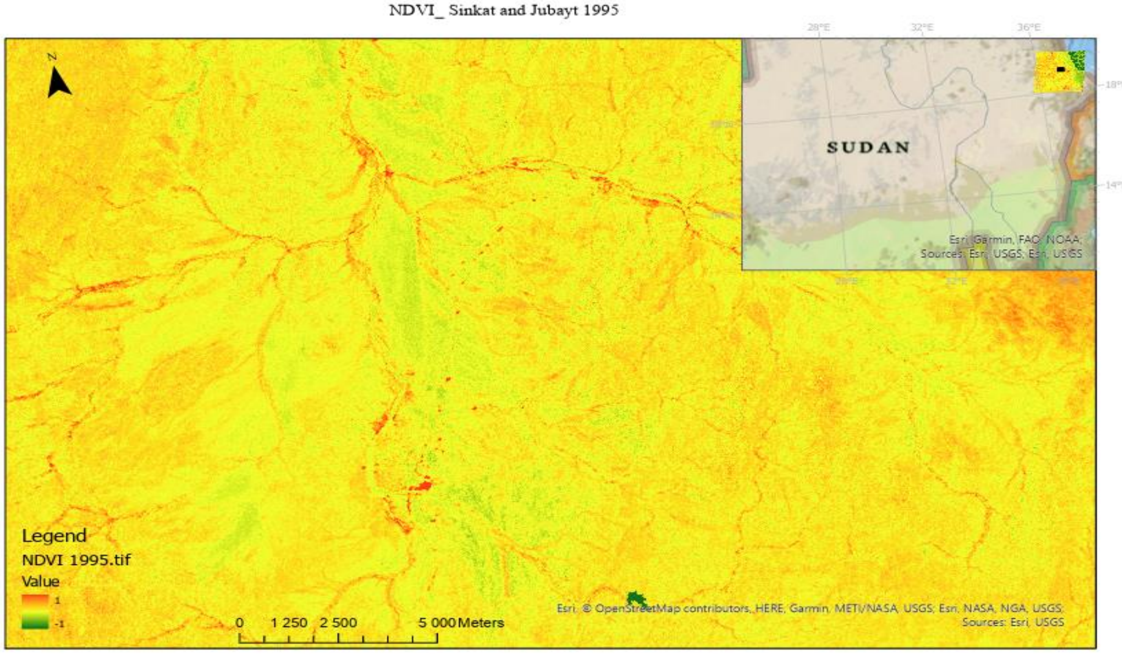


Fig 13.2: NDVI Map _1995 (Sinkat and Jubayt)

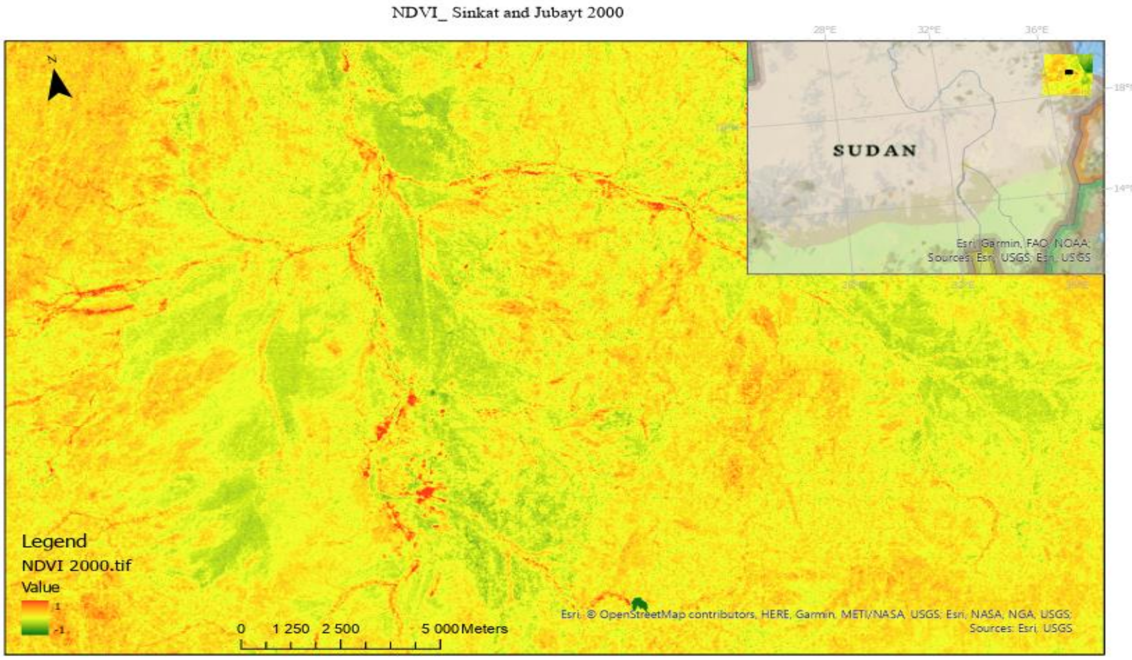


Fig 13.3: NDVI Map _2000 (Sinkat and Jubayt)

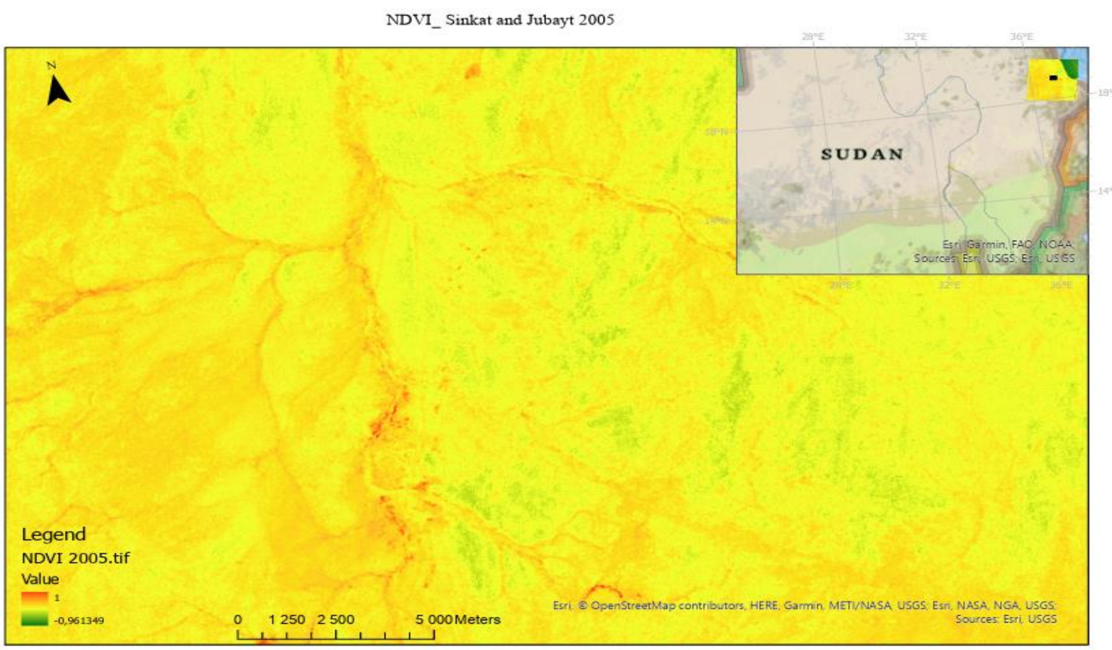


Fig 13.4: NDVI Map _2005 (Sinkat and Jubayt)

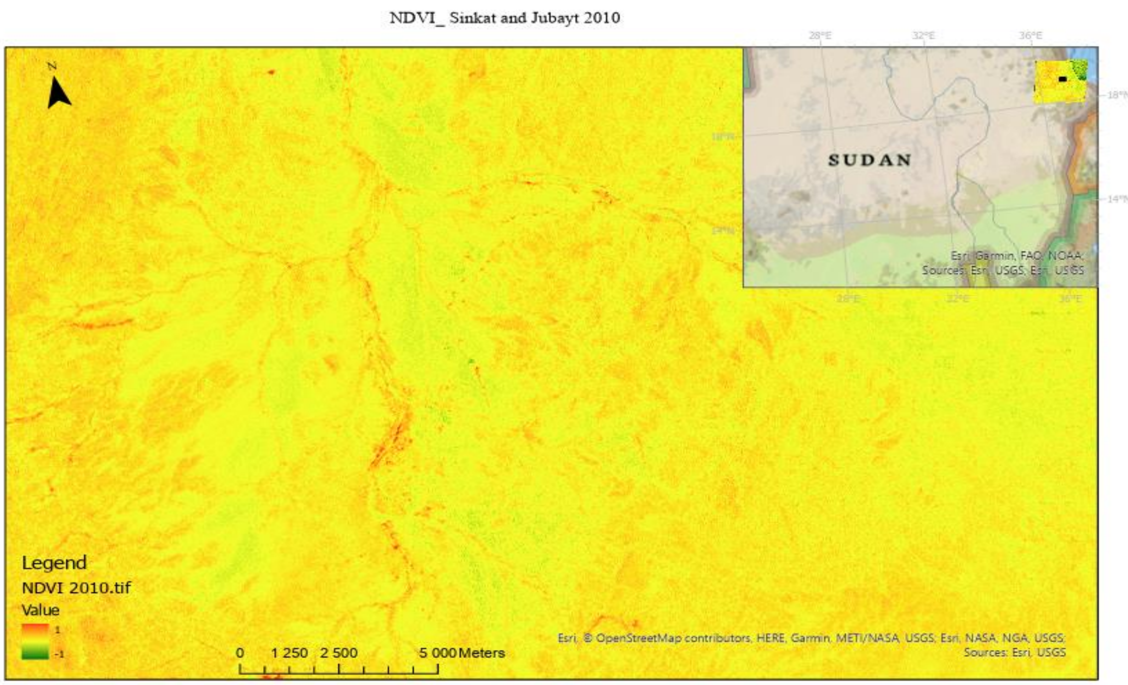


Fig 13.5: NDVI Map _2010 (Sinkat and Jubayt)

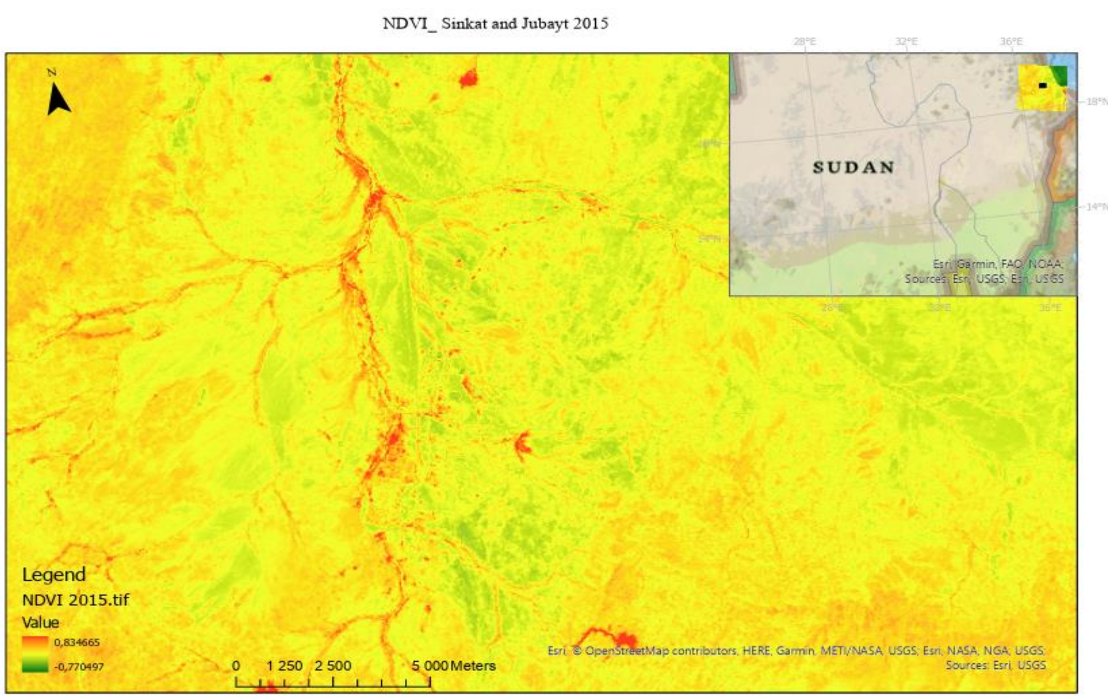


Fig 13.6: NDVI Map _2015 (Sinkat and Jubayt)

Appendix (4) NDVI _ Salum Figure 15: (1,2,3,4,5,and6)

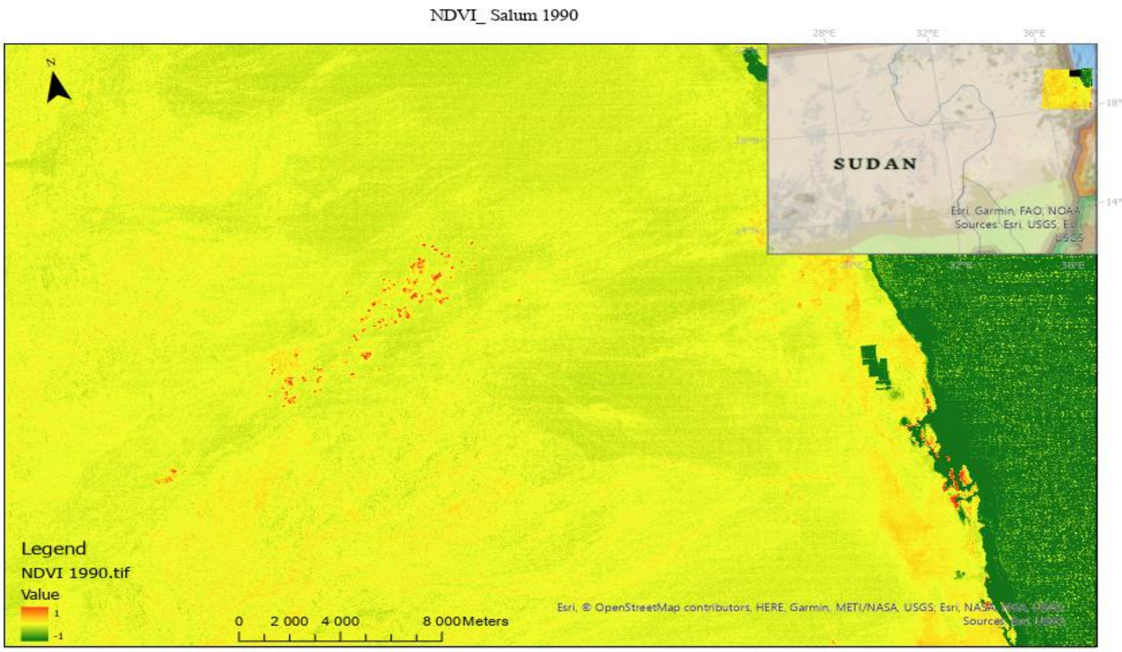


Fig 15.1: NDVI Map_1990 (Salum)

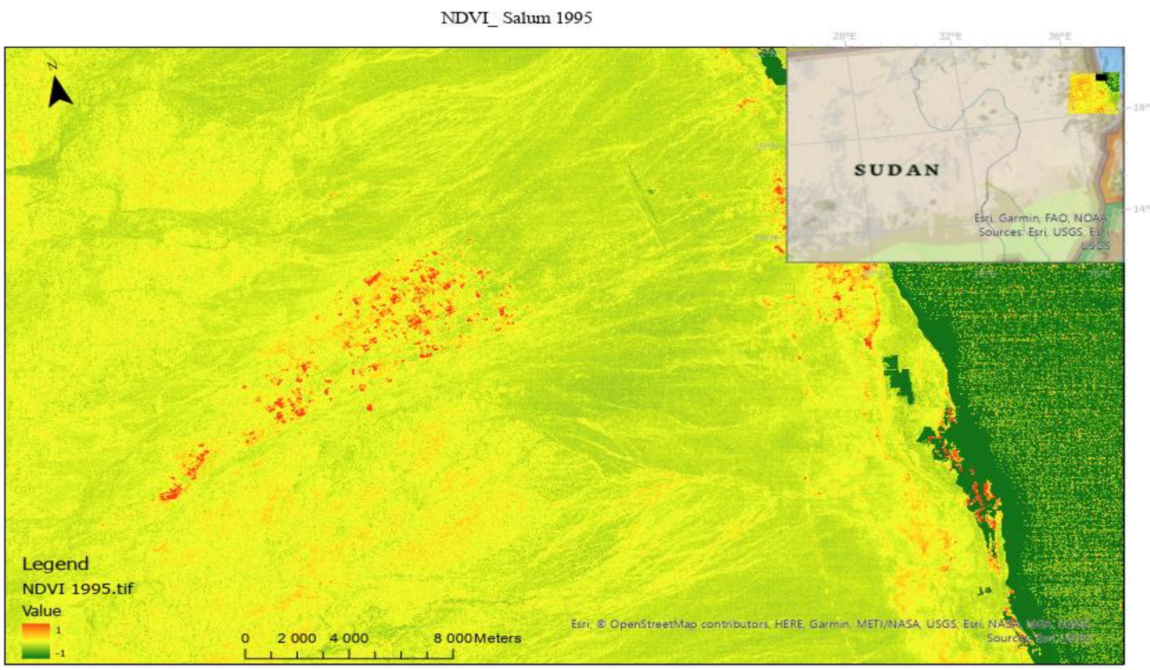


Fig 15.2: NDVI Map_1995(Salum)

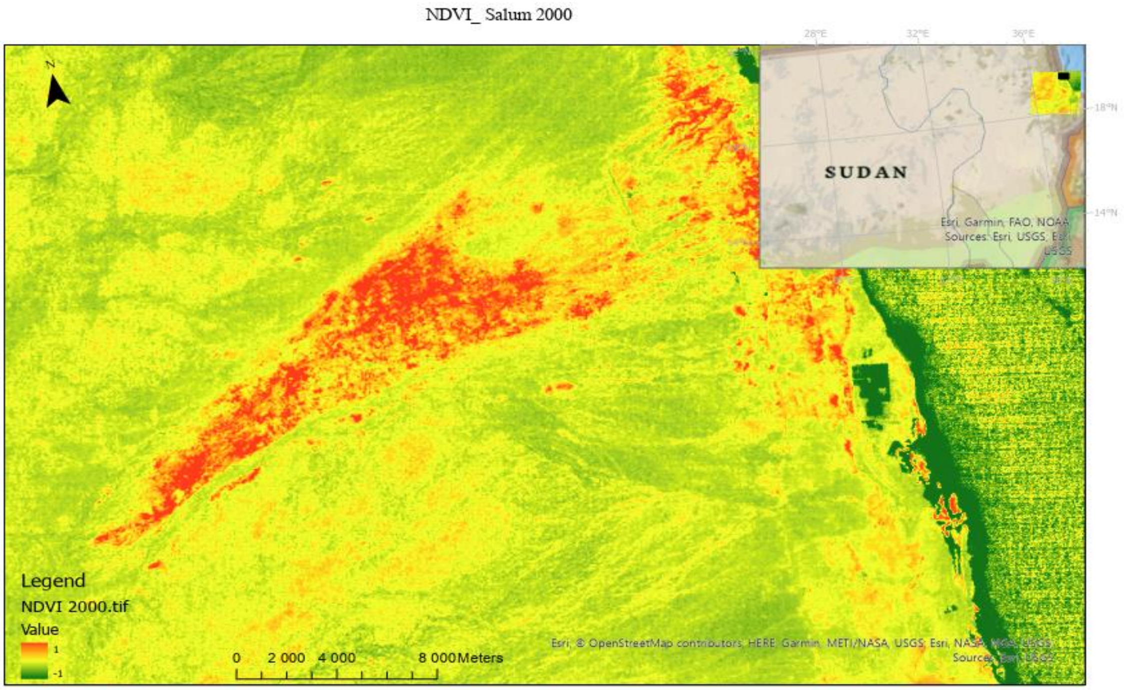


Fig 15.3: NDVI Map_2000(Salum)

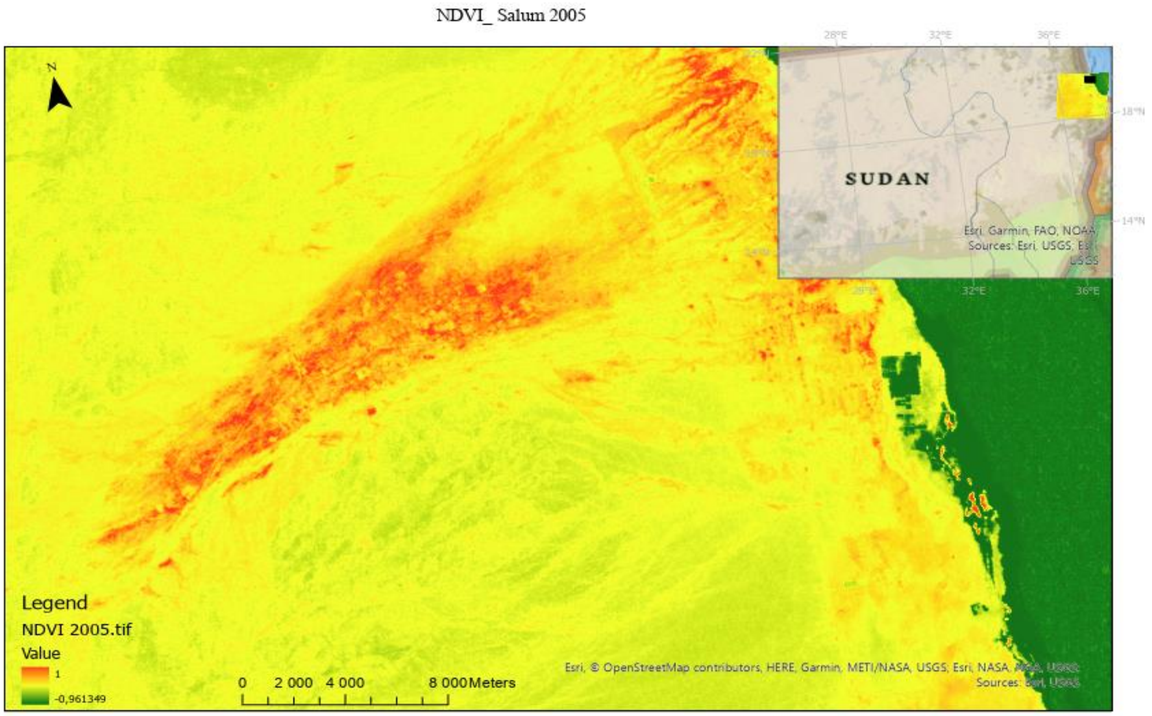


Fig 15.4: NDVI Map_2005 (Salum)

NDVI_ Salum 2010

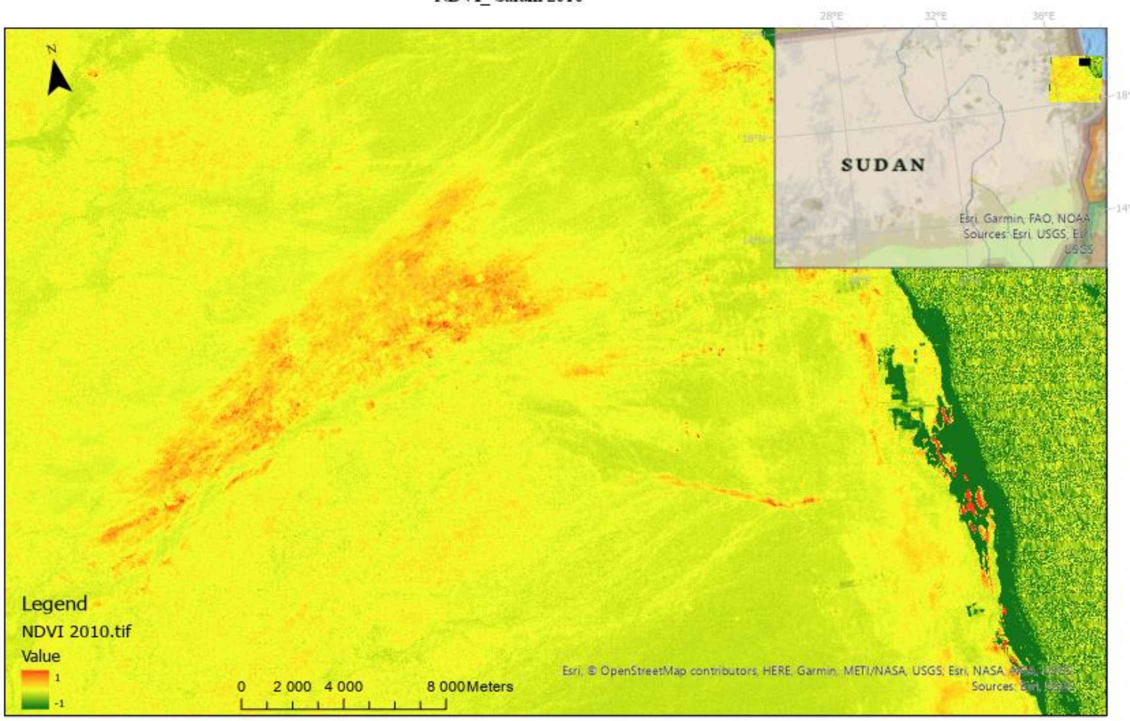


Fig 15.5: NDVI Map_2010 (Salum)

NDVI_ Salum 2015

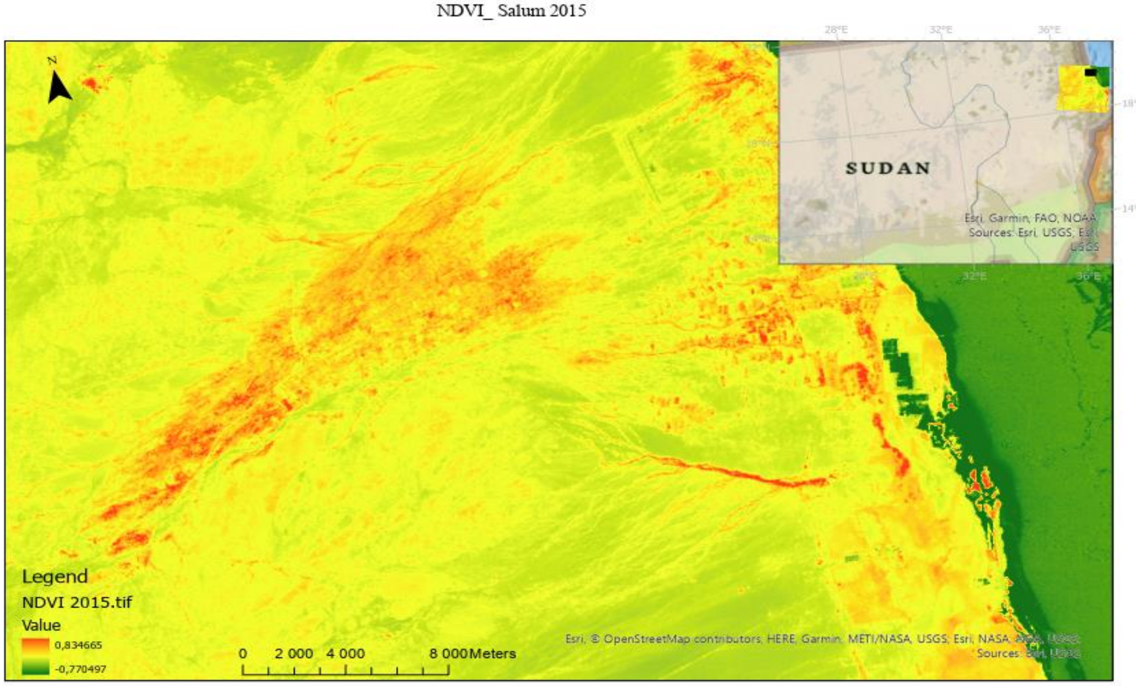


Fig 15.6: NDVI Map_2015 (Salum)

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Appendix (5) NDVI _ Ashat Figure 17: (1,2,3,4,5, and6)

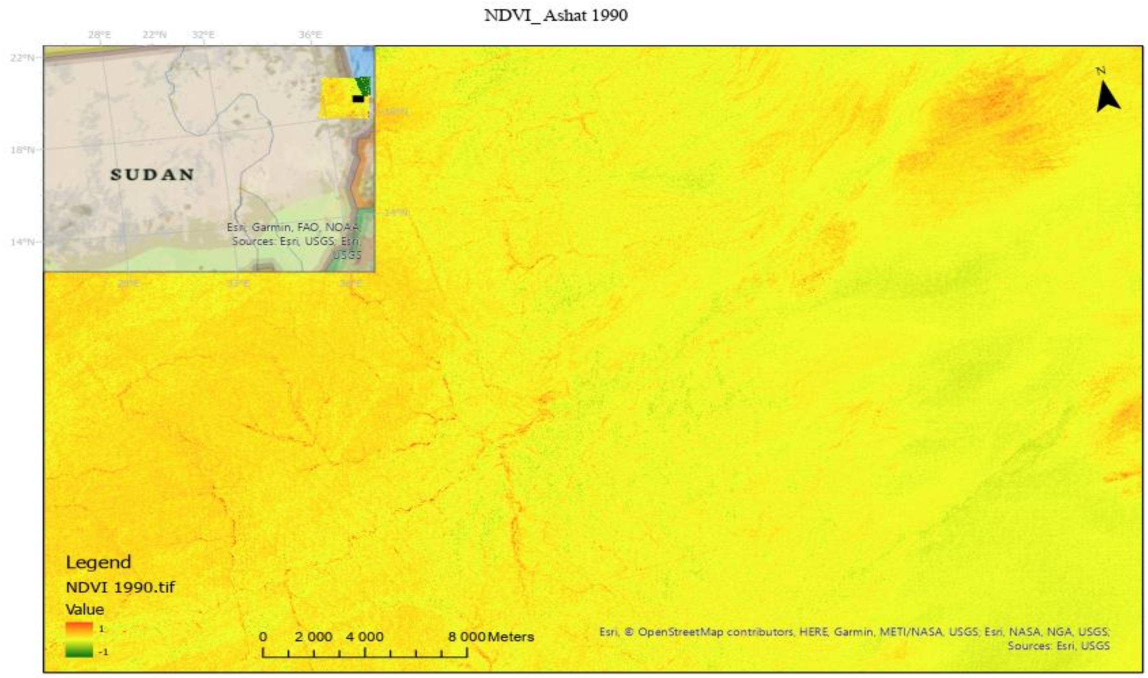

Fig 17.1: NDVI Map_1990(Ashat)

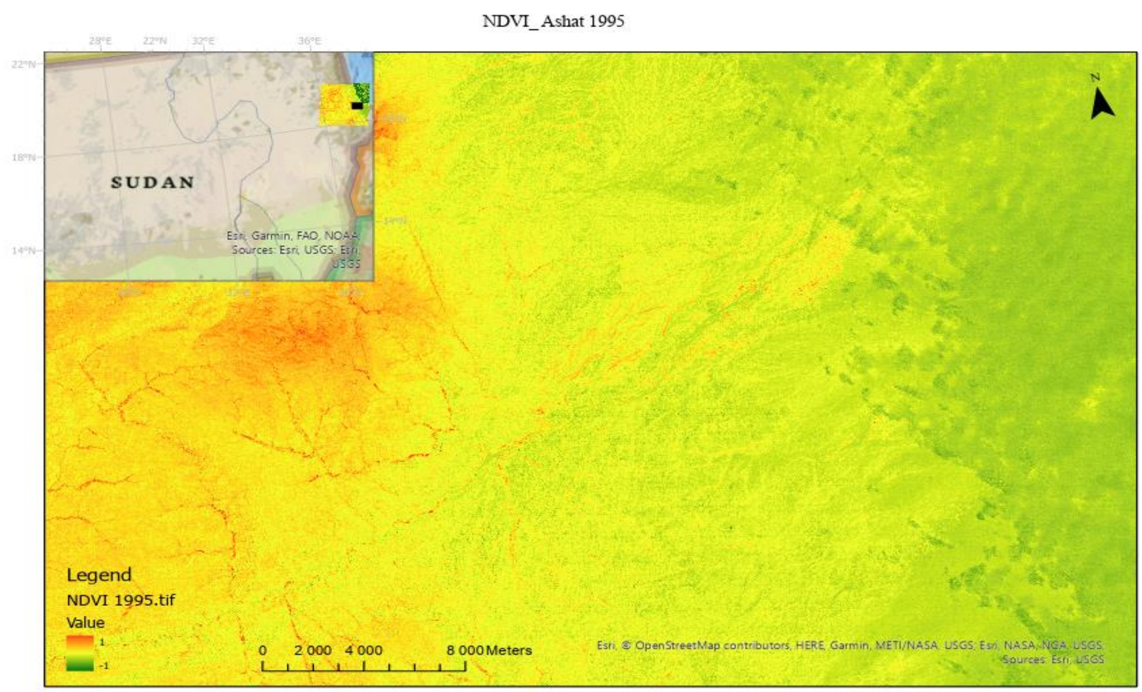

Fig 17.2: NDVI Map_1995 (Ashat)

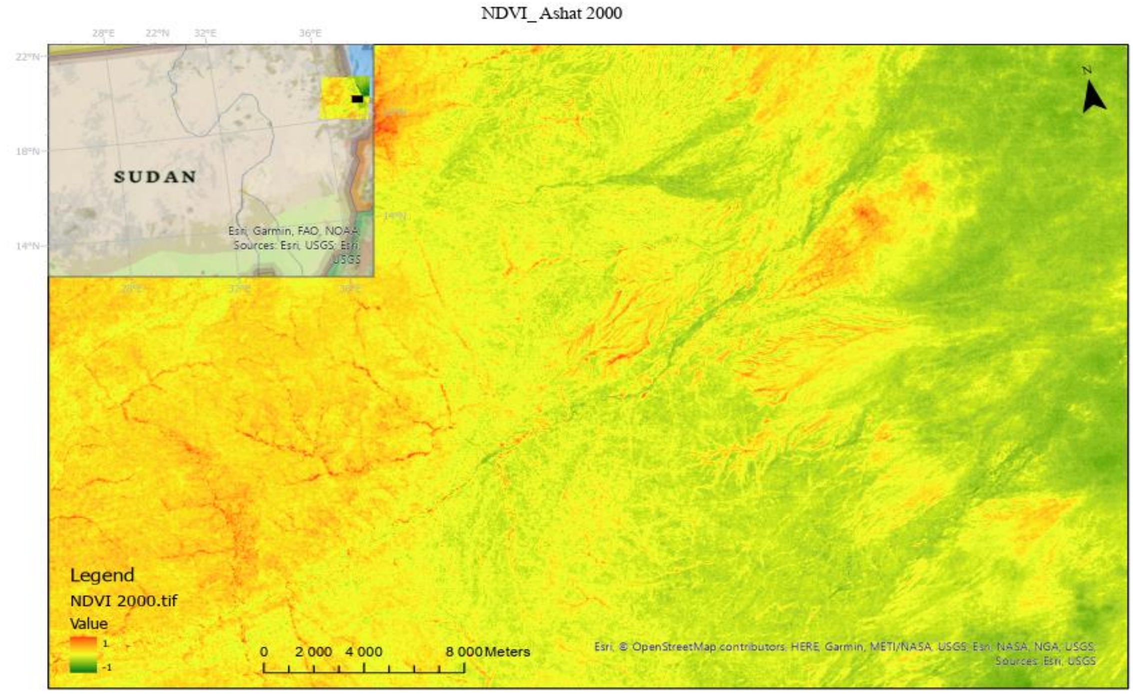

Fig 17.3: NDVI Map_2000 (Ashat)

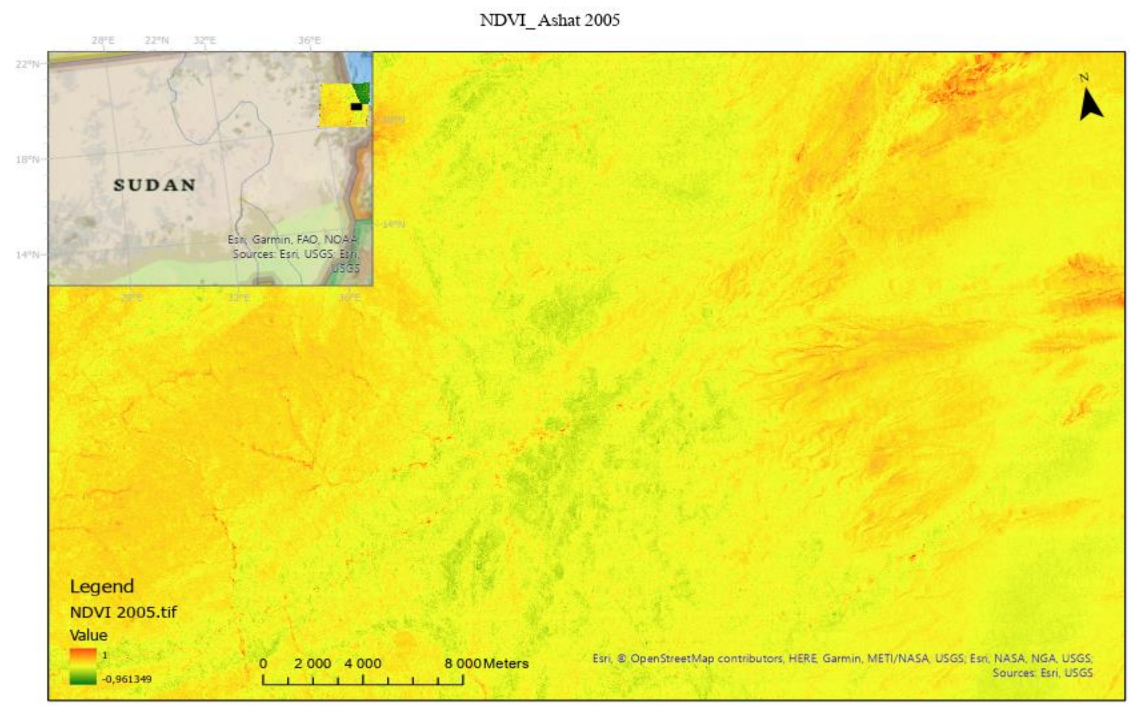

Fig 17.4: NDVI Map_2005 (Ashat)

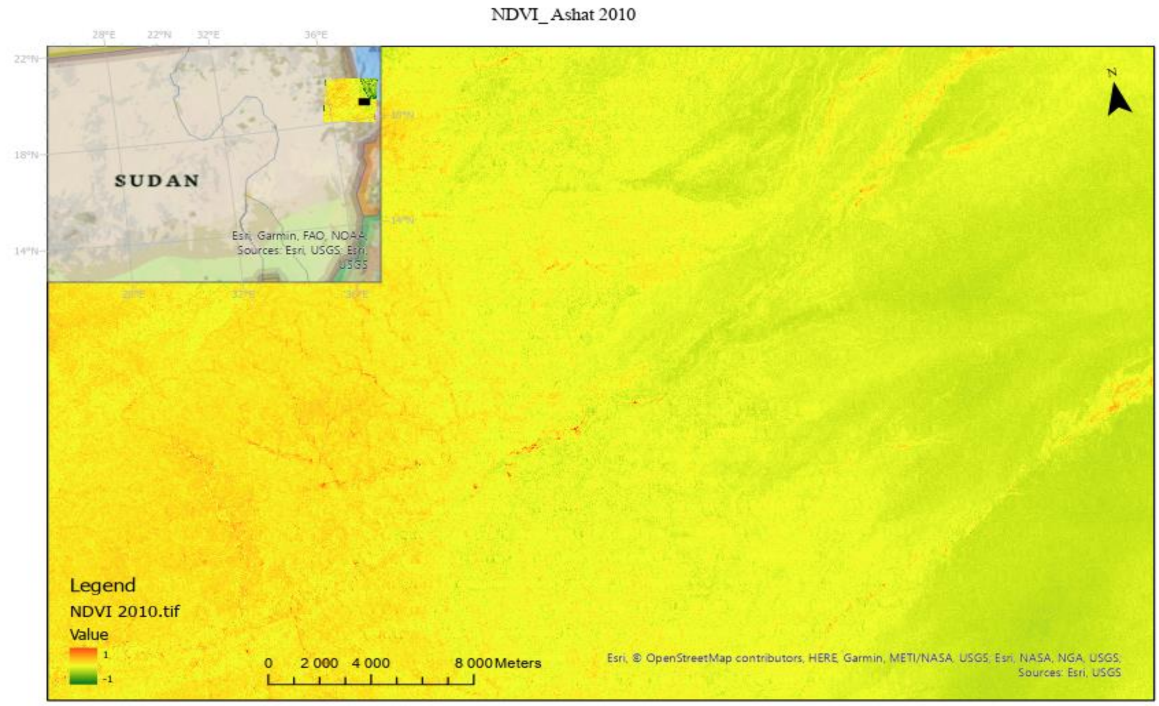

Fig 17.5: NDVI Map_2010 (Ashat)

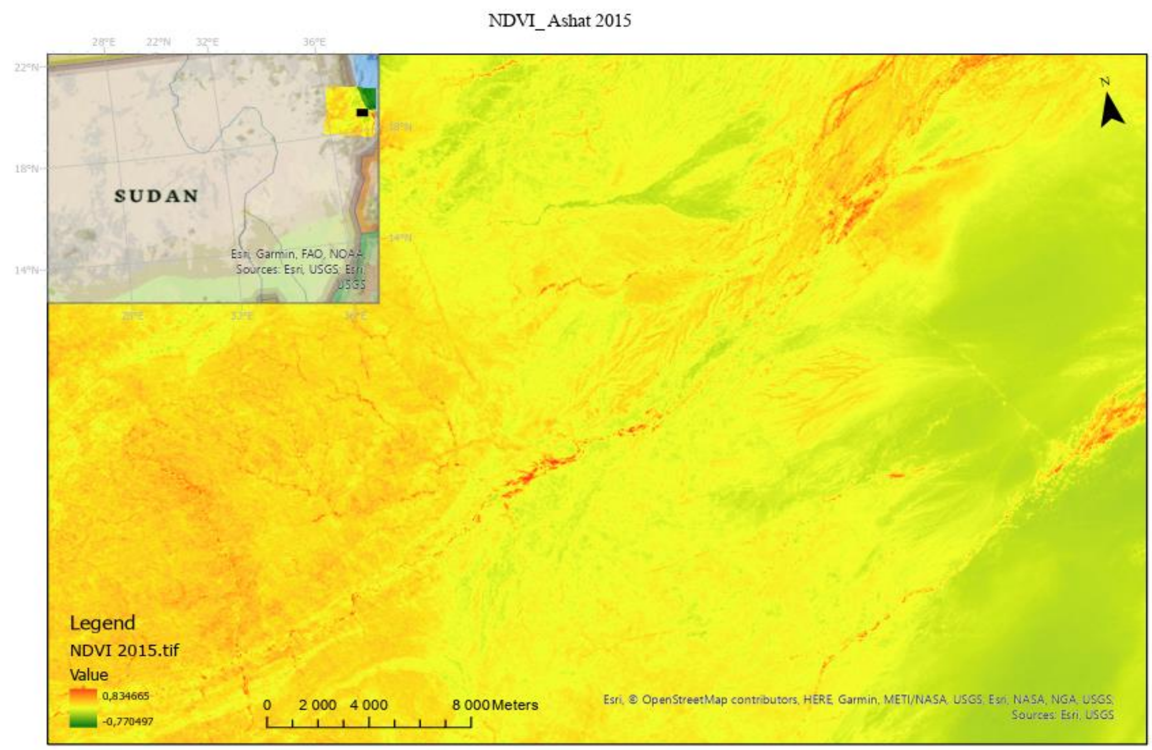

Fig 17.6: NDVI Map_2015 (Ashat)