DROUGHT ASSESSMENT IN AFGHANISTAN USING REMOTELY SENSED DATA

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ABSTRACT

DROUGHT ASSESSMENT IN AFGHANISTAN USING REMOTELY SENSED DATA

Afghanistan's climate ranges from arid to semi-arid because it is a landlocked country in central and southern Asia. The vast majority of people work in agriculture, and agriculture accounts for a significant portion of the nation's GDP. Climate change-related droughts that have occurred repeatedly have made it increasingly difficult to implement practical water resources management techniques. Another noteworthy concern involves transboundary water flowing downstream to neighboring countries without any established sharing arrangements. Consequently, this study aims to examine drought assessment in Afghanistan over the period from 1992 to 2021. This assessment will be based on various indices, including the Standardized Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI), Reconnaissance Drought Index (RDI), and Surface Runoff Index (SRI). Data used in this study are remotely sensed precipitation, temperature and surface runoff data. In order to make compression between short term period and long-term period each of the indices are calculated in three different time scales (3_month, 6_month and 12_month). At the end Afghanistan's yearly drought maps of each four indices for each of the three-time scales are drawn by Geographic Information System (GIS) and the results obtained are discussed. Accordingly, the results revealed that most of the country, notably the west of Afghanistan, has endured several, significant droughts over the last 20 years at least, and also due to regional climate variations (arid and semi-arid), these four indexes behave differently in specific situations.

Keywords: Drought, SPI, SPEI, RDI, SRI

ÖZET

UZAKTAN ALGILANAN VERİ KULLANILARAK AFGANİSTAN'DA KURAKLIK DEĞERLENDİRMESİ

Afganistan'ın iklimi, Orta ve Güney Asya'da karasal bir ülke olması nedeniyle kurak ila yarı kurak arasında değişmektedir. Ülkenin büyük çoğunluğu tarım sektöründe çalışmakta ve tarım, ulusal gayri safi yurtiçi hasılanın önemli bir kısmını oluşturmaktadır. Tekrarlanan iklim değişikliği kaynaklı kuraklıklar, pratik su kaynakları yönetim tekniklerini uygulamayı giderek daha zor hale getirmiştir. Bir diğer önemli sorun, anlaşma olmadan akış gösteren sınır ötesi suların bulunmasıdır. Bu nedenle, bu çalışmanın amacı, 1992'den 2021'e kadar olan dönemde Afganistan'da kuraklık değerlendirmesini Standart Yağış İndeksi (SPI), Standart Yağış Evapotranspirasyon İndeksi (SPEI), Keşif Kuraklık İndeksi (RDI) ve Yüzey Akış İndeksi (SRI) kullanarak incelemektir. Bu çalışmada kullanılan veriler, uzaktan algılanan yağış, sıcaklık ve yüzey akışı verileridir. Kısa vadeli dönem ile uzun vadeli dönem arasında karşılaştırma yapmak için her bir endeks üç farklı zaman ölçeğinde (3 ay, 6 ay ve 12 ay) hesaplanmıştır. Sonuç olarak, Afganistan'ın yıllık kuraklık haritaları, Coğrafi Bilgi Sistemi (GIS) yardımıyla her dört endeksin her üç zaman ölçeği için hazırlanmış ve elde edilen sonuçlar tartışılmıştır. Bu doğrultuda, sonuçlar ülkenin büyük bir kısmının en azından son 20 yılda birkaç önemli kuraklık yaşadığını ortaya koymaktadır. Ayrıca bölgesel iklim varyasyonları (kurak ve yarı kurak) nedeniyle bu dört indeksin belirli durumlarda farklı davrandığını göstermektedir.

Anahtar kelimeler: Kuraklık, SPI, SPEI, RDI, SRI

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LIST OF ABBREVIATIONS

CMDI–Composite Multivariate Drought Index

PET–Potential Evapotranspiration

RDI –Reconnaissance Drought Index

RDIe–Modified Reconnaissance Drought Index

RS–Remotely Sensed

SPI – Standardized Precipitations Index

SPEI– Standardized Precipitations Evapotranspiration Index

SRI–Surface Runoff Index

SPERI–standardized precipitation evapotranspiration runoff index

SDI–Streamflow drought index

WSDI– Water Storage Deficit Index

CHAPTER 1

INTRODUCTION

1.1. Background

Drought, as a natural occurrence, carries adverse consequences for the environment, agriculture, individuals, wildlife, the economy, and society at large (Tayfur & Alami, 2022). It is marked by an extended duration of insufficient rainfall and a scarcity of water resources, which can result in far-reaching and frequently severe repercussions. According to Palmer (1965) drought is a metrological abnormality that is characterized by an extended and abnormal lack of precipitation. It is characterized as an extended period of notably arid conditions that persists long enough to induce a substantial hydrological imbalance(IPCC, 2014). Yet, no single definition of drought is universally agreed upon (Tsakiris et al., 2013). Typically, there exist four distinct types of droughts: meteorological, agricultural, hydrological, and socioeconomic. As a recurrent natural disaster, droughts can disrupt food and water supplies, strain agricultural systems, exacerbate water resource challenges, and fuel economic losses. Climate change further compounds these challenges, altering precipitation patterns and intensifying the severity and frequency of drought events in various regions. Understanding the causes, impacts, and effective mitigation strategies for drought is not only critical for disaster preparedness but also essential for building resilience in the face of an increasingly uncertain climatic future.

The people of Afghanistan are particularly vulnerable to be harmed by droughts and other natural calamities following 40 years of subsequent conflict. The aggravation of drought has caused the destruction of agricultural fields and increased the crisis of hunger and poverty in Afghanistan. According to McCarthy, (2021), During the 2018–19 drought, a significant portion of Afghanistan, exceeding two-thirds of its land area, felt its effects. This event led to the displacement of over 371,000 individuals and left around four million residents in the hardest-hit provinces requiring critical life-saving assistance Drought conditions also caused millions of people to experience food insecurity.

Afghanistan’s geographical positioning and prolonged environmental degradation make it exceptionally prone to recurrent and severe natural disasters, including flooding, earthquakes, avalanches, landslides, and droughts. These events frequently result in the tragic loss of lives, livelihoods, and property (Ranghieri et al., 2017). Iqbal et al. (2018) also says that drought has caused substantial adverse economic consequences. These include job losses, reduced agricultural and livestock yields, and a limited range of livelihood choices for farmers, all of which have exacerbated their financial well-being. In addition, there have been social repercussions such as population displacement, a prevailing sense of despair and grief, conflicts arising from competition for water resources, health-related challenges, disruptions to children's access to education, instances of hunger, and limitations on available food varieties. In terms of GHG emissions, Afghanistan is among the middle-class nations in the world. However, because of its susceptibility to droughts, floods, and landslides/avalanches, Afghanistan is among the nations facing the greatest peril from the consequences of climate change (Thomas et al., 2016).

In an era marked by climate variability and change, the need for comprehensive and timely drought assessments has become increasingly evident. Drought assessment involves the systematic measurement and analysis of various indicators, including precipitation, temperature, soil moisture, and water levels. Across continents, nations, and regions, experts, meteorologists, and environmental scientists employ a range of tools and methodologies to monitor and evaluate drought conditions. Although drought cannot be avoided, its effects on the environment and on people can be lessened through preparation and management. The effectiveness of drought preparation and management depends on how precisely the drought is characterized and its features (severity, intensity, length...) are measured (Traore, 2016). Some specific drought assessment and analysis methods that are commonly used such as Drought Severity Index of Palmer (Palmer, 1965). According to Lloyd-Hughes & Saunders (2002), the Palmer Drought Severity Index (PDSI) incorporates rainfall, evapotranspiration, soil water recharge, runoff, water loss from soil, and an empirical weighting factor.

McKee et al. (1993) created the Standardized Precipitation Index (SPI). It relies on the contrast between the monthly precipitation anomaly and the precipitation standard deviation for that particular time frame. The fact that just the precipitation data is required is considered a significant benefit. The SPI, on the other hand, is unable to account for the vases where increased evapotranspiration occurs when the temperature increases as a result of climate change, which in that case the Standardized Precipitation Evapotranspiration Index (SPEI) will be used. It is derived from measurements of precipitation (P) and potential evapotranspiration (PET) (Almeida-Ñauñay et al., 2022).

Surface Runoff Index (SRI) is another index formulated by (Shukla & Wood, 2008) for evaluating hydrological drought by utilizing stream flow data. This approach involves the fitting of an appropriate distribution to the flow records of a specific location.

The Reconnaissance Drought Index is another measure of drought (Tsakiris et al., 2007). Its foundation is the proportion of precipitation to possible evapotranspiration (PET). An et al. (2022) constructed and examined the reconnaissance drought index (RDI) and standardized precipitation index (SPI) for upcoming droughts in Korea using climate data based on SSP scenarios. Examination and assessment were carried out on temperature and precipitation data derived from the SSP1-2.6 and SSP5-8.5 scenarios. Katipoğlu et al. (2020) also applied Reconnaissance Drought Index (RDI) in Euphrates basin in Türkiye. In this study, data from 16 meteorological observation stations were collected and computed over a 12-month timeframe. The frequencies of drought classes were determined, and the index values were subsequently analyzed using runs analysis. This analysis aimed to identify the maximum and average drought characteristics, such as drought duration and severity, within the basin and to explore the meteorological drought phenomenon. The Mann-Kendall (MK) and Modified Mann-Kendall (MMK) tests were employed to examine the autocorrelation of the RDI values. Additionally, the study involved the mapping of increasing and decreasing trend values within the Geographic Information System (GIS) environment. Tigkas et al. (2016) Introduced a modified Reconnaissance Drought Index (RDIe) incorporating effective precipitation instead of precipitation. This change improves the effectiveness of the index for agricultural drought analysis by appropriately depicting the amount of water that agricultural systems use to their advantage.

The relative SPI and PDSI indicators were developed by(Dubrovsky et al., 2009) with the intention of using them to determine whether the drought features in Czech Republic may be affected by the upcoming climate change. To assess the prevailing climate drought conditions, initial relative indices were generated using monthly weather data collected from 45 Czech sites. Subsequently, drought indices were created by adjusting the observed data based on five climate change scenarios derived from Global

Climate Models (GCMs). This process allowed for the evaluation of future climatic drought conditions.

To assess the effectiveness of different standardized drought indices and identify the most suitable time scale in relation to the standardized vegetation index, Almeida-Ñauñay and colleagues (2022) conducted an evaluation. They examined the performance of various climate drought indices, including SPI and SPEI, alongside agricultural drought indices like VHI and SVHI, within semiarid grassland regions across multiple time scales. The results showed that SPEI was better correlated with VHI compared to SPI. Additionally, SVHI outperformed VHI in the crucial vegetation periods. Wang et al. (2019) used runoff data to develop a multi-scalar meteorological drought index which uses the same calculation principles as the standardized precipitation evapotranspiration index (SPEI). Using techniques like Penman-Monteith and Copula, (Wang et al., 2019) harnessed precipitation, temperature, relative humidity, sunshine hours, wind speed, and runoff data to construct a multi-scalar drought index termed the Standardized Precipitation Evapotranspiration Runoff Index (SPERI). The development of this index was grounded in the principles that underlie the computation of the Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI). Along with the SPI and SPEI, this index is applied to the Chinese province of Yunnan.

To create the regionally independent integrated drought, (Jiao et al., 2019) established a framework for a new integrated drought index and incorporated certain variable data. The idea of meteorological, agricultural, and vegetation drought serves as the foundation for geographically independent integrated drought. Bageshree et al. (2022) studied a multivariate drought index considering multidimensional hydro-climatological drought propagation, and the applicability of the developed index examining for spatiotemporal drought characterization in the highly drought-prone Marathwada region of central India by using two approaches: principal component analysis (PCA) and copula. Based on the notion of agricultural drought, (Wu et al., 2021) constructed a number of novel drought indices using soil moisture and evapotranspiration. These drought indicators represent the North China Plain's winter wheat's water stress (NCP).

Jahangir & Yarahmadi, (2020) employed an investigation of streamflow drought index (SDI) method in Lorestan province of Iran to predict the drought onset and its duration. This approach incorporates both the cumulative flow rate of the river and the spatial extent of drought to assess and monitor hydrological droughts. The research involved the investigation of four distinct time periods, namely 3, 6, 9, and 12 months, at selected locations within the province.. (Gulmez et al., 2021) also conducted an investigation through streamflow drought index (SDI) in the Aegean region, which has an important economic, historical and socio-cultural role in the western Türkiye. The average discharge was used in the related stations. Then SDI is acquired with 1-, 3-, and 12-month moving averages to describe the degree of drought severity related to streamflow in the Basins. (Hasan et al., 2021) applied a Streamflow Drought Index (SDI) and theory of runs (ToR) research to identify the drought characteristics and temporal assessment of drought. Almost the same study is done by (Tareke & Awoke, 2022), conducting the streamflow drought index (SDI) to measure historical hydrological drought in Ethiopia in order to better comprehend its effects on the construction of infrastructure for water resources.

Arid and semi-arid regions could face substantial consequences, even in the scenario where future drought severity, duration, and intensity are projected to rise (Bisht et al., 2019). Afghanistan's semi-arid and arid climate has already caused country to experience more droughts in recent years of 1999, 2000, 2001, 2005, 2007, 2010, 2016, and 2017. Also, it is expected that droughts will become more frequent and commonplace, elevating the risk of desertification, land degradation, and severe soil erosion in Afghanistan (Rousta et al., 2020). That’s why the overall object of this thesis is to asses four drought indices such as SPI, SPEI, RDI and SRI over all Afghanistan. In this study the drought indices are calculated for 30 years which start from 1992 until 2021.

1.2. Drought and Conflicts

Afghanistan is hydrographically divided into five major river basins, the Amu Darya, Harirud-Murghab, Helmand, Northern and the Kabul River Basin, all of which cross international boundaries. Afghanistan's entire water area in land is 61 million acres (Salman, 2007). The Amu Darya River is one of the longest rivers in Central Asia. These transboundary waters often create conflicts with neighbors specially with Iran and Pakistan. Unlike the tensions between Afghanistan and Pakistan or Pakistan and India, Iran and Afghanistan don't have any significant geographical conflicts. However, as each side is affected by droughts, climate change, and improper water management, a simmering dispute over the distribution of water from the Helmand River is endangering their partnership (Aman, 2016). The history behind the recent conflict goes back to 1870s when Afghanistan was under British control and Iran-Afghan border was drawn along the main branch of the Helmand River (Aman, 2016). Then in 1939, 1948, 1951 and 1973, treaties on sharing the river's waters were signed but due to government changes and problems in both sides the treaties were never completely ratified. According to (Hafeznia et al., 2006) the Hirmand River originates from Afghanistan and the life of the people of Sistan depends on it. The flow of Hirmand water and the reduction of water flowing towards Sistan (Iran) have always caused problems in the last hundred years.It has created political relations between Iran and Afghanistan at the local and national levels. Hirmand River in the eastern border of Iran enters Sistan from Afghanistan and is the only water source supplying the Sistan plain. The Hirmand river, a significant water source for agriculture, is the main source of water for the Hamon lakes (Miri, 2006). According (Moosazadeh & Abbaszadeh, 2016) the areas of dispute between the two governments of Iran and Afghanistan are as follows.

The Hirmand legal system, which was established in 1972 between Iran and Afghanistan, resolved the water issue, although Iran has continued to claim its downstream rights ever since the regime's creation and implementation. The primary issue arose when Afghanistan's political elite crossed the Hirmand River at the beginning of the 20th century. They believed a river to be internal and thought the Afghan government had the exclusive right to use its water.

Before the Congress of Vienna in 1815, governments considered international rivers as part of their territory. In fact, the dominant view before the Congress of Vienna was the principle of absolute territorial sovereignty. This view, more or less since the separation of Afghanistan from Iran, has always been considered by the leaders of this country.

Throughout the bilateral water conflict, the Afghan government has diverted water on numerous occasions for instance, the Hirmand river in 1886. In general, this situation persisted over the years when the Afghan government built the "Baqarah" canal and dam between 1947 and 1957. With a capacity of 2800 cubic feet of water per second, it is 70 km long. Additionally, the 1.5 million cubic foot Kajaki Reservoir Dam, the Arghandab Dam on the Arghandab branch of Hirmand, as well as several canals such the "Gohargan", "Kashetchi" and "Hoqian Kamraq" has been constructedKajaki Reservoir Dam, Arghandab Dam and lately Kamal khan Dam on the Hirmand river can be named water storage issues between the two countries.

According to 1973 agreement, the Afghan government should deliver the determined amount of Iran's water right at the border. Therefore, the Afghan government is responsible for all the obstacles to its joint "delivery" with Iran to this country, including the intentional obstacles and the obstacles created unintentionally on the water path of the Hirmand River.

But Afghans officials always says that the water rights were delivered more than it was supposed to and also claims that the treaties were never completely ratified by their side. The conflict rose between the two countries to extent that Ashraf Ghani, the (former) president of Afghanistan, stated in March 2021 at the opening of the Kamal Khan Dam on the Helmand River close to the Iranian border that "from today, the control of water in the province is now in the hands of Afghans" and emphasized that Afghanistan "would no longer give free water to anyone," while "Iran can get extra water if it gives oil in return,"(Nagheeby & Warner, 2022). Iranian officials of course reacted to such statement.

Afghanistan also shares the water coming from Kabul River basin with Pakistan. Afghanistan supplies a sizable amount of the water used in Pakistan. The Kabul River provides 16–17% of Pakistan's total water supply (Nagheeby & Warner, 2022). The Kabul River in Afghanistan serves as a source of power and drainage for the Pakistani region of Khyber Pakhtunkhwa. Since there is no water agreement between the two countries, the situation in both of them is complicated due to a variety of natural causes and an increasing global demand for water. As a result of the rising population, climate change, and increased industrial and municipal demand in the absence of such an agreement, tensions between Afghanistan and Pakistan frequently resurface and are likely to worsen in the future (Ranjan & Chatterjee, 2020). For instance, water has previously been utilized according to each state's demands, but when Afghanistan decided to construct a dam (Shahtoot Dam) on Kabul River the Pakistani side Express their unpliancy (Nagheeby & Warner, 2022).

1.3. Objectives of the Study

The overall goal of this thesis is to assess historical drought conditions in Afghanistan using various drought indices, and connect them to the effects of climate change. The research consists of the following sub-objectives.

1. to produce comprehensive historical drought maps covering the entire country for a 30-year span, utilizing three distinct time intervals (3 months, 6 months, and 12 months).
2. To identify the primary characteristics of droughts such as frequency, magnitude and duration.
3. To compare the differences of drought in three different time periods (3-month, 6 month and 12month).

1.4. Significance of the Study

Droughts are one of the most expensive natural disasters on an annual basis; they have enormous, widespread effects on many different economic sectors and human populations at once. Drought is significant because it can cause food insecurity when corps fail and increase the risk of famine. Famine occurs when a sizable portion of the population no longer has access to food. It causes widespread acute malnutrition, sickness, and mortality throughout the affected area. Drought threatens crucial access to safe drinking water. This can result in people drinking contaminated water, which can lead to epidemics of diseases like cholera and typhoid. These diseases can also spread in areas with inadequate sanitation, which is another side consequence of a lack of clean water. Dry weather can spark wildfires, destroying remaining vegetation and putting buildings in peril. Fires can also have an impact on air quality and aggravate chronic lung diseases. Many people must leave their houses permanently during a drought because they lack access to clean water and food. According to the World Health Organization, "Water scarcity impacts 40% of the world's population, and as many as 700 million people are at risk of being displaced as a result of drought by 2030”.

Considering drought in the climate change era its likelihood gets worse. Climate change is a major driving force that impacts the hydrological cycle, resulting in a rise in natural hazards. Drought is one of the most damaging natural dangers, and it is becoming more complex as a result of climate change. Floods and droughts are two extreme natural catastrophes that are becoming more often as a result of climate change's effects on the hydrological cycle and water supplies. Having less precipitation than typical for a period of months or years causes drought. Evaporation is accelerated by warmer temperatures, which lowers surface water and dries out soils and vegetation. Because of this, dry spells last longer than they would in colder weather. The period of water supply is also changing due to climate change. Climate change is anticipated to increase the frequency and severity of droughts in the world. Notably in semi-arid regions already experiencing substantial water stress. Numerous studies have demonstrated that greenhouse gas (GHG)-induced global warming may result in increased surface aridity and more droughts in the twenty-first century due to decreased precipitation in the subtropics and increased evaporative demand caused by higher vapor pressure deficits under warmer temperatures.

After 40 years of ongoing war, the people of Afghanistan are especially susceptible to being hurt by droughts and other natural disasters. The loss of agricultural fields and the escalating hunger and poverty problem in Afghanistan are results of the drought’s worsening. Moreover, millions of people experienced food insecurity as a result of the drought. Afghanistan is extremely vulnerable to severe and frequent natural disasters like flooding, earthquakes, avalanches, landslides, and droughts because of its location and decades of environmental degradation, which frequently cause the loss of lives, livelihoods, and property (Ranghieri et al., 2017). Given the issues raised above, there is a clear need to comprehend and evaluate droughts in the country in order to create a plan for mitigating its effects in the future. Additionally, it is anticipated that it will promote researches in this field of study and enable future advanced studies of drought analysis.

1.5. Thesis Structure

This thesis is typically organized into six key sections, starting with Introduction chapter, which provides a comprehensive overview of the research background, Drought and conflicts, its significance, and the objectives of the study. The second chapter is dedicated to the literature review, where a thorough examination of existing literature related to drought is conducted. This chapter aims to establish the theoretical framework and also provides a critical analysis of relevant studies and serves as the foundation upon which the research methodology is built. The 'Study Area and Data' chapter offers an in-depth overview of Afghanistan, including its five major river basins and its shared borders with neighboring countries. Additionally, this chapter includes the remote sensing (RS) data used in this study. In the methodology chapter, the research approach, and data analysis techniques are detailed. This section outlines how the research questions or hypotheses will be addressed and explains the rationale behind the chosen methodology**.** The fifth chapter presents the results and discussion of the analysis that includes tables, figures, and textual descriptions related to the indices (SPI, SPEI, RDI, SRI).in the discussion part of this chapter the results obtained will be interpreted in monthly and yearly discussion. The thesis will be finalized with the conclusion and recommendation chapter that summarizes the key findings and contributions of the research. Following the conclusion, recommendations will be presented at the end of this chapter.

CHAPTER 2

LITERATURE REVIEW

In this chapter drought definitions, worldwide effect of climate change and drought indexes will be discussed. An overview of climate change adaptation processes and drought index techniques is provided globally. Considering Afghanistan, where drought, together with 40 years of war, has brought about many unpleasant situations, including decreased food production, environmental destruction, hunger, and social hardship.

2.1. Drought Definition

It's crucial to distinguish between conceptual and operational definitions of drought (Mishra & Singh, 2010). Definitions that are conceptually sound aid in comprehending the idea of drought and its repercussions. For instance, a drought is an extended period of inadequate precipitation. Conceptual definitions are frequently used as an introduction in scientific publications and reports even if they do not offer quantitative answers to the questions of "when", "how long" or "how severe" a drought is. Operational definitions aid in determining the start, extent, and end of drought periods. The frequency, intensity, and length of drought for a specific historical period can be examined using a generally operationally defined drought.

A drought is defined as "the percentage of years when crops fail due to a deficit in moisture," according to the Food and Agricultural Organization (FAO) of the United Nations (Mishra & Singh, 2010). According to the World Meteorological Organization (WMO) (Mishra & Singh, 2010), drought is caused by a lack of precipitation, which causes a shortage of water for specific uses or for some groups of people. According to the UN Convention to Combat Drought and Desertification (General, 1994), "drought is the naturally occurring phenomenon that exists when rainfall has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems". Furthermore, drought is defined in four categories which is defined as bellow.

2.2. Drought Classifications

According to Heim Jr (2002), there are generally four different forms of drought: meteorological, agricultural, hydrological, and socioeconomic. Meteorological droughts are typically caused by precipitation that deviates from normal over an extended period of time and agricultural drought is referred to a period of insufficient soil moisture that reduces the amount of accessible moisture for crops and other types of plants. Hydrological drought is frequently discussed in relation to water resources (supply), such as streamflow, groundwater, and reservoir levels. Socioeconomic drought has features of the three preceding forms of drought and is related to the supply and demand of particular economic goods.

2.3. Drought Indices

A drought index is a single variable used to define many drought factors, such as intensity, duration, severity, and spatial extent, and to evaluate the impact of droughts. Streamflow, temperature, rainfall, and other quantifiable factors are often continuous functions of drought indices. Following are short summaries of the drought indices, which are categorized according to the volume of data utilized in this thesis.

2.3.1. Standardized Precipitation Index (SPI)

The SPI is one of the most often utilized indices in the world for drought monitoring, and Table 2.1 illustrates the drought categories associated with the SPI numerical values. The mean SPI for the location and desired period is set to zero by fitting this long-term rainfall record to a probability distribution, which is then transformed into a normal distribution using an equal-probability transformation. As a result, values above zero denote wet periods, and values below zero denote dry periods (McKee et al., 1993). The SPI has been praised by many scholars as a useful and simple technique for monitoring droughts due to the ease in application and the relatively low amount of data required for its calculation. For instance, in order to define and monitor drought, researchers from Colorado State University presented the SPI as a reasonably straightforward method (Hayes et al., 1999). Onuşluel Gül et al., 2022) analyzed drought behavior using SPI in transects of Turkey's main river basins in the Thracian, Aegean, and Mediterranean. (Wu et al., 2001) utilized this approach in their study covering arid and humid regions in China, whereas Surendran et al., 2017) applied the SPI method to a semi-arid region in India.

Table 2.1 Categorization of meteorological drought using the SPI

State Description	Criterion
Extremely wet	SPI≥2.0
Very wet	1.5≤SPI<2.0
Moderately wet	1.0≤SPI<1.5
Near Normal	-1.0≤SPI<1.0
Moderately dry	-1.5≤SPI<-1.0
Severely dry	-2.0≤SPI<-1.5
Extremely dry	SPI<-2.0

2.3.2. Standardized Precipitation Evapotranspiration Index (SPEI)

Standardized Precipitation Evapotranspiration Index (SPEI) is a recently created drought index (Vicente-Serrano et al., 2010). It is based on precipitation (P) and PET measurements on how precipitation and PET differ from one another (Vicente-Serrano et al., 2010). According to (Almeida-Ñauñay et al., 2022), Standardized Precipitation Evapotranspiration Index (SPEI) is another common statistic for keeping track of drought periods, which is offered as an upgrade of the SPI index, in which Potential evapotranspiration (PET) is computed and deducted from precipitation data. Due to the incorporation of the temperature influence in its computation, SPEI is found to be a better drought indicator than SPI overall. He et al.(2022) examined a drought index taking irrigation factors according to traditional drought index framework for the performance's comparison of Standardized Precipitation Evapotranspiration Index for Irrigation (SPEII), SPEI, and scPDSI in cropland vegetation response to drought and to evaluate drought change and provide some strategies for regional irrigation and water resource scheduling management in the future based on CMIP5 model.

2.3.3. Reconnaissance Drought Index (RDI)

By accounting for the balance between inputs and outputs in a water system, (Tsakiris et al., 2007) created the reconnaissance drought index in Greece to provide a comparatively more accurate approach to water shortage. The RDI is designed to provide a quick and simple assessment of drought severity, making it a valuable tool for early warning and decision-making. Its foundation is the proportion of precipitation to possible evapotranspiration (PET). Using climate data based on Shared Socioeconomic Pathway (SSP) scenarios, (An et al., 2022) created and assessed the reconnaissance drought index (RDI) and standardized precipitation index (SPI) for prospective droughts in Korea. Studies on RDI can be found in the literature such as Mornos and Nestos basins in Greece. In six synoptic stations in South Khorasan, Iran, (Khosravi, 2013) investigated the similarities and differences between the SPI and RDI indices. By utilizing different drought indices in RDI, (Payab & Türker, 2019) attempted to describe drought occurrences and compare meteorological drought. (Katipoğlu et al., 2020) also applied Reconnaissance Drought Index (RDI) in Euphrates basin in Türkiye.

2.3.4. Surface Runoff Index (SRI)

Shukla & Wood (2008) created SRI to evaluate hydrological drought taking into account stream flow data. It entails adapting an appropriate distribution to flow records from a certain location. The SPI principle is similar to the SRI suggested by (Shukla & Wood, 2008), with the exception that runoff data was used in place of precipitation data.

To incorporate more hydrometeorological data (Shah & Mishra,2020) developed a combined SRI, standardized groundwater index, and other indices. A composite multivariate drought index (CMDI) based on a copula combining three univariate drought indices (standardized runoff index (SRI), water storage deficit index (WSDI), and standardized precipitation index [SPI]) was used by Yang et al., 2023) to fuse multiple timescales of SPI and SRI, to combine the marginal distribution characteristics of multiple univariate indices of SPI, SRI, and WSD

2.4. Effect of Climate Change

Climate change can be defined as the rising of sea levels and increasing frequency of weather events such as droughts, floods and severe storms (Hassan Gana, 2018). Droughts have a natural occurrence, but climate change has typically speed up the hydrological processes to hasten their onset and intensify them. This has various effects, not the least of which is a higher danger of wildfires (Mukherjee et al., 2018)**.** Less rainfall and greater evaporation, which are mostly caused by rising temperatures, will likely lead to an increase in the frequency of droughts (Sheffield & Wood, 2012). The effects of climate change-related disasters, particularly drought, have gotten worse, resulting in significant losses of livelihood, ecological and environmental degradation, harm to human health, and other negative effects (Thương, 2013). One of the greatest issues of the twenty-first century is thought to be climate change (Change, 2014). Over 157 years of observations revealed an increase in global surface temperatures (Savo et al., 2016) Climate-related disasters will become more frequent due to extreme weather, which will have disastrous effects on social well-being, habitat disruption, and economic suffering (Kusangaya et al., 2014). These have an effect on every aspect of the ecosystem and human health, and they may result in a loss of life, decreased agricultural output, the extinction of some species, and water crises (Kusangaya et al., 2014). A drought is caused on by a lack of precipitation (below average) over an extended length of time, usually a season or more. (Wilhite & Glantz, 1985 ; Bordi & Sutera, 2007). Droughts are regarded as one of the cumulative climate risks. The most expensive climatic hazard worldwide is drought, which causes problems in many parts of the world (Wilhite, 2000). According to the third IPCC report on climate change (Houghton et al., 2001), based on data, it is likely that increased summer drying over the majority of mid-latitude continental interiors and the related danger of drought existed throughout the 20th century and are predicted to continue into the 21st.. The atmosphere's temperature increased in two periods throughout the past century, from the 1910s to the 1940s by 0.35°C, and from 1970 to the present by 0.55°C (Hassan Gana, 2018). In many parts of the world, rainfall variability and drought intensity are likely to grow (Kusangaya et al., 2014; Mosley, 2015). Although the climate does change naturally, the production of more greenhouse gases causes those changes to occur more quickly and has an impact on the frequency of extreme weather occurrences.

2.5. Drought in Afghanistan

In order to evaluate the meteorological and agricultural dryness that occurred during the monsoon season, Baig et al. (2020) conducted drought research in the Chitral Kabul River Basin (CKRB) utilizing remote sensing and GIS techniques. The analysis came to the conclusion that the driest year was 2000, which also had a meteorological and agricultural drought during the monsoon season. The results also revealed that the agricultural and meteorological droughts varied spatially, but that there was a declining tendency between 2000 and 2018 in terms of duration. The intensity of the drought is at its highest between 2020 and 2022, but there has since been a declining tendency, according to forecasts for the years between 2020 and 2030. Rousta et al. (2020) used a variety of indices derived from the MODIS, TRMM, and LST datasets to study the link between vegetation covering and drought stress in Afghanistan. The research tried to answer questions such as whether the occurrence of the drought solely influenced by the precipitation, or the temperature and precipitation should be taken into account simultaneously. The findings showed that, given the current trend of rising precipitation, particularly after 2009, and the lack of any discernible trend in LST during the research period, vegetation in Afghanistan will not diminish any time soon. The result, however, did not take into account additional elements that might have an impact on the management of water and vegetation, such as the nation's political climate Rousta et al. (2020). The environmental and socioeconomic conditions in Afghanistan are characterized by a number of elements that compound the difficulties related to drought and water resources such as: continental climate, that characterized by hot summers and cold winters, with vast arid or semi-arid regions featuring deserts and dry mountainous terrain. The irregular and uneven distribution of rainfall is a common feature, leading to low and erratic precipitation in many regions.

Afghanistan's untamed terrain, which is made up of plateaus and mountains, adds to the unpredictability of its precipitation and weather patterns. Orographic factors frequently affect rainfall, resulting in localized differences in precipitation.

Water scarcity is a persistent issue in Afghanistan, which is made worse by inadequate infrastructure for storing water and ineffective water management techniques. For its water supply, the country mostly depends on precipitation and snowmelt.

Agriculture, most of the population's livelihood is derived from agriculture, which is primarily rain-fed. Afghanistan is particularly vulnerable to droughts as a result of this reliance, which affects crop output and raises food insecurity.

The country's limited economic resources and infrastructure, coupled with political instability, hinder the development and implementation of effective drought mitigation and adaptation measures. This limits the adaptive capacity of the nation in the face of recurring water-related challenges.

Drought on Afghanistan's water resources necessitates a multifaceted strategy that includes resilient water infrastructure development, sustainable agriculture methods, and enhanced water management practices. Furthermore, ensuring the region's long-term water security depends on taking action to both mitigate and adapt to climate change.

CHAPTER 3

STUDY AREA AND DATA

3.1. Study Area

The research area covers the entire country of Afghanistan which is located between central and south west Asia with the coordinate of 33°56'2.54" N 67°42'12.35" E, and a total area of 652,000.00 km2. Afghanistan shares its borders with several countries: Pakistan to the east and south, China in the northernmost region, Iran to the west, and Tajikistan, Uzbekistan, and Turkmenistan to the north, as illustrated in Figure 3.1. Precipitation varies significantly across the country, ranging from 16 mm to 209 mm in the arid southwestern region, while it ranges from 89 to 846 mm in the high-altitude northern areas, with an average annual precipitation of 270 mm. Extreme temperatures in Afghanistan span from -50°C to 50°C, with an average temperature of -2°C in January and 32°C in July. The entire country of Afghanistan is included in the research area. The country is split into five primary river basins based on hydrological parameters. The five RBs are such as Helmand, Hari rod Murghab, Northern, Penj Amu, and Kabul Indus River basins.

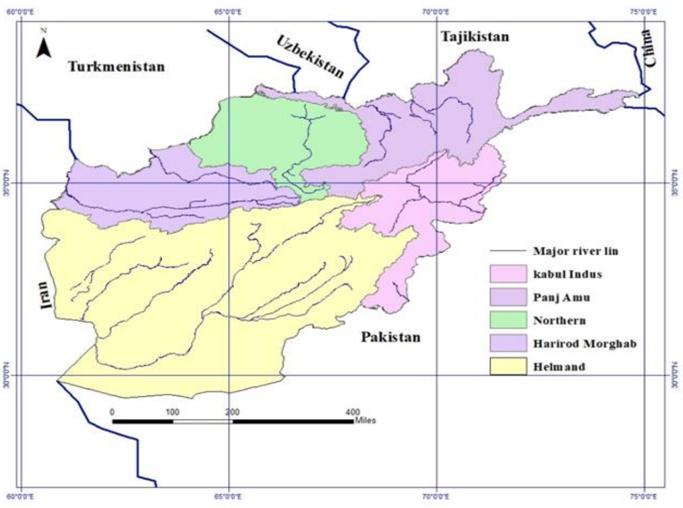


Figure 3.1. Study Area (Afghanistan)

3.2. Data

3.2.1. Remotely Sensed Data (RS)

Many different RS data sources are available, each of which provides global hydrometeorological variables with a different level of temporal and spatial resolution. In this study, a few factors related to drought were utilized as drought indicators to assess how well they may be used to identify and track drought occurrences over Afghanistan. In order to extract climatic data, in situ precipitation datasets form the European Centre for Medium-Range Weather Forecasts (ECMWF), ERA5 atmospheric reanalysis dataset of Runoff (R), Temperature(T), ET, and Potential Evapotranspiration (PET) data were used. The ERA5 reanalysis data project uses complex data assimilation models to simulate a wide range of hydrometeorological parameters, incorporating historical observations into global estimations. Table 3.1 is a summary of data variable with their types, temporal, special resolution and the access links.

Table 3.1. Specification of Datasets Applied in the Research

Data	Category	Temporal	Spatial	Description and access link
Precipitation(P)	In_situ	Monthly (1992-2021)	0.25	https://doi.org/10.24381/cds.11dedf0c
Temperature(T)	Reanalysis	Monthly (1992-2021)	0.25	The Climate Data Source ERA5-Land Monthly Average Data: https://cds.climate.copernicus.eu/cds app#!/search?type=dataset
Surface Runoff	Reanalysis	Monthly (1992-2021)	0.25	The Climate Data Source ERA5-Land Monthly Average Data: https://cds.climate.copernicus.eu/cds app#!/search?type=dataset

The monthly averaged precipitation, temperature and surface runoff data from 1992 till 2021 are used in this study. The employed monthly in situ precipitation showed in Figure 3.2 indicated that the year 2018 had the maximum precipitation value. As it is shown in the Table 3.2 maximum and minimum precipitation value is about 179.98 mm and 0.0313 mm respectively with the mean value of 24.54 mm and standard deviation of 25.71.

According to thirty years averaged temperature graph shown in Figure 3.3 there is not seen a very dramatic changes in temperature between thirty years ago and now. It almost kept the same path and event. Regarding with the maximum and minimum events the values are 26.95 and -7.01 degree Celsius respectively. The mean and standard deviation is also 12.35- and 9.35-degree Celsius respectively.

Monthly reanalysis surface runoff data from 1992 until 2021 is downloaded in meter. As it is shown in the figure 3.4 the maximum value is around 2 meter and the minimum value of 0.0076 m. The mean and standard deviation is 0.47 and 0.48 respectively.

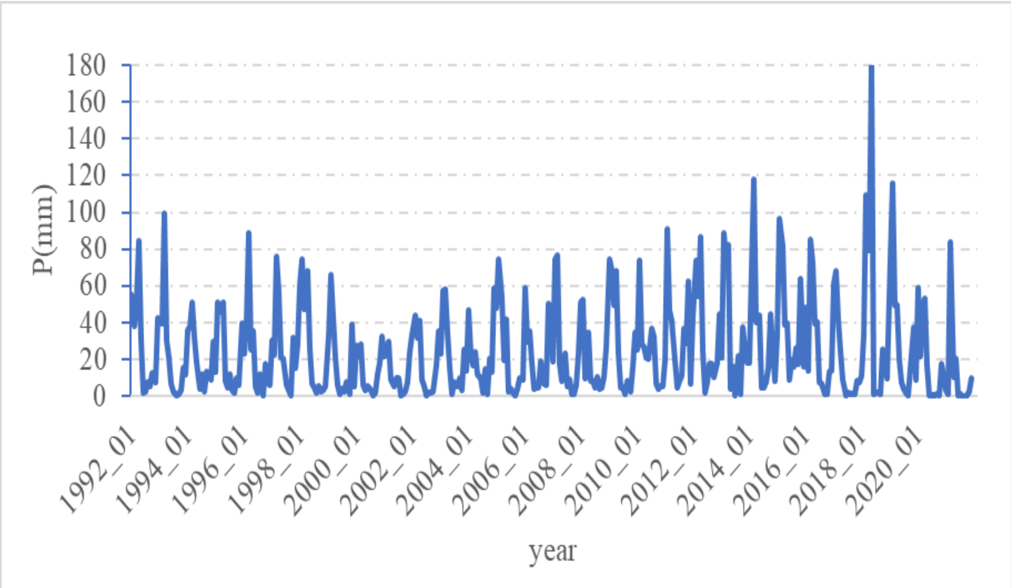


Figure 3.2. Average precipitation

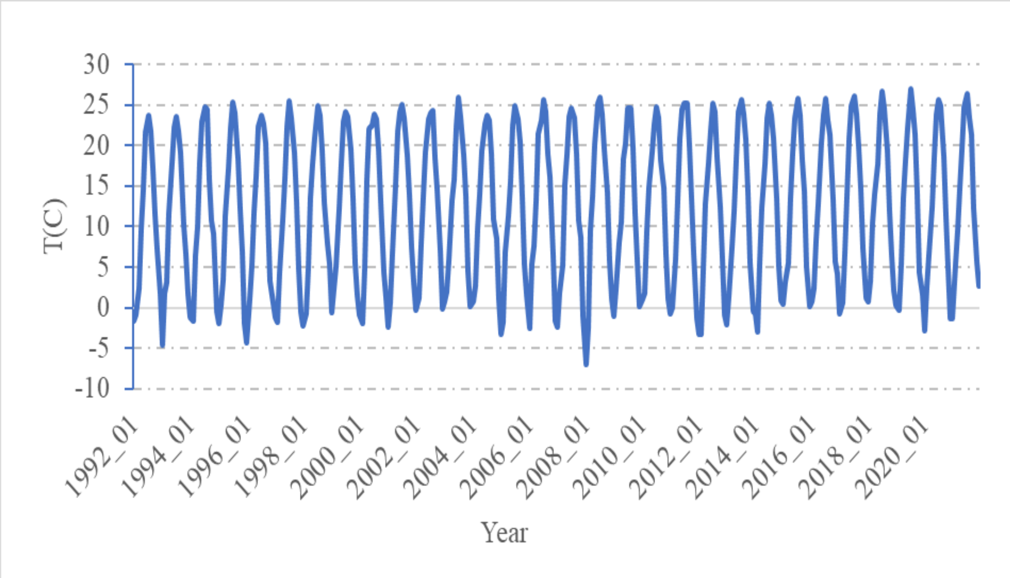


Figure 3.3. Average Temperature

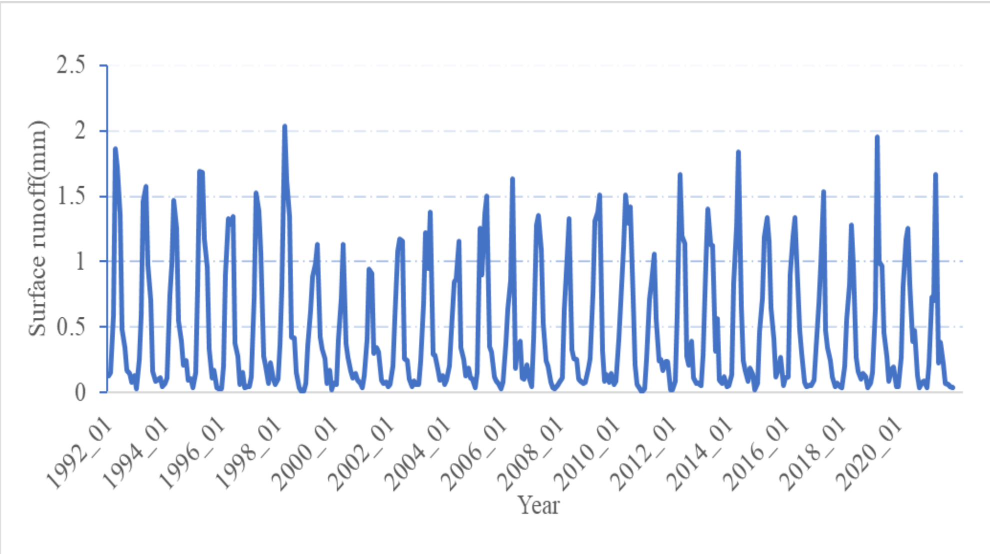


Figure 3.4. Average Surface Runoff

The Table 3.2 is provided with maximum, minimum, mean, and standard deviation values for three different data types: Precipitation, Temperature, and Surface Runoff. These statistics describe the characteristics of these data types. For example, the maximum value of 179.98 indicates the highest recorded precipitation amount, the minimum value of 0.0313 is the lowest recorded precipitation amount, the mean of 24.54 is the average precipitation amount, and the standard deviation of 25.72 measures the variability or spread of the e precipitation data. The same descriptions are valid for temperature and surface runoff data.

Table 3.2. Precipitation, Temperature and Surface runoff

Data type	Maximum	Minimum	Mean	Standard deviation
Precipitation (mm/month)	179.98	0.0313	24.54	25.72
Temperature (ºC)	26.95	-7.01	12.35	9.35
Surface Runoff (mm/month)	2.03	0.0076	0.47	0.487

CHAPTER 4

METHODOLOGY

4.1. Drought Analysis

We employed four distinct types of drought indices for the aim of evaluating the drought in the country for 3, 6, and 12- months based on monthly precipitation, temperature, potential evapotranspiration, and surface runoff date data over 30 years. These techniques were utilized to determine the features of dry spell (frequency, amplitude, and duration), and they were also assessed to find the best drought index(es) that could be used for drought evaluation in the region. Moreover, the drought maps for each index are drawn and provided in Appendix section.

4.2. SPI

The "Lincoln declaration on drought indices" lists the SPI as one of its top-choice indices (Stagge et al., 2015). The index's primary application is to distinct monthly precipitation time scale data series (1, 3, 6, 9, 12, and 24 months). SPI is calculated by fitting the raw precipitation data to a gamma distribution and then transforming it into a normal distribution. (Khorrami & Gündüz, 2022).

$$\mathrm{SPI} = \frac{X_i - X_j}{\sigma}$$

where, respectively, X_i, X_j, and 1 stand for the precipitation that has been observed in the current time frame, the average precipitation across the time frame, and the standard deviation over the time series(Dikici & Aksel, 2021). Using the excel program, we estimated the SPI values in this study.

Gamma Distribution Function

The observed probability distribution function of the amount of precipitation is frequently approximated using the gamma distribution. Through this method, we discern periods of wetness and dryness by first modeling a time series of monthly precipitation data using a probability distribution, covering a continuous timeframe of no less than 30 years (McKee et al., 1993). As seen in Table 4.1, SPI values larger than the mean (zero) indicate no drought conditions, whereas values less than the mean (zero) indicate drought conditions. This method used to categorize drought into four distinct levels. These levels include near-normal conditions, indicated when SPI values fall between 0.99 and -0.99, moderately dry conditions for SPI values ranging from -1.0 to -1.49, severely dry conditions for SPI values between -1.5 and -1.99, and finally, extremely dry conditions when SPI values are equal to or less than -2. 0. (Morid et al., 2006). The SPI is adaptable to using various time scales (e.g.,1,3,6, and 12 months). Gamma distribution is typically the best model for data on observational precipitation. The Gamma distribution's density probability function is represented as (Guenang & Kamga, 2014).

$$g(x) = \left(\frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{(\alpha-1)}\right) e^{-x}/\beta\,, \qquad \text{for } x > 0,$$

where α> 0 is a shape parameter, β> 0 is a scale parameter, x >0 is the amount of precipitation, and Γ(a) is the gamma function. α and β are estimated from the sample data in order to fit the distribution parameters. These can be calculated as using the approximation for ML established by Thom (1958).

$$\alpha = \frac{1}{4A}(1 + \sqrt{1 + \frac{4A}{3}})$$

$$\beta = \frac{x^{-}}{\alpha}$$

where x^{-} is the mean precipitation and A is calculated as following formula.

$$A = \mathrm{Ln}(x^{-}) - \frac{\sum \mathrm{Ln}(x)}{n}$$

where n is the amount of data.

Table 4.1. Categorization of meteorological drought using the SPI

State Description	Criterion
Extremely wet	SPI≥2.0
Very wet	1.5≤SPI<2.0
Moderately wet	1.0≤SPI<1.5
Near Normal	-1.0≤SPI<1.0
Moderately dry	-1.5≤SPI<-1.0
Severely dry	-2.0≤SPI<-1.5
Extremely dry	SPI<-2.0

4.3. SPEI

The Thornthwaite equation (Thornthwaite 1948) was used to estimate the potential evapotranspiration in order to generate the SPEI index because there is no direct availability to in situ PET readings. The monthly precipitation totals, monthly mean air temperature, and the station's latitude were factors considered in the PET calculations shown below.

$$\mathrm{PET} = 16\mathrm{K}\left(\frac{10\mathrm{T}}{\mathrm{I}}\right)^{\mathrm{m}}$$

I represent the heat index, which is determined by adding the values of the 12 monthly indexes, as shown in the following formula, T is the monthly average temperature (°C), m is an I-dependent coefficient., and K stands for the correction coefficient, which is calculated based on latitude and month.

$$\mathrm{i} = \left(\frac{\mathrm{T}}{5}\right)^{1.514}$$

$$\mathrm{I} = \sum_{\mathrm{i}=1}^{12} \mathrm{i}$$

$$\mathrm{m} = 6.75\mathrm{x}10^{-7}\mathrm{I}^{3} - 7.71\mathrm{x}10^{-5}\mathrm{I}^{2} + 1.79\mathrm{x}10^{-2} + 0.492$$

Thornthwaite Method (1948)

The most popular methods (Thornthwaite method) for estimating potential evapotranspiration (PE) based on the monthly average temperature have been used. In dry and semi-dry areas, it is extensively used. The empirical formula is known as the Thornthwaite technique, and despite the fact that it is purely based on the temperature relationship and has no theoretical backing, it is still extensively used today. This is mostly because it is simple to use and can be found in tables and monographs. After creating an experimental temperature formula, Thornthwaite realized there was required for a more straightforward formulation that could make use of the readily available climatic data. He created an exponential relationship between the mean monthly potential evapotranspiration and the average monthly temperature in degrees centigrade since the temperature was a good indicator of energy in a zone of essential balance. The result was then corrected by adjusting the sunlight and the days in a month. Table 4.2 represent the correction coefficient (K) of Thornwaite method which is based on latitude and months.

Table 4.2. Correction Coefficient (K)

Lat	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
60	0.54	0.67	0.97	1.19	1.33	1.56	1.55	1.33	1.07	0.84	0.58	0.48
50	0.71	0.84	0.98	1.14	1.28	1.36	1.33	1.21	1.06	0.9	0.76	0.68
40	0.8	0.89	0.99	1.1	1.2	1.25	1.23	1.15	1.04	0.93	0.83	0.78
30	0.87	0.93	1	1.7	1.14	1.17	1.16	1.11	1.03	0.96	0.89	0.85
20	0.92	0.96	1	1.05	1.09	1.11	1.1	1.07	1.02	0.98	0.93	0.91
10	0.97	0.98	1	1.03	1.05	1.06	1.05	1.04	1.02	0.99	0.97	0.96
0	1	1	1	1	1	1	1	1	1	1	1	1
10	1.05	1.04	1.02	0.99	0.97	0.96	0.97	0.98	1	1.03	1.05	1.06
20	1.1	1.07	1.02	0.98	0.93	0.91	0.92	0.96	1	1.05	1.09	1.11
30	1.16	1.11	1.03	0.94	0.89	0.85	0.87	0.93	1	1.07	1.14	1.17
40	1.23	1.15	1.04	0.93	0.83	0.78	0.8	0.98	0.99	1.1	1.2	1.25
50	1.33	1.19	1.05	0.98	0.75	0.68	0.7	0.82	0.97	1.13	1.27	1.36

The linear interpolation method was used to compute for the desired latitude of study area.

$$y = y_0 + \frac{y_1 - y_0}{x_1 - x_0}(x - x_0)$$

According to Equation below, the extracted PET values were first used to determine the difference between P and PET (D values), after which SPEI values were calculated similarly to SPI, transferring D values to the cumulative standard normal distribution with an average and standard deviation of 0 and 1, respectively.(Khorrami & Gündüz, 2022).

$$\mathrm{D^k}_\mathrm{n} = \sum_{\mathrm{i=0}}^{\mathrm{k-1}} \mathrm{P(n-1) - PET(n-1)}$$

where $D^{\mathrm{k}}_{\mathrm{n}}$ is the total (P-PET) from the month (n – k + 1) to month (n) on time scale k.

4.4. RDI

By accounting for the balance between inputs and outputs in a water system, (Tsakiris et al., 2007) created the reconnaissance drought index in Greece to provide a comparatively more accurate approach to water shortage. It can be explained in terms of standardization $\mathrm{RDI_{st}}$, initial value $\mathrm{a_k}$, and normalization $\mathrm{RDI_n}$ (Zarch et al., 2015). Standardized outputs can be directly compared and have a structure resembling SPI. Monthly temperature and precipitation values serve as input parameters (Katipoğlu et al., 2020).

$$a^{\mathrm{i}}_{\mathrm{k}} = \frac{\sum_{j=1}^{k} \mathrm{Pji}}{\sum_{j=1}^{k} \mathrm{PETji}}, \mathrm{i} = 1(1)\mathrm{N}, \mathrm{j} = 1(1)\mathrm{k}$$

where N is the total number of years for which data are available, $\mathrm{P_{ji}}$ and $\mathrm{PET_{ji}}$ are the precipitation and potential evapotranspiration for the jth month of the ith year, respectively. For various time scales that they were examined, the values of $\mathrm{RDI_k}$ match both the gamma and the lognormal distributions in various positions (Tigkas, 2008). The following equation can be used to calculate $\mathrm{RDI_{st}}$ if lognormal distribution is used.

$$RDI^{i}{}_{st} = \frac{y^{i} - \overline{y}k}{\overline{\sigma}_{k}}$$

in the above formula y^{i} is the Ln $(a)^{i}{}_{k}$, $\overline{y}k$ mathematical mean and $\overline{\sigma}_{k}$ is its standard deviation.

In addition, if the gamma distribution is utilized, it is possible to calculate RDI_{st} by using the pdf of the gamma distribution, which is (Vangelis et al., 2013)

$$g(x) = \left(\frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{(\alpha-1)}\right) e^{-x}/\beta\,, \qquad for\ x > 0,$$

The variables and calculation methods are explained in SPI explanation part in this chapter.

The following formula is used to compute the normalized RDI_{n}:

$$RDI^{i}{}_{nk} = \frac{a_{k}}{a_{\bar{k}}} - 1$$

where $a_{\bar{k}}$ is the numerical average of a_{k}.

The density probability function of the Gamma distribution is employed in this study since it is often the best model for data on observational precipitation.

4.5. SRI

Surface runoff is the term for the volume of water that runs over the ground and into a river or canal. According to (Shukla & Wood, 2008) the same formula used to calculate the standardized precipitation index (SPI) is used to calculate the hydrological drought index known as the standardized runoff index (SRI) (Sinha et al., 2019). In this study, the surface runoff time series were extracted from the reanalysis data and used to compute the SRI values using the gamma distribution function.

$$g(x) = \left(\frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{(\alpha-1)}\right) e^{-x}/\beta\,, \qquad for\ x > 0,$$

The variables and calculation methods are explained in SPI explanation part in this chapter.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1. SPI

Based on yearly averaged data all over Afghanistan, the SPI study shows historical dry and wet conditions across the country in the categories of near normal, moderately, and very, in three separate time periods. The amount of severity associated with each time period's documented historical drought episodes is explained using SPI calculations. The accompanying Figure 5.1 shows detailed data over the course of the study. According to SPI, the following hydrological years are significant dry episodes in Afghanistan:

- **Severely dry:** Sever dry conditions happened in 1993,2002,2017,2018 ,2019 ,2020, and 2021 for 3-month period of SPI. While for SPI 6 it occurred in the years of 1998,1999, 2000,2001,2002, 2005, 2008,2017, and 2021. But under SPI 12, Afghanistan only faces severe drought conditions in 2021.
- **Moderately dry:** Regarding SPI 3 Afghanistan experienced moderate dry conditions once in each of the years 1992, 1994, 1996,1997, 1998, 1999, 2003, 2004, 2006, 2007, 2011, 2013, 2014, and 2016. Nearly the same results were obtained for SPI 6. But for SPI 12 moderately dry conditions happened at 2000-2002, 2018, and 2021.
- **Near normal**: Near normal drought occurred for SPI 3 and SPI 6 in the years of 1995, 2000, 2001, 2002, 2004, 2006, 2008, 2010, 2020, 2021. But for SPI 12 it happened in the years from 1992 to 2000, from 2002 to 2008, and 2020.
- **Moderate wet**: Beginning of 2020 is detected as moderate wet condition under SPI 12 but under SPI 3 and SPI 6 moderate wet condition were detected for brief periods of time every year.
- **Very wet:** Years of 2018 and 2019 are detected very wet across the country for SPI 3 and SPI 12 respectively. Under SPI 6 there is no sign of very wet condition.

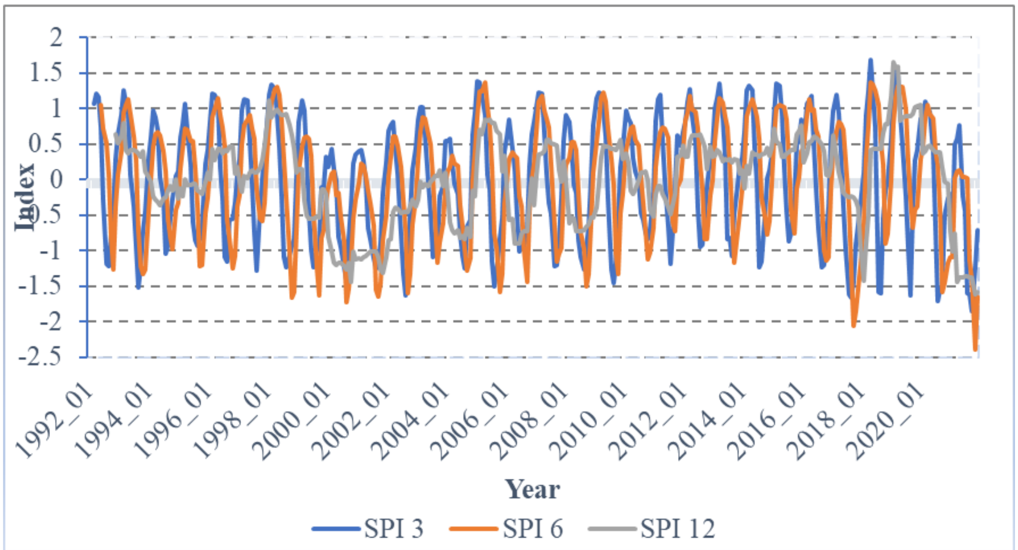


Figure 5.1. SPI's Drought Graphs

5.2. SPEI

The analysis including yearly SPEI drought detection for entire country of Afghanistan illustrate historical dry and wet conditions across the country in the categories of close to normal, moderately, extremely, and very, in three different time periods. SPEI computations are used to explain the degree of severity connected with each time period's reported historical drought occurrences. Detailed statistics from the study are also included in the Figure 5.2. The following hydrological years are considered important dry events in Afghanistan by SPEI:

- **Extremely dry**: No extreme drought happened under SPEI 12, but we have just a few cases of extremely dry condition in November 2001 and November 2011 for SPEI 3 and May 2005 for SPEI 6.
- **Severely dry**: Severe drought condition was observed under SPEI 3only once in 30 years in July 1994 and no observation is detected under SPEI 12. But there have been more severely dry years under SPEI 6 such as November 1996, November 2000, December 2004, 2007, 2013, 2016, 2019, and 2021.

- **Moderate dry**: No moderate drought has been recorded under SPEI 12, but under SPEI 3, and SPEI 6 it has been observed constantly in 1992, 1993, 2002, 2003, 2006, 2010, 2017 and 2020.
- **Near Normal**: This condition was detected only for SPEI 12, which means that from 1992 to 2010, and from 2019 to 2021 SPEI 12 is recorded as near normal condition.
- **Moderate wet**: Hydrological years from 2009 to 2017 were categorized as moderate wet condition in term of SPEI 12.
- **Extreme wet:** Hydrological years from 1992 to 2019 were categorized as extreme wet condition for SPEI 3 and SPEI 6.

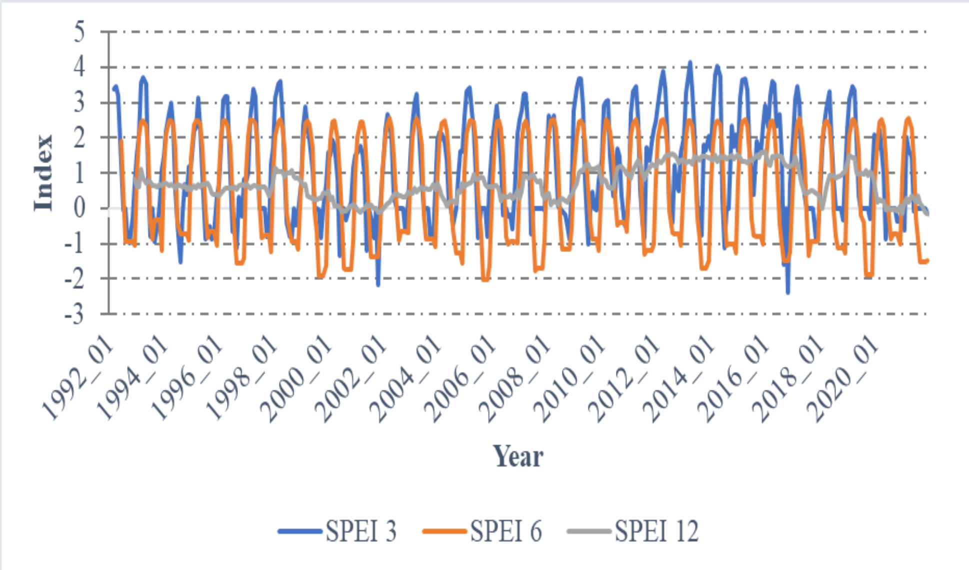


Figure 5.2. SPEIs Drought Graphs

5.3. RDI

The analysis looks at averaged annual RDI drought detection for all Afghanistan under RDI 3, RDI 6 and RDI 12. The geographical representation of RDI results presented in Figure 5.3 indicate that Afghanistan is experiencing severe dry under RDI 3 from1993 to1998, from 2000 to 2004 and from 2007 to 20011.Moderate dry in 1993,1994,1997,2000,2002,2003,2006,2010,2016, and 2021 under RDI 6. Mostly category of near normal is detected under RDI 12 except in 1993, 2007, 2008, 2009, and

2017 which is severe drought, and 2011 which is extremely dry. To discuss the wet condition of RDI we can obviously say that Afghanistan is in category of near normal in.

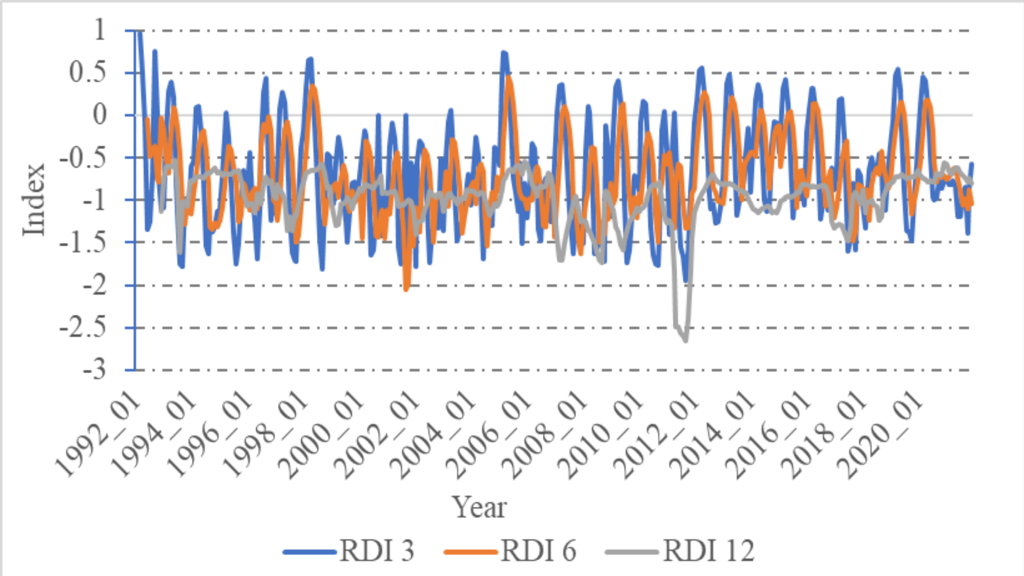


Figure 5.3. RDIs Drought Graphs

5.4. SRI

The analysis uses annual SRI drought detection for all of Afghanistan to show historical dry and wet conditions in three separate time periods that range from close to normal to moderately, severely, and very. According to SRI results, Afghanistan experienced the following hydrological years as significant dry periods. Additionally, the SRI outcomes in respect to each time period are graphically depicted in Figure 5. 4.

- **Severely dry:** No severe drought event is observed for SRI 6 in 30 years, but it has been detected under SRI 3 in 1998,2007, and 2011. Under SRI 12 Afghanistan only face severe drought condition from 2000 to 2002.
- **Moderately dry:** 2018 and 2021 were observed as moderate drought condition under SRI 12. But drought years with moderate classification under SRI 3 and SRI 6 were detected in 1993, 1995, 1996,1997 ,2000,2001,2002, 2005, 2010,2012,2011,2012.2013, 2014, 2015,20162017,2018.2019,2020, and 2021.
- **Near normal**: Except 1995,1996,1998,2010,2018 and 2021 all hydrological years were observed near normal condition under SRI 12. Drought years with near

normal condition under SRI 3 and SRI 6 were detected in 1992,1993,1994,1999,2000 to 2006 to 2007,2018, 2019and,2021 for SRI 3 and SRI 6.

- **Moderate wet**: Hydrological years with moderate wet classification under SRI 3 and SRI 6 were detected in 1992, 1995, 1996, 1997, 1998, 2005, 2007, 2009, 2010, 2014, 2016, 2019, and 2020. But the same classification under SPI 12 it is detected from 1995 to 1996, in 1998, and 2010.
- **Very wet**: For this classification, we have just observed one events in 1998 under SRI 3 and SRI 6

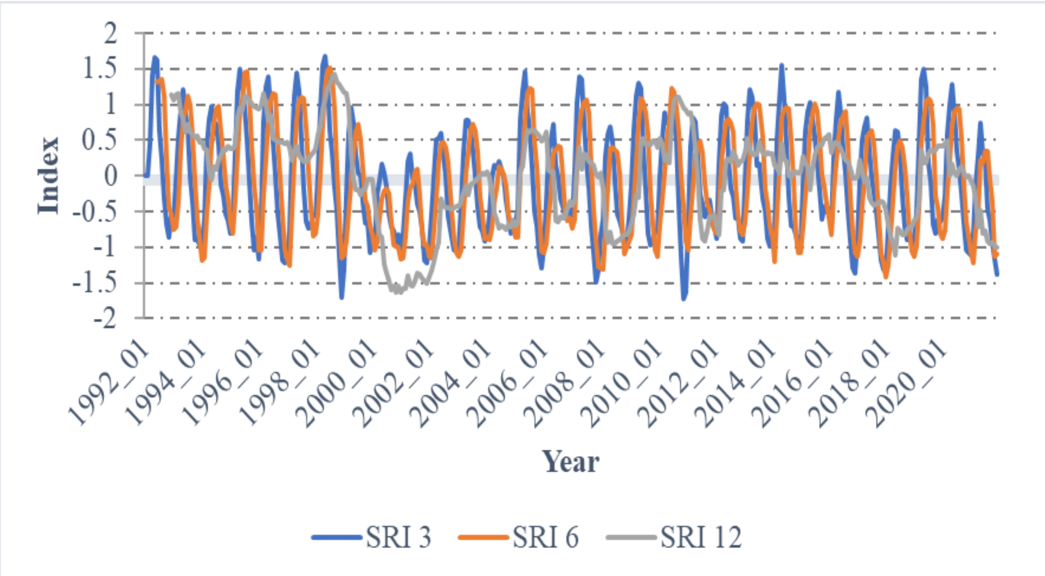


Figure 5.4. SRIs Drought Graphs

5.5. Discussions of Results

5.5.1. SPI

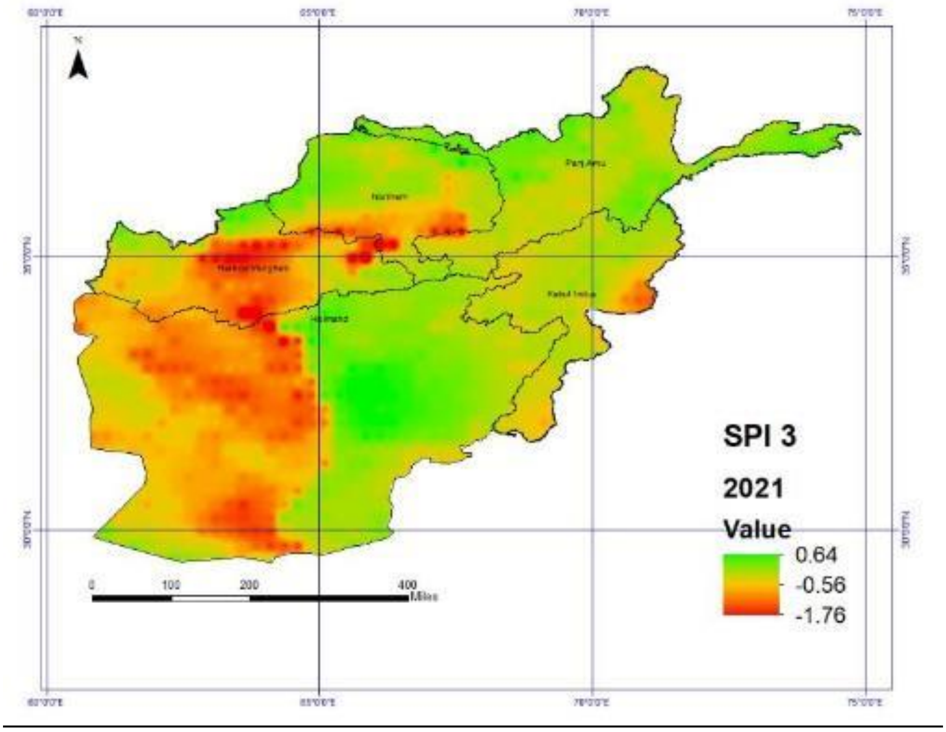
Table 5.3 summarize the yearly average SPI severe and moderate drought indices by Gamma distribution method. According to the table number of severe drought occurrences under SPI 6 is 8 times with the maximum event of 1.728 in 2000, while it occurred 4 times in SPI 3 and 1 time in SPI 12 with the maximum event of 1.85 and 1.61 in 2021, respectively. Moderate drought occurred 17 times under SPI 3, 13 times under SPI 6 and 3 times under SPI 12 with the maximum events of 1.274 in 1997,1.44 in 2006 and 1.48 in 2018 for SPI 3, SPI 6, and SPI 12 respectively. Moreover, the Figure 5.5 represent the years with the maximum event of SPI 3, SPI 6 and SPI 12. Results from SPI indicates two things about Afghanistan.

1. The past two decades Afghanistan experienced more drought according to its intensity (extreme, severe, moderate).

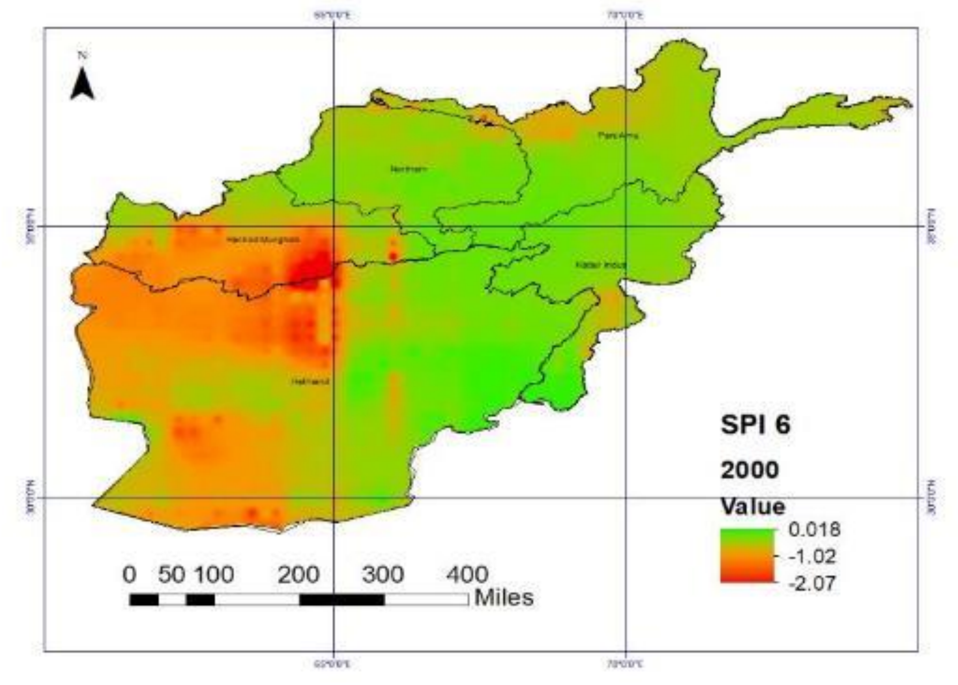
2. The number of occurrences is inversely proportional to monthly period indices. For example, as long as the accumulated period get closer to 12-month SPI the number of occurrences get lesser.

Table 5.2. Maximum Drought Events of SPI in 30 Years

Indices	**Severe dry**		**Moderate dry**	
	Drought Occurrences	**Max Event**	**Drought Occurrences**	**Max Event**
SPI 3	7	1.85 (2021)	17	1.274 (1997)
SPI 6	9	1.728 (2000)	13	1.44 (2006)
SPI 12	1	1.61 (2021)	3	1.48 (2018)



(a)



(b)

Figure 5.5. Yearly SPI 3(a), SPI 6(b), SPI 12(c)

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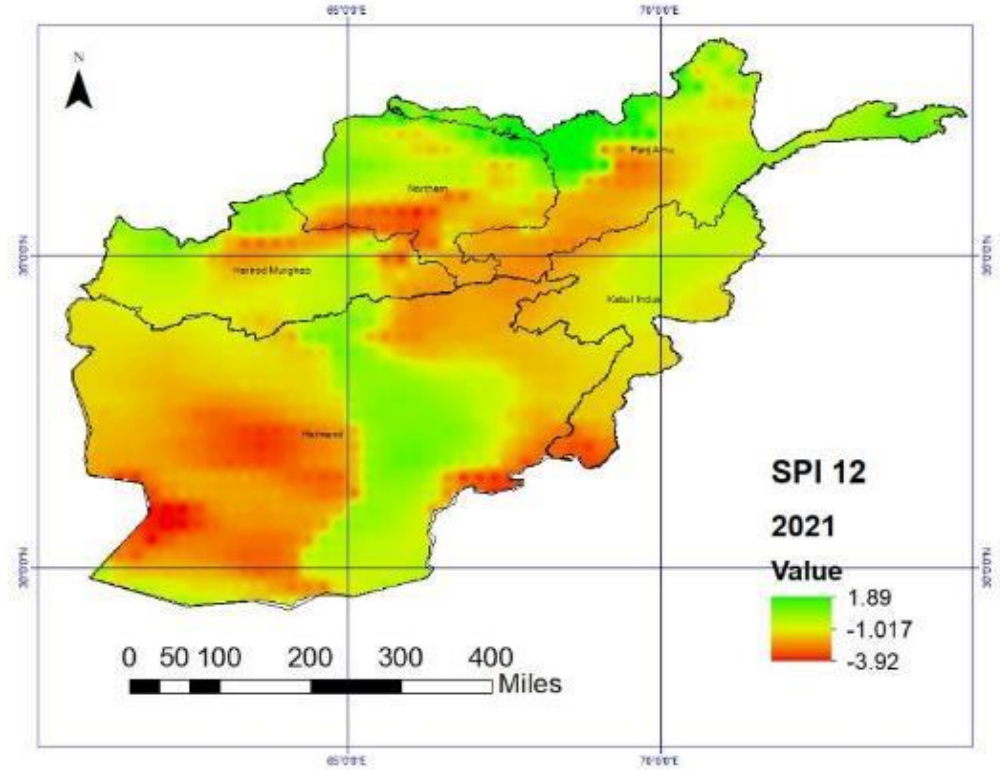

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Figure 5.5 (cont.)

Regarding with the yearly average SPI results, the monthly maps of SPI 6, SPI 12 and SPI 3 with their indices are shown in Figures 5.6, 5.7 and 5.8. From the monthly SPIs one can see that there is extreme drought happening. Because of taking average of 12 months to show yearly indices no extreme drought is seen in yearly part of the calculation so it would be better to have an idea about monthly calculation. According to the Figure 5.7, SPI 6 monthly maps show that in 2000 the months May, June, July, August, September, October, November, and December facing extreme drought in some part of Afghanistan but the locations of mostly drought zones are different for each month (mostly west part). For instance, in the figure 5.6 under SPI 3 for 2021 and Figure 5.7 under SPI 6 for 2000 west part of Afghanistan (Helmand basin and partially Harirod Morghab basin) facing extreme drought condition. This period is from the month January to June which means that in first 6 months of the years west part of the country had extreme monthly drought condition. But for the second 6 months of the year extreme drought conditions are diversely populated over all Afghanistan. In 2021 under SPI 12 every month there is a sign of extreme drought event in Afghanistan with the maximum events in west of country. There is seen extreme drought event in the months of August, September, October, November, and December with the magnitude around 3. From the monthly results we can conclude the following.

1. There is extreme drought event under SPI 3 in 2021, SPI 6 in 2000 and SPI 12 in 2021.
2. Drought zones are very mostly in west part of the Afghanistan.
3. The magnitude of drought events is around 3
4. The months of August, September, October, November, and December facing more droughts
5. Maximum drought events happened in west part of Afghanistan under the territory of Helmand River basin Harirod Morghab river basin.

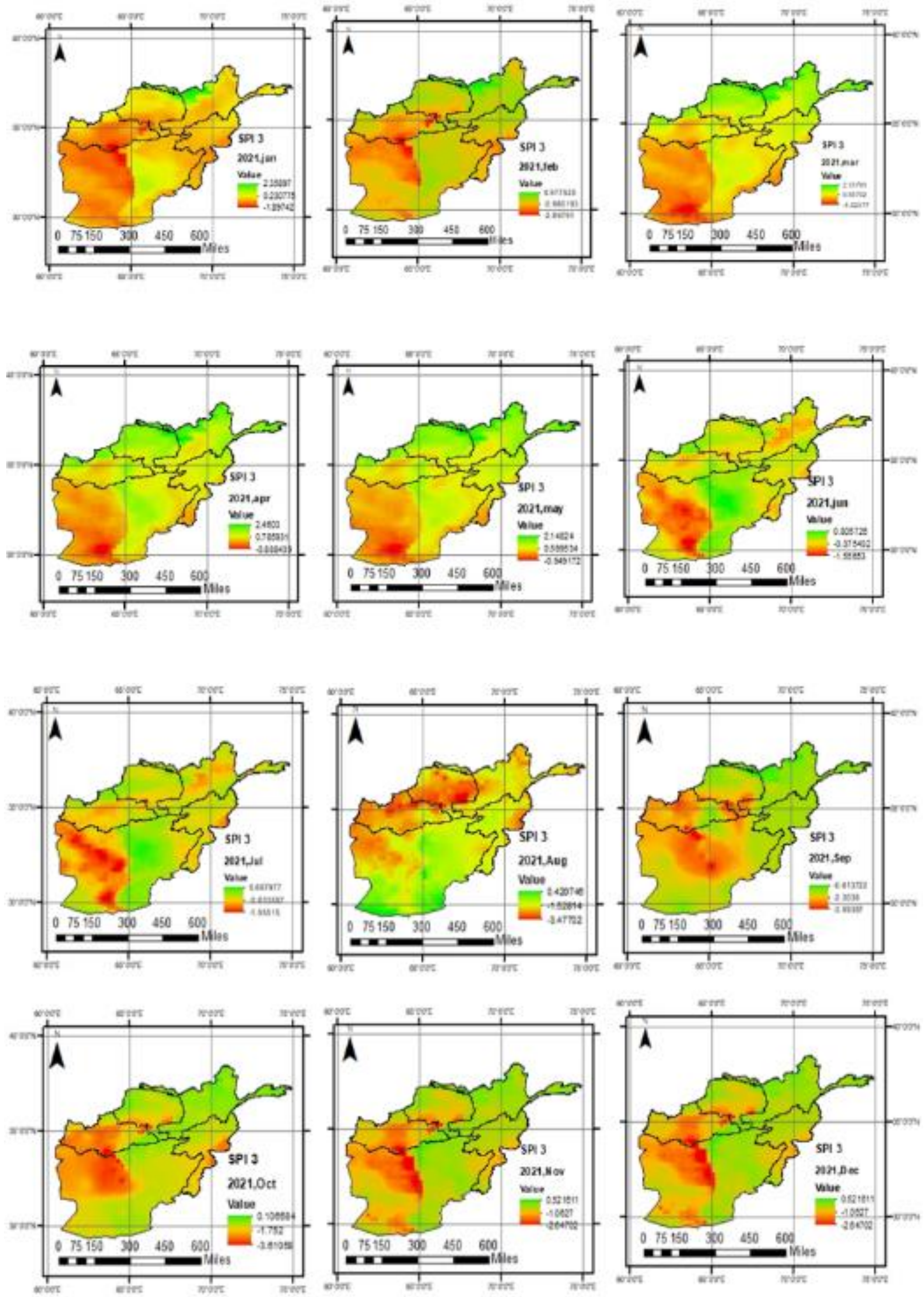


Figure 5.6. Monthly SPI 3 For 2021

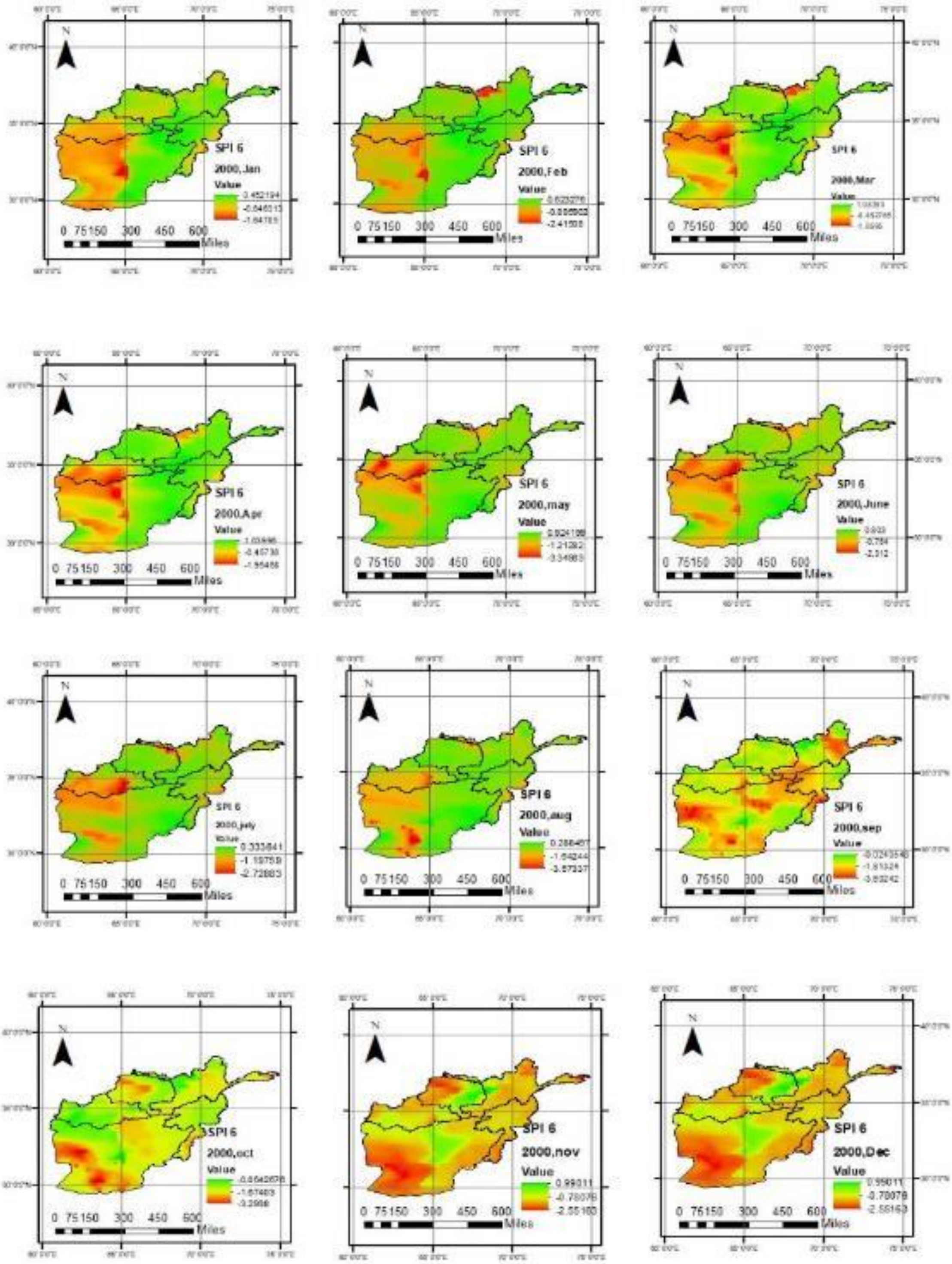


Figure 5.7. Monthly SPI 6 for2000

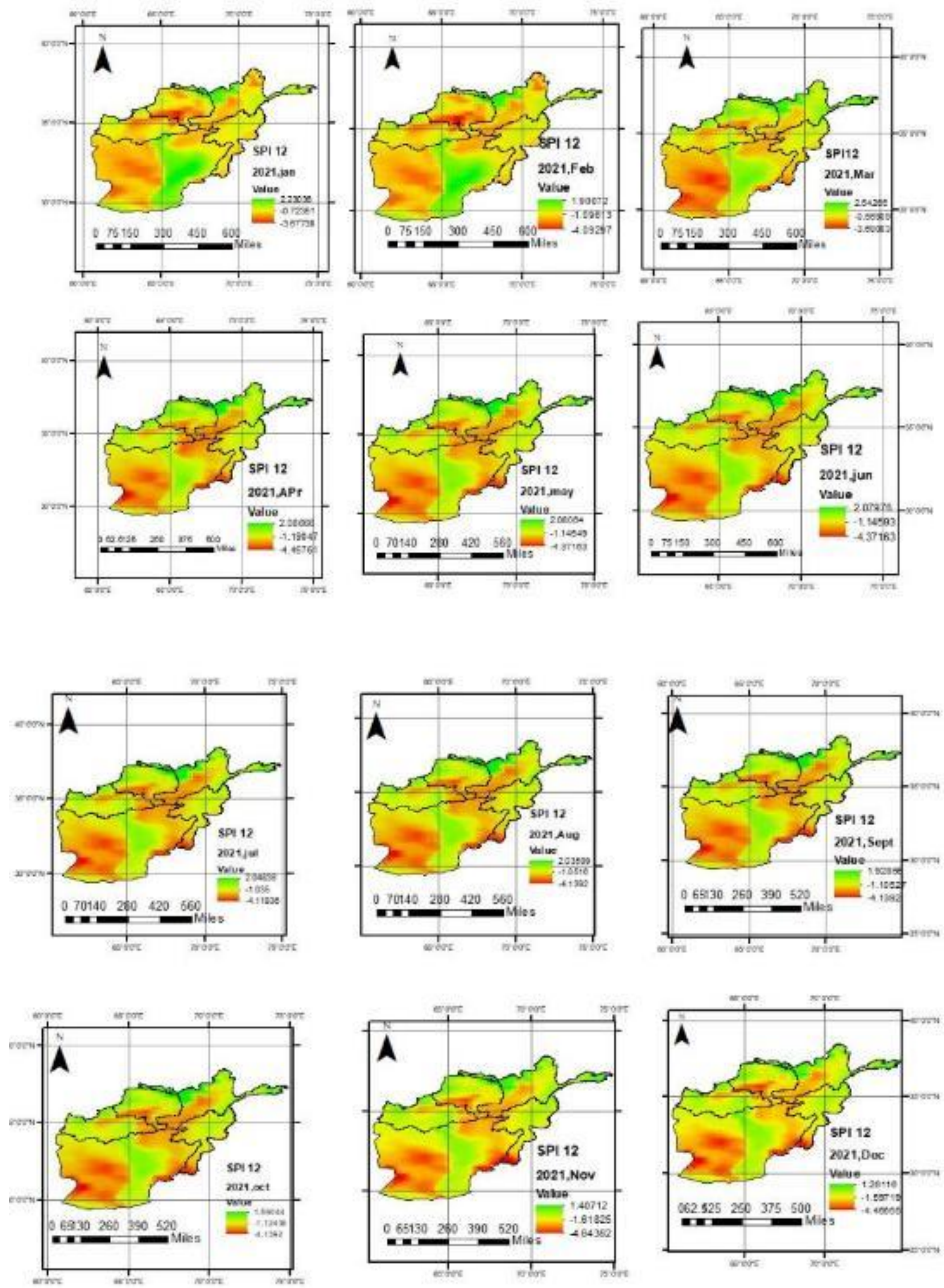


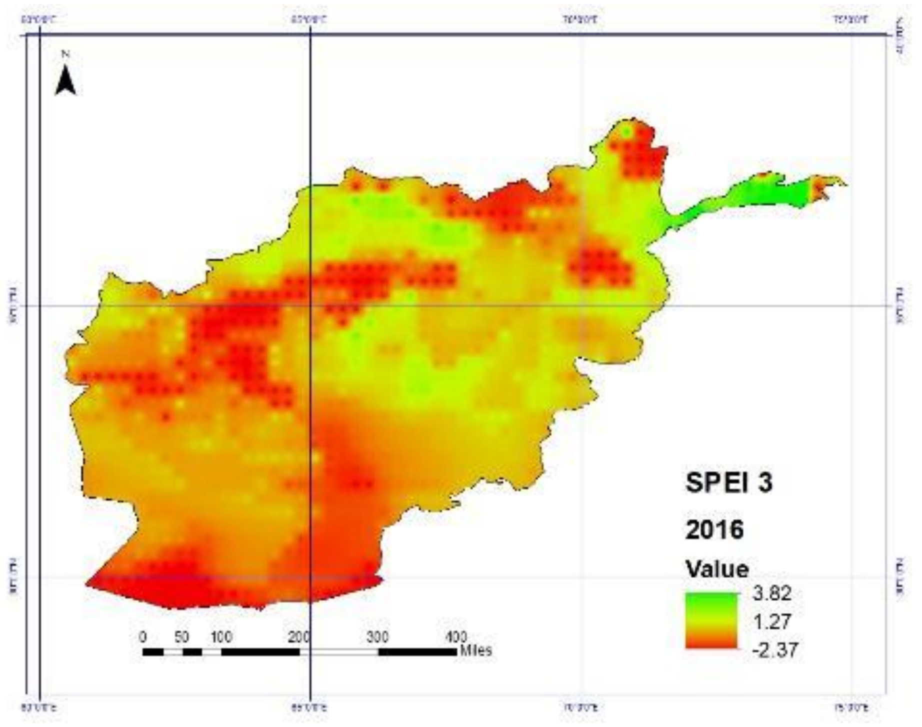
Figure 5.8. Monthly SPI 12 for 2021

5.5.2. SPEI

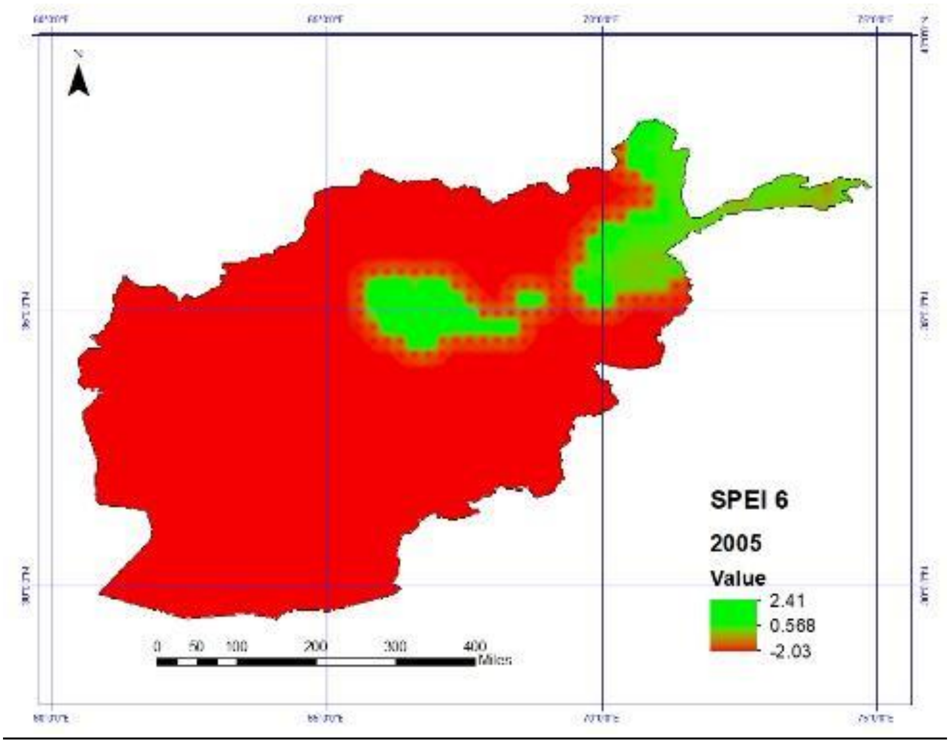
Table5.4 presents a summary of SPEI results. According to the summarized table, extreme, severe and moderate droughts have occurred in Afghanistan. For example, in 30 years under SPEI 3 two extreme drought events happened with the maximum value of 2.37 in 2016, and one extreme drought occurred under SPEI 6 with maximum value of 2.03 in 2005 while there is no sign of extreme drought under SPEI 12. Similar results can be seen for severe drought. For instance, under SPEI 3 there is only one severe drought occurrence in 1994 with the value of 1.51, and 5 occurrences with the maximum value of 1.91 in the year of 1999 and again no sign of severe drought under 12-month SPEI. To discuss moderate drought of Afghanistan under SPEI the number of occurrences under SPEI 3 is two times in 30 years with the highest event of 1.35 in 2000- and 9-times occurrences under SPEI 6 which its maximum point is 1.49 happened in 2016. Results from SPEI generalizes that most of the drought conditions occurred in the past two decades which there is highly drought intensity (extreme, severe, moderate) in short term period of SPEI 3 and SPEI 6 and normal condition for long term of SPEI 12. More occurrences with low duration always occurred under short term accumulation period. Moreover, the Figure 5.9 represent the yearly SPEI 3 and SPE 6 in 2016 and 2005 respectively that consist of highest value in term of extreme drought event.

Table 5.3. Maximum Drought Events of SPEI in 30 Years

Indices	Extreme		Severe		Moderate	
	Drought Occurrences	Max Event	Drought Occurrences	Max Event	Drought Occurrences	Max Event
SPEI 3	2	2.37 (2016)	1	1.51 (1994)	2	1.35 (2000)
SPEI 6	1	2.03 (2005)	5	1.91 (1999)	9	1.49 (2016)
SPEI 12	0	-	0	-	0	-



(a)



(b)

Figure 5.9. Yearly SPEI 3 (a) and SPEI 6 (b)

Considering monthly results of SPEI Afghanistan is mostly moderately dry. From the monthly SPEI 6 results in Figure5.11, it can be detected that the east part of Afghanistan bordering with China (Wakhan valley), a very small area is under extreme drought condition in term of SPEI 6 from months of August to December. And from January to July almost all Afghanistan except a very tiny region in east part is under moderate drought condition in term of SPEI 6. Discussing monthly SPEI 3 it can be stated that from January to April Afghanistan experienced moderate drought condition in 2016 in central Afghanistan and west part of it. But from May to December the country is almost

totally under drought condition. The Figure 5.10 represent the monthly SPEI 3 in 2016. to December the country is almost totally under drought condition.

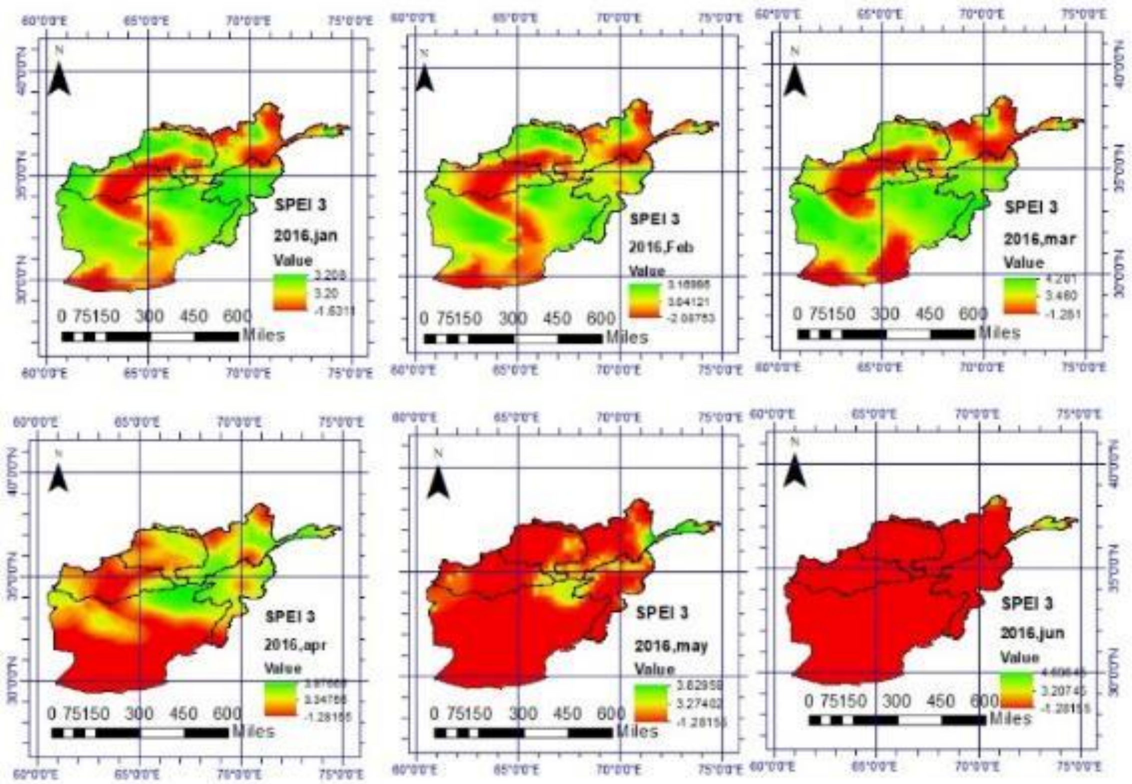


Figure 5.10. Monthly SPEI 3 For 2016

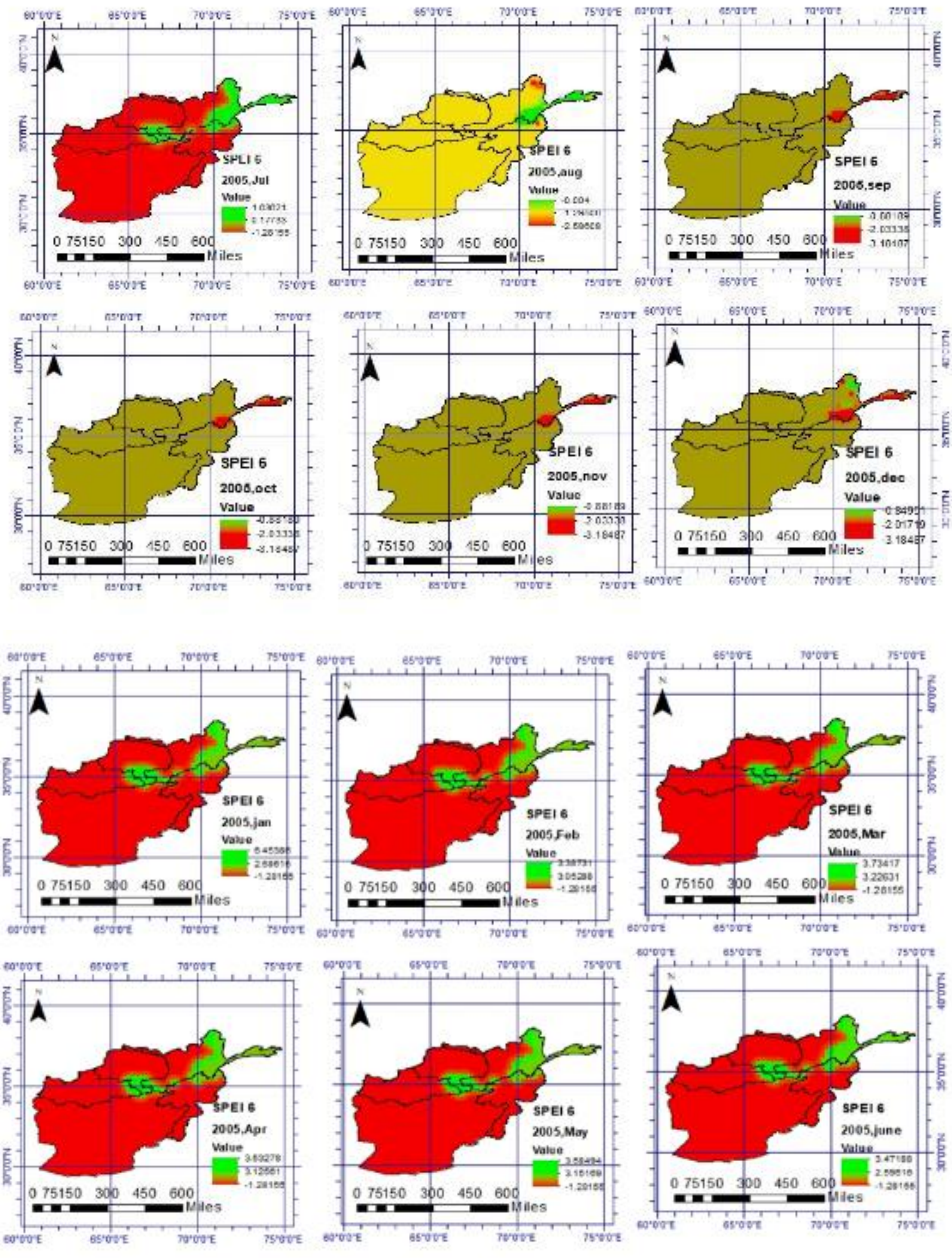


Figure 5.11. Monthly SPEI 6 for 2005

5.5.3. RDI

Table 5.5 is a summary of yearly average of RDI over all Afghanistan. According to the table for the past 30 years Afghanistan has been challenged with extreme drought, severe drought and moderate drought under RDI 3, RDI 6, and RDI 12. As one can see it from the table under RDI 3 no extreme drought has been occurred, but severe drought has been seen 18 time with the maximum value of 1.94 in 2011. And moderate drought has occurred 8 time in 30 years with the maximum number of 1.39 in 2021. Under the RDI 6 and RDI 12 one extreme drought has been seen each with maximum event of 2.05 in 2001 and 2.65 in 2011 respectively. Accordingly, under RDI 6 and RDI 12 each shows 10 and 9 moderate drought occurrences with high events in 2017. No severe drought is seen under DRI6 but for RDI 12 it is 4 time with the maximum event of 1.73 in 2008. Moreover, the Figure 5.12 represent the yearly RDI 6 and RDI 12 in 2001 and 2011 respectively. To generalize the results from DRI we can say that: more occurrences with the highly events happened in past two decades which means from the year 2000 onwards. extreme drought happened less than severe drought and moderate drought (either one occurrence or no occurrence).

Table 5.4. Maximum Drought Events of RDI In 30 Years

Indices	Extreme		Severe		Moderate	
	Drought Occurrences	Max Event	Drought Occurrences	Max Event	Drought Occurrences	Max Event
RDI 3	0	-	18	1.94 (2011)	8	1.39 (2021)
RDI 6	1	2.05 (2001)	0	-	10	1.49 (2017)
RDI 12	1	2.65 (2011)	4	1.73 (2008)	9	1.45 (2017)

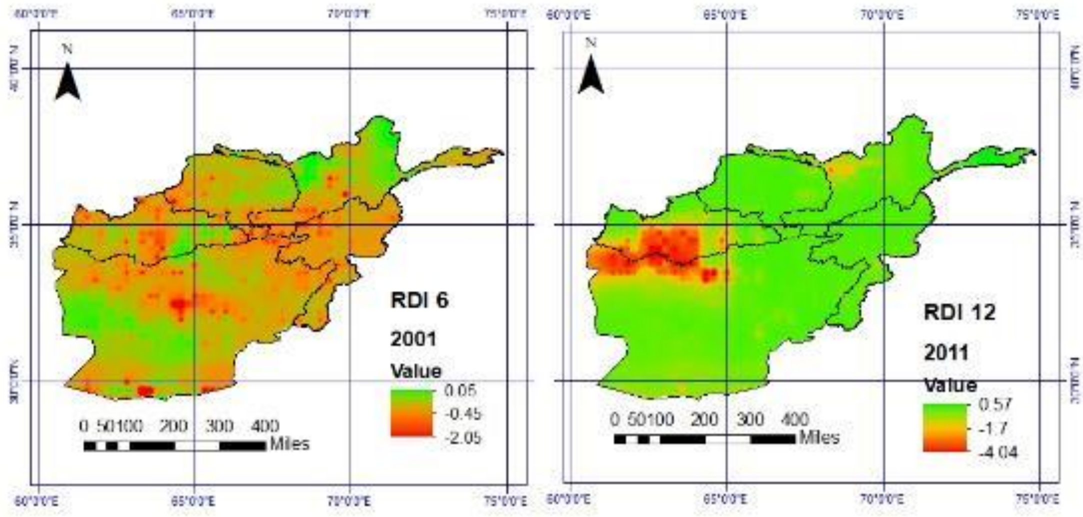


Figure 5.12. Yearly RDI for 2011 and 2001

Discussing the yearly average results of RDI it came up with the results that in 2001 and 2011 there is extreme drought event under RDI 6 and RDI 12 respectively. In order to elaborate the results, the monthly maps of these two years are separately drawn in Figures 5.13 and Figures 5.14. The results under RDI 6 in 2001 show that almost all of the country is under extreme dry in the months of February, March, April, May, June, July and August. But in months October, November and December west part of Afghanistan is under extreme drought condition. Monthly result of RDI 12 in 2011 indicates that January, February and March have very scattered drought conditions over the country. But from the month April till December the west Part of Afghanistan is under extreme RDI 12 drought conditions.

Eventually the overall results of monthly RDI detected extreme drought conditions with mostly effected region in the west part of the country (Helmand River basin Harirod Morghab river basin) which extreme events are expected to be greater than 3 in some areas. This should also be noted the dry regions are different in different months

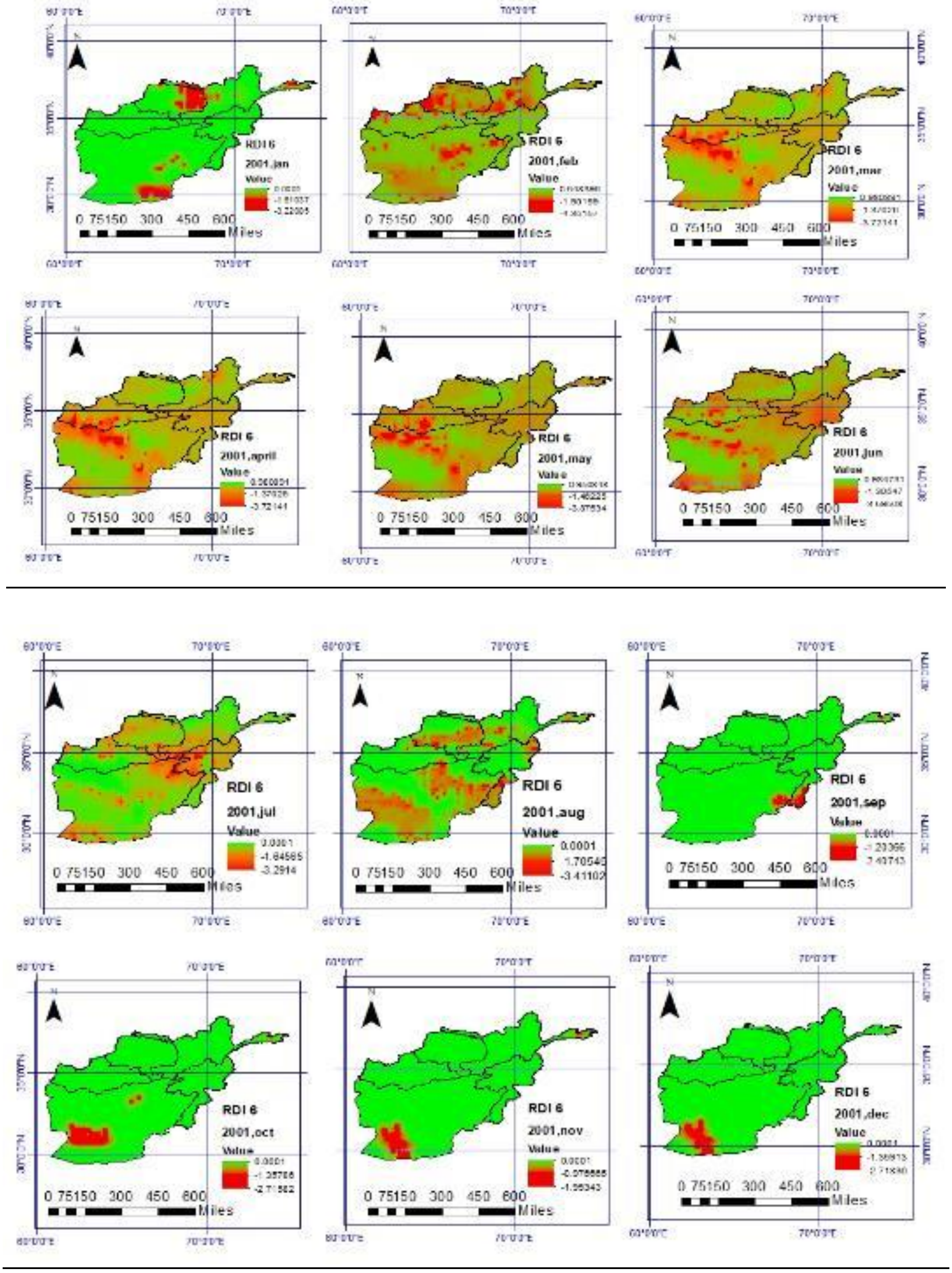


Figure 5.13. Monthly RDI 6 for 2001

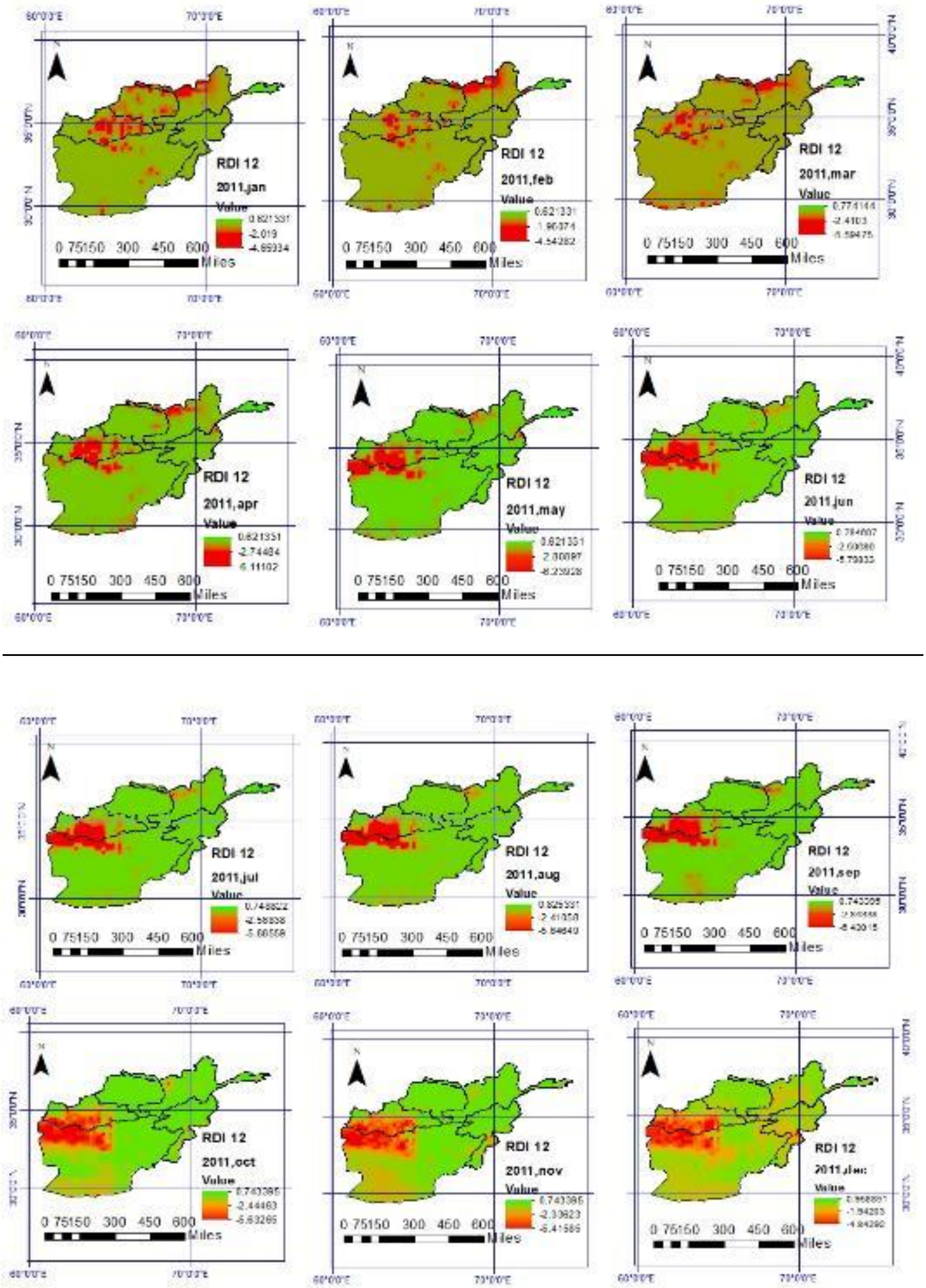


Figure 5.14. Monthly RDI 12 for 2011

5.5.4. SRI

According to yearly SRI summary Table 5.6 no extreme drought has ever happened for past 30 years in Afghanistan. But severe and moderate drought has been occurred repeatedly. For instance, under RDI 3 two severe droughts occurred which its highest event can be named in 2011 with a number of 1.7. And 24 moderate droughts occurred under RDI 3 with maximum value of 1.38 in 2016. Almost the same moderate drought (23 occurrences) happened for RDI 6 with highest value of 1.42 in 2018. But no sever and extreme drought is under RDI 6. Under RDI 12 only one severe and two moderate droughts has been occurred which the occurrence of severe is in 2000 with 1.63 value, and maximum event of moderate drought is 1.11 in 2018. To generalize the SRI results we can say that: no extreme drought happened under SRI, but instead more moderate drought occurred which all the maximum events is in the past 20 years with short duration. Furthermore, Figure 5.15 represents the yearly SRI 3 and SRI 12 consists of extreme drought with highly event.

Table 5.5. Maximum Drought Events of SRI in 30 years

Indices	**Extreme**		**Severe**		**Moderate**	
	Drought Occurrences	**Max Event**	**Drought Occurrences**	**Max Event**	**Drought Occurrences**	**Max Event**
SRI 3	0	-	2	1.7 (2011)	24	1.38 (2016)
SRI 6	0	-	0	-	23	1.42 (2018)
SRI 12	0	-	1	1.63 (2000)	2	1.11 (2018)

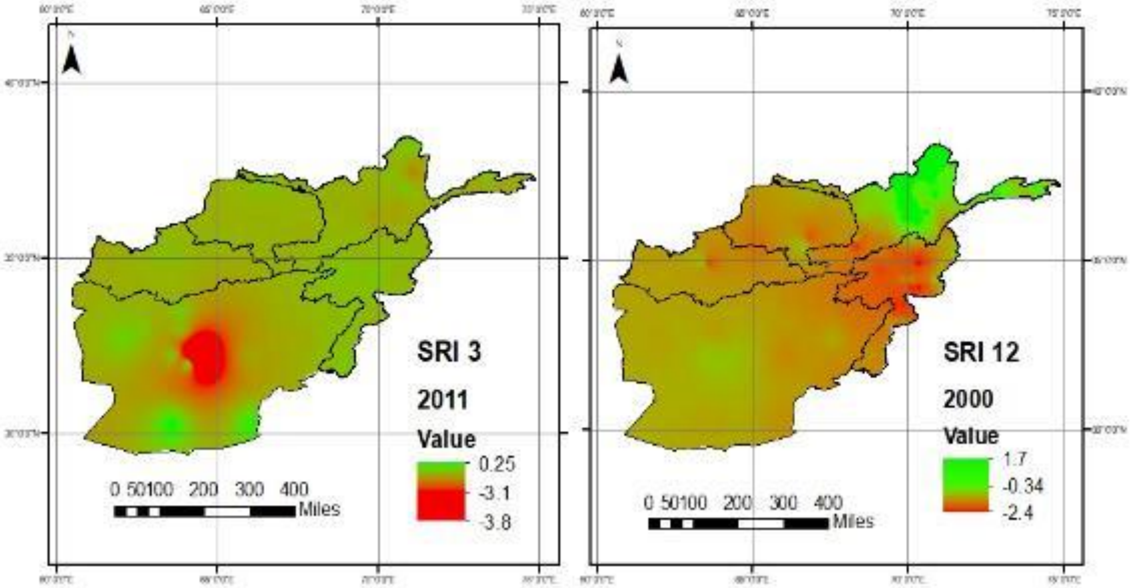


Figure 5.15. Yearly SRI for 2000 and 2011

Talking about monthly SRI, the years 2000 for SRI 12 and 2011 for SRI 3 are considered to have extreme event with high values. According to Figure 5.16 of SRI 3 Afghanistan has extreme drought in months of January, February, March and April in territory of Kabul, Penjamu, and northern river basins. From the month May till December west Part of Afghanistan (Helmand River basin) is under SRI 3 extreme drought condition. In Figure 5.17 of SRI 12 in 2000 shows that extreme drought condition starts from the month of February in Kabul River basin and separate to the west part of the country till the months of May, and from June till December most of the country is under drought condition with the severity region of Kabul River basin, Penj Amu River basin, Northern River basin and Harirod Morghab River basin. The main argument about monthly results of SRI can be stated that extreme drought condition was occurred mainly in west part of Afghanistan with the magnitude of around 3 in some areas.

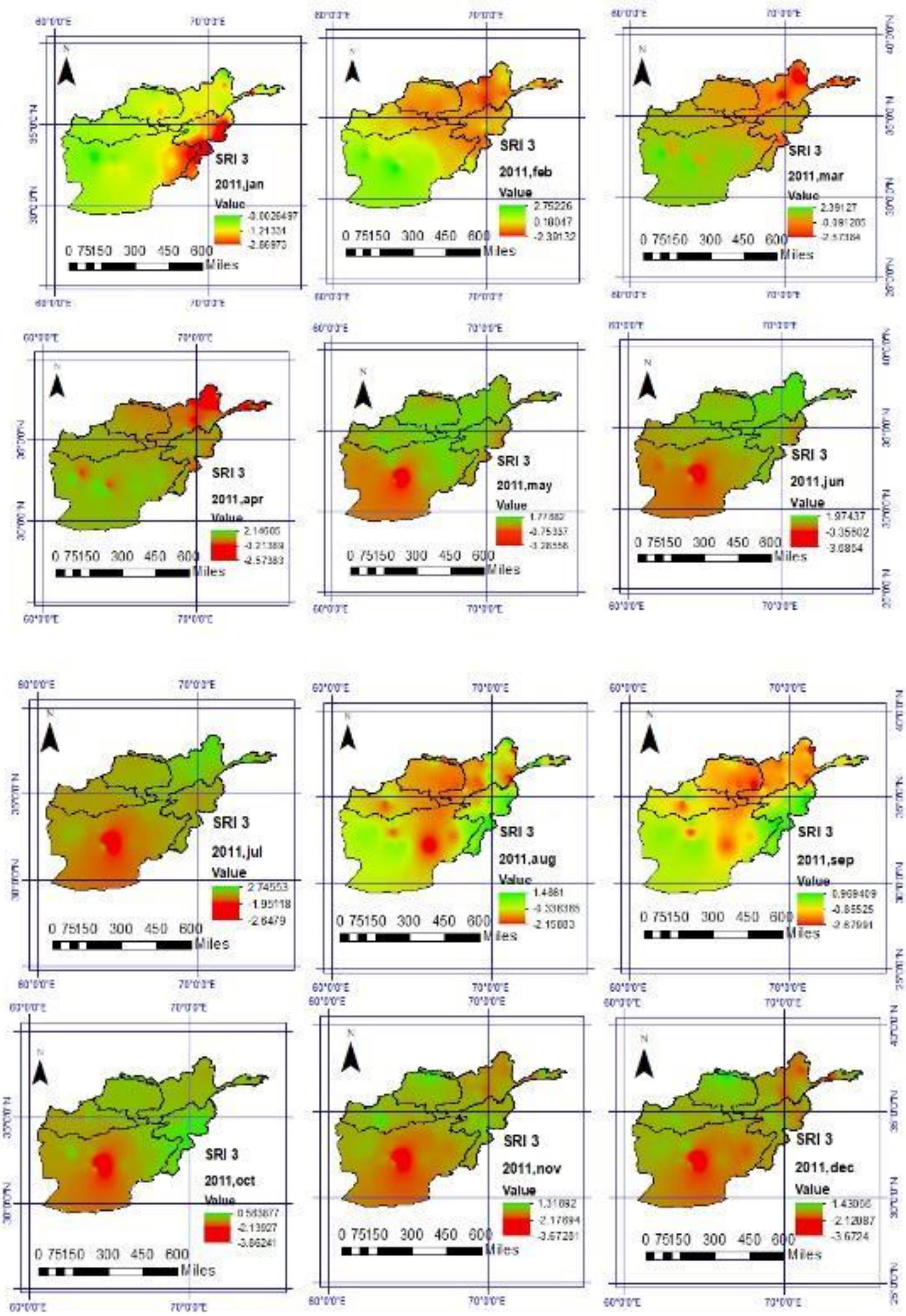


Figure 5.16. Monthly SRI 3 for 2011

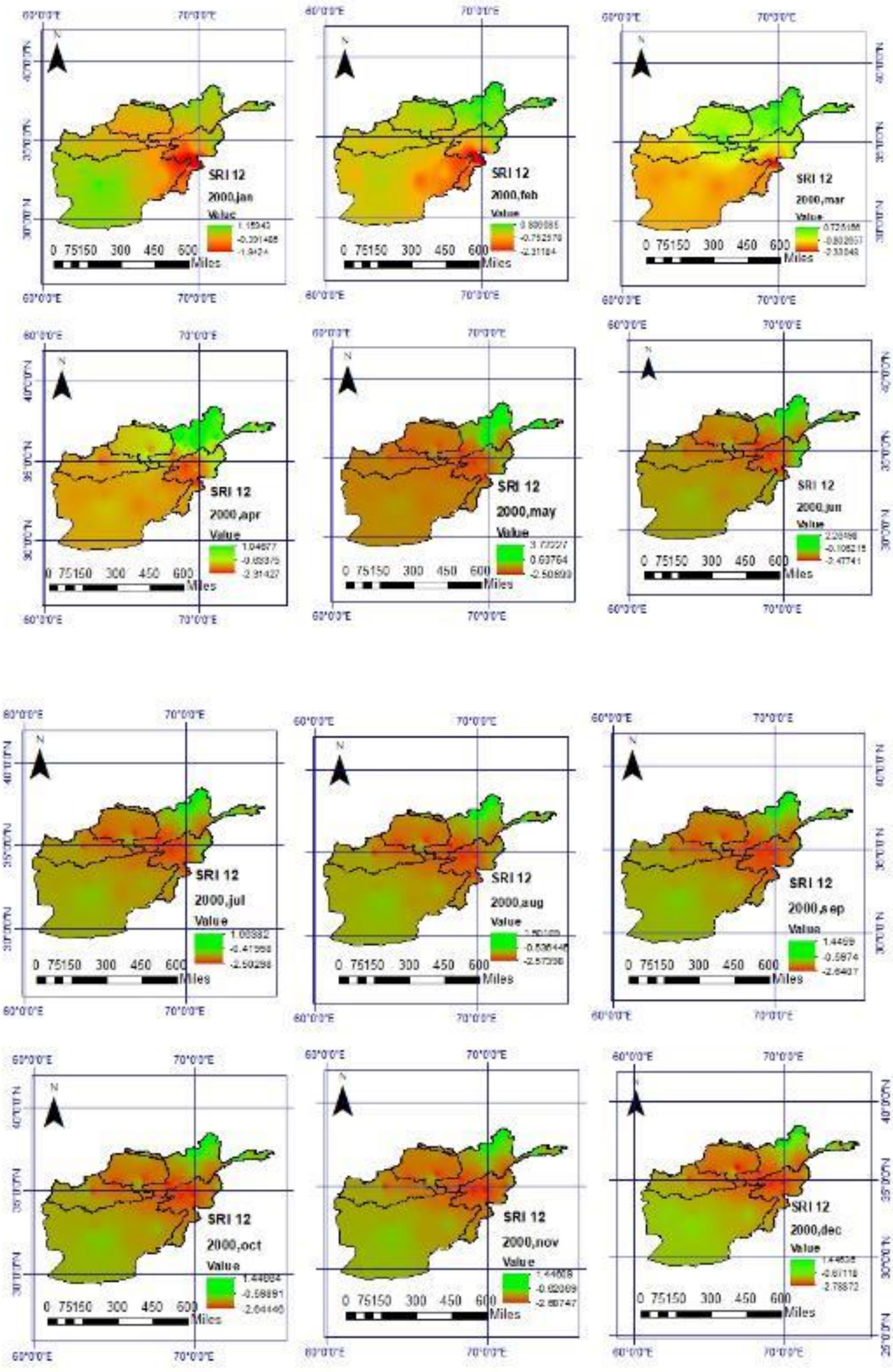


Figure 5.17. Monthly SRI 12 for 2000

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

In closing, this thesis has undertaken a comprehensive study of drought assessment methods and their applicability in Afghanistan. Throughout this research, we have explored various aspects of drought, from its causes and impacts to the evaluation of different assessment techniques. As we reach the final chapter, we are poised to synthesize our findings, draw meaningful conclusions, and provide recommendations that can contribute to more effective drought management strategies in the face of an increasingly uncertain climate. Based on remotely sensed monthly precipitation, temperature and surface runoff data from 1992 till 2021 four drought indices (SPI, SPEI, RDI, SRI) were analyzed in this study. Each Indices were calculated in three different periods of time (3 months,6 months and 12 months). This thesis main objective was to evaluate past drought conditions in Afghanistan using the mentioned drought indices and relating them to the impacts of climate change with the sub objectives of creating historical drought maps for the entire country over a 30-year span using three different time frames (3-, 6-, and 12-months), determining the main drought features, such as frequency, magnitude, and duration. Comparing the variations of drought over three different time periods (three months, six months, and a year) was another sub objective of this research. The methodology used for all four indices was based on long term RS precipitation, temperature and surface runoff data. All four indices were determined by fitting the related RS data to gamma distribution and then converting it to a normal distribution probability function. With this method, values greater than the mean (zero) signify the absence of drought, but values less than the mean (zero) signify the presence of drought. Near normal (0.99 > SPI > -0.99), moderately dry (-1.0 > SPI > 1.49), severely dry (-1.5 > SPI > 1.99), and extremely dry (SPI -2.0) are the four categories for drought according to this method. The following conclusions are drawn.

1. SPI results with respect to yearly average data over all Afghanistan indicate that no extreme drought happened under SPI 3, SPI 6 and SPI 12, but there is yearly extreme drought event under SPI 6 in 2000 and 2021, and SPI 12 in

1999,2000,2007,2017,2020 and 2021 mostly in west part of Afghanistan (Helmand River basin Harirod Murghab river basin).

2. Monthly SPI results show extreme drought generally in August, September, October, November, and December which is mostly in west part of the country (Helmand River basin Harirod Morghab river basin) and rarely central Afghanistan.
3. Under SPI western and central part of the country experienced more drought events in the past two decades.
4. According to yearly average data over all Afghanistan there is extreme drought events from 1992 to 2021 under RDI 12 except 2000, 2001 and 2002 with significant events under RDI 6 in 2001 and RDI 12 in 2011. Most of drought events happened in western part of the country (Helmand River basin Harirod Morghab river basin).
5. Monthly results of RDI indicates that there are Extreme drought under RDI which is very scattered all over the country.
6. According to the years which had extreme drought event the months of January, February and March have very scattered drought all over Afghanistan especially under RDI 12, but in months October, November and December west part of Afghanistan (Helmand River basin Harirod Morghab river basin) is under extreme drought condition mostly under RDI 6.
7. For more elaboration it can be concluded that under RDI due to differences in climate of Afghanistan dry region differs months to months but mostly effected region is west part of the Afghanistan (Helmand River basin Harirod Morghab river basin).
8. Yearly average of the country shows that no extreme drought happened under SRI 3, SRI 6 and SRI 12, but there are extreme drought conditions in different part of Afghanistan. For example, under SRI 3 from 1992 to 2021 Helmand River basin are under extreme dry condition with an average event of 3 except 1993, 2008. Almost the same results of SRI 3 are applicable for SRI 6 with the only differences that the drought areas are getting wider in Helmand River basin. Under SRI 12 there is extreme drought in Kabul River basin in the years of 2000 and 2001, and Helmand River basin in 2020 and 2021.
9. When it comes to monthly SRI, the years 2000 for SRI 12 and 2011 for SRI 3 are considered to have the highest event. According to SRI 3 results, Afghanistan has

extreme dry months in January, February, March, and April in the Kabul, Penjamu, and northern river basins. From May to December, the west part of Afghanistan (Helmand River basin) is classified as SRI 3 extreme dry. SRI 12 results from 2000 show that extreme drought conditions begin in February in the Kabul River basin and spread to the west of the country until May, and from June to December, most of the country is under drought conditions, with the severity region in Kabul River basin, Penj Amu river basin, northern river basin and Harirod Morghab river basin.

10. Based on yearly average calculation there is extreme drought in 2001 and 2016 under SPEI 3 and in 2005 under SPEI 6. Yearly results of SPEI shows that Afghanistan is almost totally under moderate drought condition except some central part and east part of the country where is under wet conditions.
11. Monthly results of SPEI indicates almost the same as yearly results (mostly moderate drought) except for months of August, September, October, November and December under SPEI 6 of 2005. A very small east part of the country has extreme drought.

According to the aforementioned conclusion, the SPI, SPEI, RDI, and SRI are highly helpful indices that can determine drought events depending on various time periods. Only the 3-month, 6-month, and 12-month time frames were taken into account in this study. However, these four indices act differently in some cases due to differences in climate (arid and semi-arid) in some region. Over all conclusions of this study can be summarized that Afghanistan is suffering from drought. At least for the past 20 years most part of the country experienced many extreme droughts especially west part of Afghanistan. drought can effect water resources in Afghanistan such as Reduced Surface Water Flow, Diminished Groundwater Recharge, Impact on Snowmelt, Agricultural Water Stress, Impact on Livestock, Water Quality Issues, Infrastructure Stress, Humanitarian Impacts, and Long-Term Environmental Impact. Thus, the assessment of drought in Afghanistan is very crucial. Another important issue to assess drought in Afghanistan is that all of its major basins are transboundary water sharing with the neighbors. Most of the time lack of water create problems especially with Iran and Pakistan about Helmand River basin and Kabul River basin respectively. For the past ten to twenty years of droughts and recently effect of climate change there is always water problems among the neighboring country.

As one of the most vulnerable areas in the world, Afghanistan should be taken into consideration for early and prompt intervention before, during, and after drought. Drought management and mitigation strategies must be implemented by the Afghan government. Over time, the Framework should be assessed and examined in order to determine its efficacy and enhance the frameworks. If the Frameworks are effective, they should be turned into long-term projects. More importantly, due to lack of weather stations together with no water management and mitigation strategies there is no comprehensive study that evaluates the water issues like drought and flood in Afghanistan. That’s why there should be more weather stations, equipment, and knowledge available to help with the investigation of drought affects and preparation methods. Moreover, in order to determine the value and cost of the harm caused by the drought in Afghanistan, more research should be conducted. In order to comprehend the potential dangers posed to water resources by population increase and climate change, researches are needed to examine how drought impacts both subsurface and surface water bodies. This can be done by looking into how water resources are used and what impacts their recharge based on human and environmental changes.

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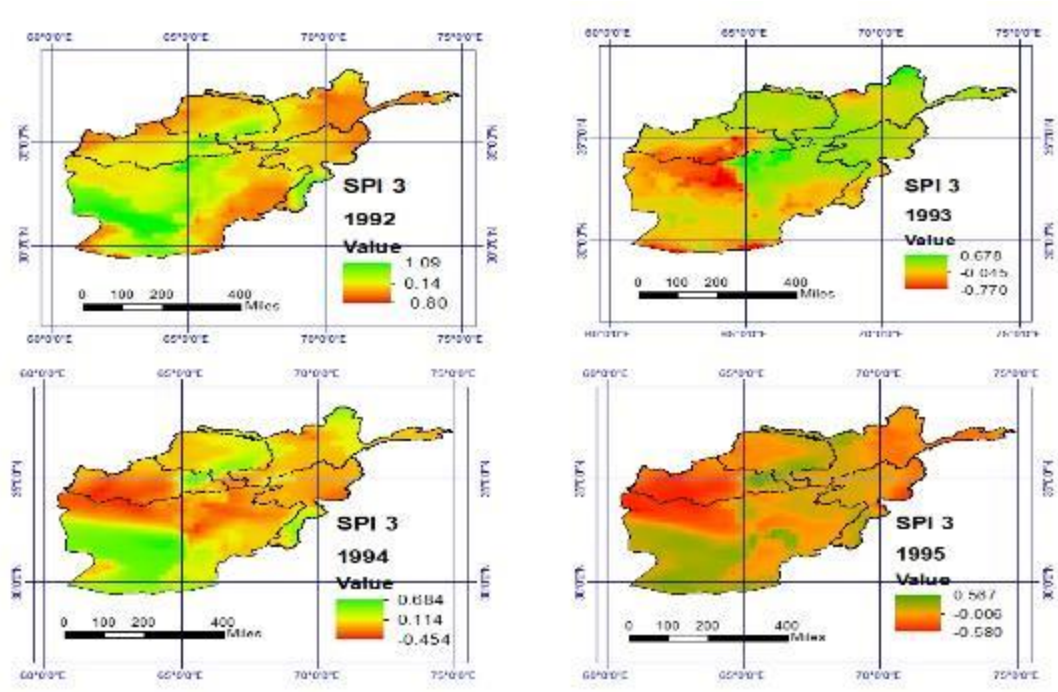
APPENDIX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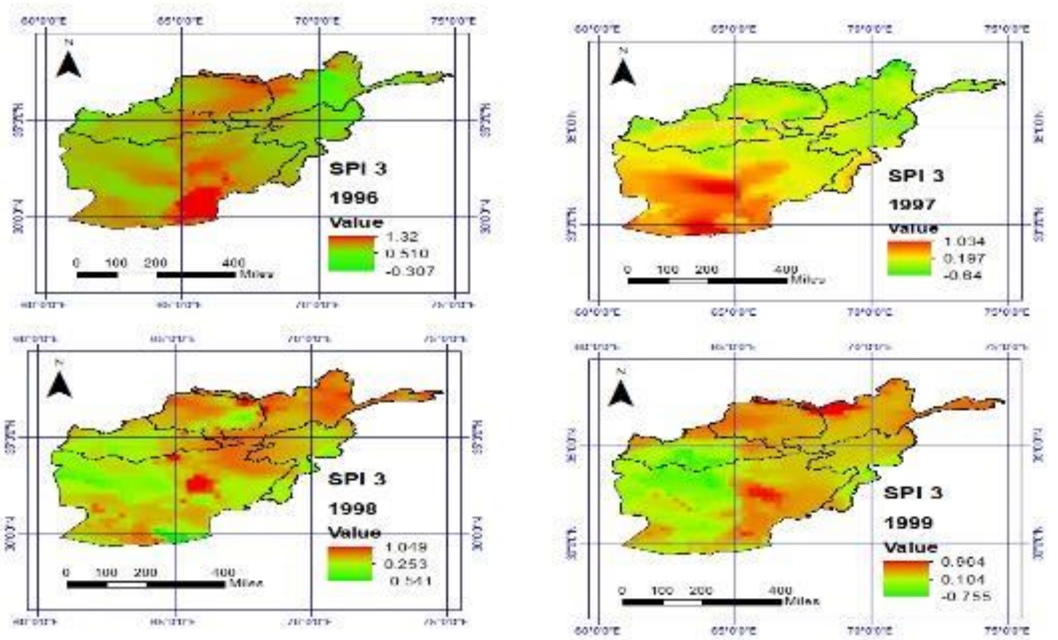
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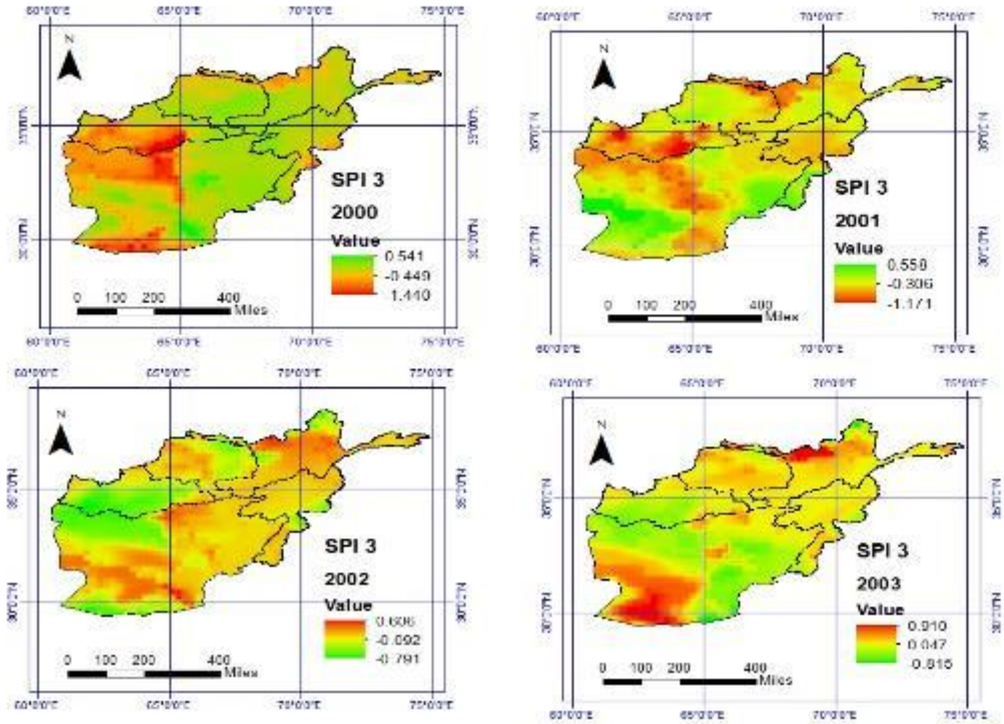
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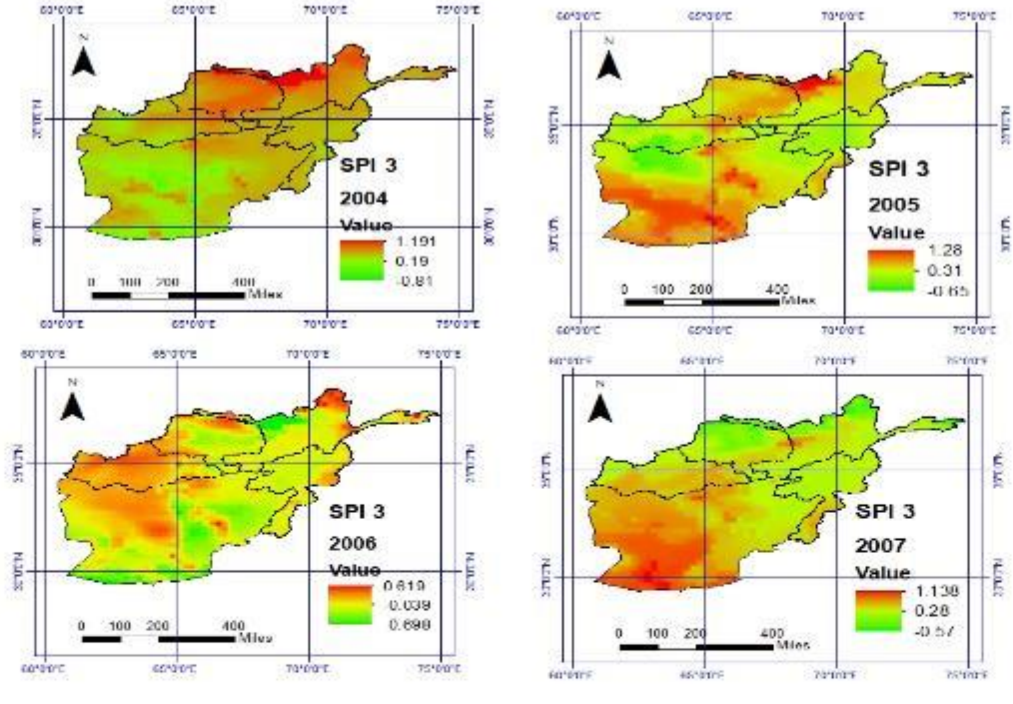
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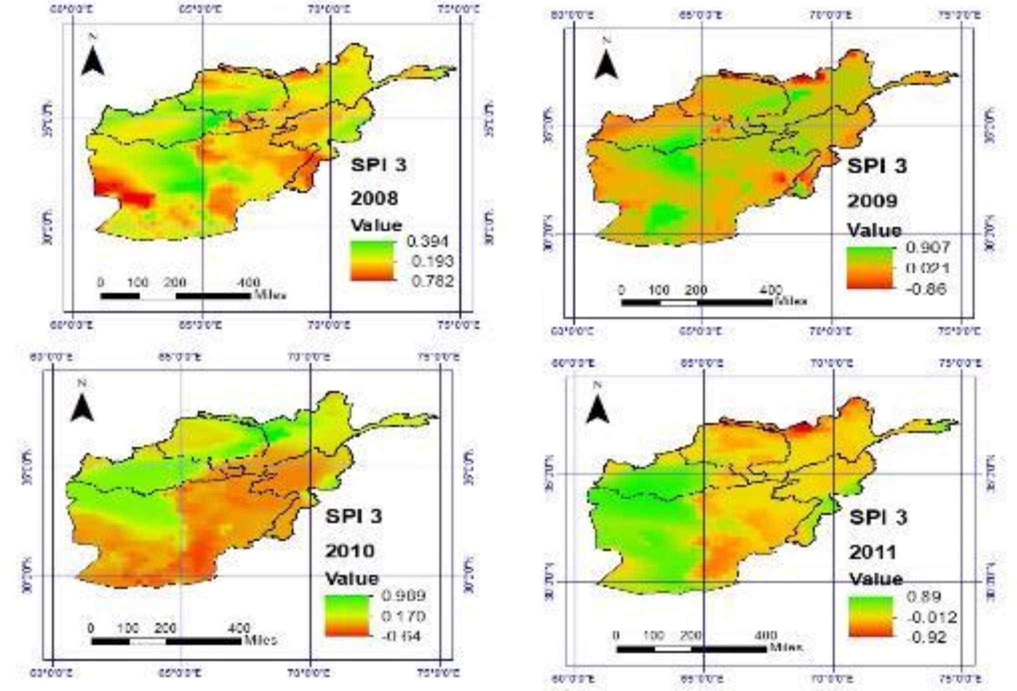
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0 100 200 400 Miles
SPI 3
2010
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0 100 200 400 Miles
SPI 3
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Value
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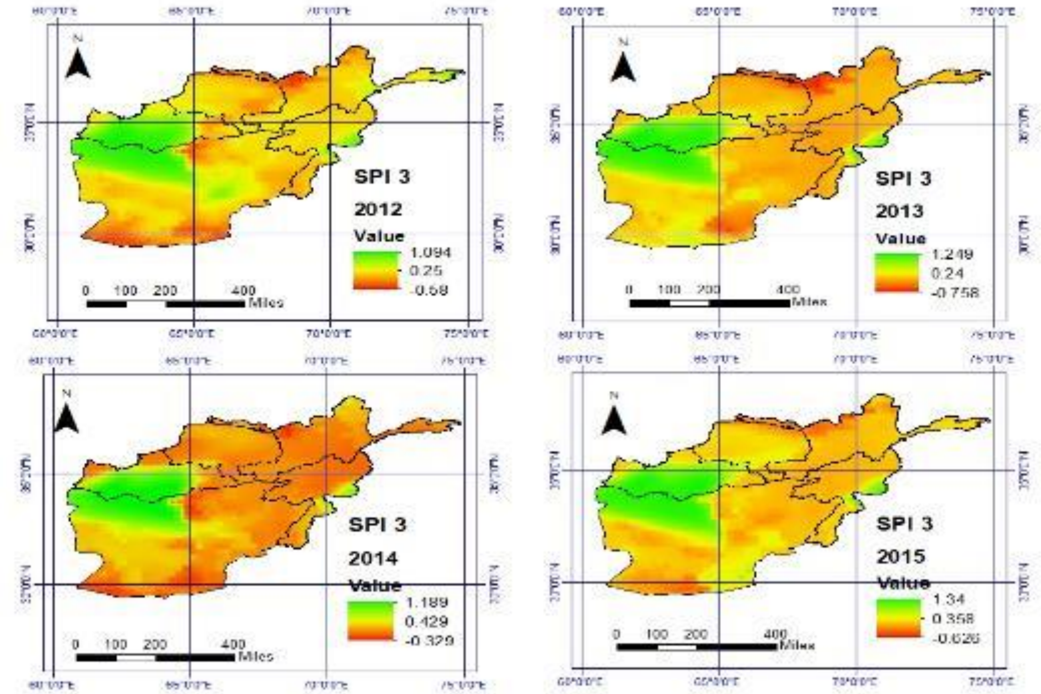
0 100 200 400 Miles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Value
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0 100 200 400 Miles
SPI 3
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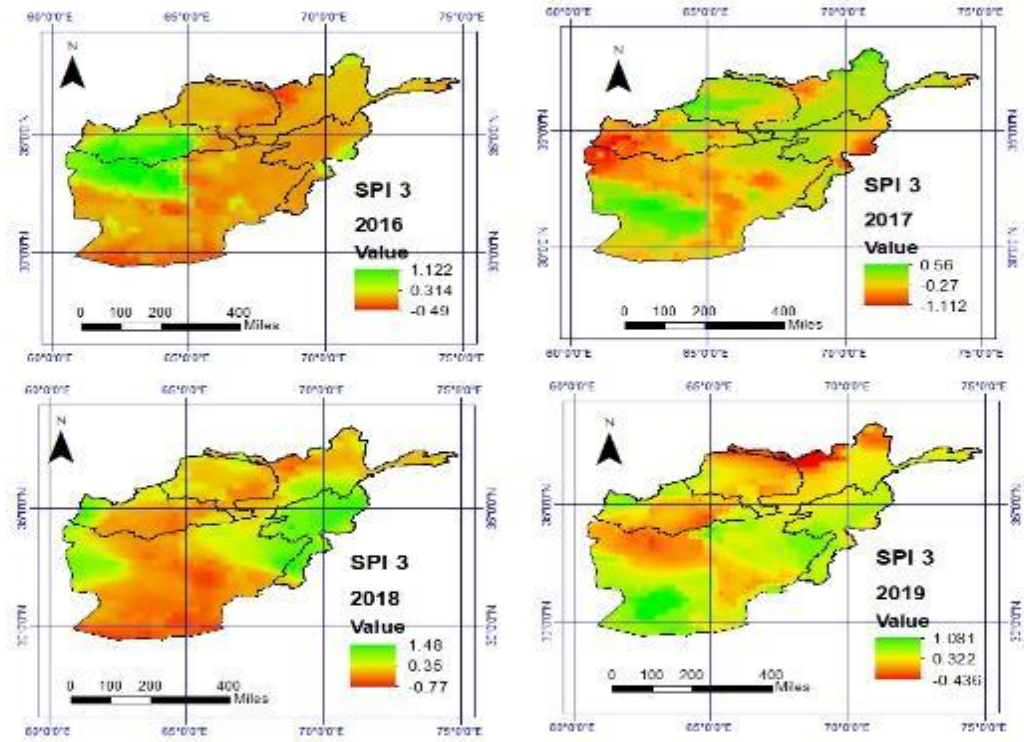
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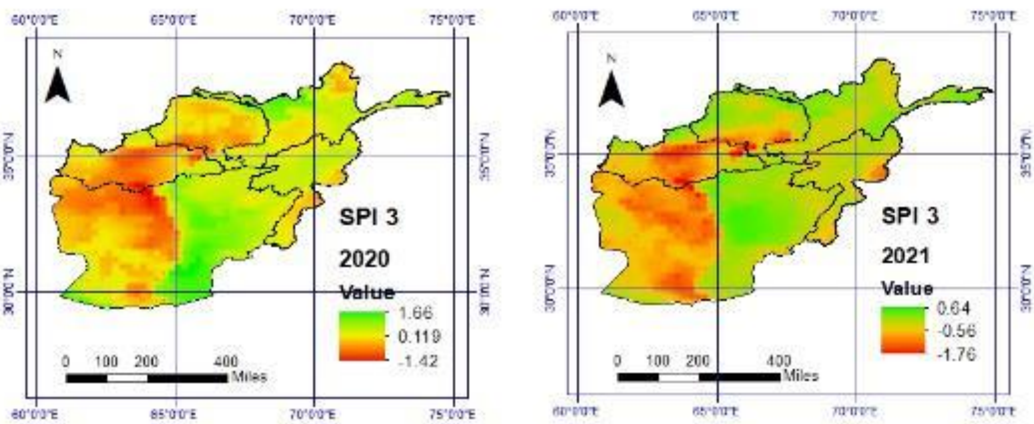
200
400
Miles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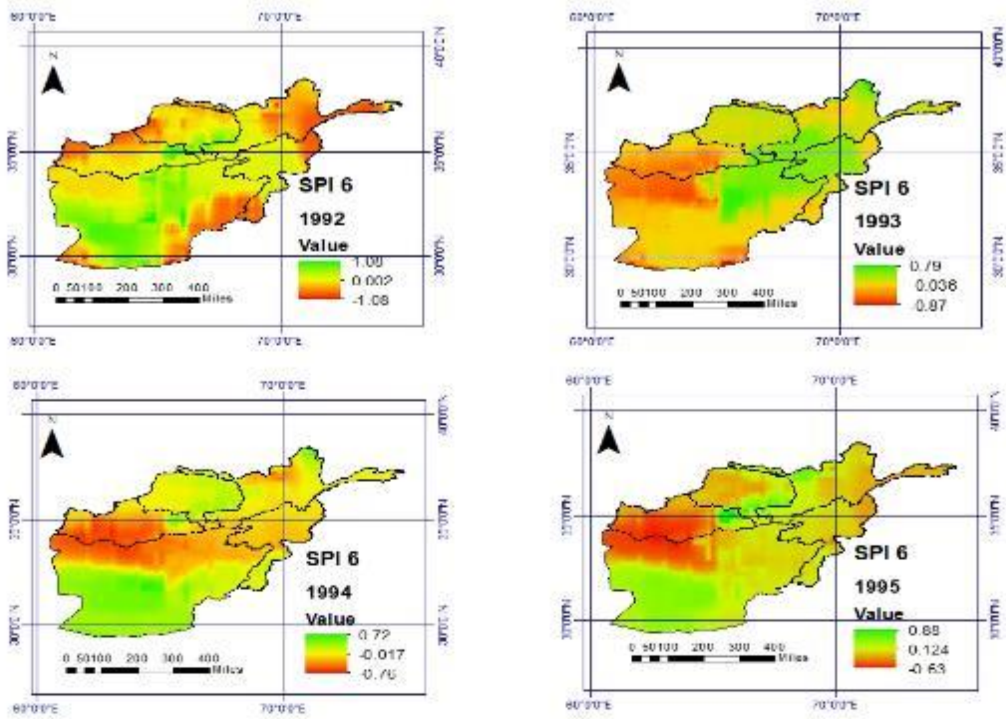
65°0'0"E
70°0'0"E
75°0'0"E
35°0'0"N
30°0'0"N
0
100
200
400
Miles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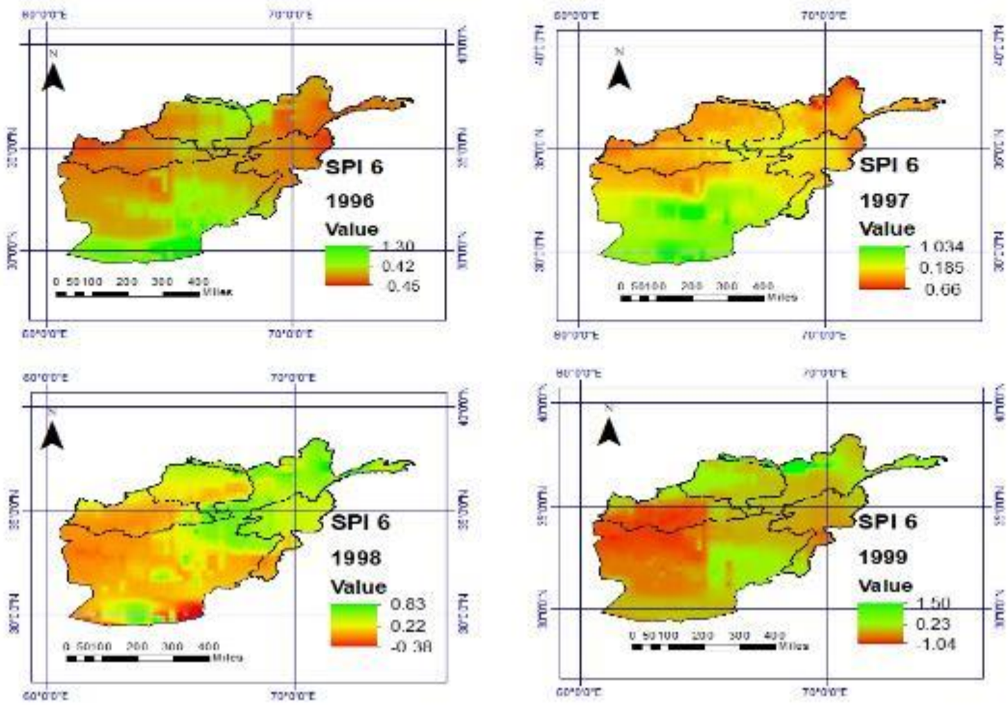
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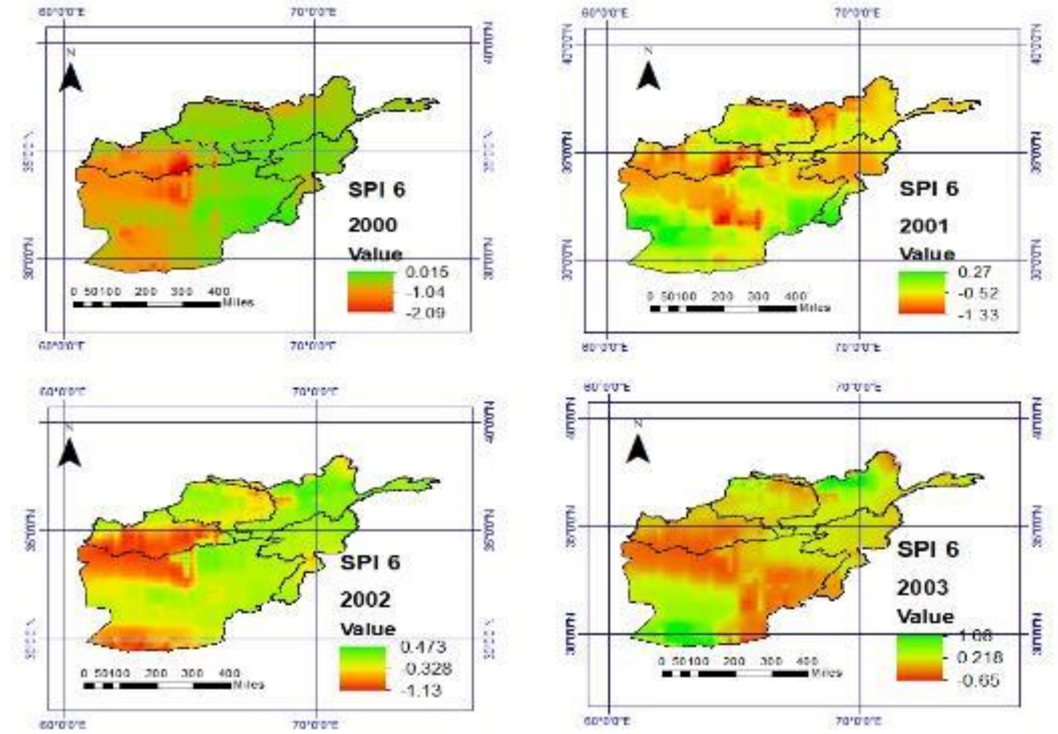
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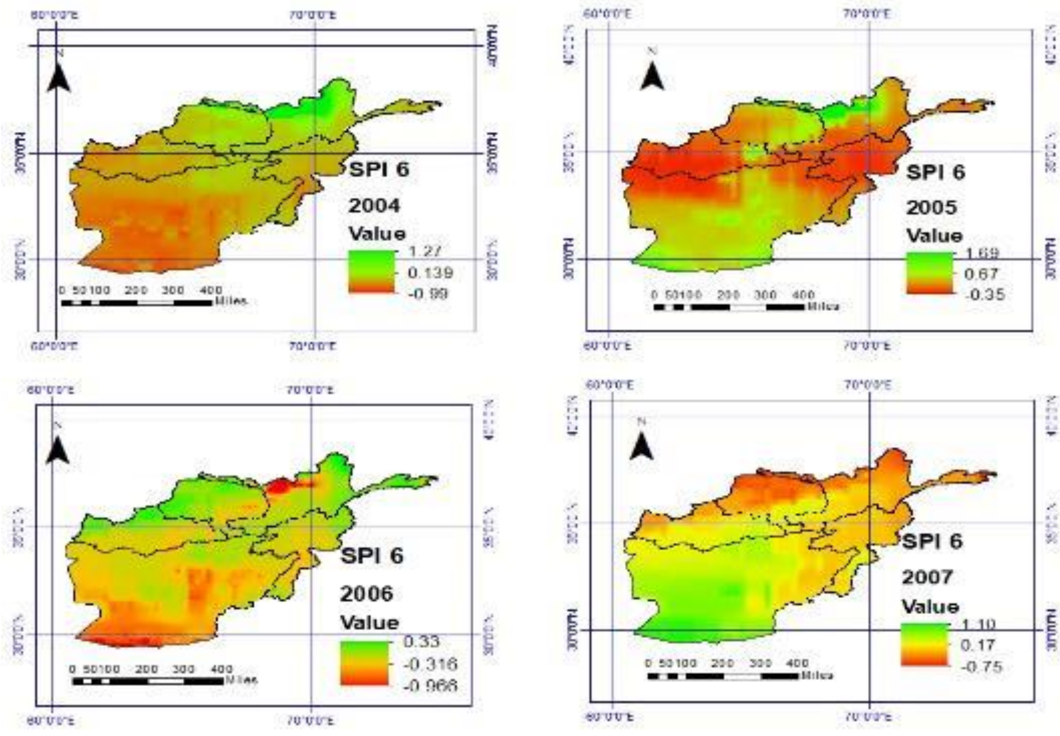
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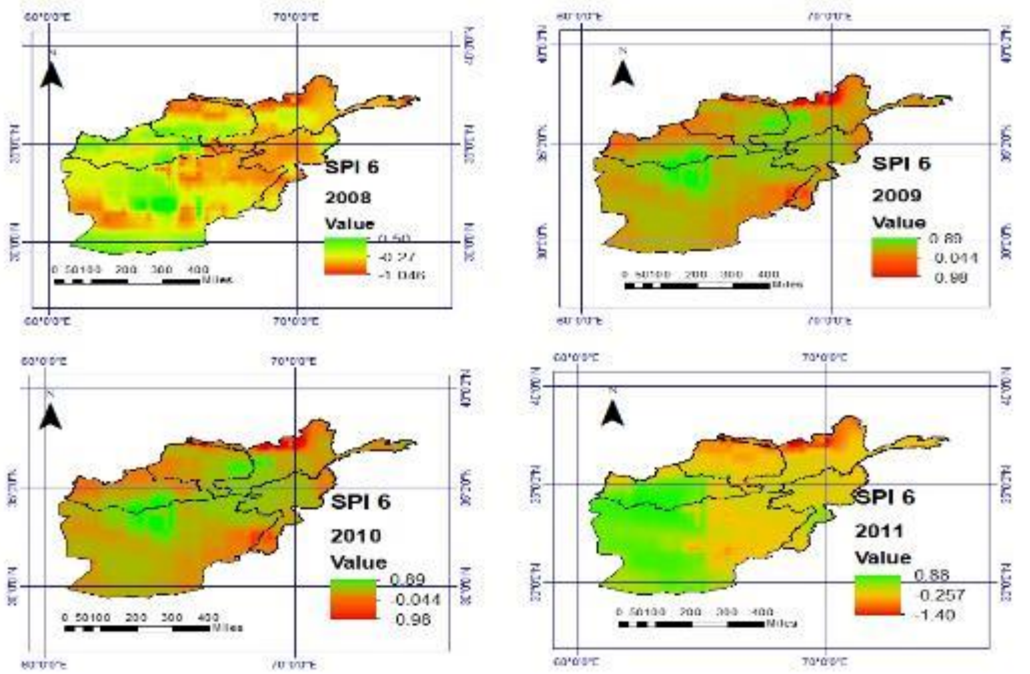
70°0'0"E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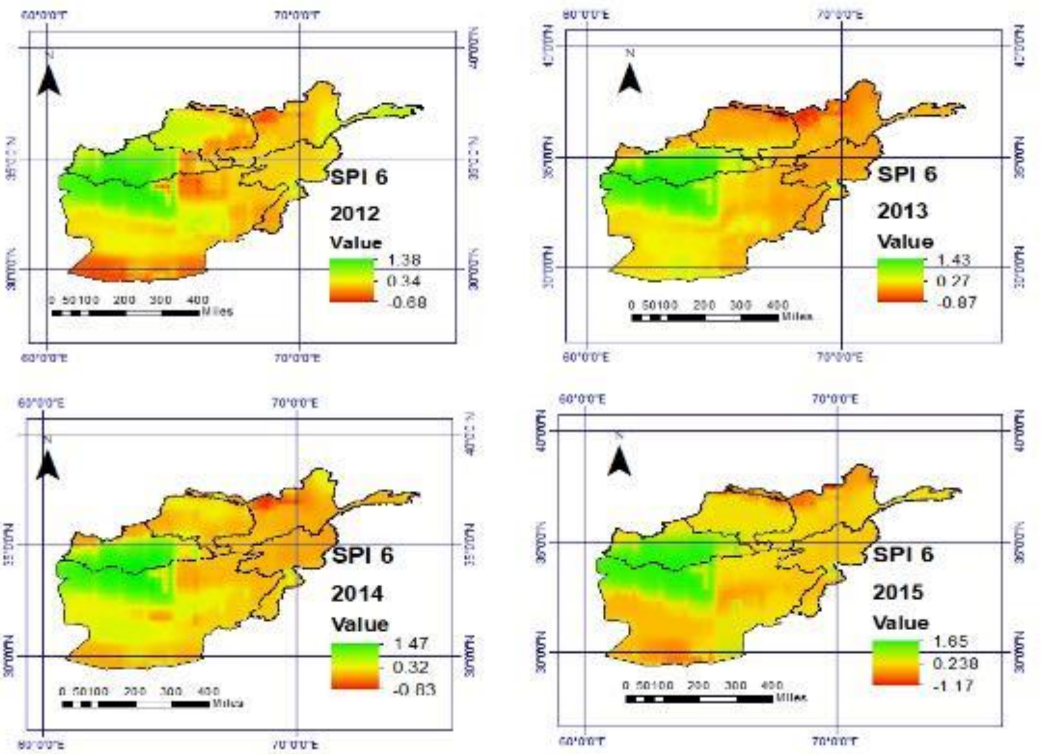
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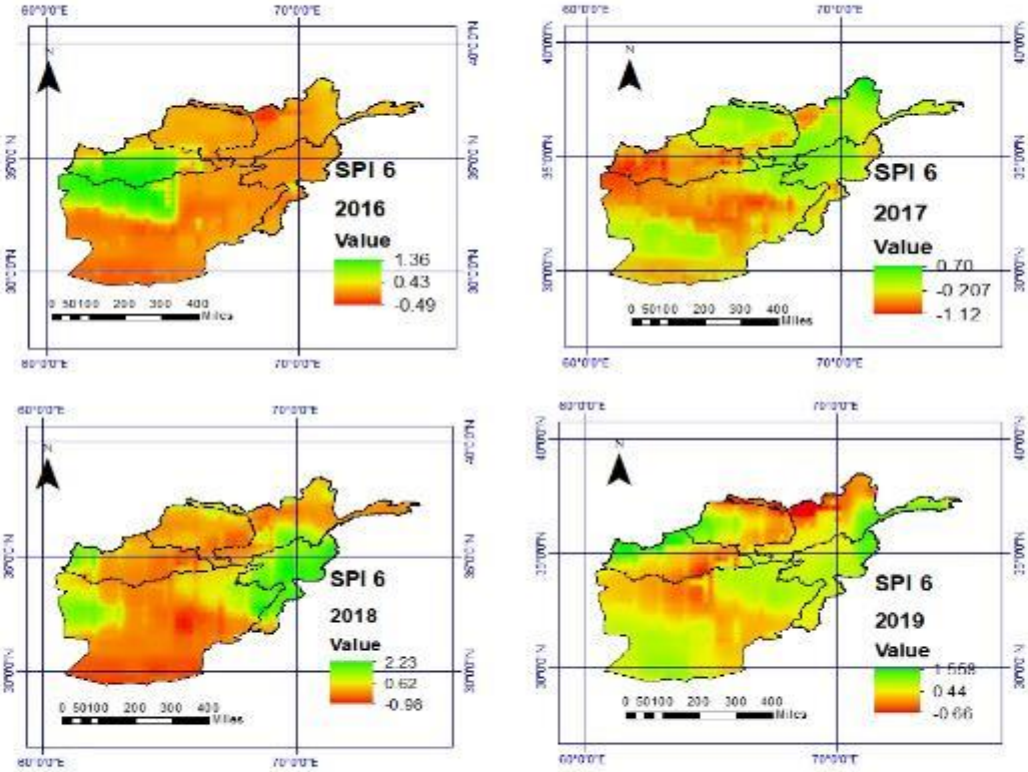
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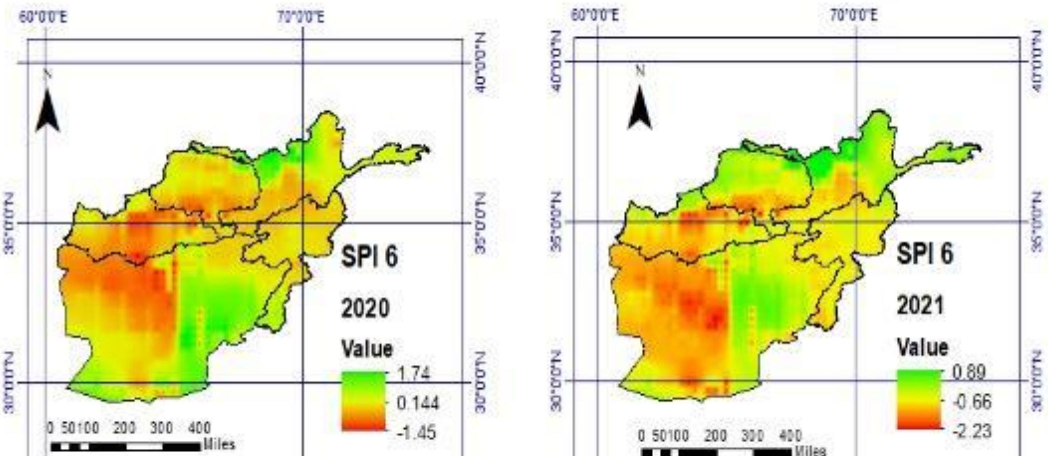
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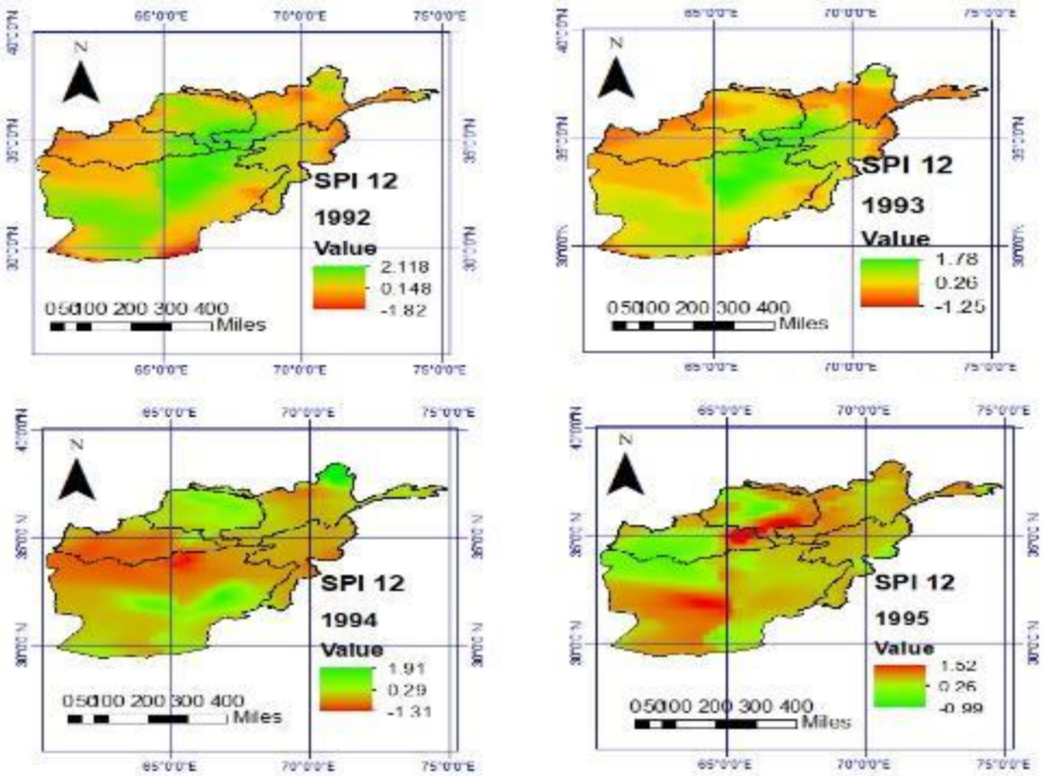
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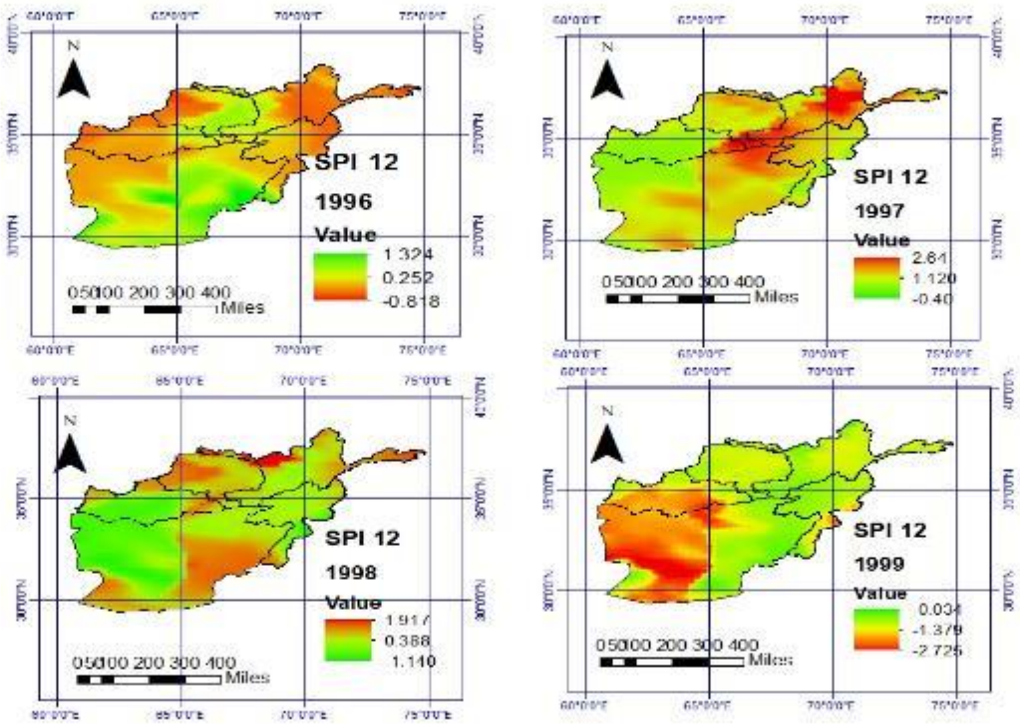
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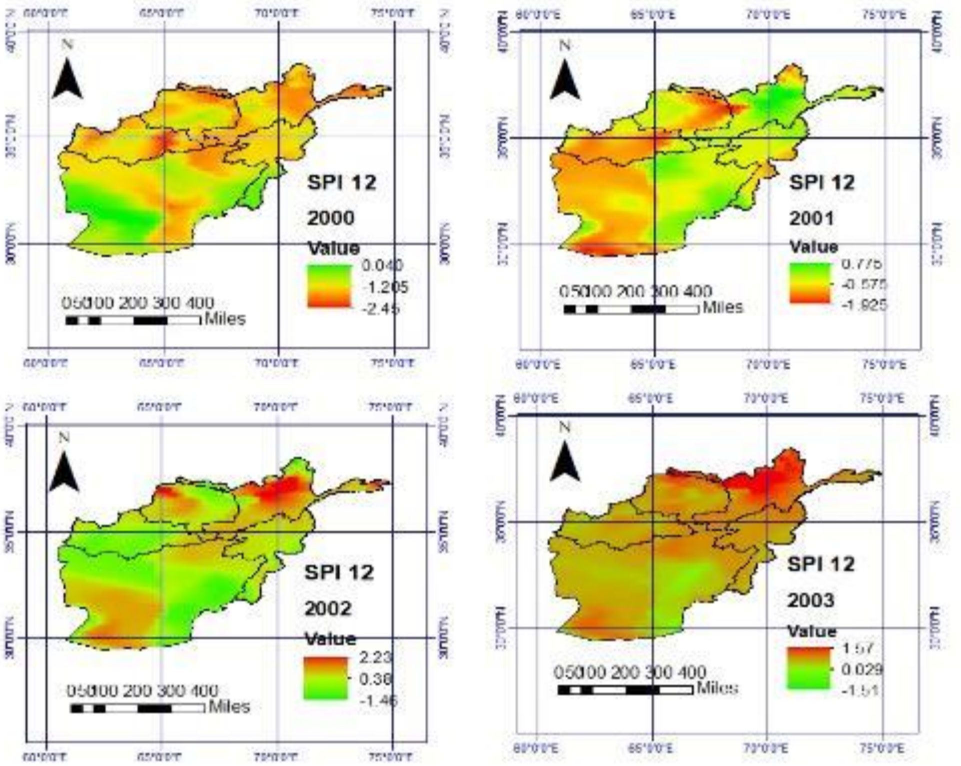
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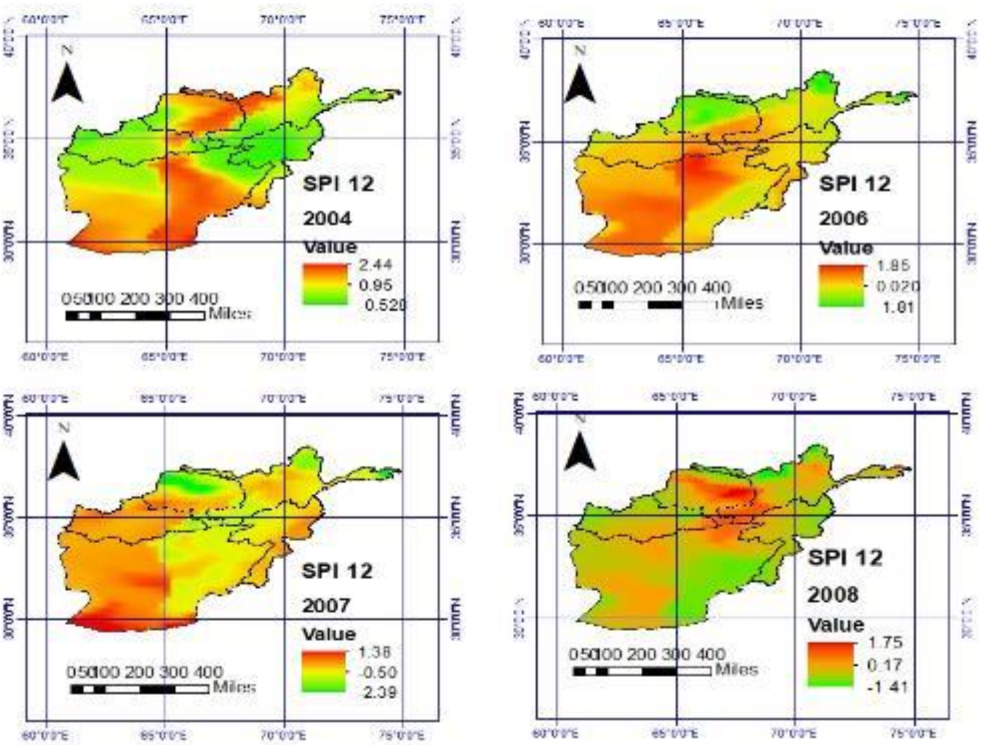
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Miles
SPI 12
2007
Value
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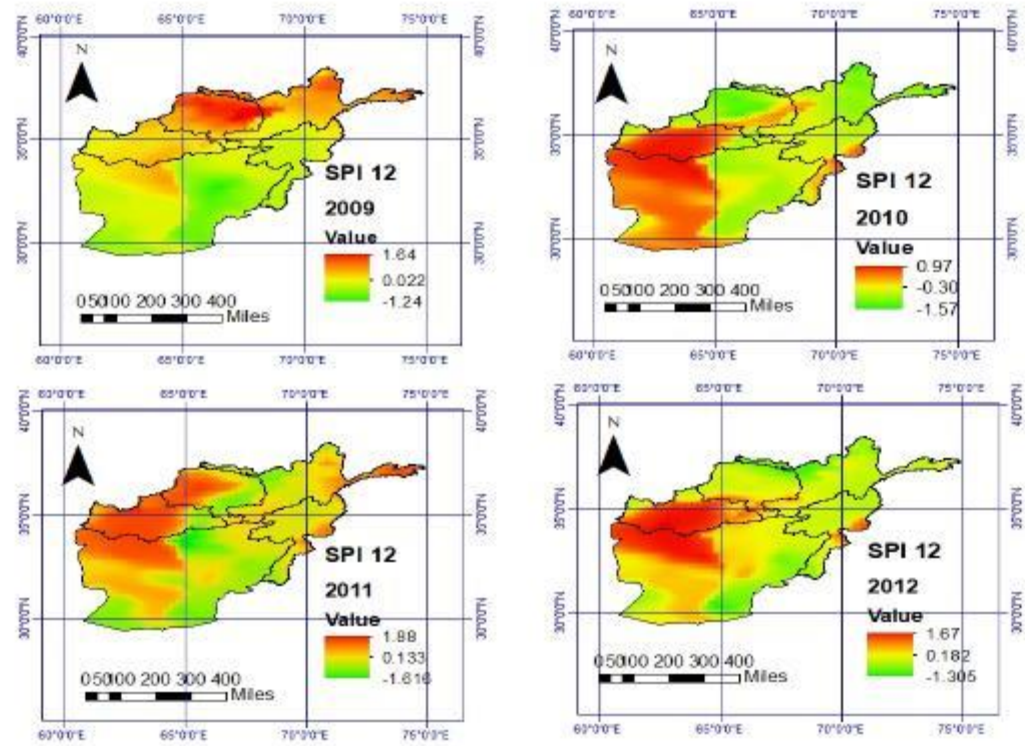
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Miles
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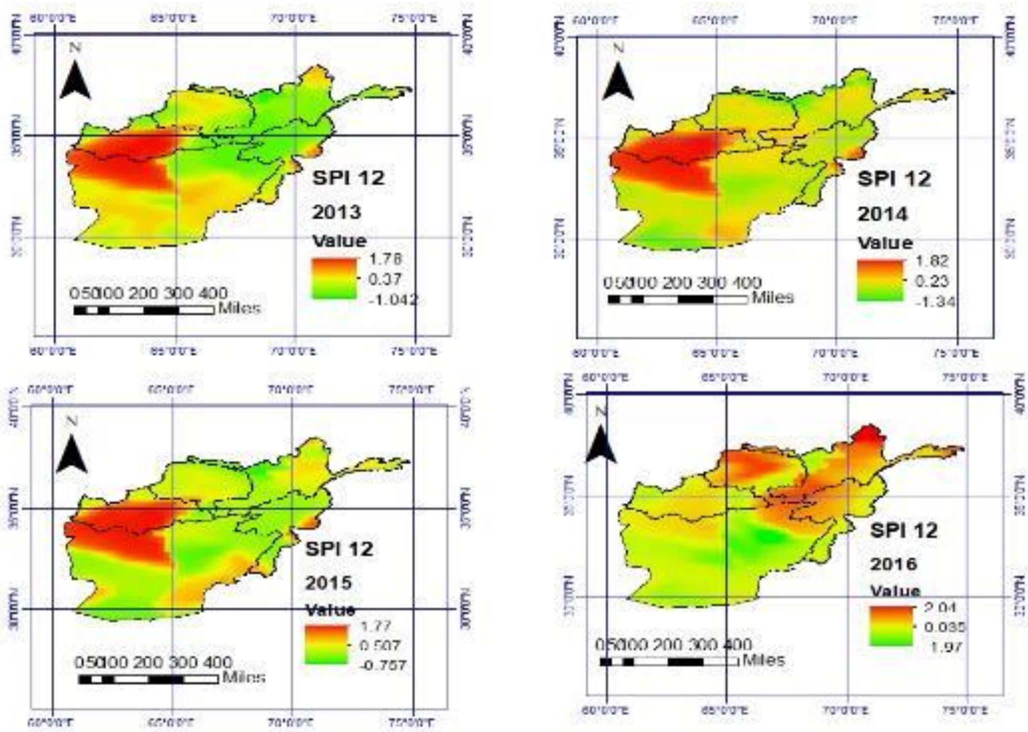
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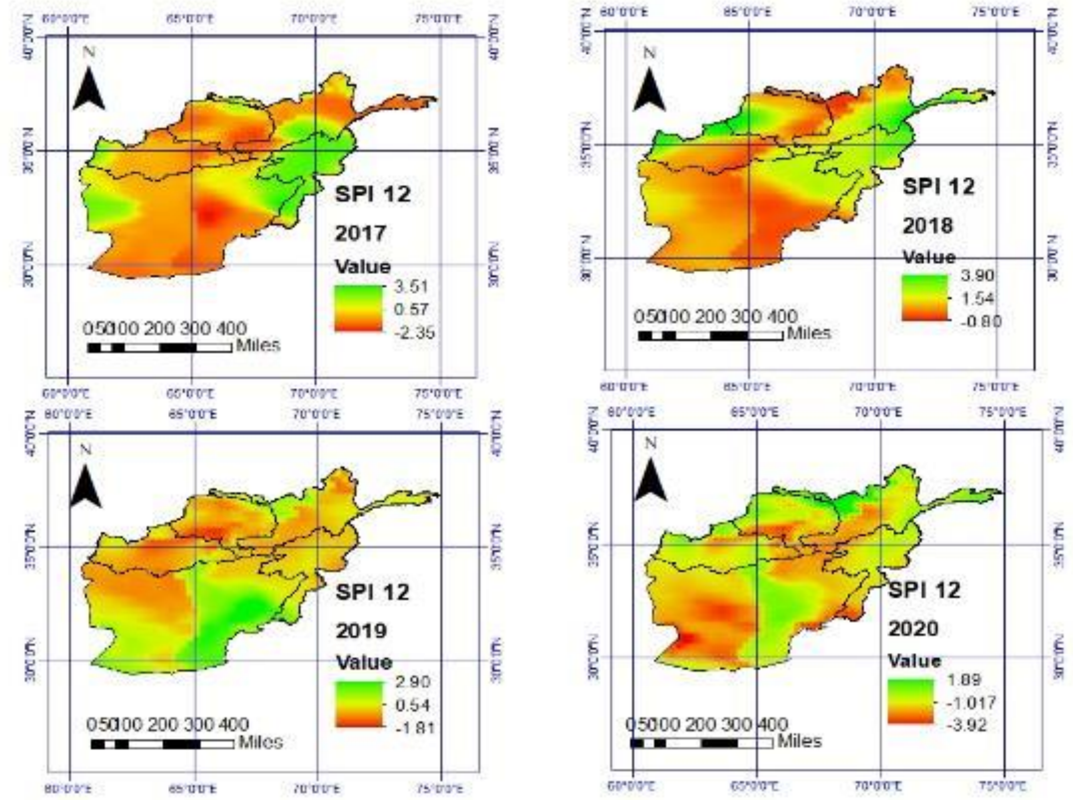
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SPI 12
2020
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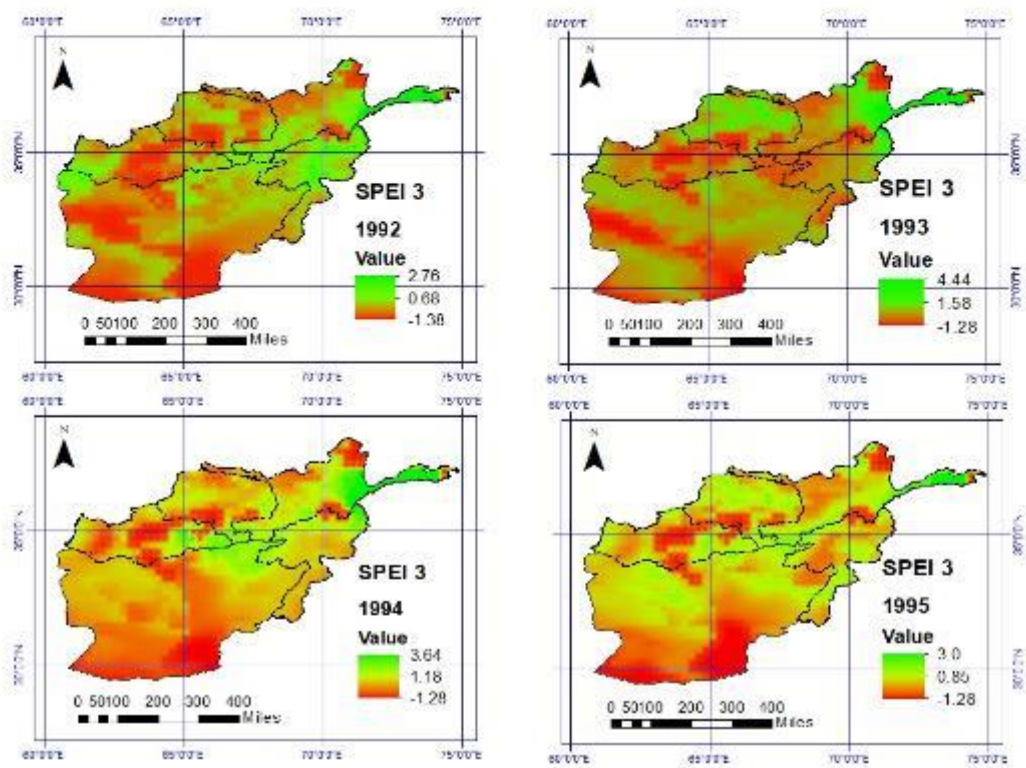
Miles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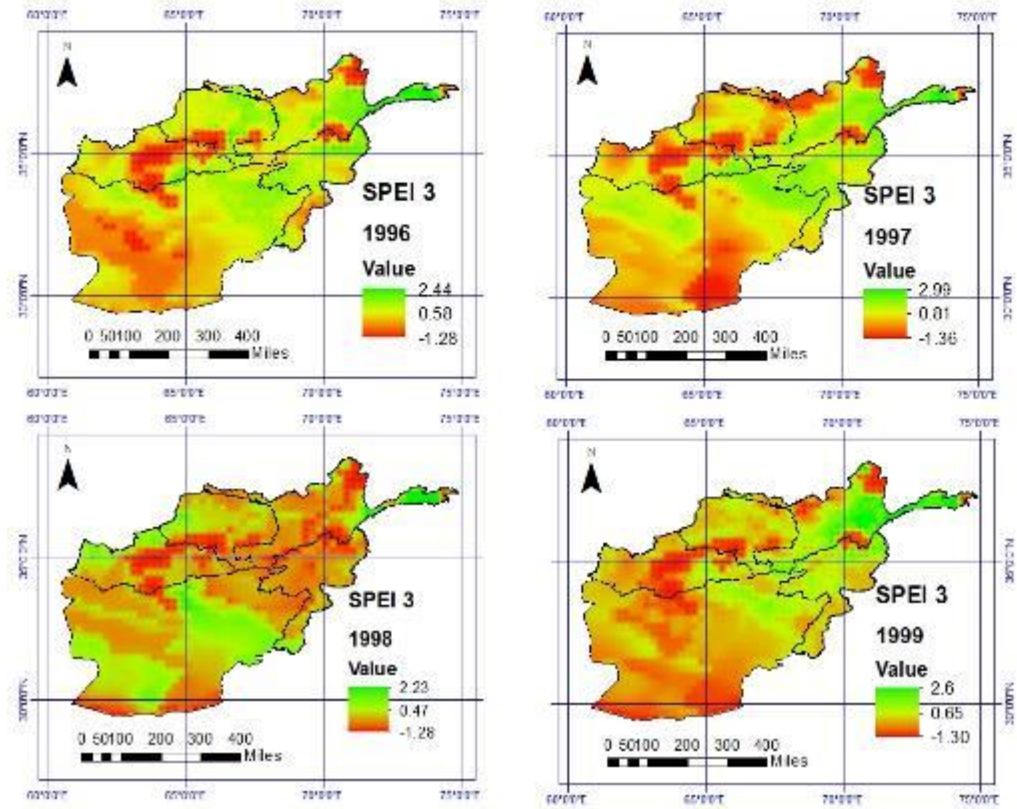
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1998
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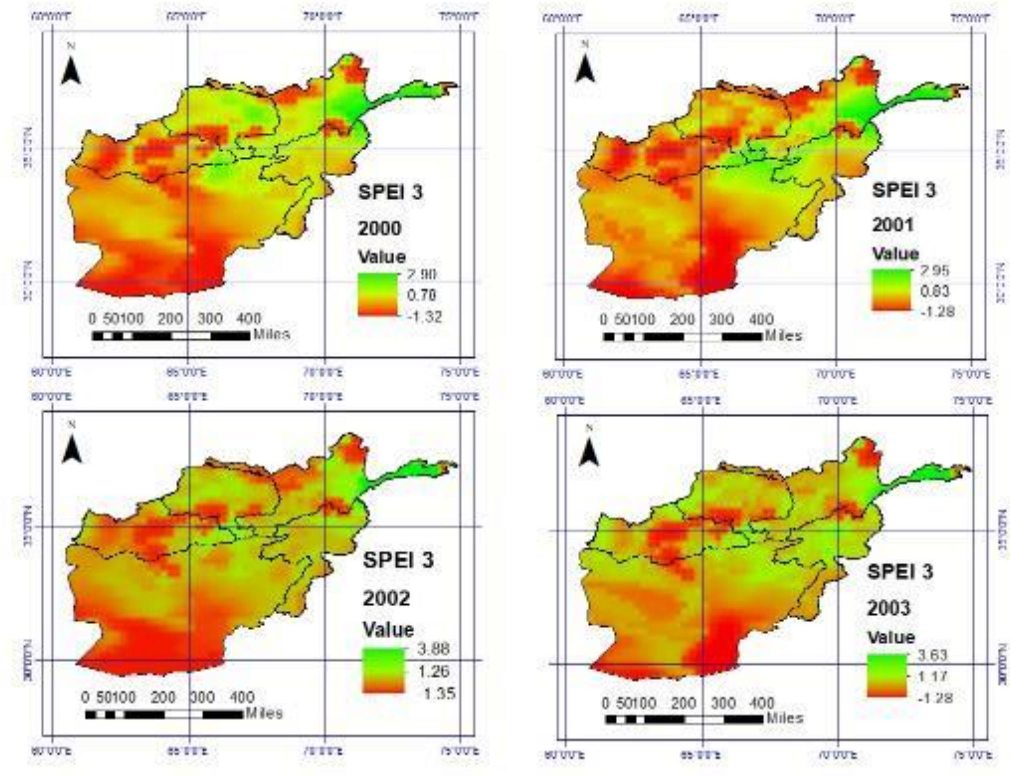
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Miles
SPEI 3
2002
Value
3.88
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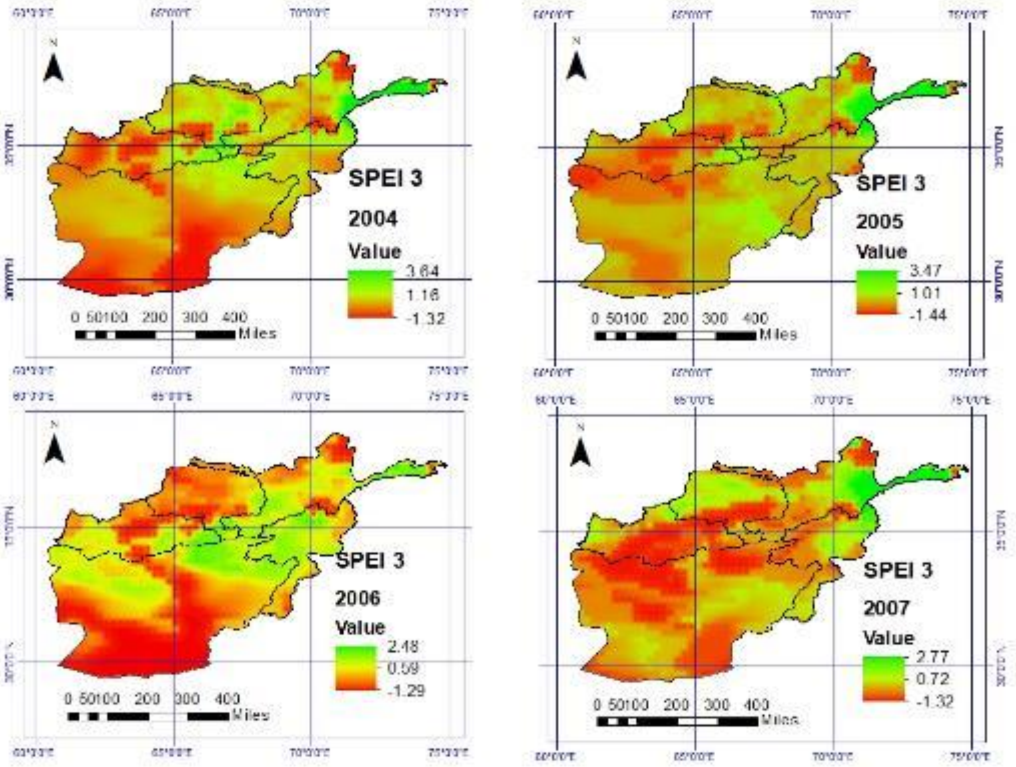
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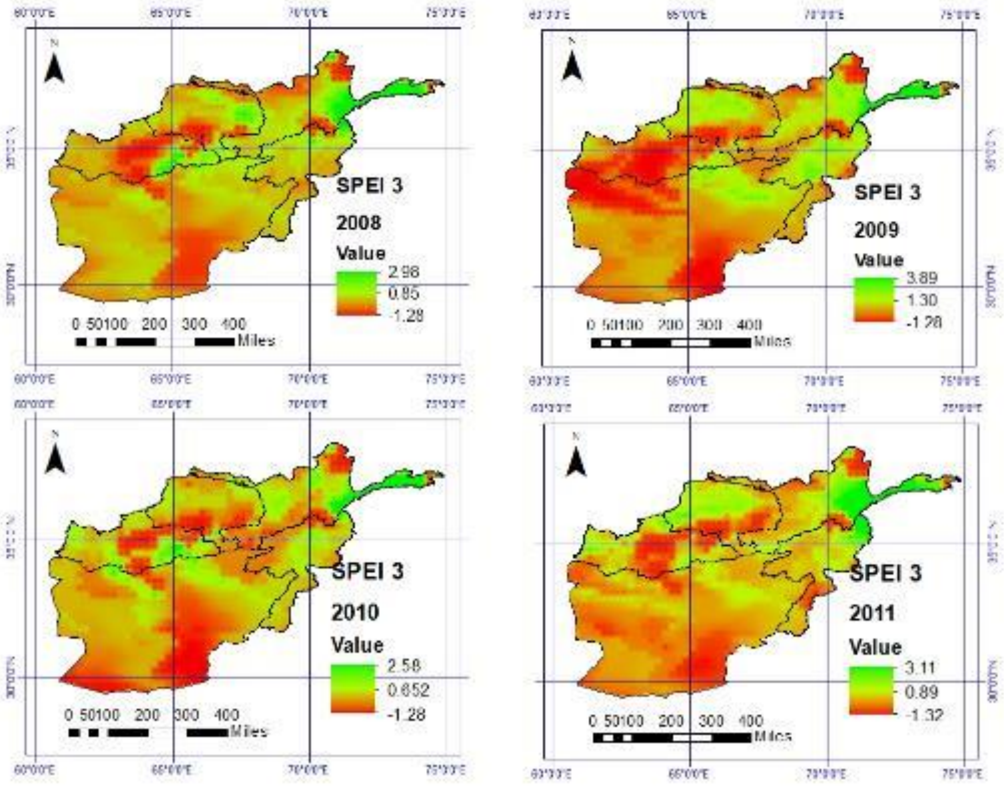
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2010
Value
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0.652
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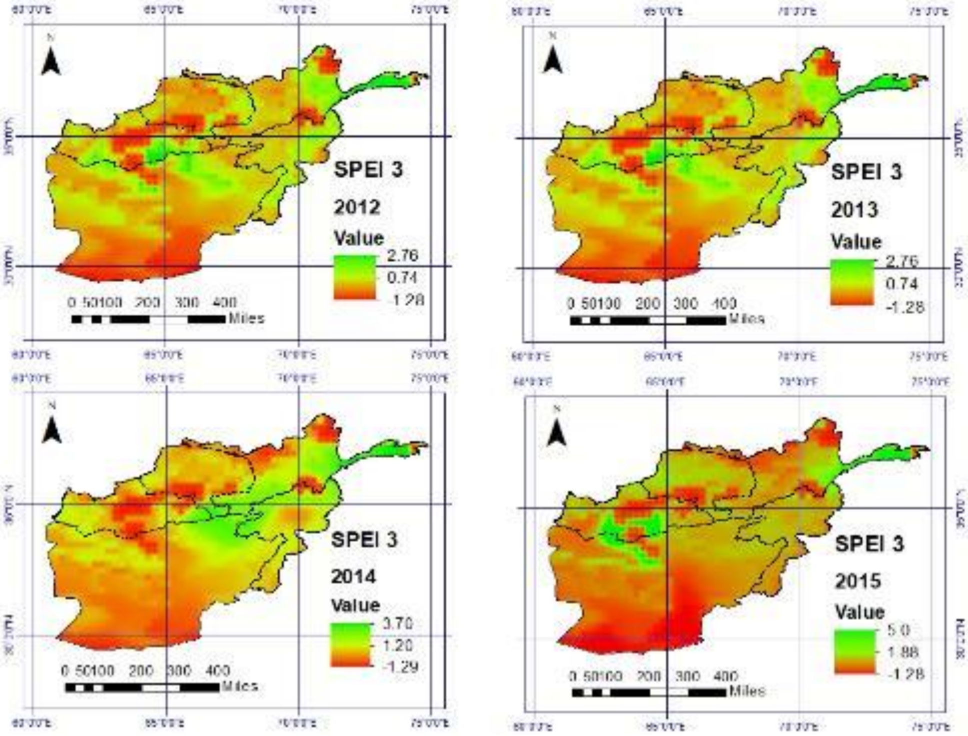
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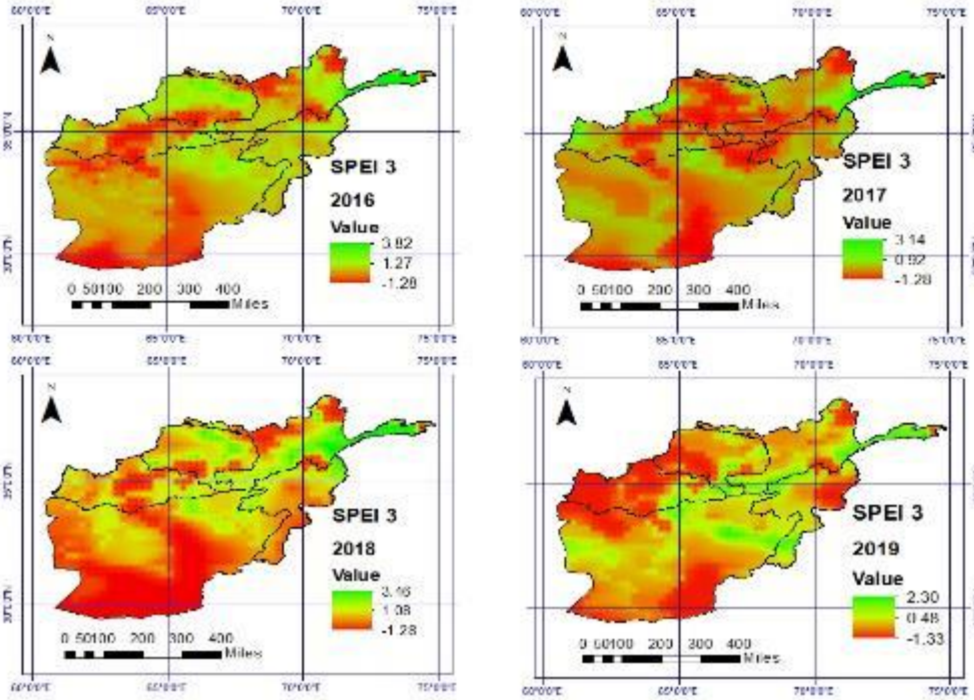
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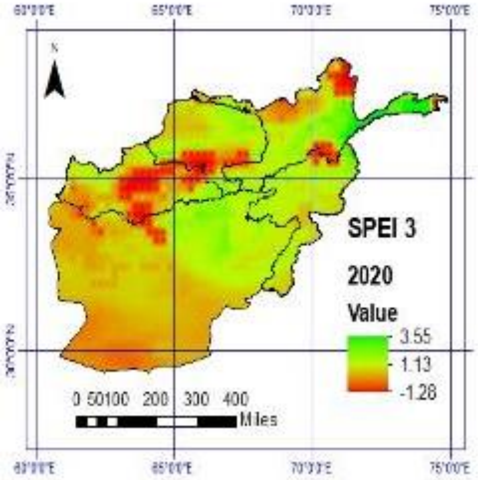
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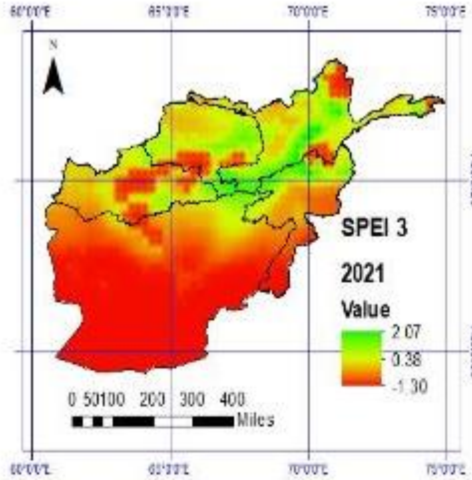
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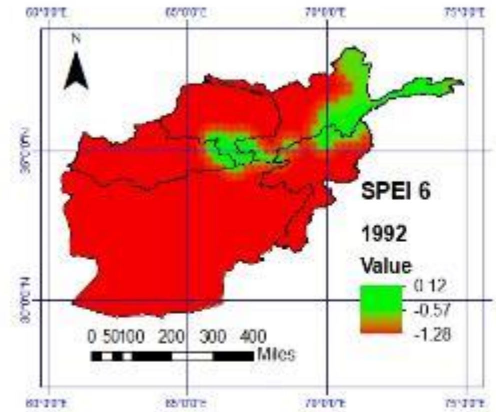
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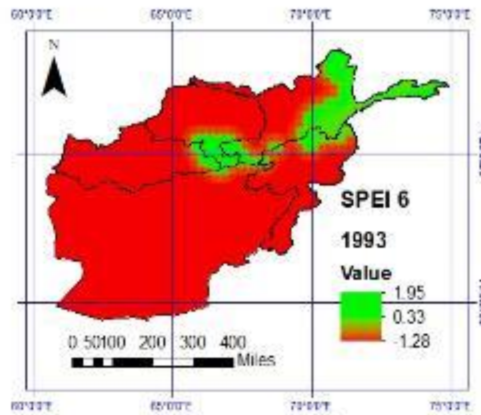
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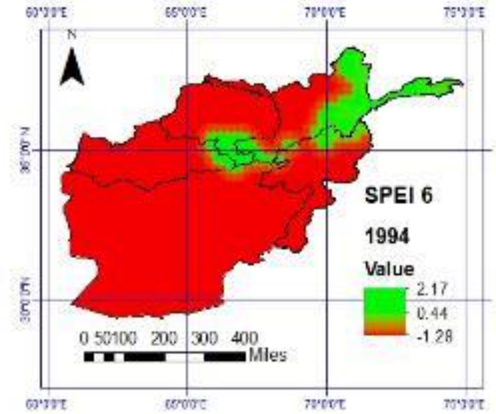
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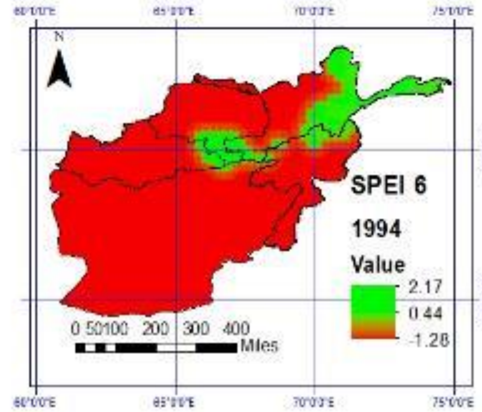
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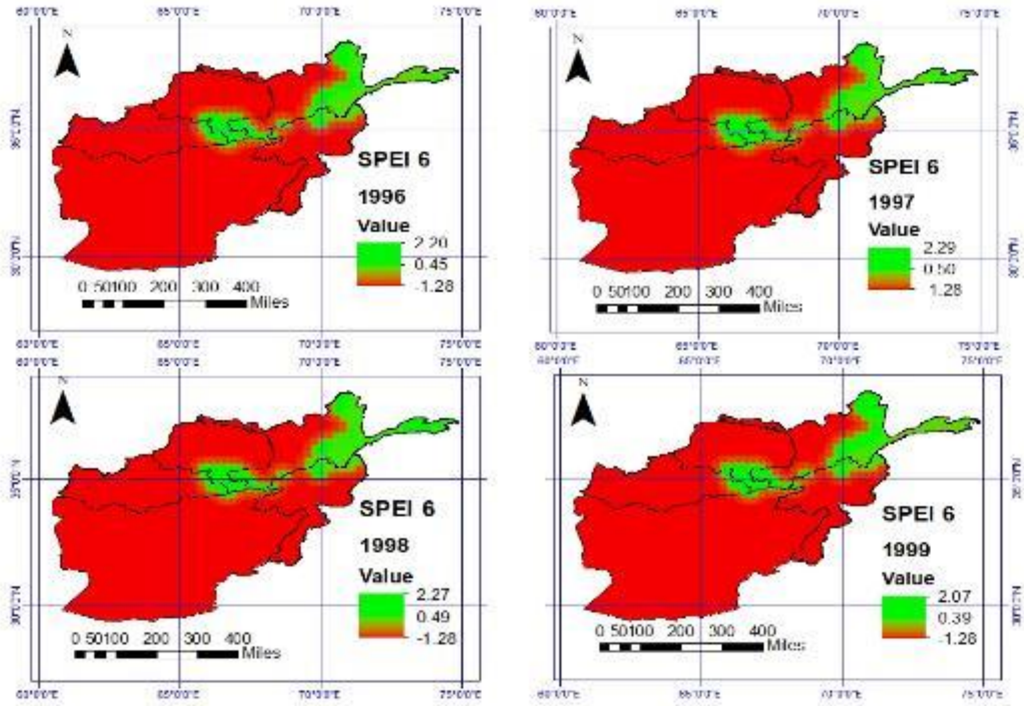
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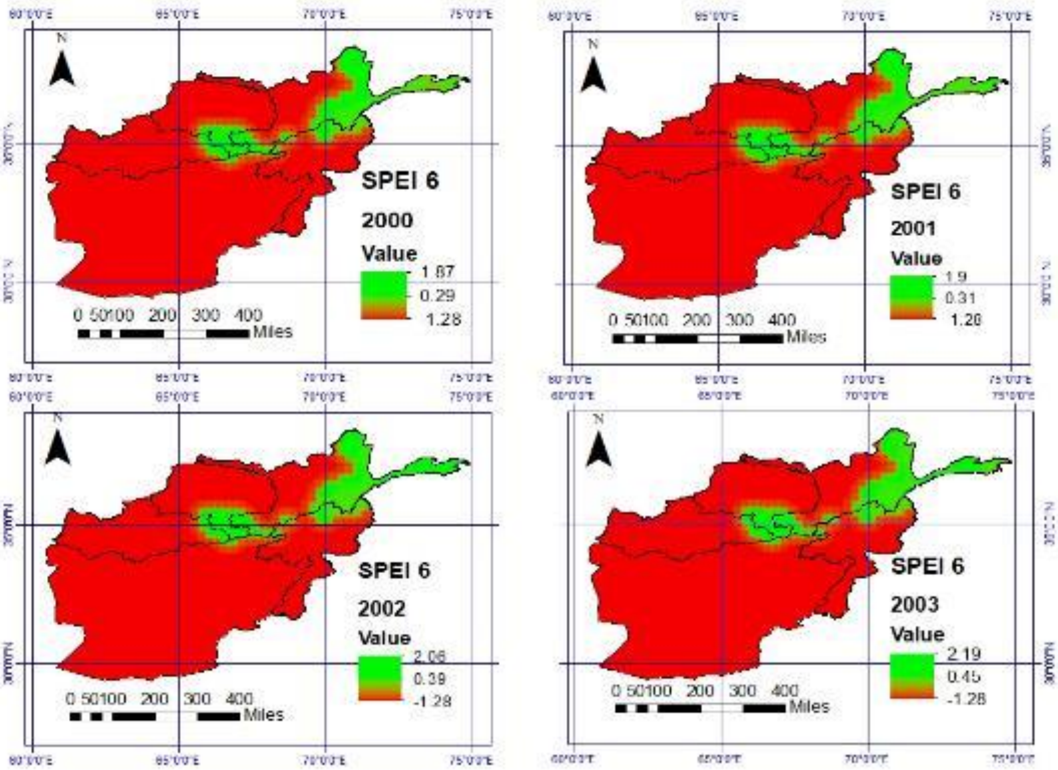
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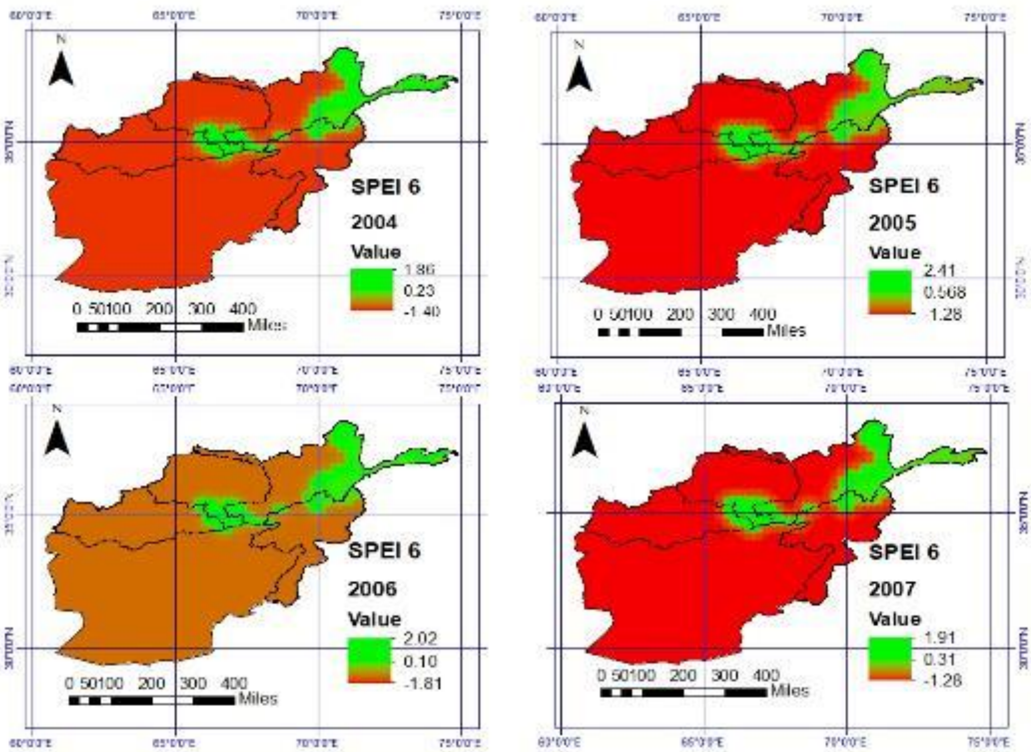
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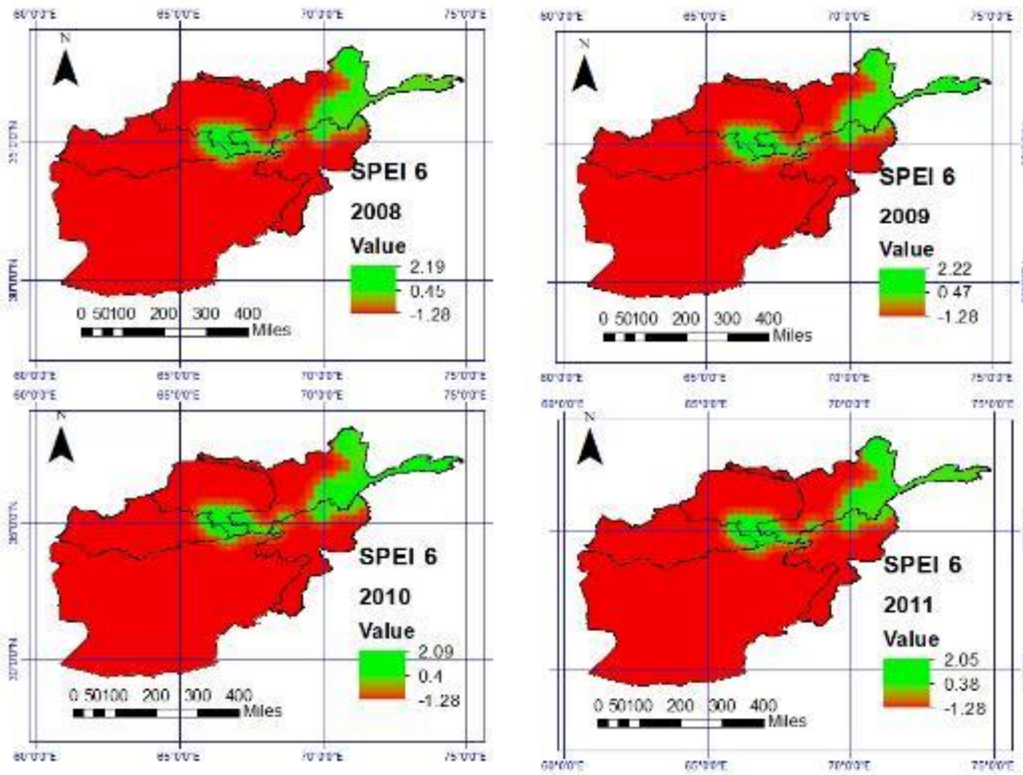
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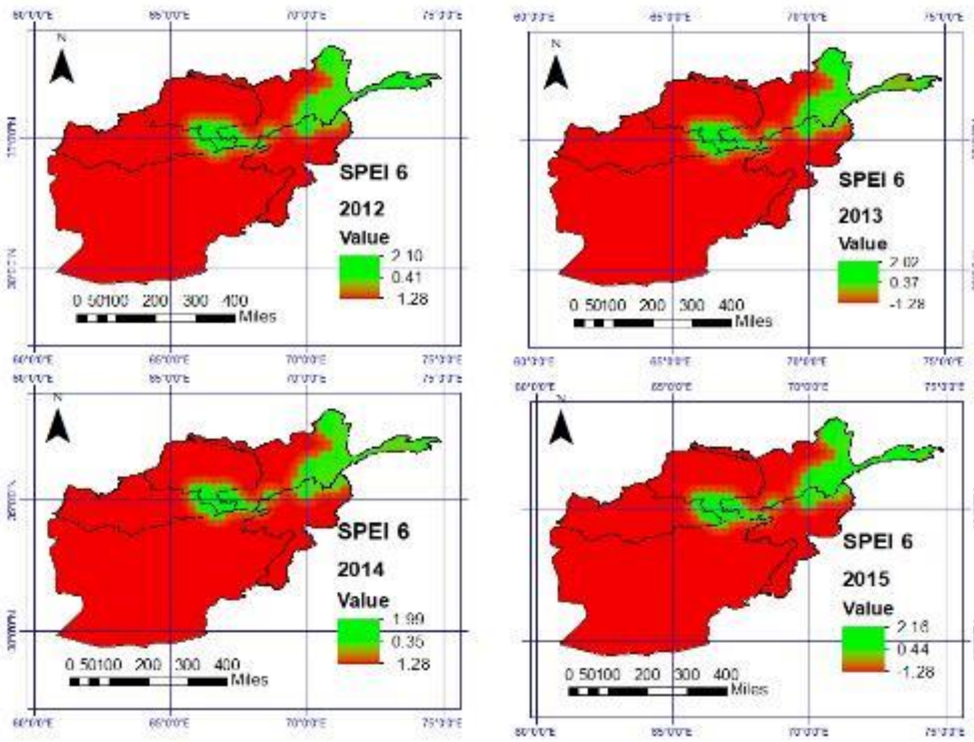
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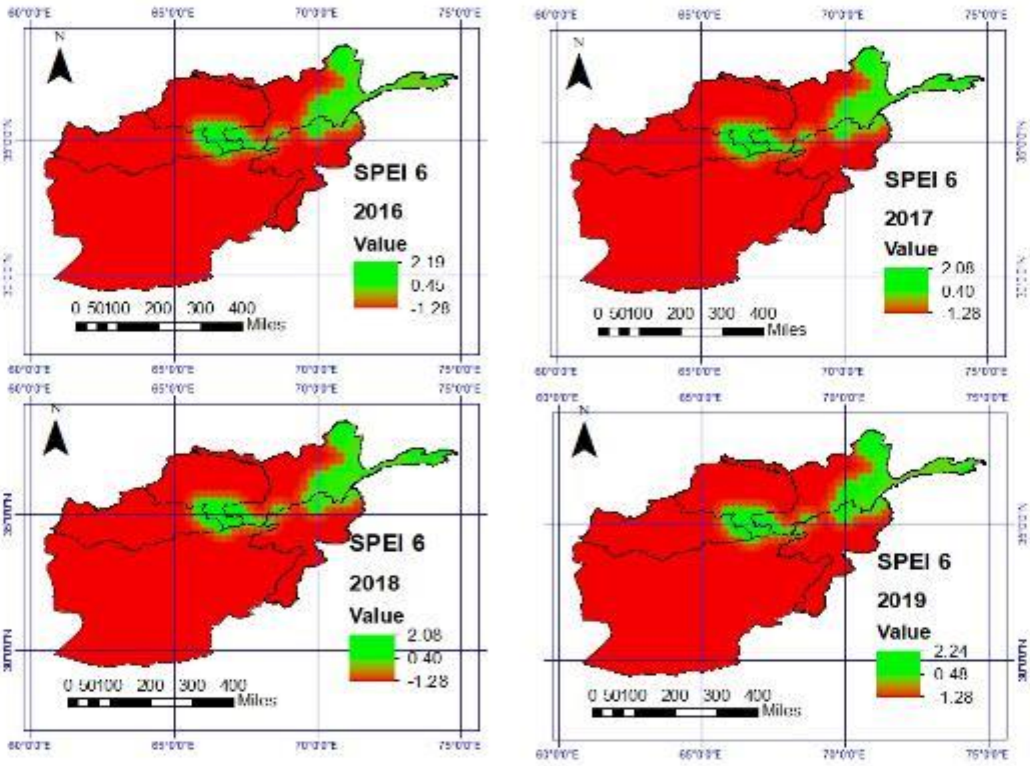
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SPEI 6
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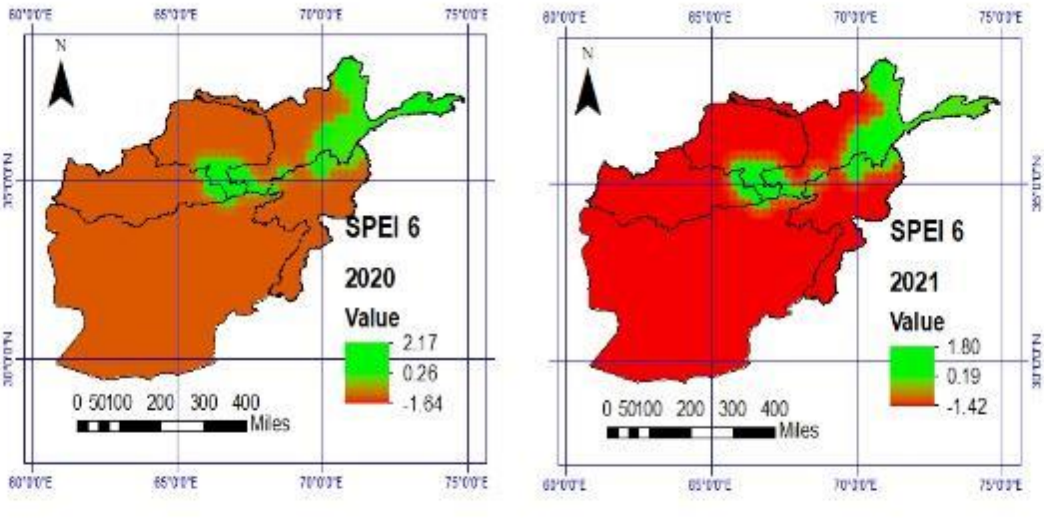
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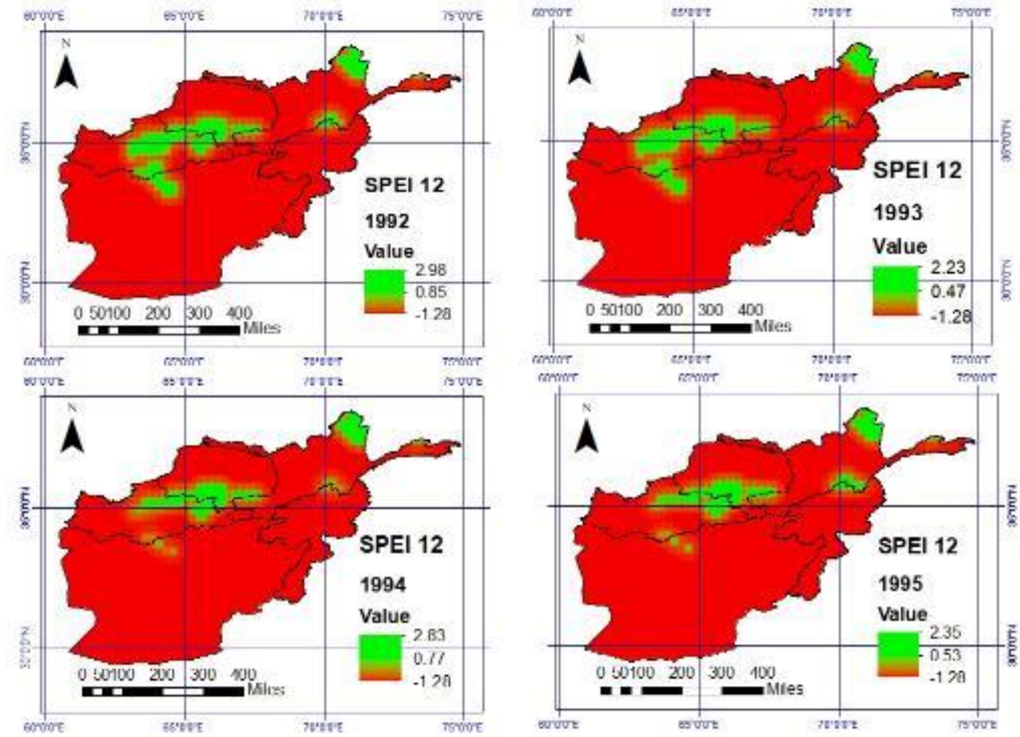
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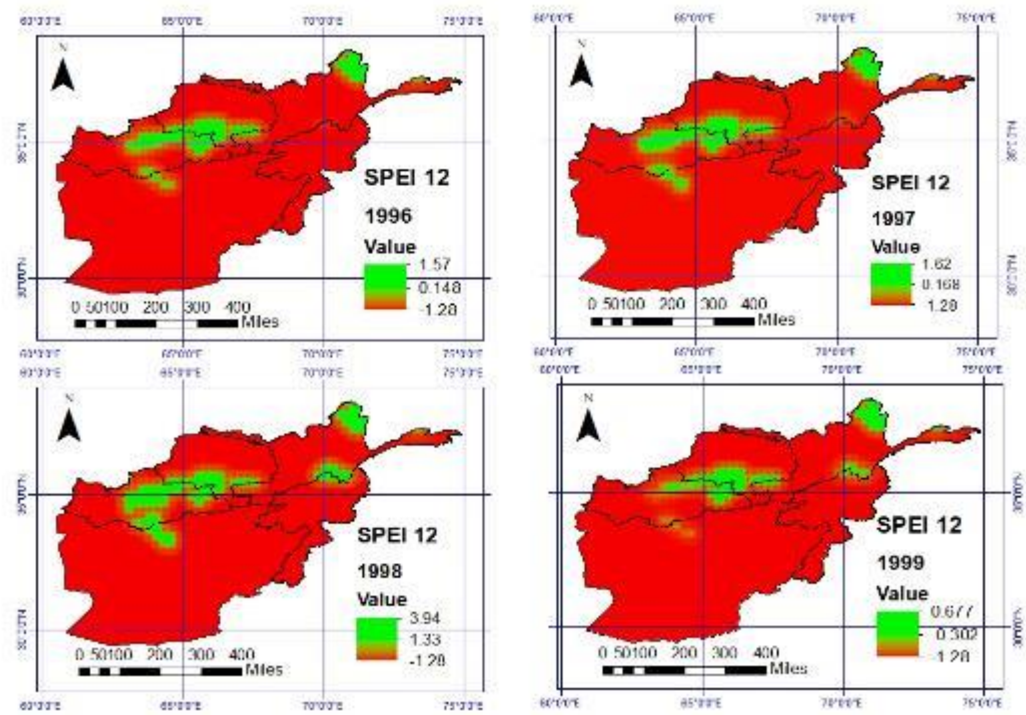
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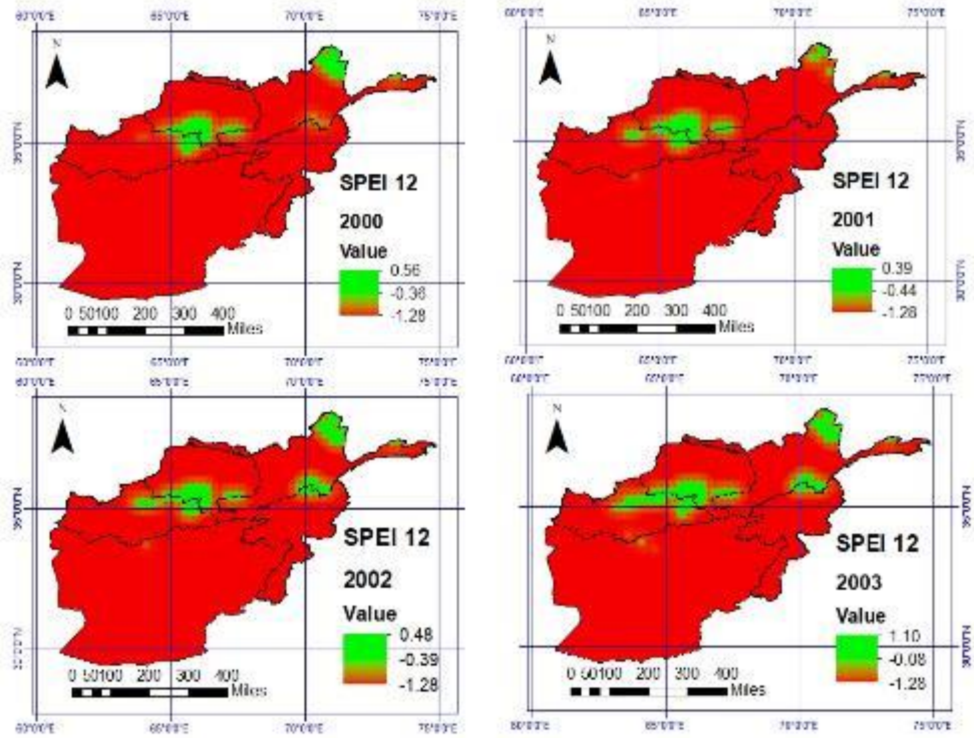
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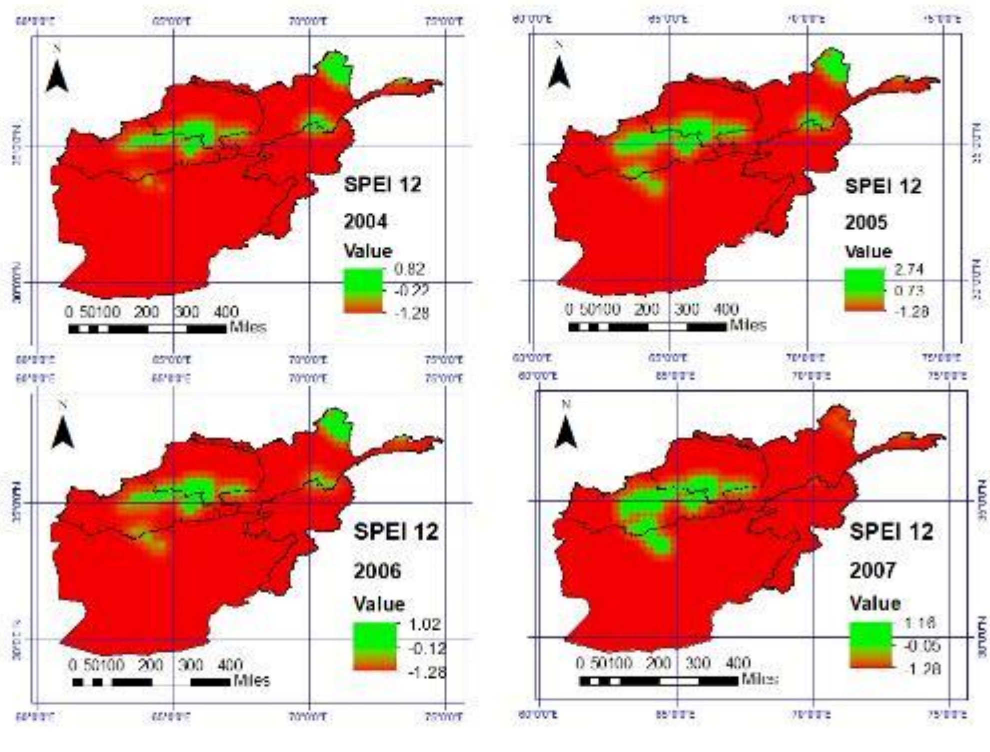
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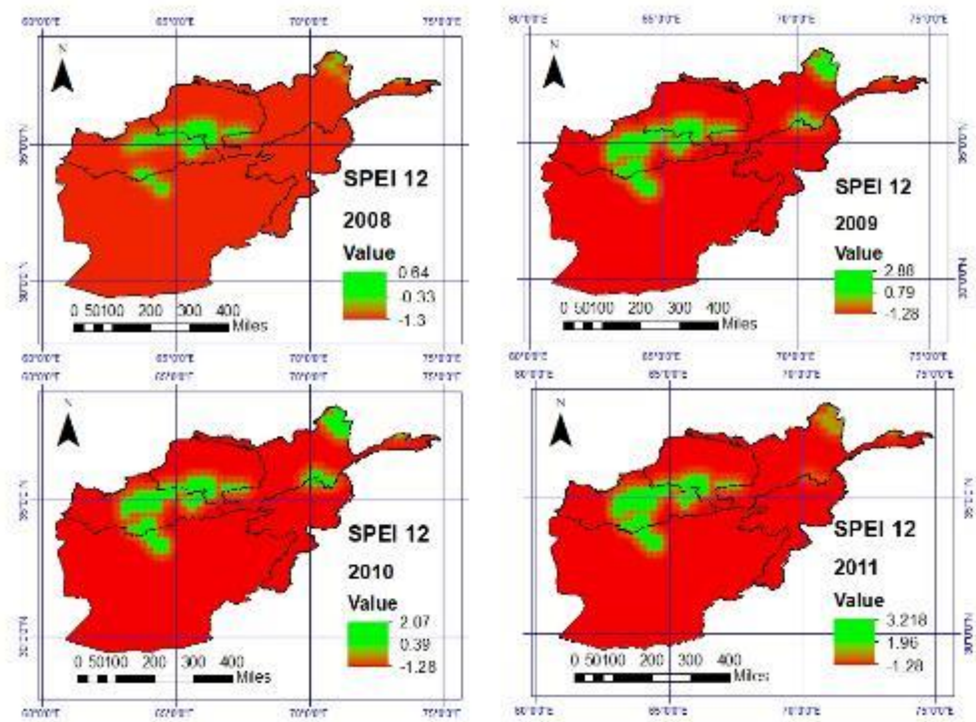
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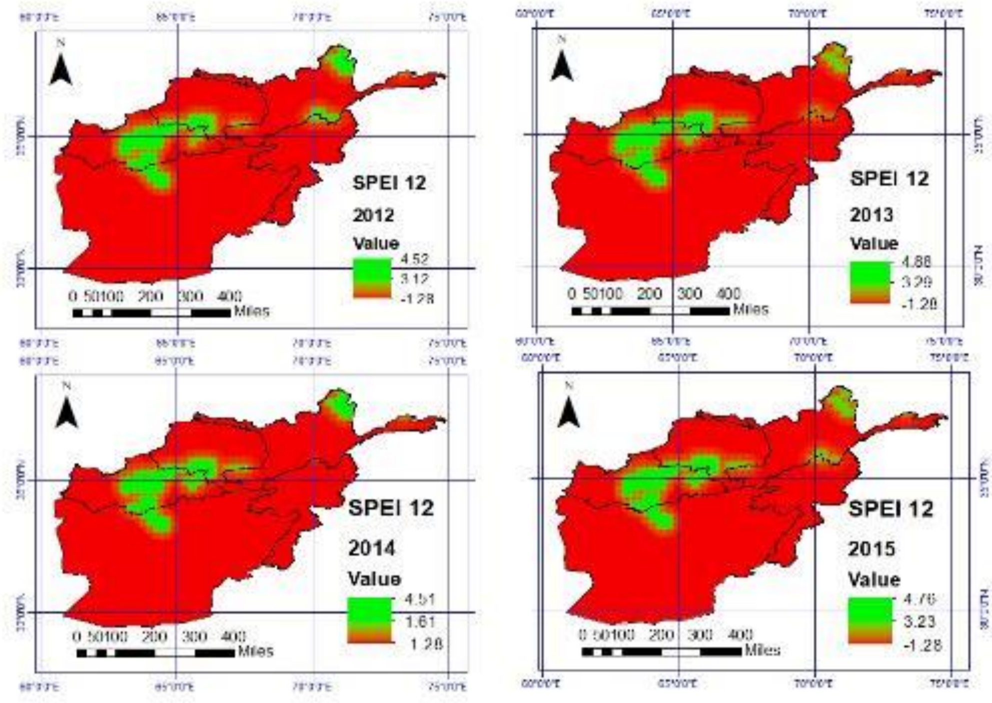
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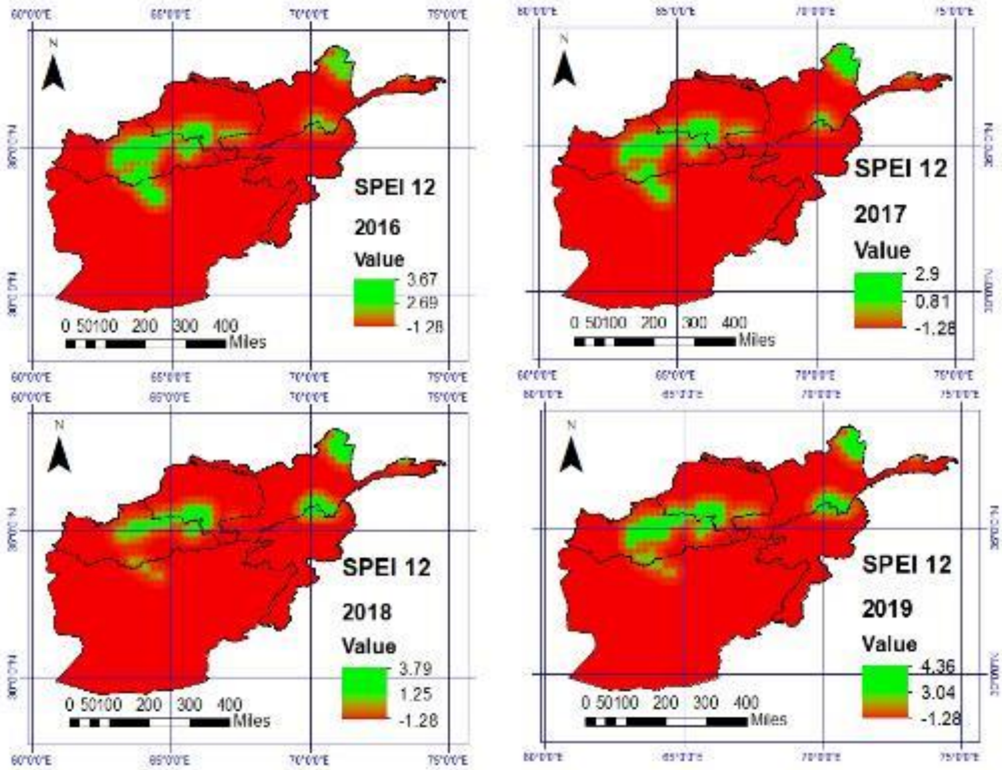
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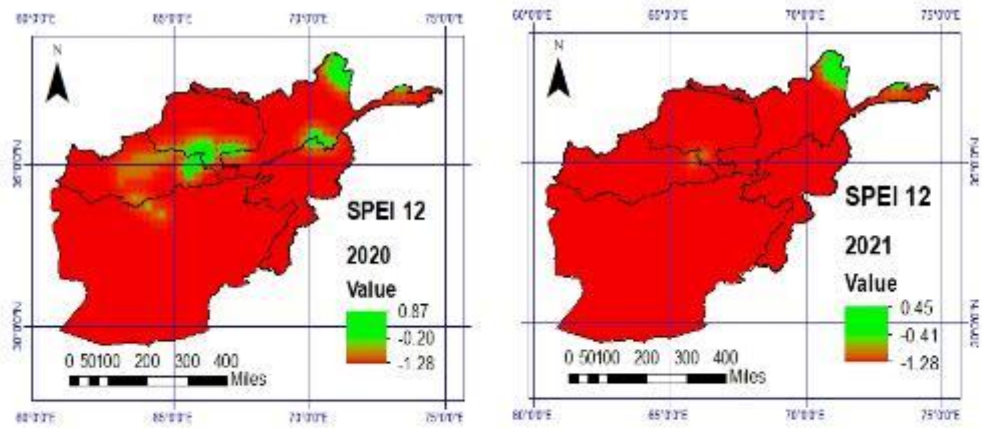
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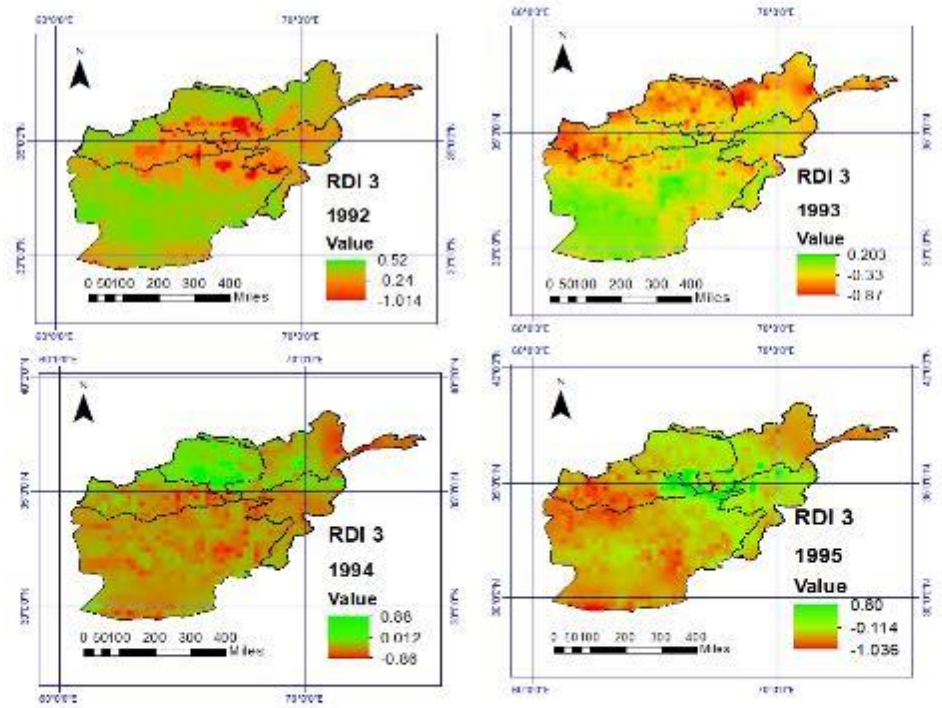
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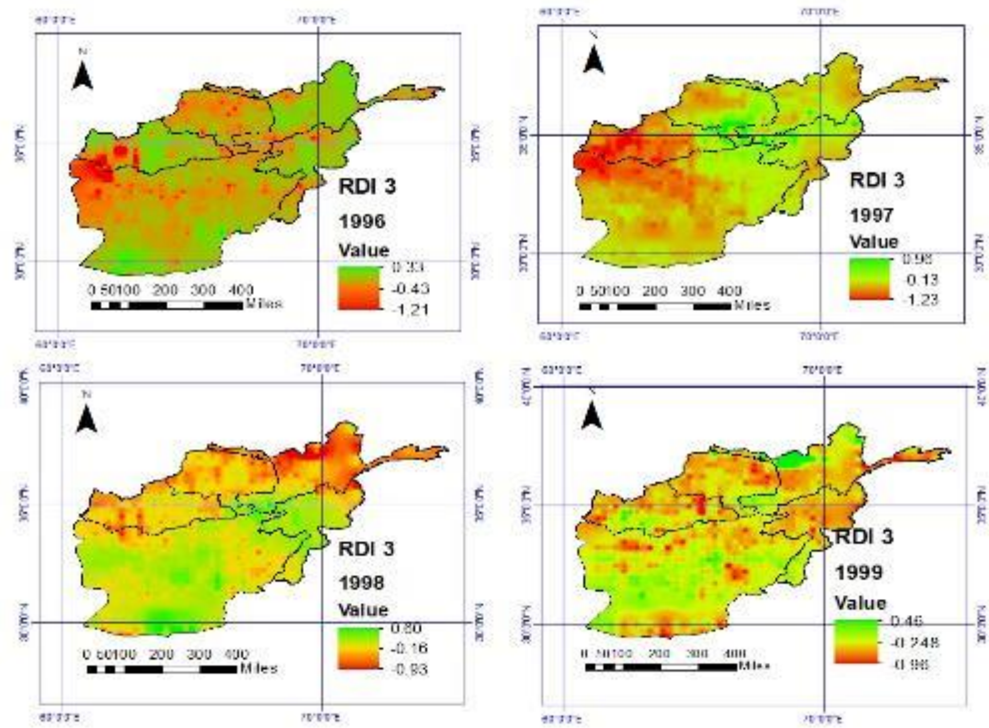
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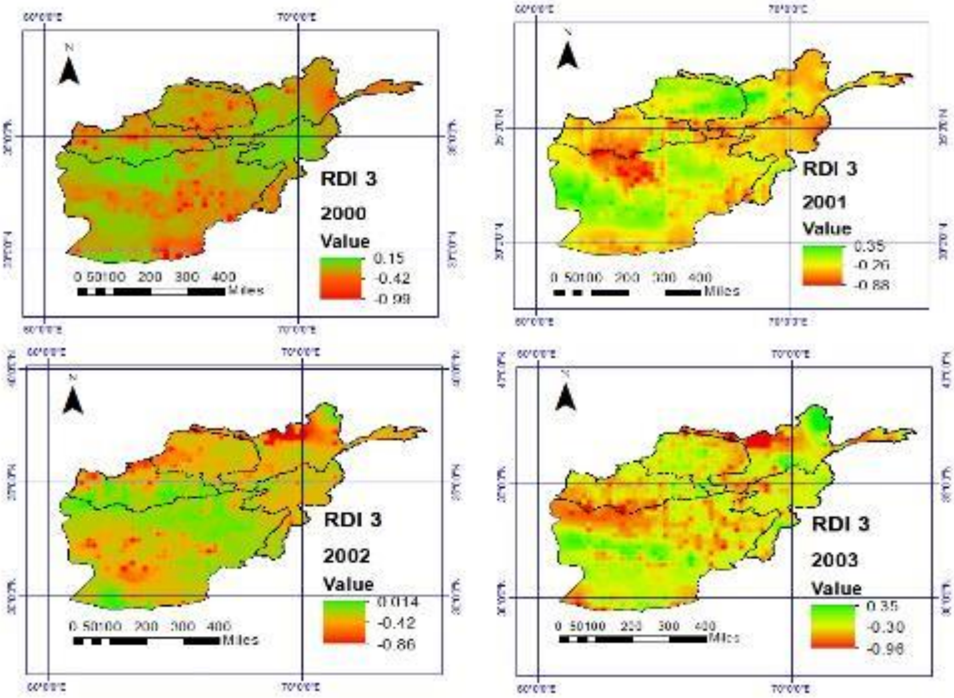
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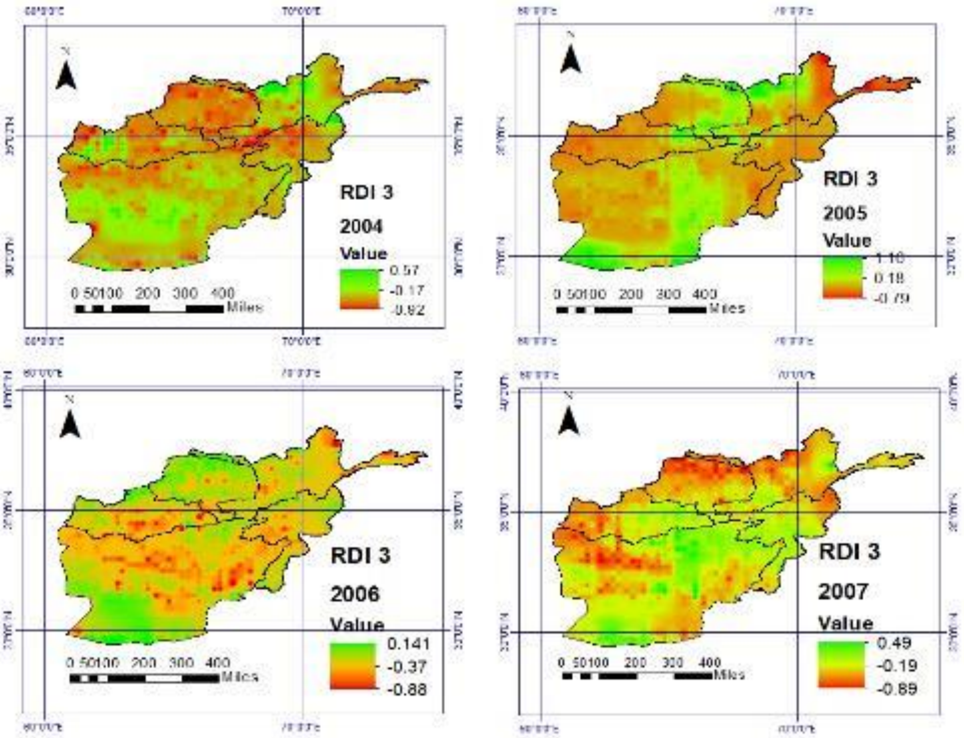
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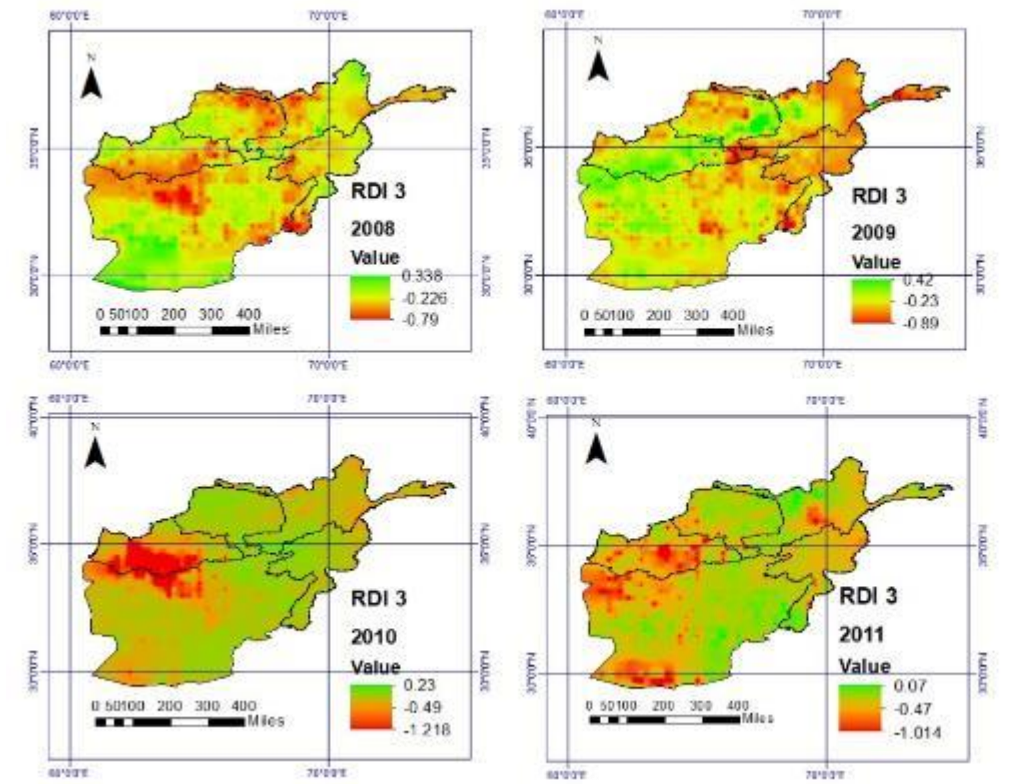
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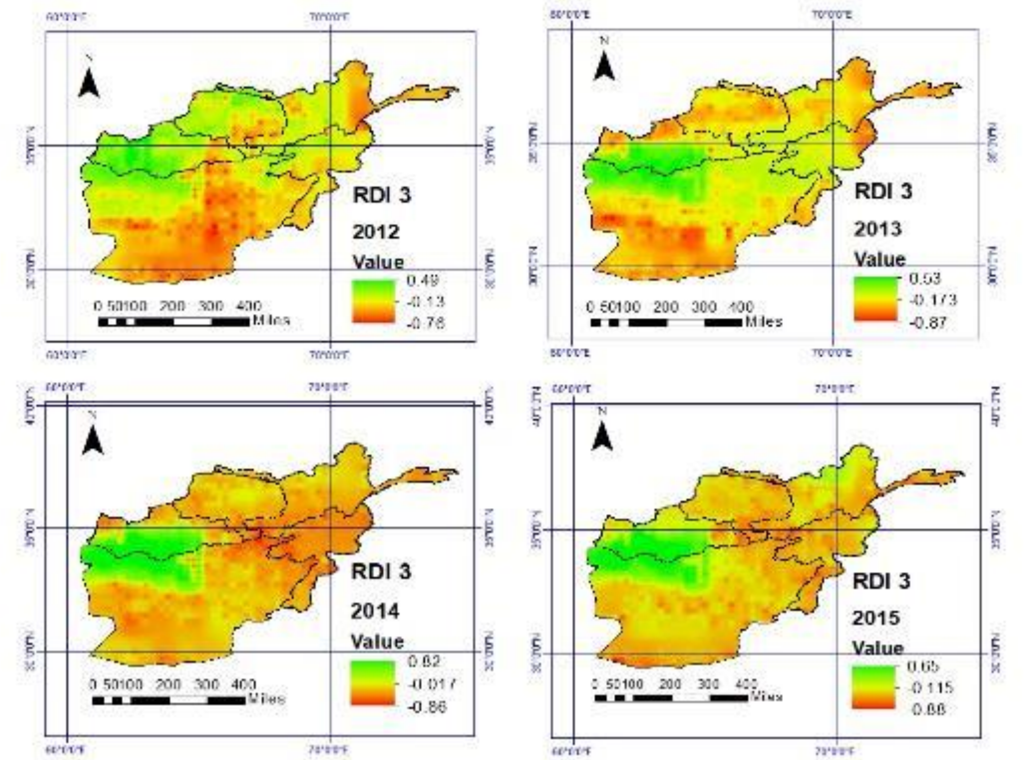
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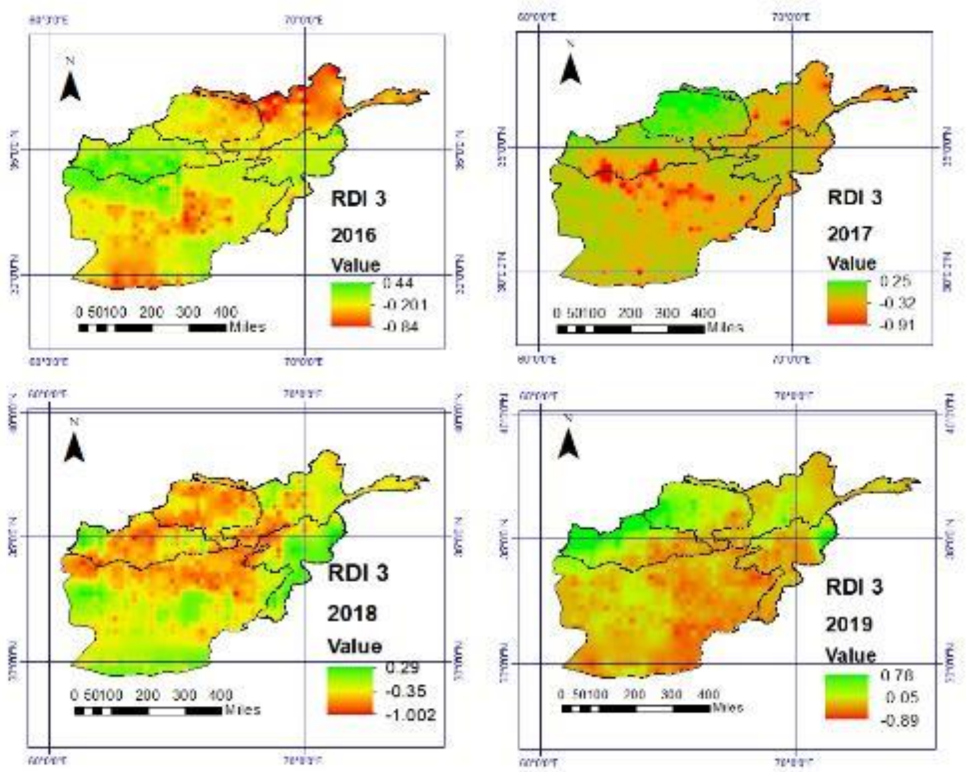
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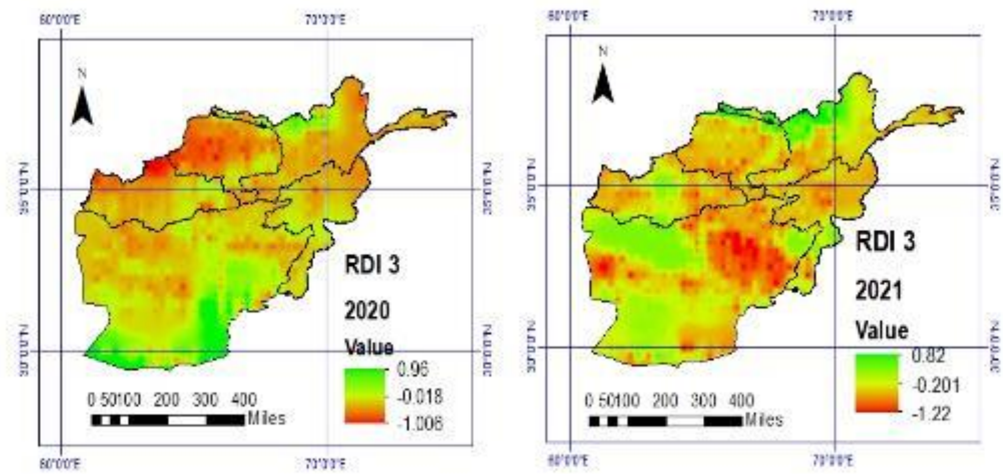
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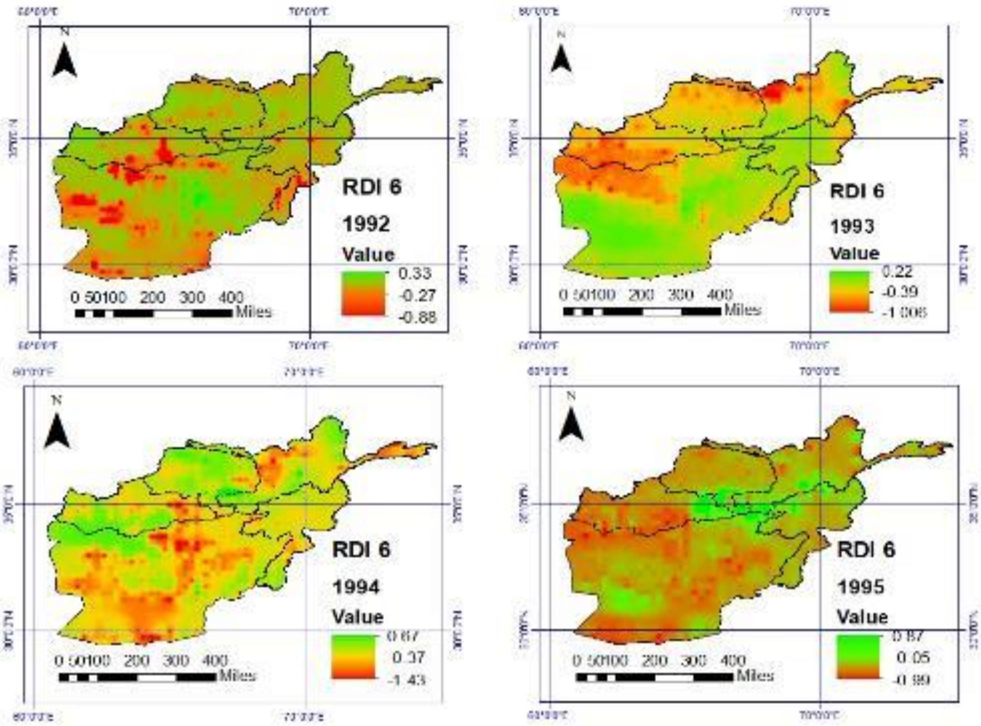
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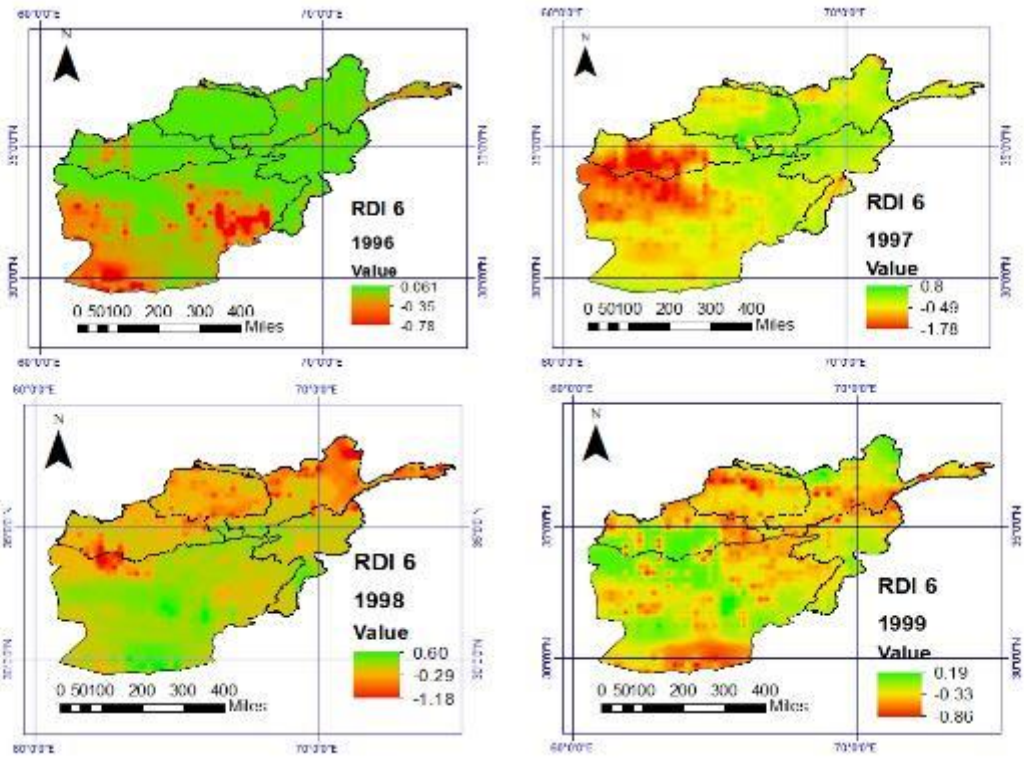
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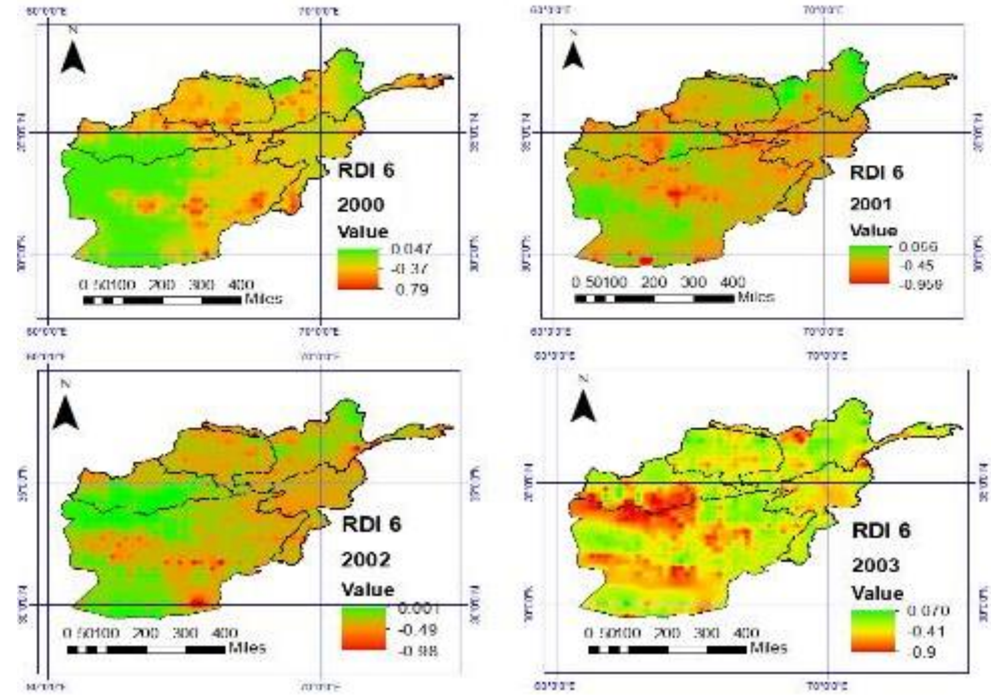
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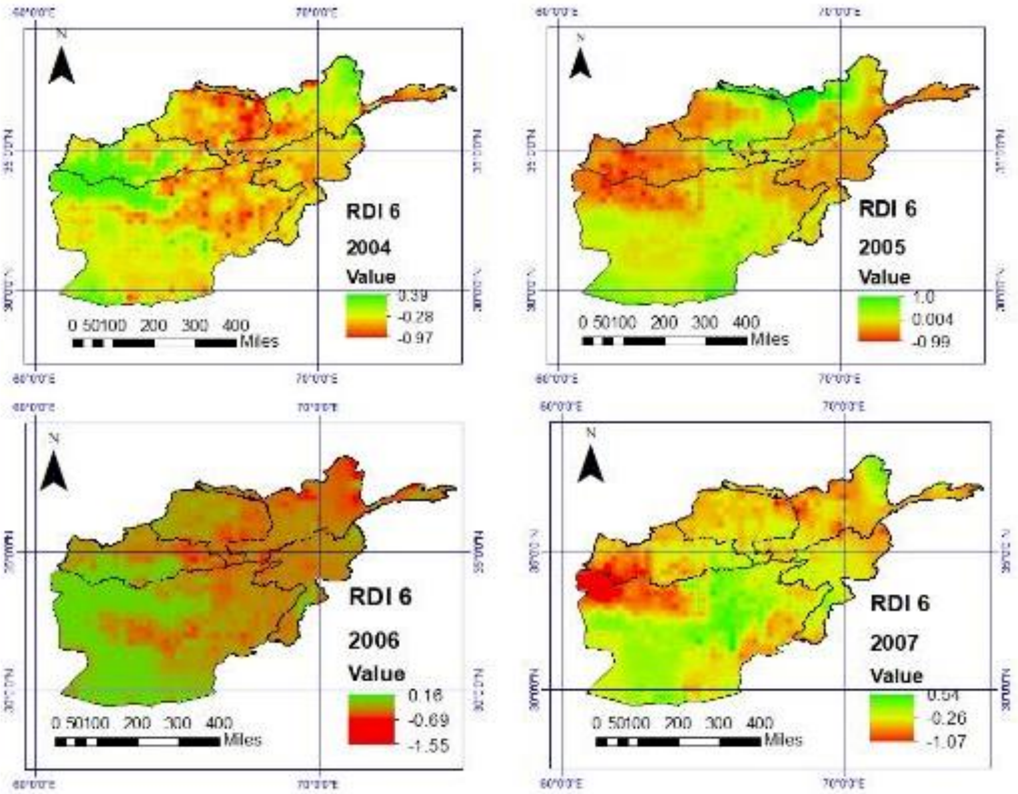
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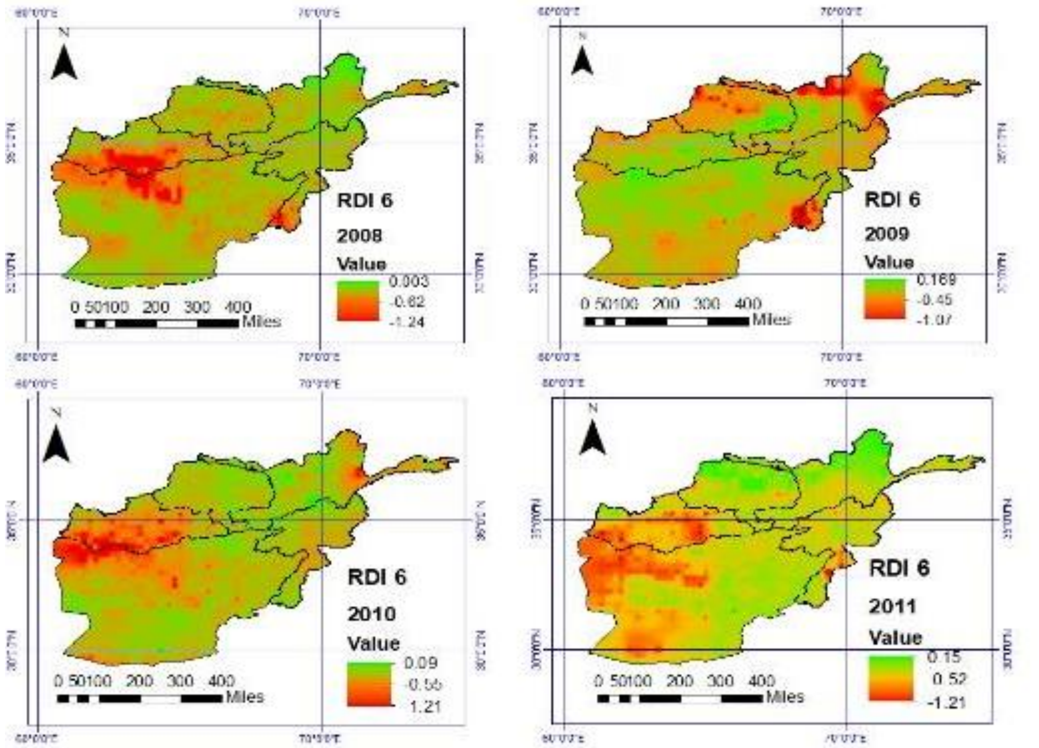
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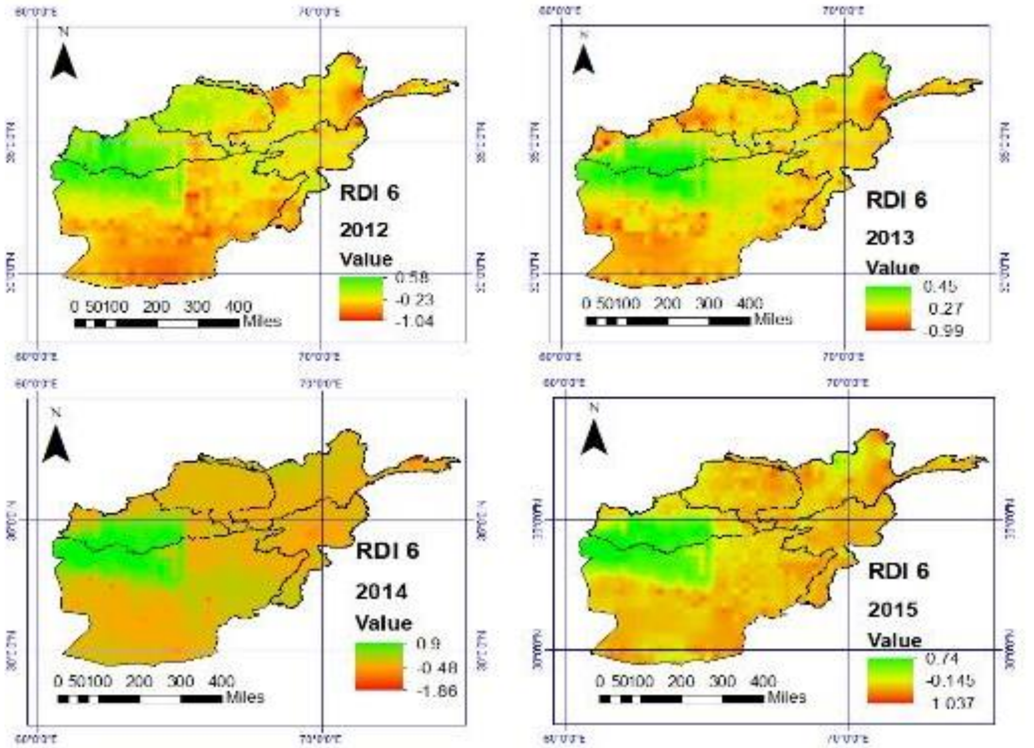
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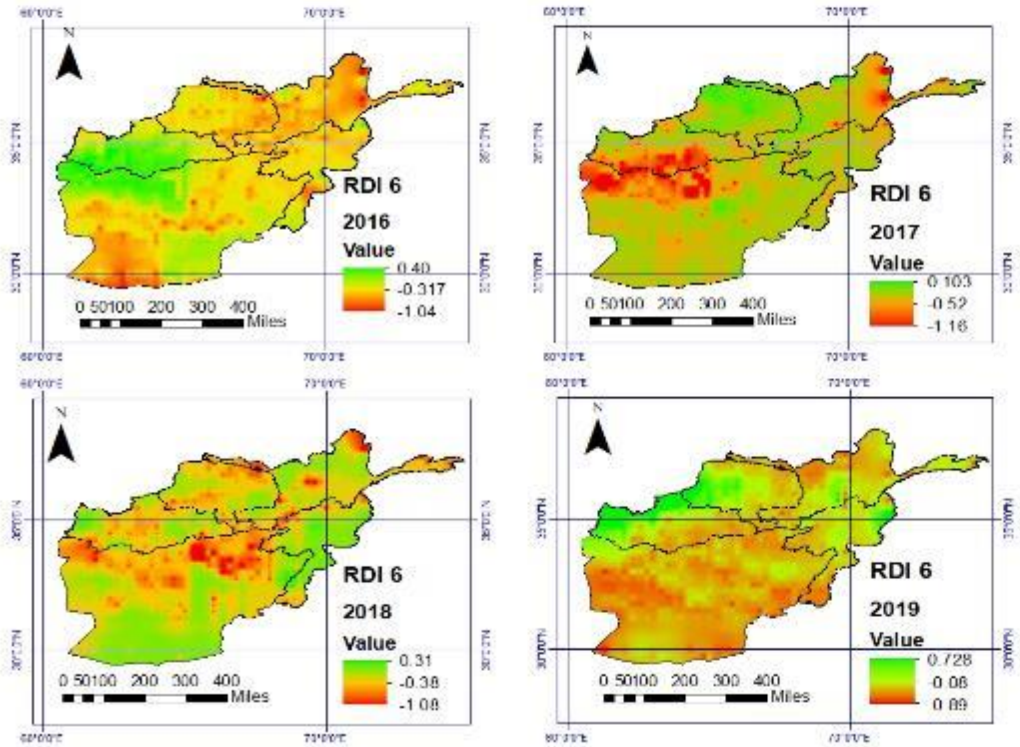
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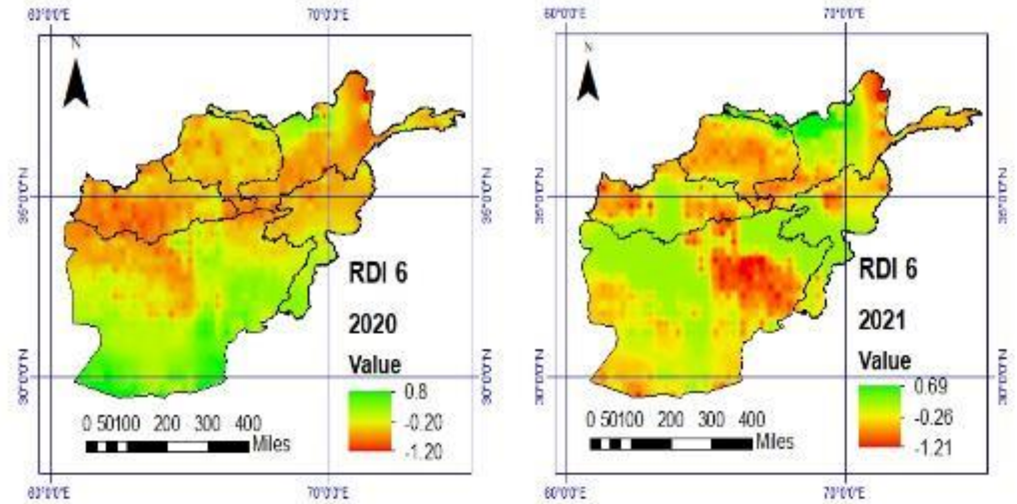
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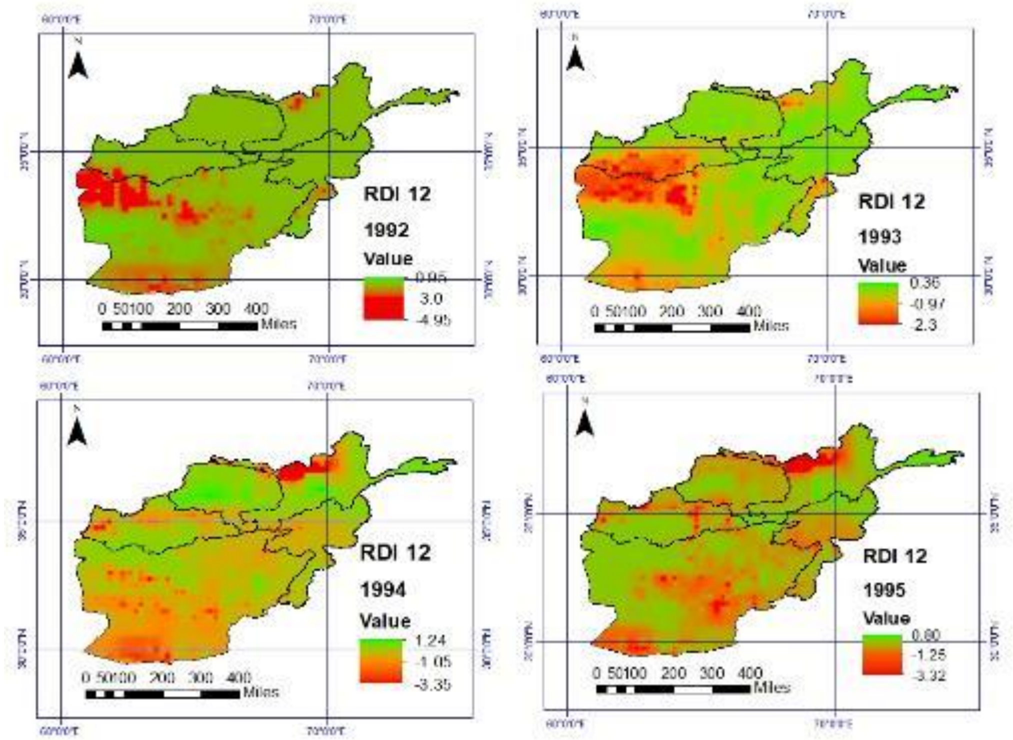
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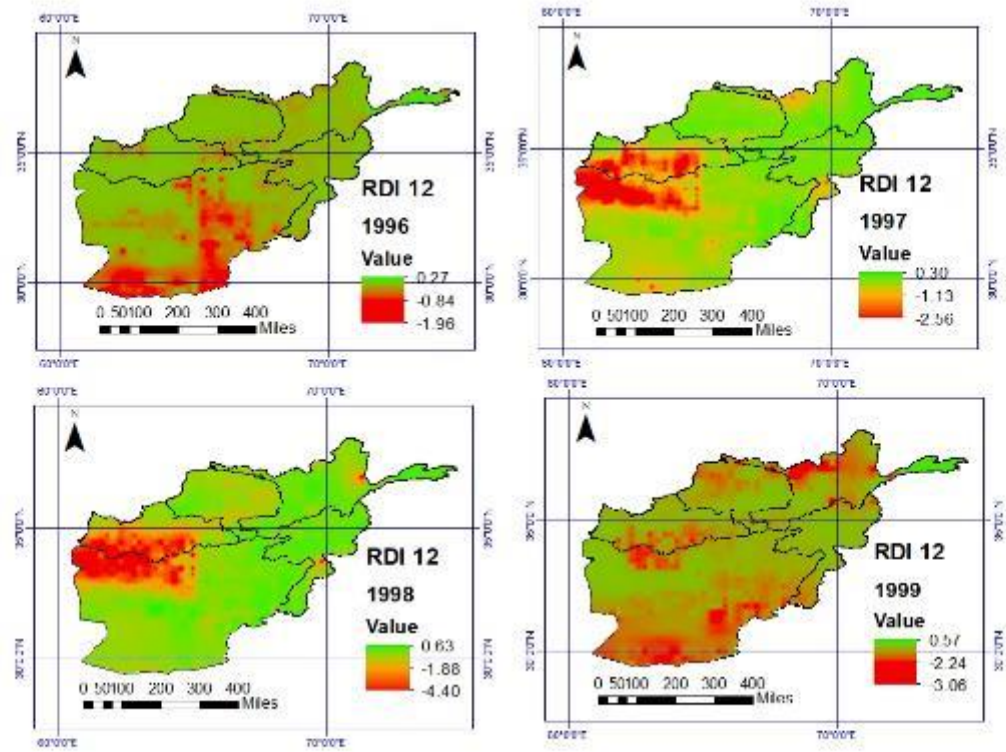
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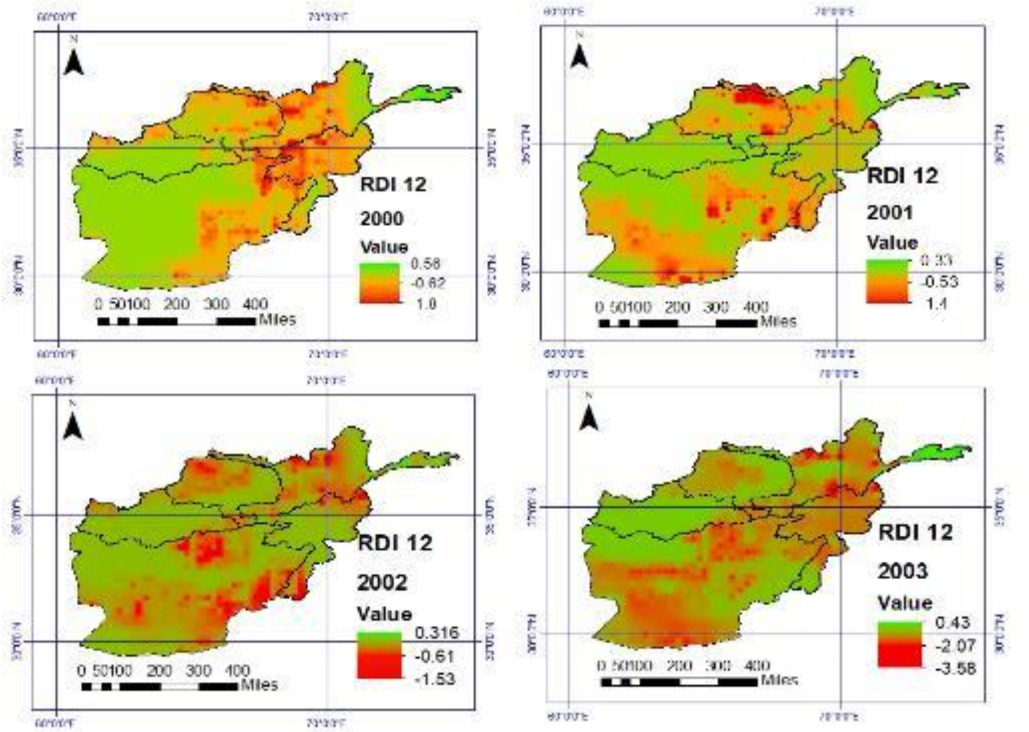
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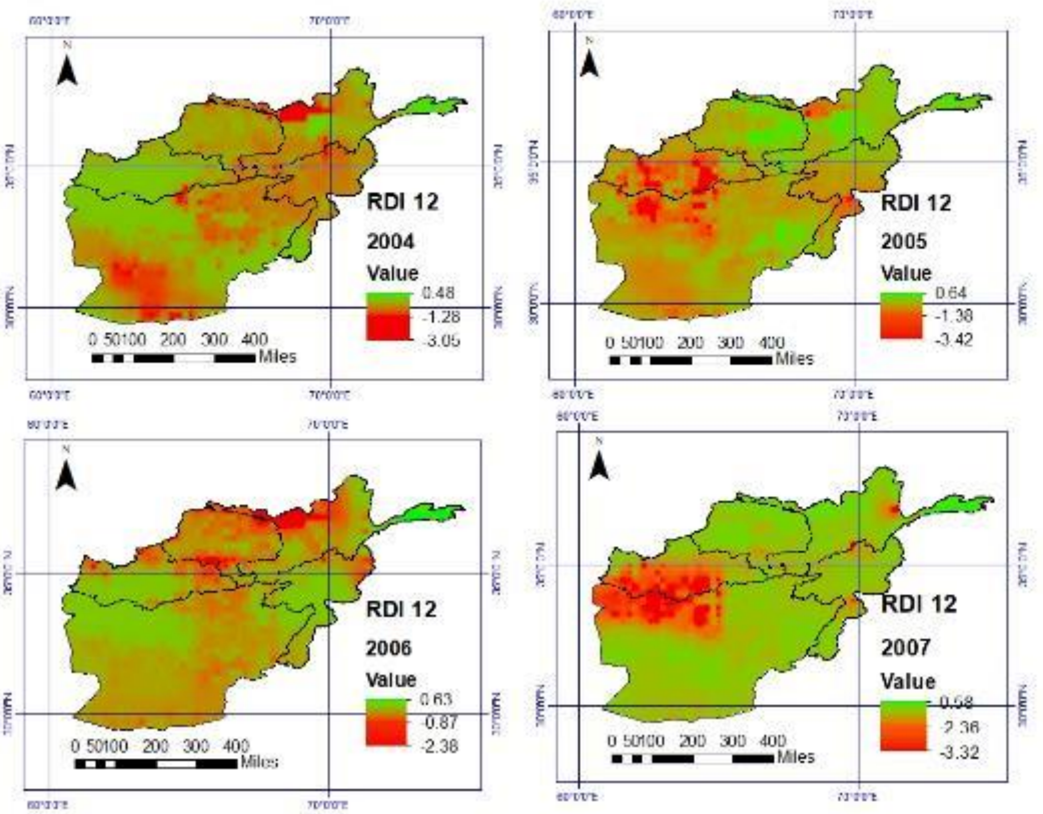
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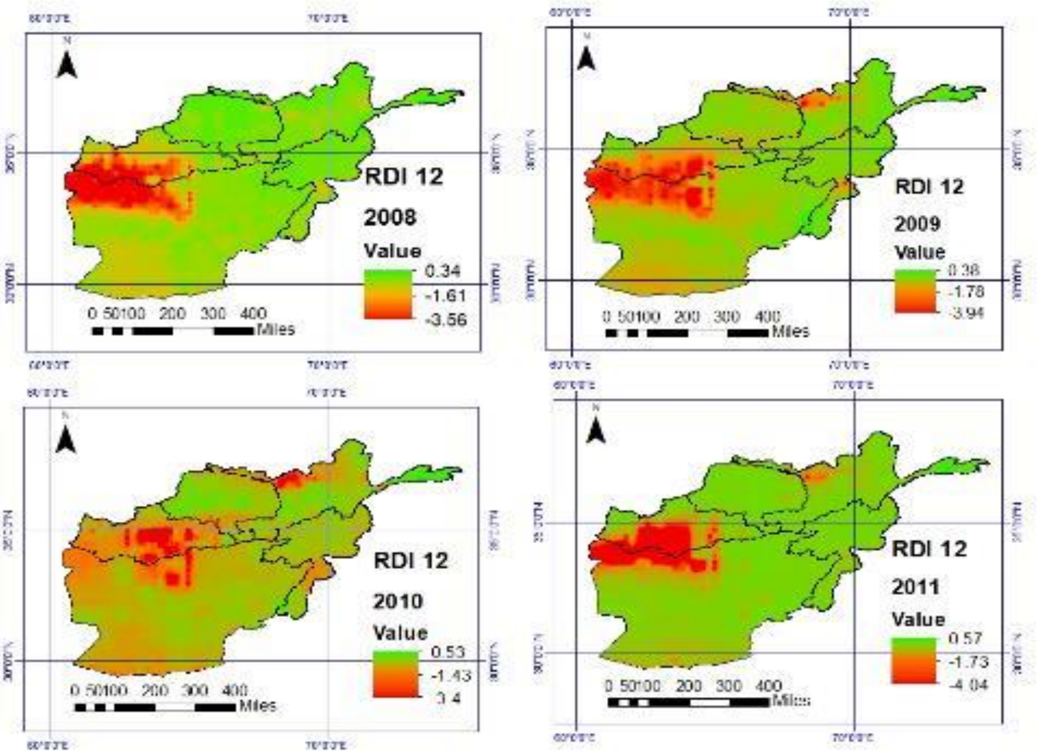
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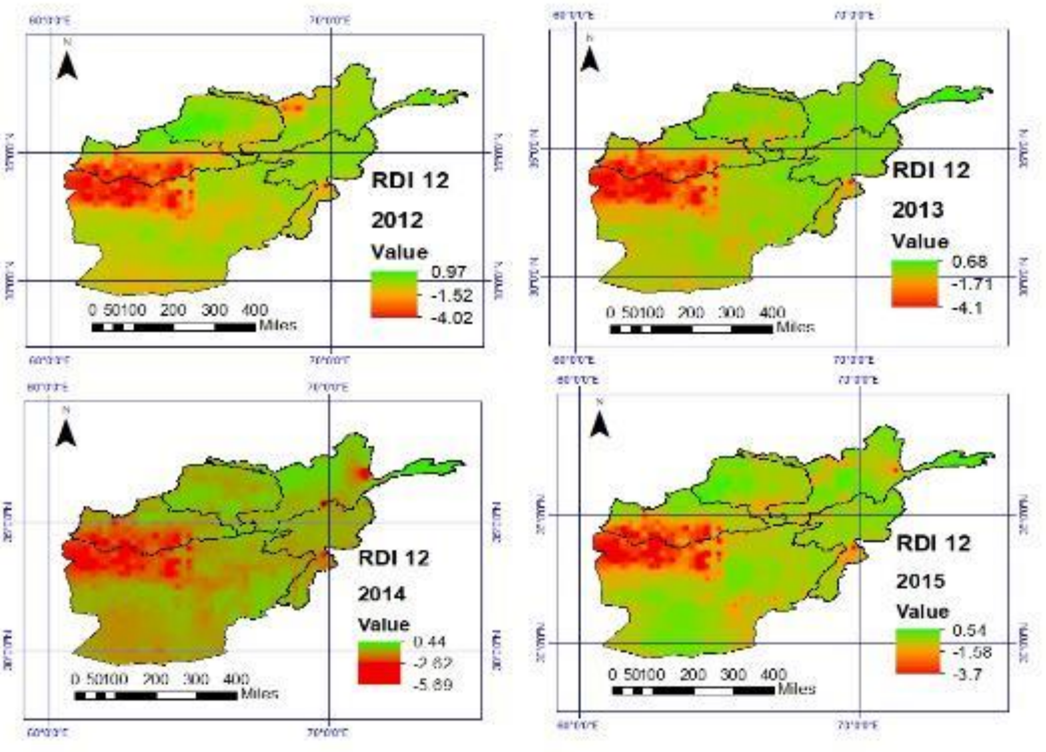
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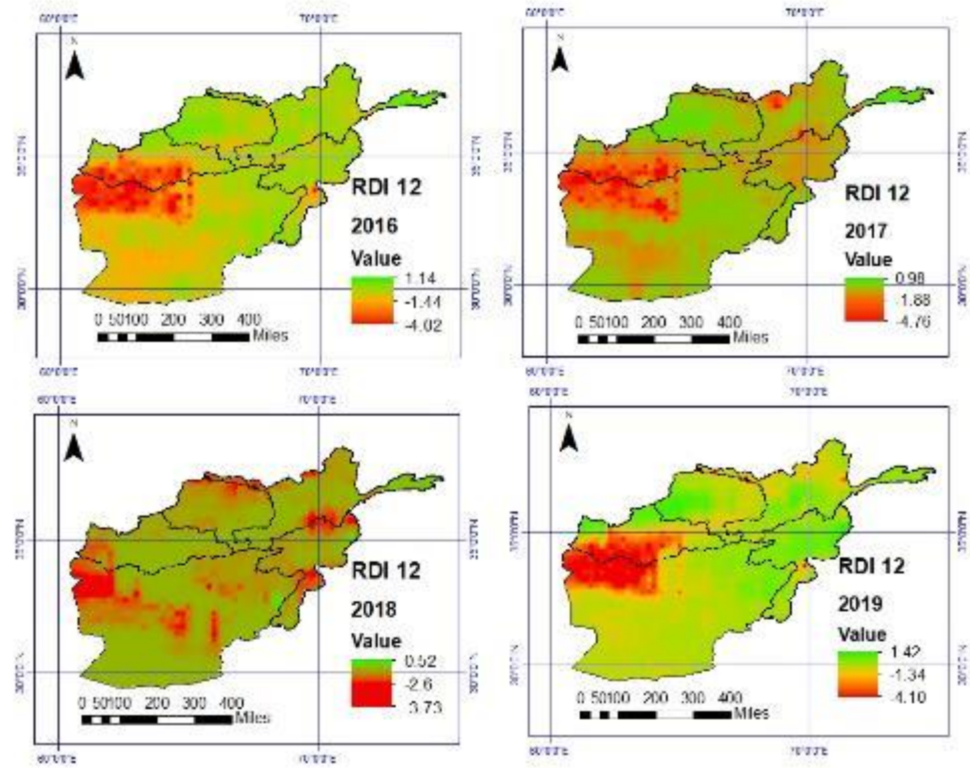
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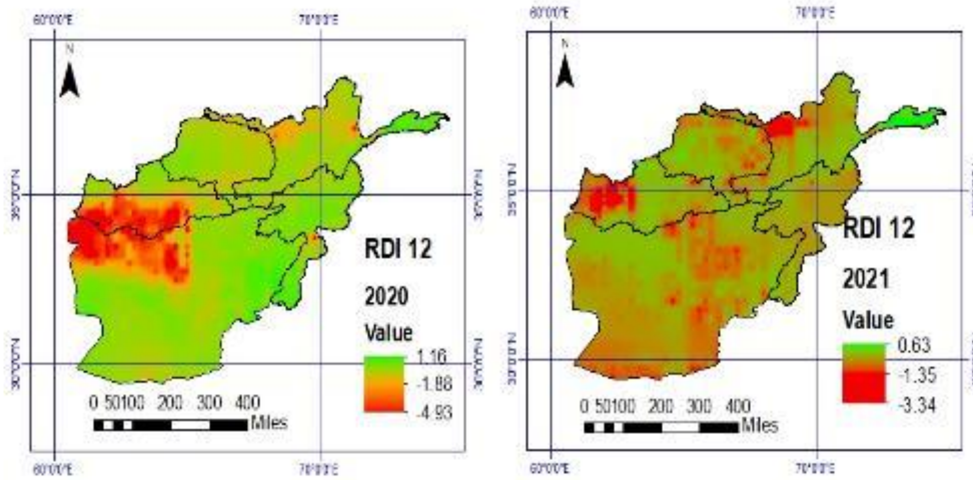
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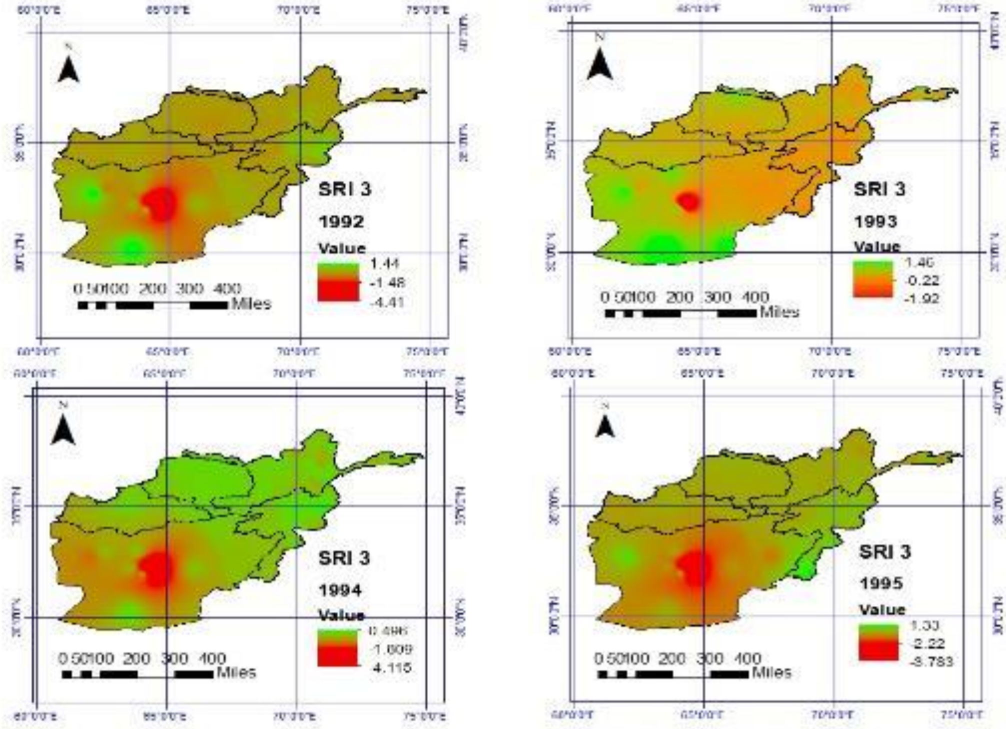
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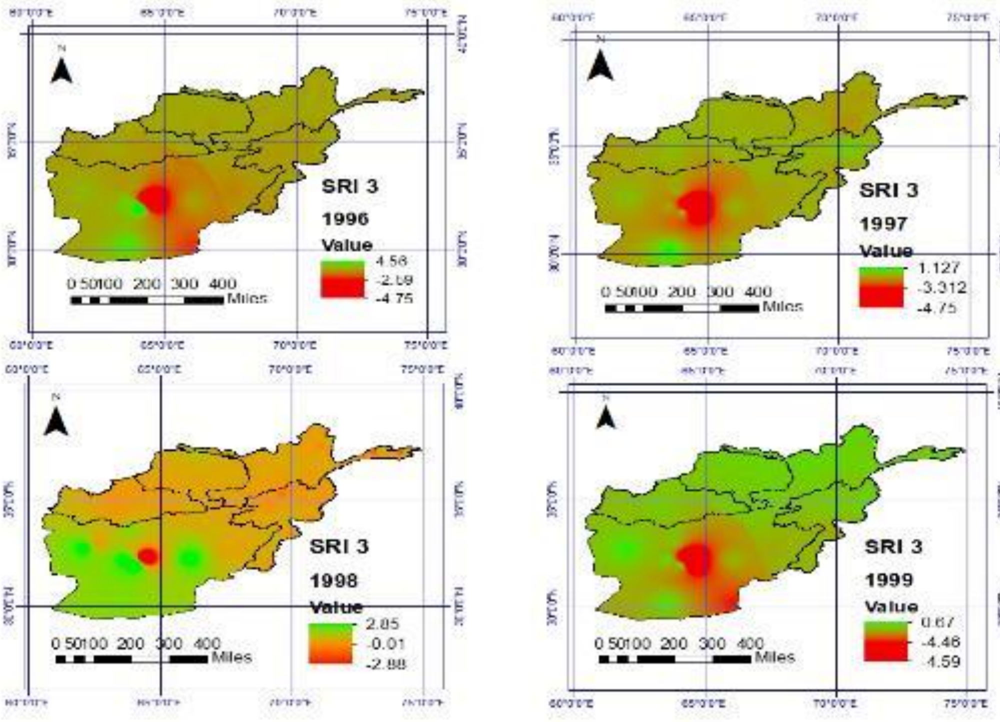
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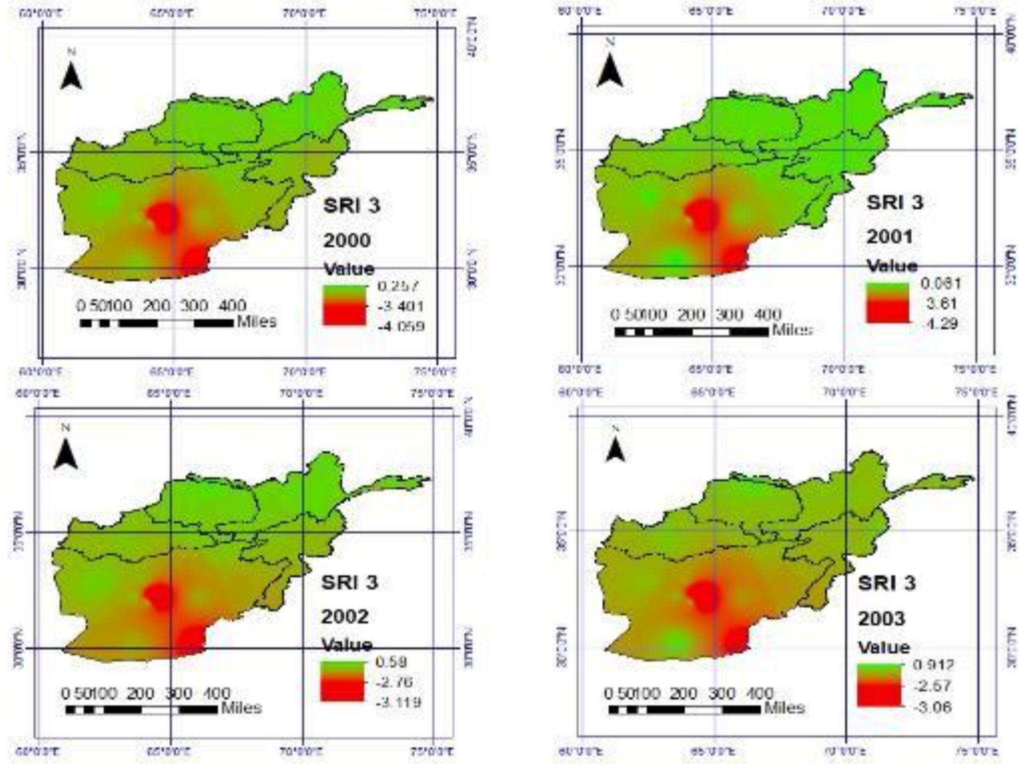
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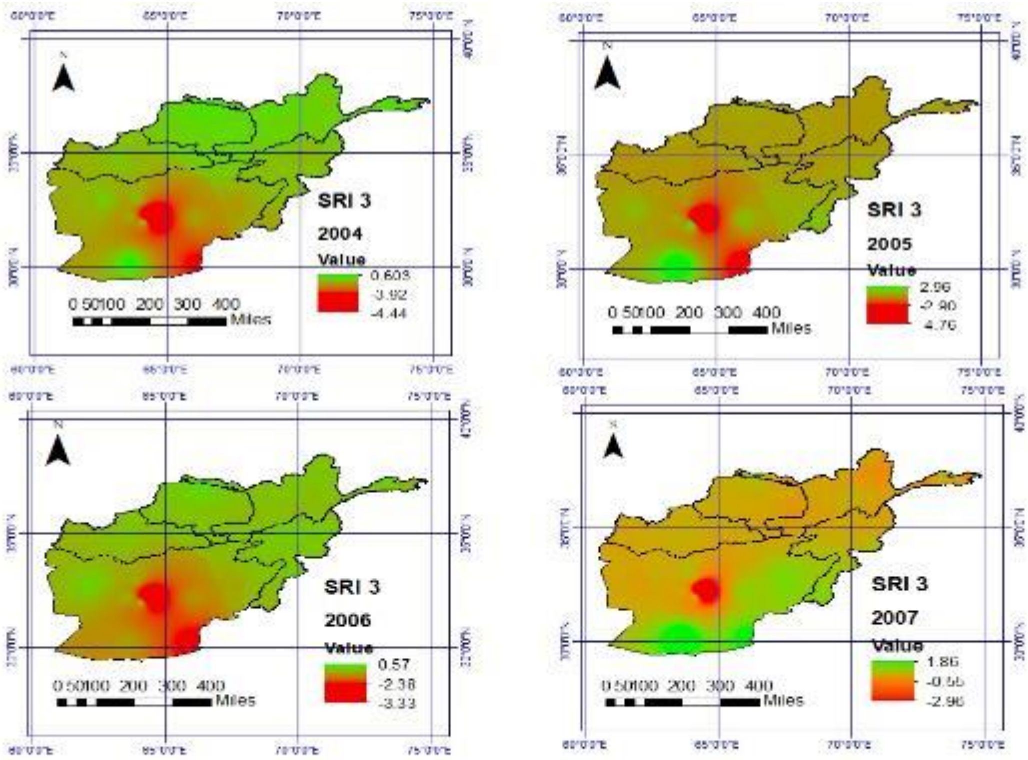
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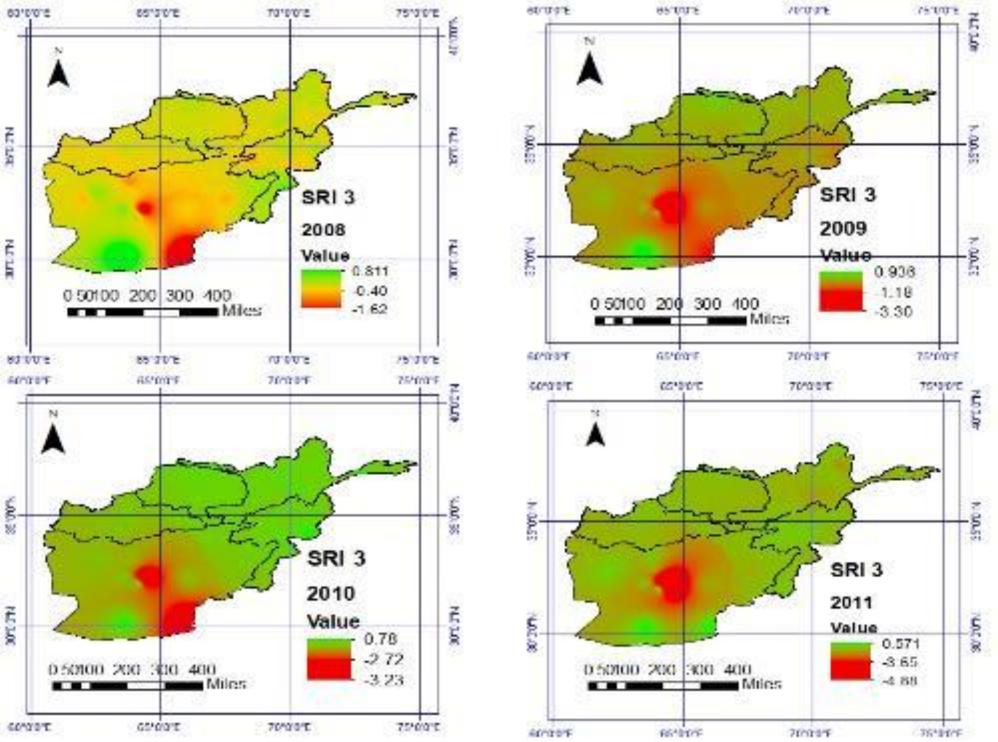
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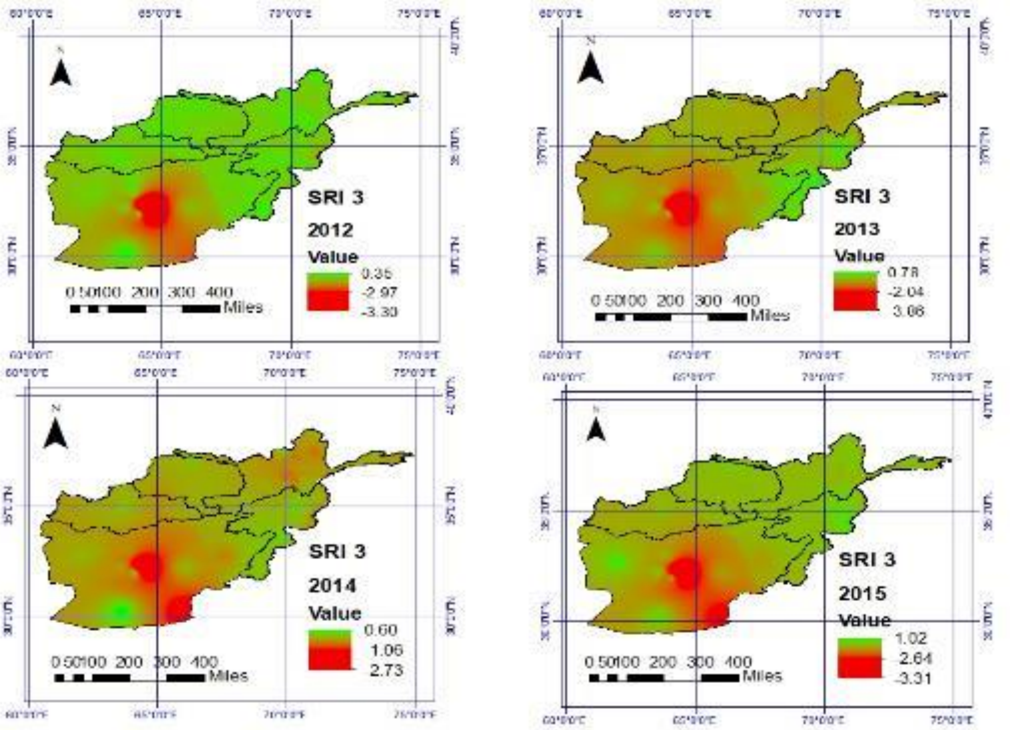
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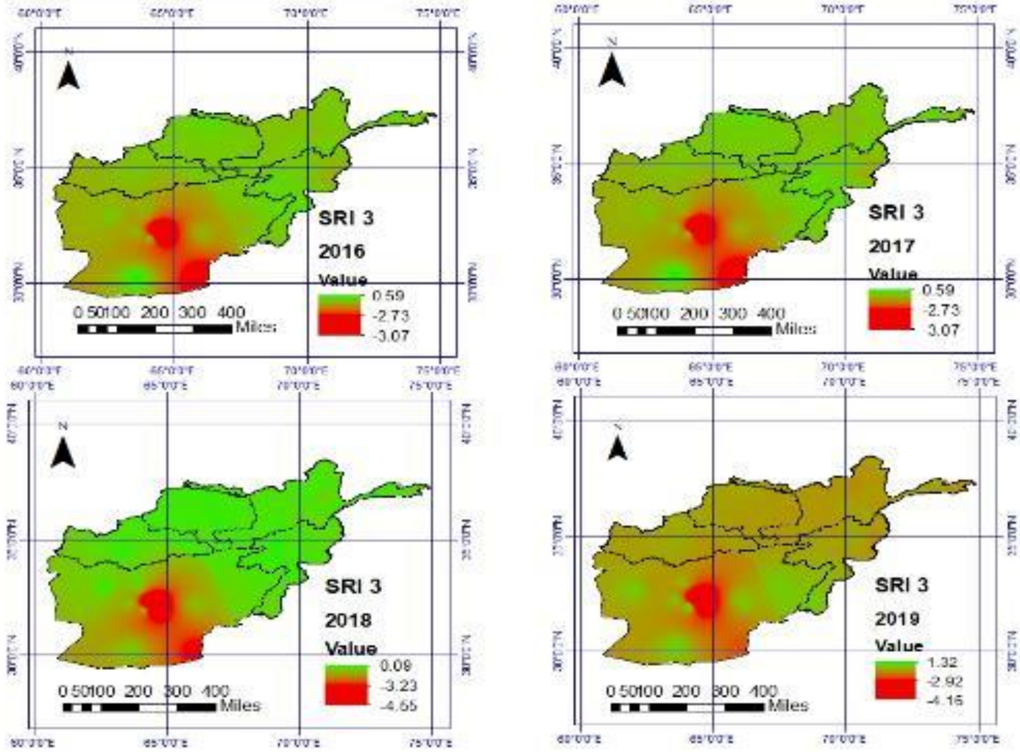
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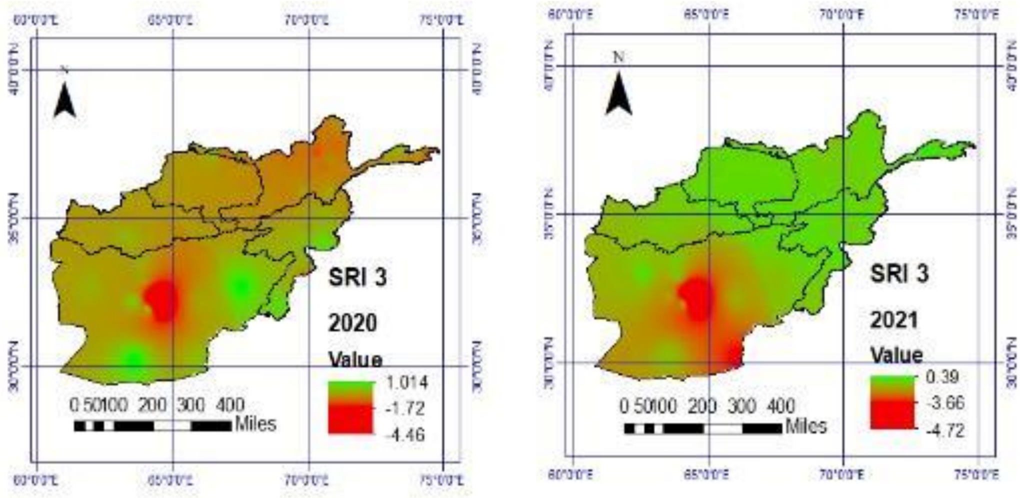
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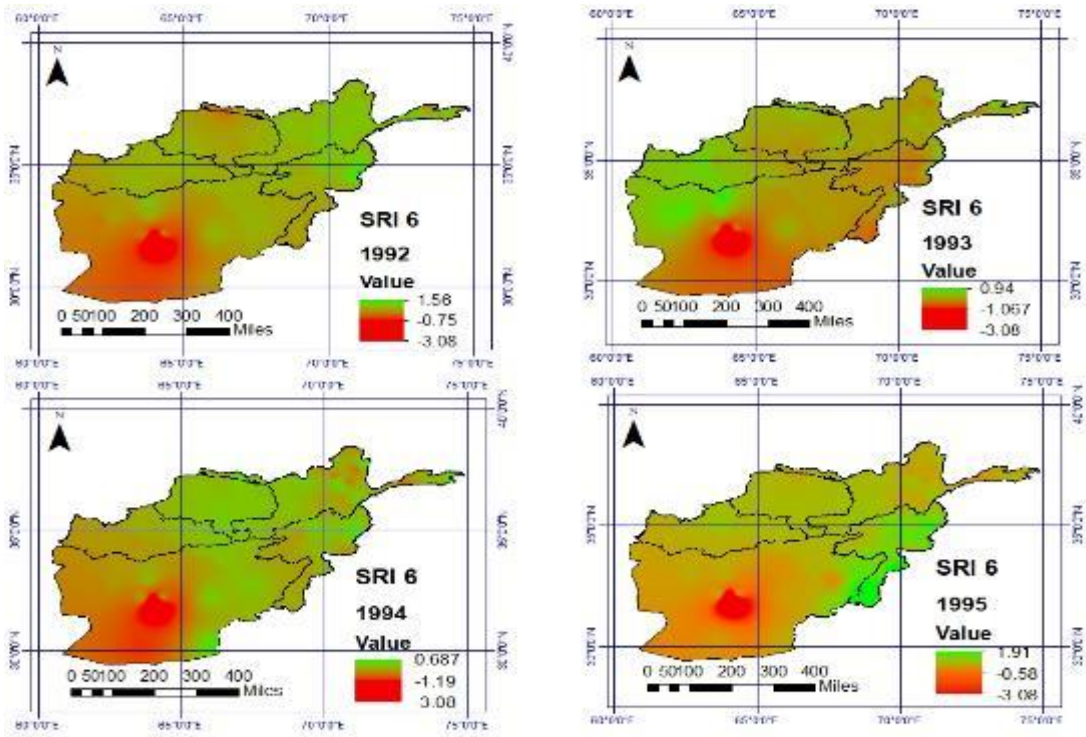
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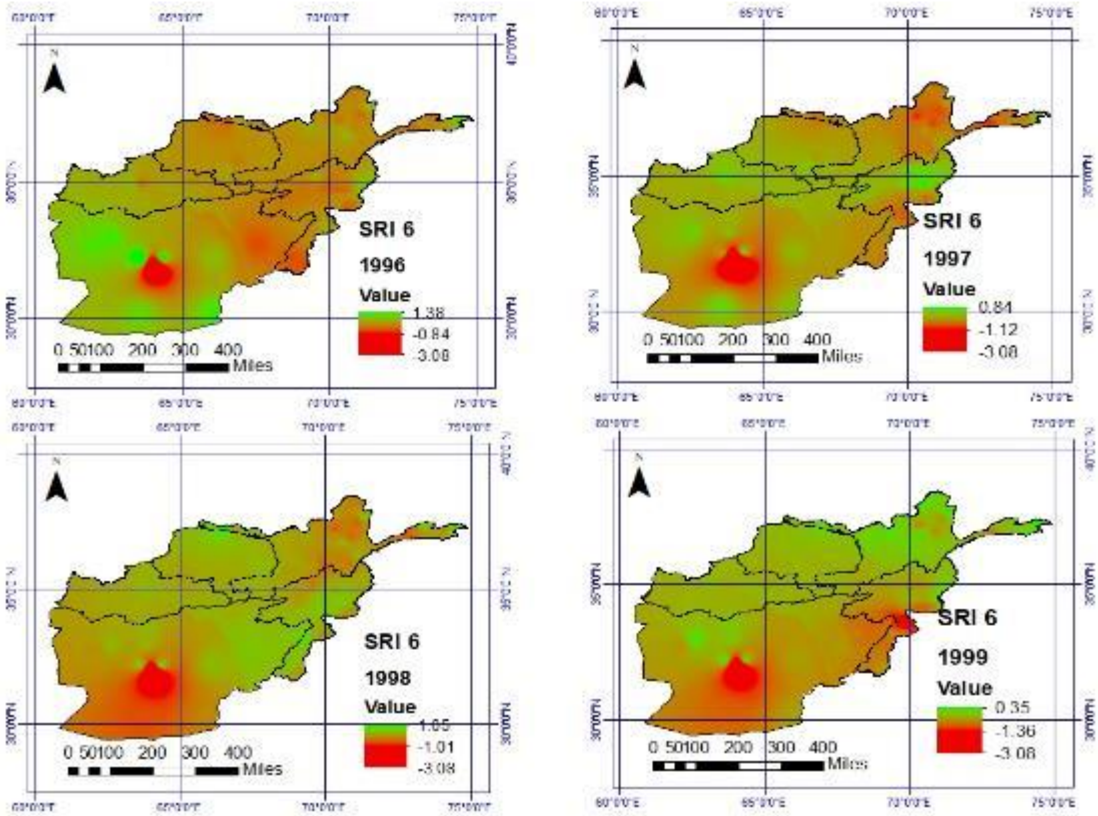
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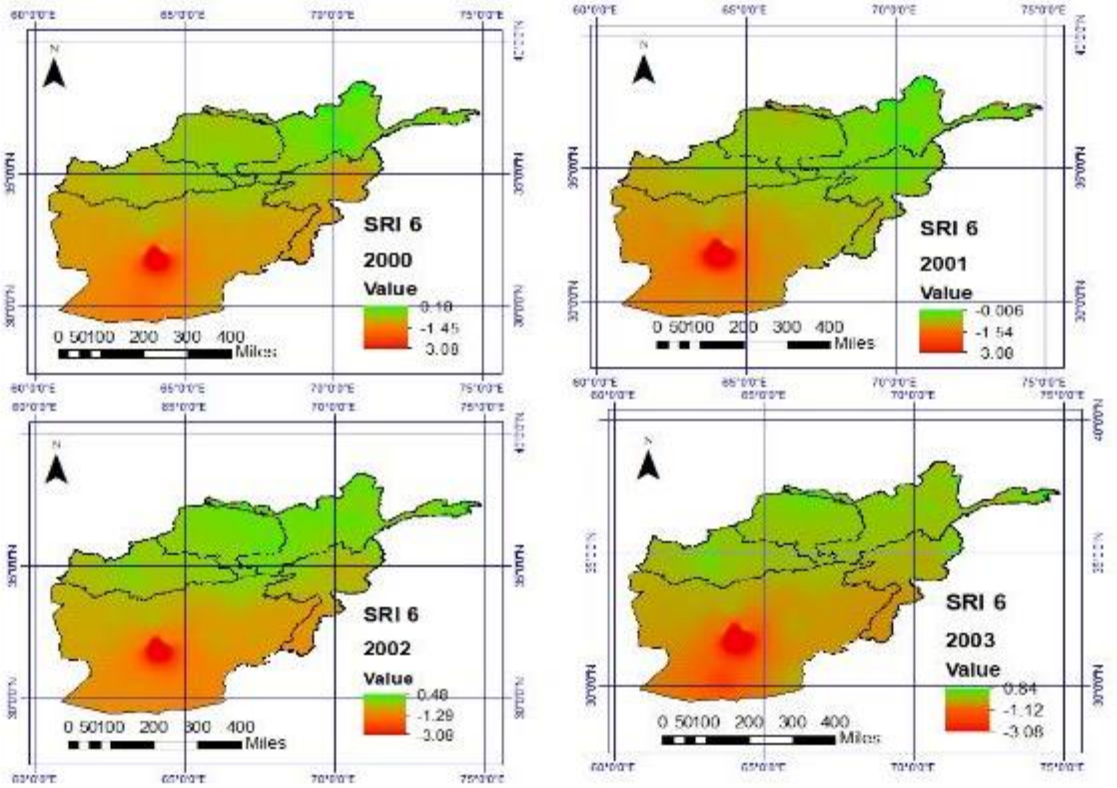
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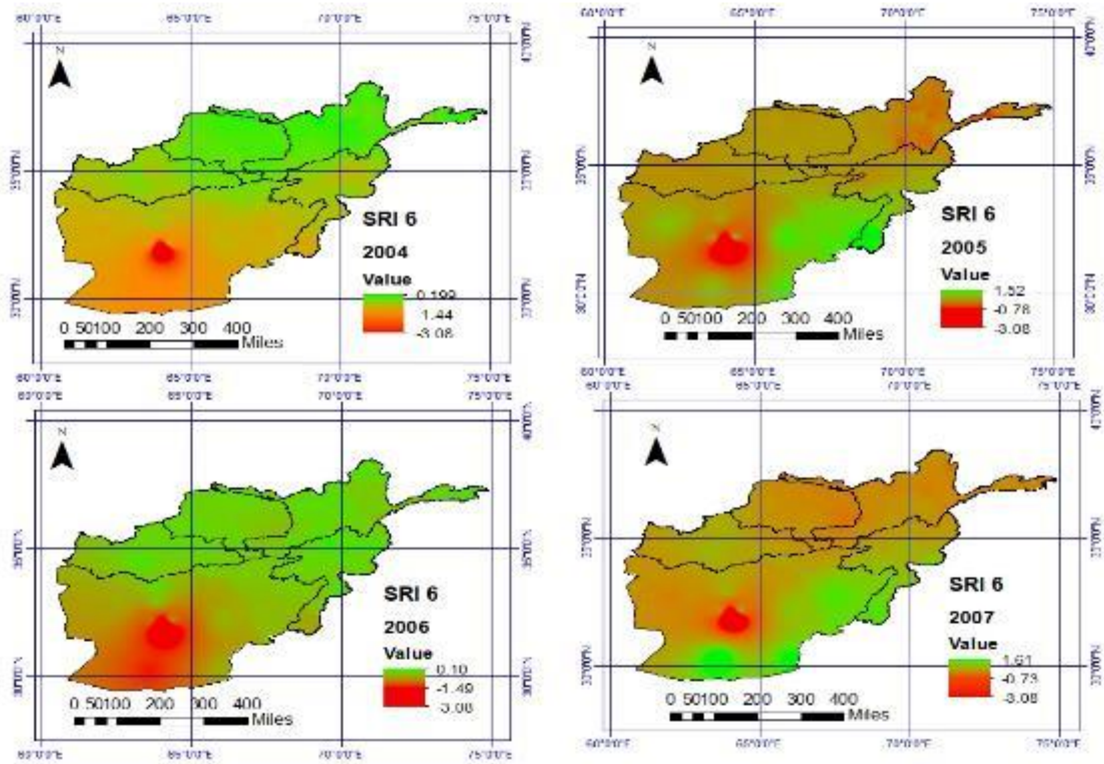
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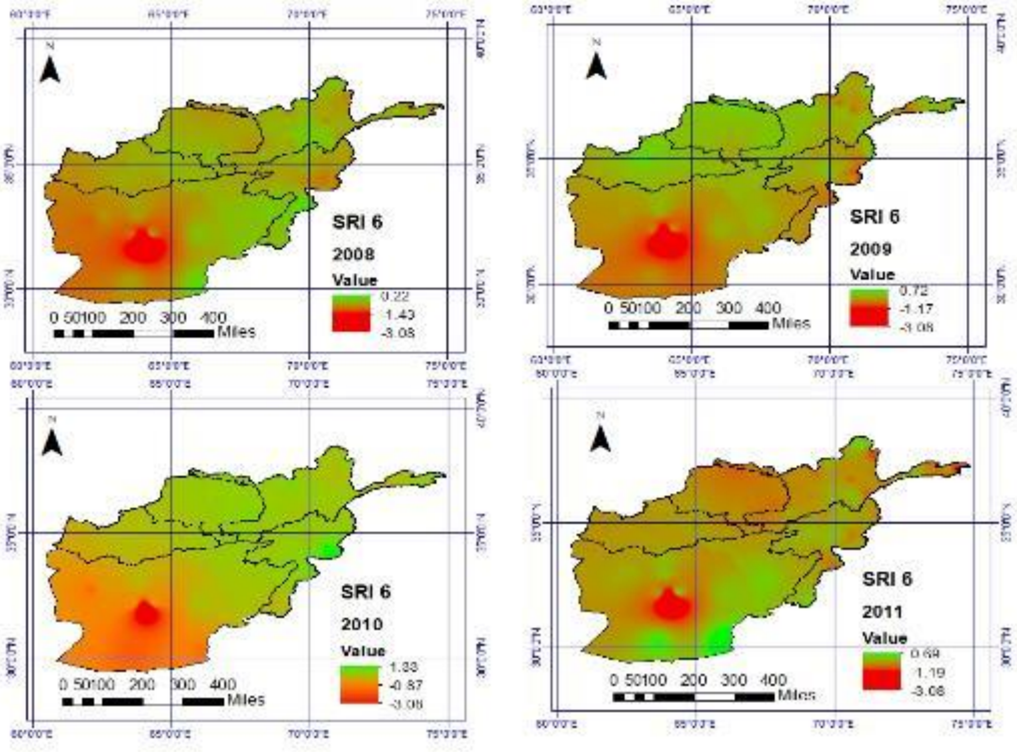
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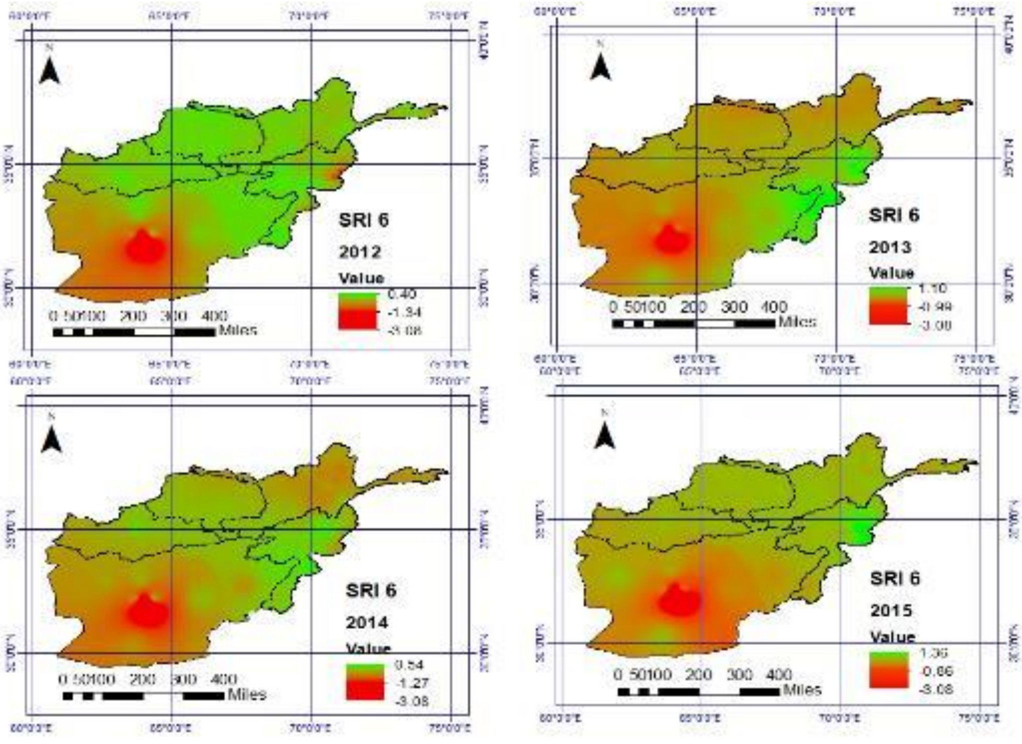
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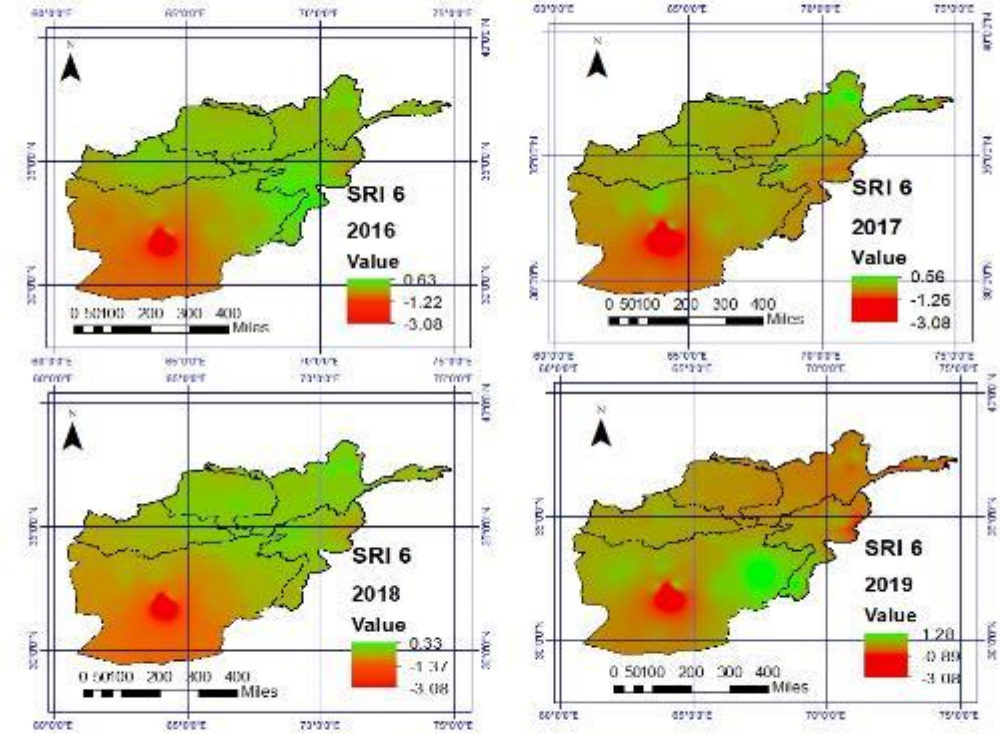
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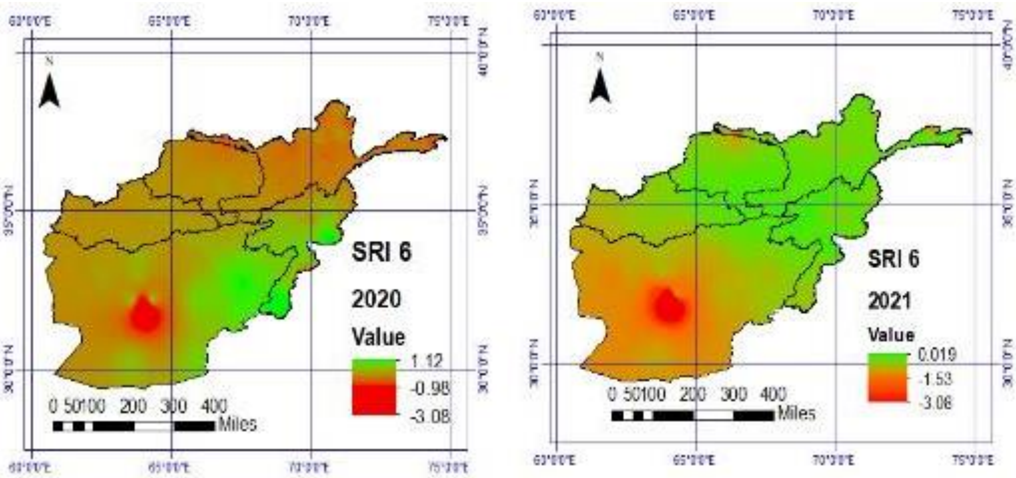
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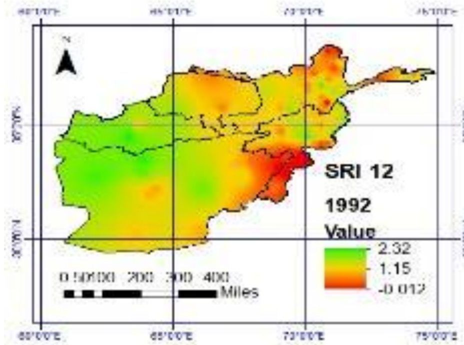
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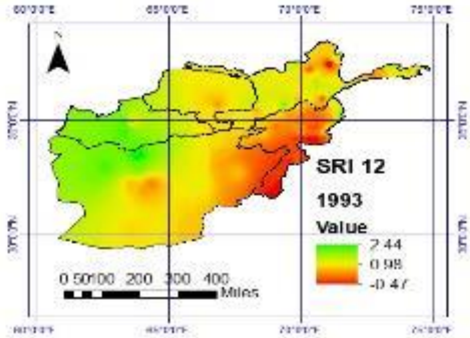
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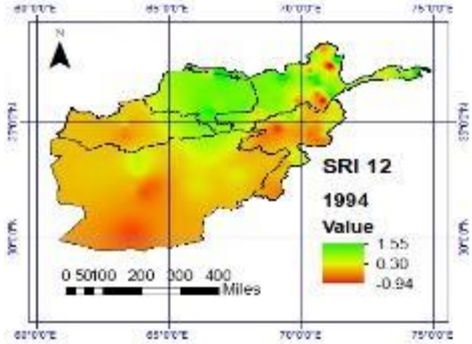
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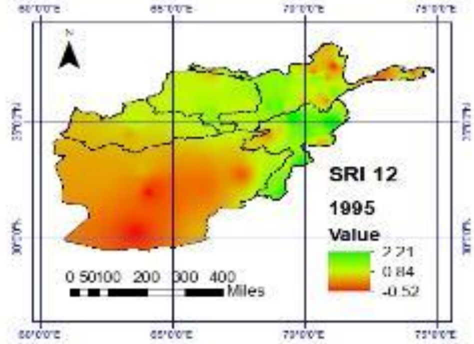
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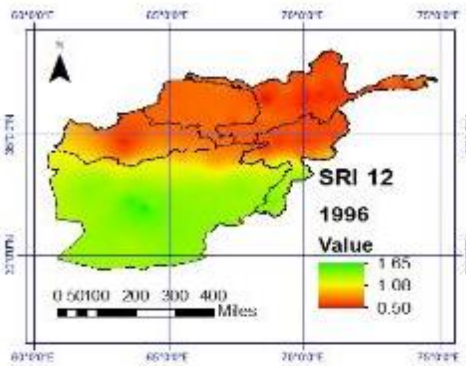
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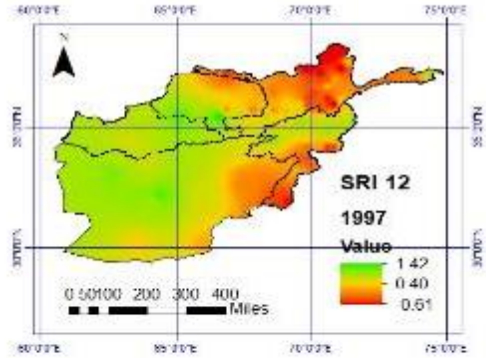
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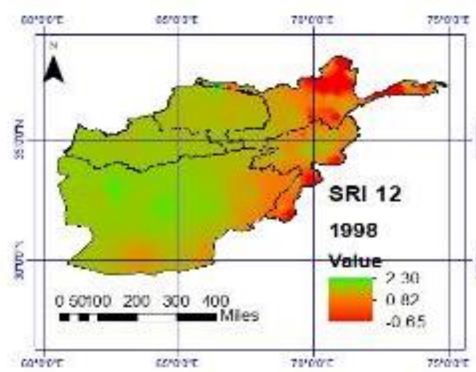
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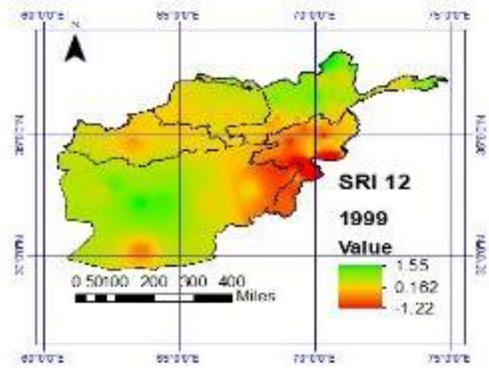
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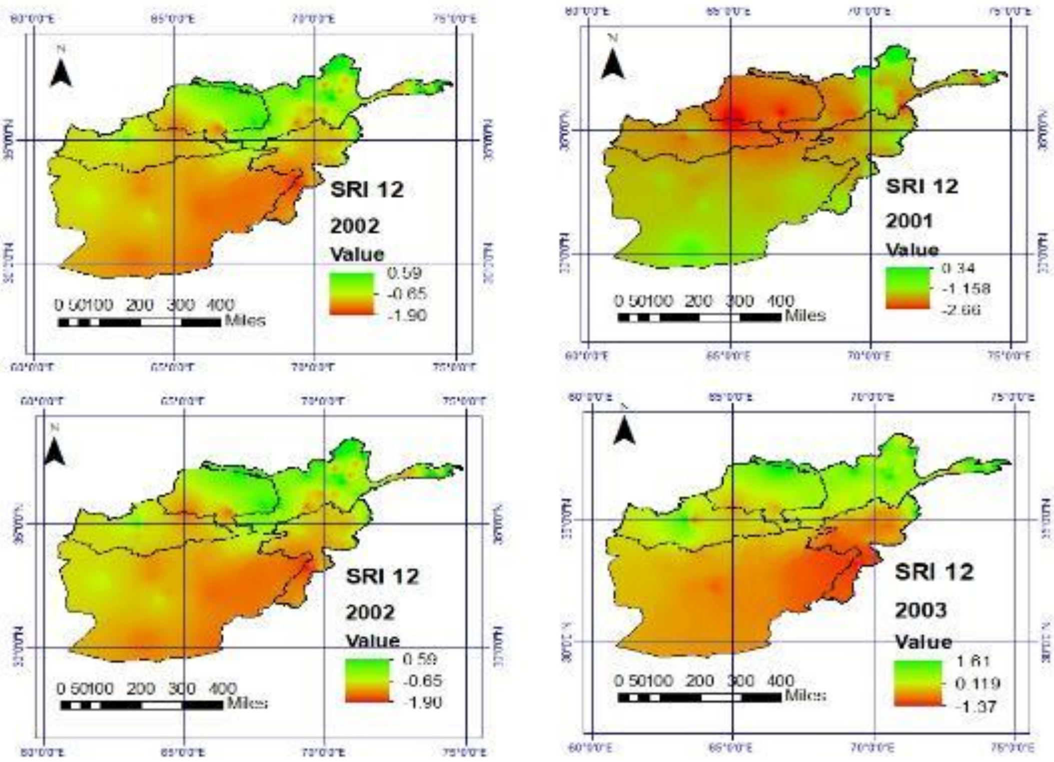
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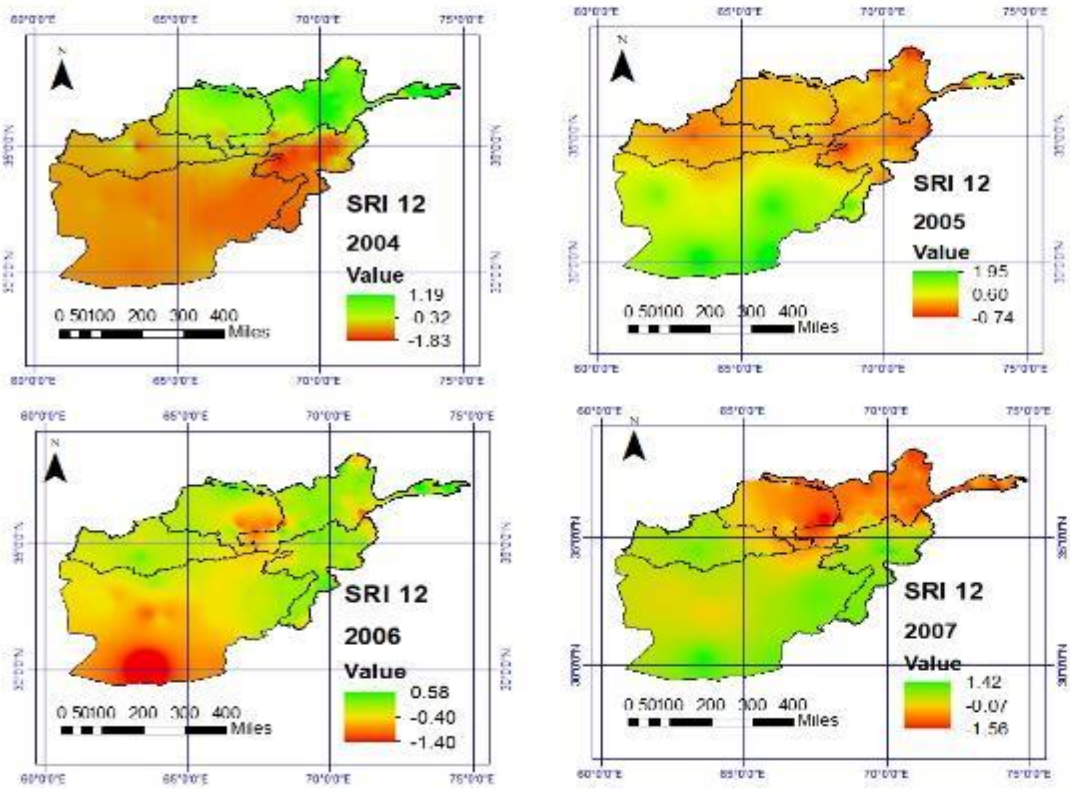
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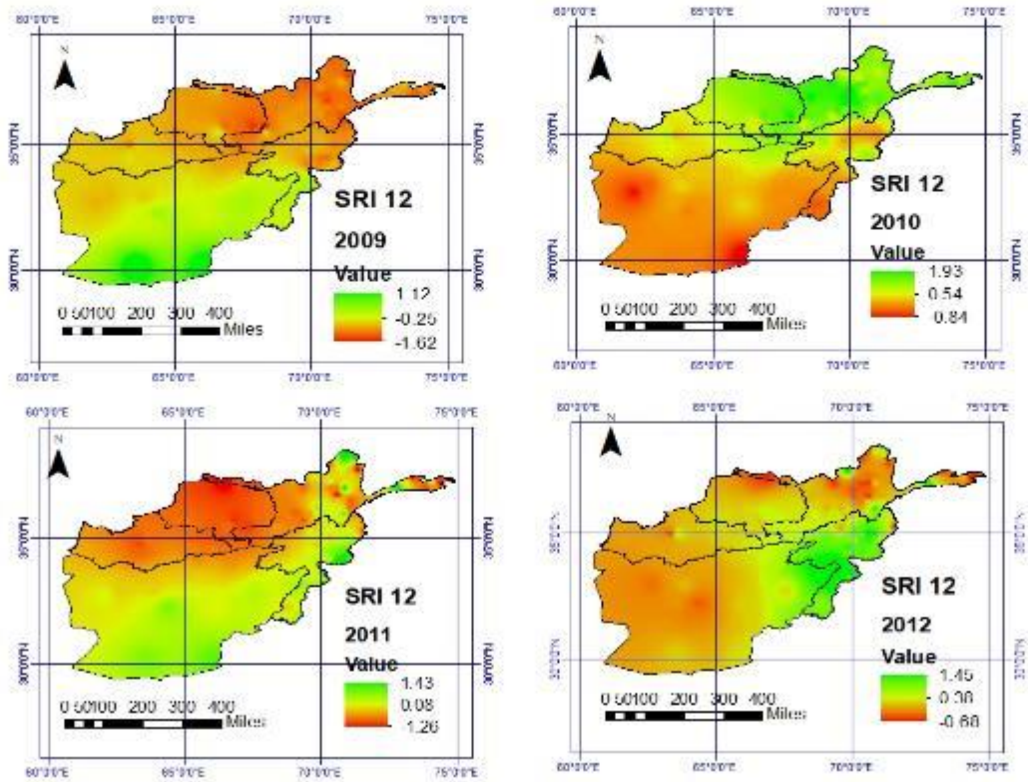
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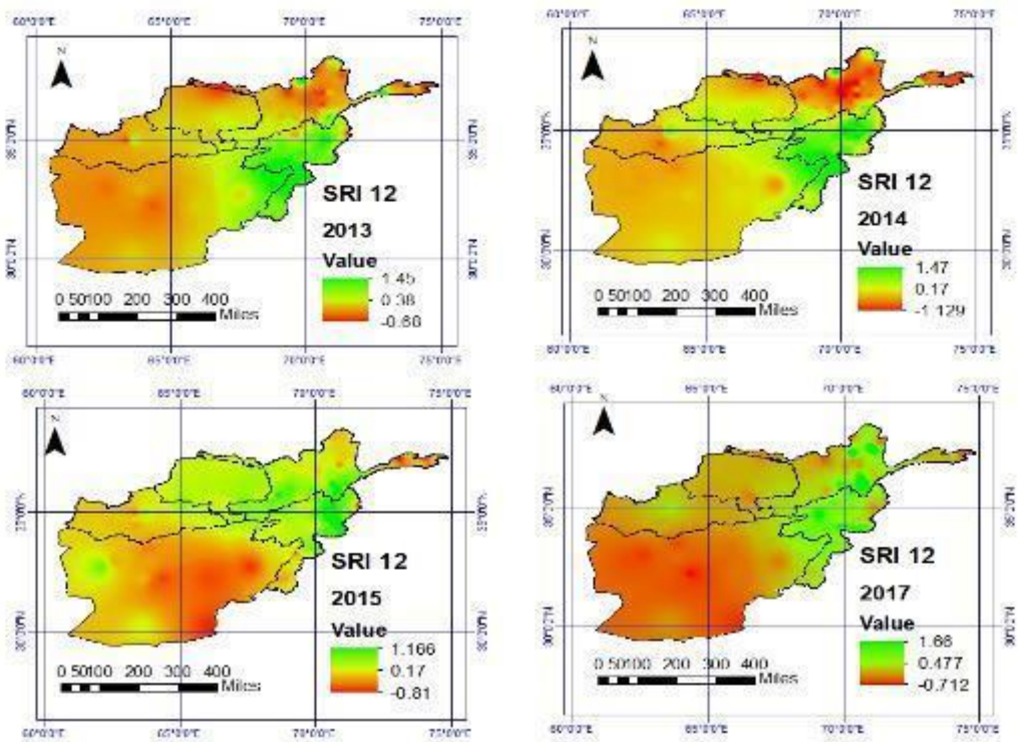
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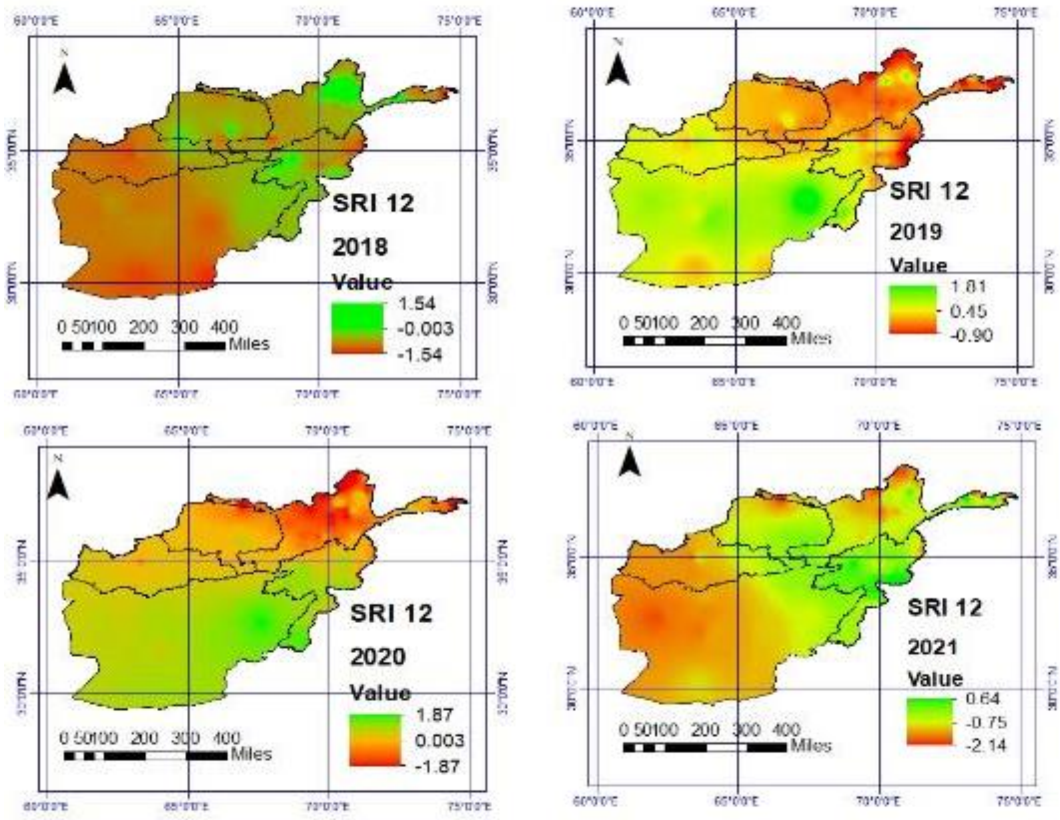
0 50100 200 300 400
Miles


SRI 12
2018
Value
1.54
-0.003
-1.54
SRI 12
2019
Value
1.81
0.45
-0.90
SRI 12
2020
Value
1.87
0.003
-1.87
SRI 12
2021
Value
0.64
-0.75
-2.14
0 50100 200 300 400 Miles