A thesis submitted to the Department of Environmental Sciences and Policy of Central European University in part fulfilment of the Degree of Master of Science

Using Open Geospatial Data to Analyze Climate Change Impact on National Food Security Factors of Central Asia (Kyrgyzstan)

Paromita Basak

AUGUST 2020

Budapest, Hungary

Basak, Paromita. 2020. *Using Open Geospatial Data to Analyze Climate Change Impact on National Food Security Factors of Central Asia (Kyrgyzstan)*. Master of Science Thesis, Central European University, Budapest.

Author’s declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Paromita Basak

Abstract of Thesis

Submitted by: Paromita Basak

For the degree of Master of Science and entitled: Using Open Geospatial Data to Analyze Climate Change Impact on National Food Security Factors of Central Asia (Kyrgyzstan)

Date of Submission: August, 2020

Food security is considered as one of the most concerning issues of the 21st century while climate change persists to insert unpredictability in the system. With the growing demand of food due to population increase and change in climatic parameters that determines the growth, quality and yields of the crops, the need for properly assessing the changes and their impact is also growing. Geospatial analysis, remote sensing technologies, satellite data and open access data sources are proving to be highly potential sources for detecting the change and production side of food security analysis. This research detects the climatic parameter change and geospatial variation in Kyrgyzstan through using free and openly accessible geospatial and statistical data. Spatial analysis of several important parameters related to agricultural production such as, temperature, precipitation, soil moisture, crop evapotranspiration, land degradation and vegetation change were conducted in this research. The visualization of these parameters through maps showed the average increase and decrease through period by period comparison. Furthermore, the analyzed maps of these parameters were combined with the statistical crop data which delivered a thorough analysis connecting climatic parameter change and production sector of food security. This research spatially identifies the vulnerable areas due to land degradation and climate change which can certainly aid in policy making processes in the national and regional level while leaving a base for further field level research on the parameters and their impact on food security.

Keywords: Remote sensing, GIS, Food Security, Climate Change, Open Data, Spatial Analysis

Acknowledgements:

My first and foremost heartfelt gratitude goes to Dr. Viktor Lagutov, who guided me through the entire research and helped me to do the kind of analysis I always wanted to perform but never thought I will. I will eternally cherish the incredible learning experience he provided me with his relentless support and wisdom throughout my masters and the thesis journey.

My second gratitude goes to the department professors and staffs for always supporting whenever I needed it. I certainly am blessed to have had the opportunity to be a student of such an amazing department. I am indeed very inspired from the people in it.

My last gratitude goes to my family and friends who somehow believed that I could write a research thesis amidst the covid situation and uncertainty when all I wanted to do was give up.

I dedicate this to my father. If possible, I would one day try to be a dedicated scientist like him and make him proud from the other side.

Table of Contents

List of Tables

List of Figures

1. Introduction

1.2 Background

Food Security and Climate Change are two cutting edge issues of the world currently. These parallelly concerning issues have strong correlation. The strong link between these two concepts is presumed to be the crop productivity or food production which influences the civilization in irreversible ways. Any potential change in the climatic parameters can impact the growth and yield of the crop production which ultimately results in food insecurity and economic crisis in the countries.

Although climate change is a phenomenon that was always present throughout the history of earth, in recent years this term is referred to the uncharacteristically increased or decreased rate of different climatic parameters due to anthropogenic activities. The biophysical parameters that are mostly noticeable in this change of global climate is usually air and land temperature, precipitation, atmospheric pressure, land-cover and vegetation change, evapotranspiration rate change, desertification, soil infertility, sea level, rate of ice meltdown in the arctic regions and so on. These parameters impact the living beings directly leading to migration, population rate change, species extinction and cause food security issues.

Food security is a complex term which refers to "a set of dynamic interactions between and within the biogeophysical and human environments which result in the production, processing, distribution, preparation and consumption of food." (Gregory, Ingram and Brklacich 2005). The socioeconomic concept of food security, due to being multidimensional and crucial to the survival of human race, is a prime sector of research for the policymakers and scientists around the world. While the relation between changes in the climate and crop yields has somehow been formed, the relation between climate change and food security has yet to be firmly established. This is the reason why it is essential now to utilize all the modern technologies we have in hand and conduct research that can aim to connect these concepts.

In recent reports of UN, Central Asia has been denoted as one of the most vulnerable areas for climate change in the world. This has the potential to impact the already vulnerable food security of the region severely. For this reason, thorough research is urgently needed to be done in the region which connects both climate change and production side of food security.

1.3 Problem Statement (Hypothesis) and Research Question

At the verge of global climate change, the countries of Central Asia, such as Kyrgyzstan, are facing significant food security problems such as decline in climatic requirements of crop production which will inevitably affect and amplify these regions existing food security problems.

This research will orient around the following questions:

1. What kind of climatic parameter change is happening in Kyrgyzstan for last two decades and how severe are they in the agricultural areas?
2. How can the changes in these climatic conditions affect the crop production and hence food security of the country?

1.4 Aims and Objective

-Identifying climatic parameters relating to food security change such as temperature, precipitation, evapotranspiration, vegetation change, soil moisture in the crop root level, land degradation problems through open data analysis and remote sensing data in of Central Asian region, especially the study area.

-Comparison of historic data of parameters related to crop production, vegetation cover with new and recent data and analyzing if there is any significant pattern of change.

-Possible correlation between climate change issues and the food security issues in the study area.

2. Literature review

2.2 Overview of Global food security issues

Global food security, a vital part of human's life, has always been a concern since the beginning of civilization. From the hunting and gathering era, people have focused on securing a continuous and uninterrupted source of food for themselves which resulted in agrarian society and modern-day agriculture.

Many definitions of 'Food Security' have emerged throughout last decades. At the 1974 World Food Summit, it was defined as "availability at all times of adequate world food supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices" (UN 1975). After almost a decade, in 1983, the Food and Agricultural(FAO), redefined the concept to include access of available supplies to vulnerable people suggesting that the demand and supply side of the food security equation should be balanced "ensuring that all people at all times have both physical and economic access to the basic food that they need" (FAO 1983). The World Bank in their 1986 report named "Poverty and Hunger" introduced the temporal dynamics of food insecurity that addresses the discrepancy between "Chronic food insecurity' related to continuing or structural poverty or low income and "Transitory food insecurity" that basically refers to sudden intensified pressure by shocks such as natural disasters, economic collapse or conflict (World Bank 1986). This concept was theorized in a simple definition of Food Security which denoted it as "access of all people at all times to enough food for an active, healthy life" (World Bank 1986). Food Security was recognized as a significant concern in global level by mid 1990s, where the FAO definition incorporated food safety and broadened it to include nutritional balance which reflected "concerns about food composition and minor nutrient requirements for an active and healthy life." (Clay 2002). On the 1994 UNDP Human Development Report, UNDP promoted the concept of human security where food security was one of the components of it (UNDP 1994). At the 1996 World Food Summit, a more complex definition of food security was adopted which stated, "Food security, at the individual, household, national, regional and global levels [is achieved] when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO 1996). FAO again polished this complex statement in The State of Food Insecurity 2001, denoting Food Security as a situation "that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO 2002).

When the complex concept of food security is understood, it becomes clear that how much it is related to undernourishment. According to FAO's last report of "The State Of Food Security And Nutrition In The World", the trend in world hunger which is measured by prevalence of undernourishment, after decades of continual decline has reverted in 2015 and remained almost unchanged since then at a level slightly below 11 percent (FAO 2019). In the meantime, the people who suffer from hunger in the world, significantly increased which resulted in present day's cumulative population of more than 820 million people who suffer from food insecurity and hunger (FAO 2019). This has created an enormous impediment towards achieving UN's Zero Hunger target by 2030 (FAO 2019).

The FAO graph at Figure 1, provides the clear trend of undernourishment from 2000 to 2018. From the graph it is seen that although there has been a steady downwards trend from 2004, the slope got steeper with each year and last some years there has been no significant change as the lines are mostly parallel to the X axis and show no change in Y axis which denotes the percentage.

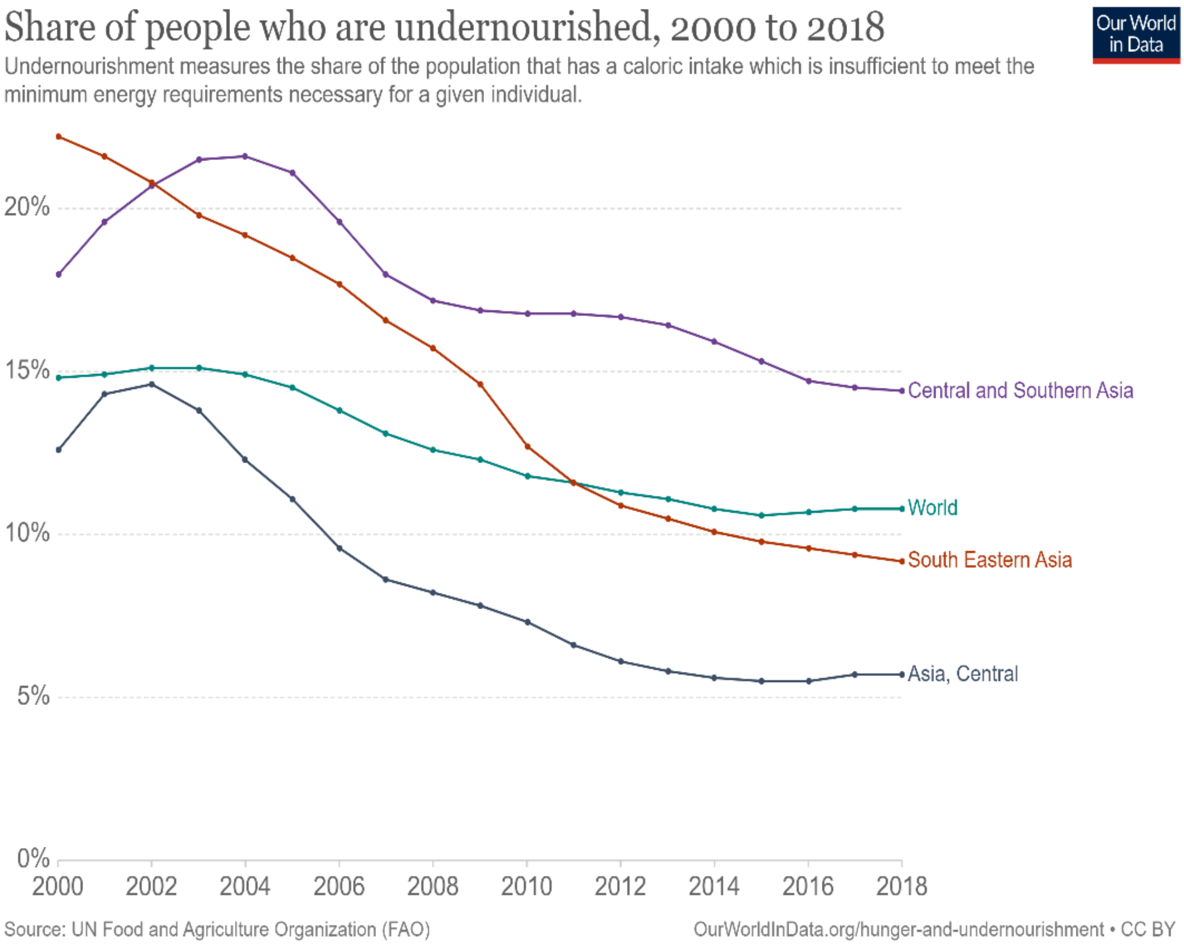


Figure 1: Graph of regional undernourished population percentage from 2000 to 2018 (FAO 2020)

From Figure 2 and Figure 3, provided by FAO Statistics, we can compare the exact percentages of the world and the regions. Only Asia was compared with the world as this study is focusing on this particular region. While there has been lowering of the percentages over these 2 decades, it is not as significant as it was expected. The world undernourished population went down to 10.8% from 18%. Central Asia's percentage went down from 12.6% to 5.7%. South Eastern Asia made the highest improvement from 22.2% lowering to 9.2%. But if the overall and combined scenario of both southern and central Asia is compared, then it can be seen that both of them had lowered only by 7.2% in last 2 decades compared to other regions.

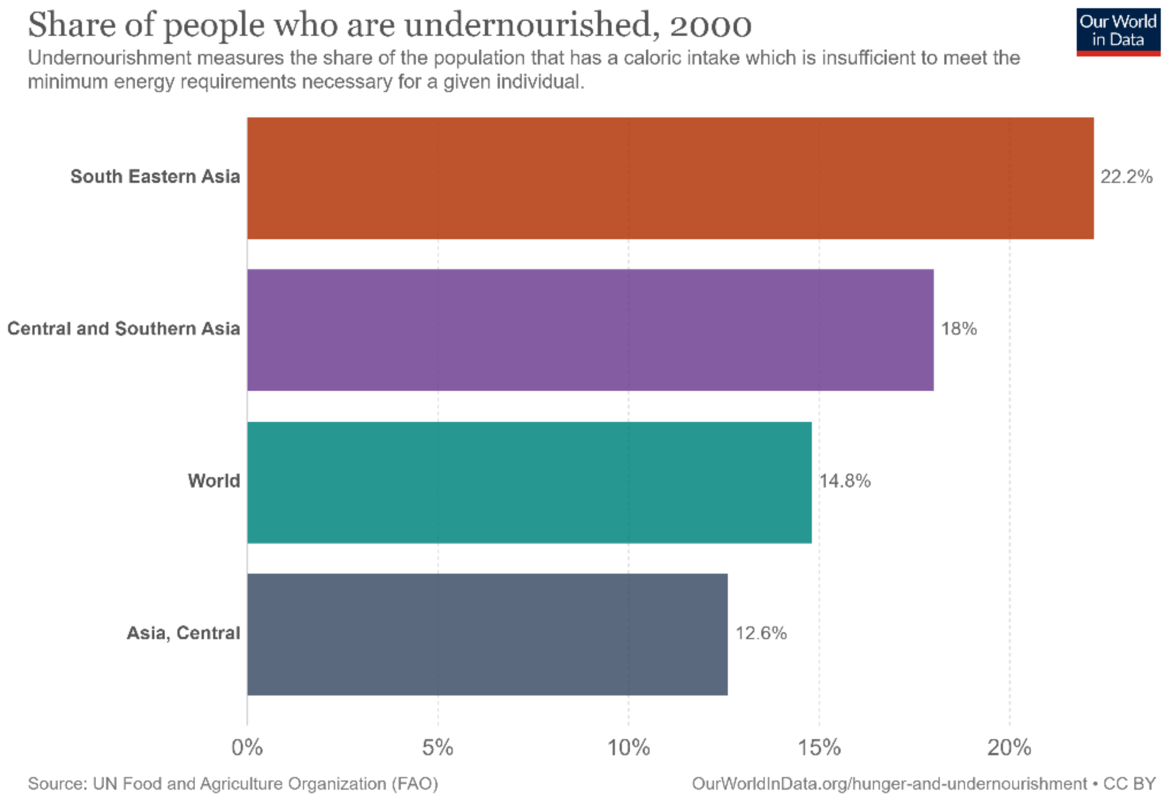


Figure 2: Graph of regional undernourished population percentage at 2000(FAO 2020)

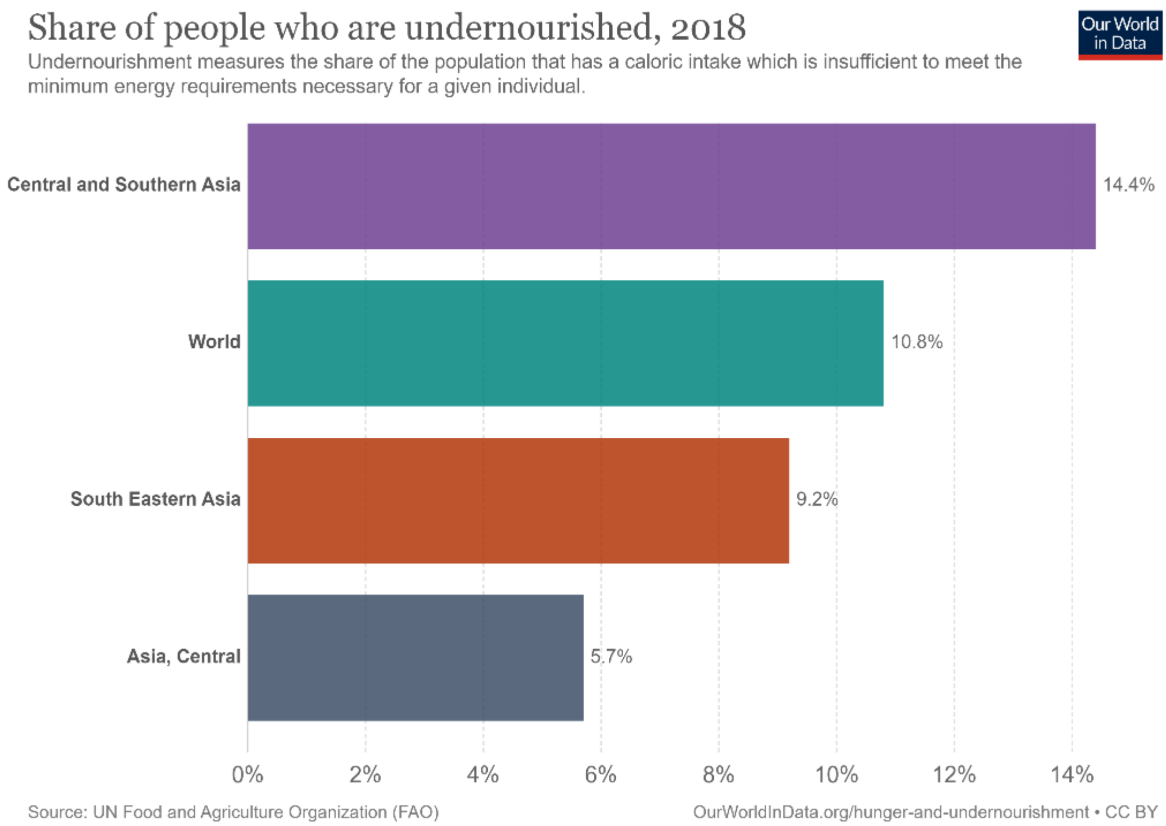


Figure 3: Graph of regional undernourished population percentage at 2018(FAO 2020)

These FAO statistics (Figure 1,Figure 2, Figure 3) give an approximate idea that a lot of research and management decision are needed to be implemented, in order to ensure food security of the affected population.

According to the FAO definitions, the four key dimensions of food supplies are availability, stability, access, and utilization (Schmidhuber and Tubiello 2007). The first-dimension availability refers to the availability of sufficient food which means the cumulative ability of the agricultural system (global or national scale) to meet the population's food demand (Schmidhuber and Tubiello 2007). The subdimensions of this parameter contain the "agro-climatic fundamentals of crop and pasture production." (Schmidhuber and Tubiello 2007). This parameter is heavily impacted by any change in the climate which brings the concern of climate change's effect on crop production into scenario.

The ways climate change impact the Food Security are complex in nature. This phenomenon directly affects the food production by altering agro-ecological conditions and indirectly affects "growth and distribution of incomes" which overall impacts the demand for agricultural products (Schmidhuber and Tubiello 2007).

When temperature and precipitation patterns associated with constant emissions of greenhouse gases change, they also alter the crop yields and land suitability (Schmidhuber and Tubiello 2007). According to the Intergovernmental Panel on Climate Change (IPCC)'s SRES emission scenario and climate models, global mean surface temperature is estimated to rise in a range from 1.8°C (1.1°C-2.9°C range for SRES B1) to 4.0°C (2.4°C to 6.4°C. range for SRES A1) by 2100 (IPCC 2007a). This will have different impacts on different regions of the world. In the temperate latitudes, the increasing temperatures will predominantly bring benefits to agriculture expanding suitable lands for agriculture which will upsurge the crop yields (Rosenzweig et al. 2002). Pasture productivity might be increased with the moderate level of incremental warming which will reduce housing needs and compound feed (Schmidhuber and Tubiello 2007). While all these possibilities draw a positive scenario for the future, they have to be set against the increased frequency of extreme events, such as heat waves, droughts, heavy precipitation, increased coastal storms and flooding in the temperate regions, that will inevitably come with the climate change (Schmidhuber and Tubiello 2007). Intergovernmental Panel on Climate Change(IPCC) in their 2007's "Climate Change: Impacts, Adaptation and Vulnerability" report draws out the alternative scenario for pastures in the semiarid and arid areas where reduced productivity and increased mortality is likely to be seen (IPCC 2007b). The climate models of the drier areas predict increase in evapotranspiration and lower soil moisture levels which will result in cultivated areas becoming unsuitable for cropping and tropical grasslands turning into arid (IPCC 2007a, 2001). The rise in temperature will also give rise to pests and increase their adaptivity to survive in winter weather and damage the spring crops (Schmidhuber and Tubiello 2007).

On the SRES (Special Report on Emissions Scenarios) of IPCC, the atmospheric CO2 concentration is estimated to increase from 379ppm in the time of the report to 550ppm by 2100 in SRES B1 and 800ppm in SRES A1F1 (IPCC 2007a, 2001). While IPCC estimated it to have a good impact on the crops by enhancing biomass accumulation capability in the plants and thereby increasing final yield, the scale of this is very unclear (IPCC 2001). Even if the yield increases according to their theory, "the nutritional quality of agricultural produce may not increase" consequently (Schmidhuber and Tubiello 2007). For example, crops like cereal and forage crops showed lower level of protein content under the exposure of elevated CO2 (IPCC 2001). This certainly addresses the issue of food security again where the possible scenario of available food with low to minimal nutritious value occurs. So, it is very necessary to determine the nutritious value of the crops to while assessing the overall food security situation of any country.

2.2.1 Overview of food security issues in Central Asia

Central Asia, which consists of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan(Figure 4), is one of the continents that is affected by climate change and have been facing food security issues for last some years. The region is considered as a very important location both geographically and strategically because the region is "situated at the heart of the Eurasian continent and form a trade link between China, the Middle East, and Europe" (Hamidov, Helming and Balla 2016). The region is given strategical importance because of carbon credits trading and the natural resources such as, oil, gas, energy, gold, and minerals. Before these five countries' independence from Soviet Union in 1991, they were socio-economically interdependent on the soviet union's economy which was planned centrally and where agriculture was a major sector of economy. The agriculture sector of the pre independence time accounted for 10-45% of their GDP (Gross Domestic Product) and created employment for 10-50% of the regional labor force (Hamidov, Helming and Balla 2016). In the post era of independence, the sector still remains as an vital sector where its GDP contribution is contributing 5.2 % of the GDP in Kazakhstan, 7.5 % in Turkmenistan, 18.5 % in Uzbekistan, 20.8 % in Kyrgyzstan, and 23.3 % in Tajikistan (Hamidov, Helming and Balla 2016). This data clearly shows the dependence of the region on its agriculture and crops. Any climate change or human induced negative impact to the agricultural products will not only impact the food security of these countries but also affect their GDP and national development.

Figure 4: Regional map of the five countries of Central Asia(Ohio State University(OSU) and Miami University)

Central Asia is already facing the impact of Climate Change, Land degradation and Desertification in many of the countries. For example, the massive extraction of irrigation water from two primary rivers named Amudarya and Syrdarya Rivers for agricultural practices have resulted in severe deterioration in the Aral Sea ecosystem which incorporates salinization of croplands, water courses; waterlogging and land degradation which impacted production of cotton and wheat, the primary agricultural crops in the region (Hamidov, Helming and Balla 2016). The land salinization has become so severe in the region that it affects "47.5 % of the irrigated lands of Central Asia (with 33 % of irrigated lands affected in Kazakhstan, 11.5 % in Kyrgyzstan, 16 % in Tajikistan, 95.9 % in Turkmenistan, and 50.1 % in Uzbekistan)" (Hamidov, Helming and Balla 2016). This problem is creating unsuitable condition for crop production that can turn towards a serious decline in agricultural product for the entire region. Desertification and increased dust storms are also impeding the sustainable land use of Central Asia.

Moreover, since the beginning of the twentieth century, there has been an increase of 1-2°C in temperature in Central Asia which resulted in change at land use practices and agricultural production (Lioubimtseva et al. 2005; Fischer et al. 2002). The global warming or climate change is predicted to accelerate this situation by decreasing the glacier reserves and snow cover which are the sole source of water for the croplands of the region (Aleksandrova et al. 2014). The future climate projections draw a future scenario where the demand gaps between water supplies in the highland and lowland regions will endanger the crop production, deteriorating the socio-ecosystems of Central Asian countries (Aleksandrova et al. 2014). Although the glacier-melt situation predicts towards an increase in the water volume of the are in short and probably mid-terms, “the reserves are ultimately limited and water scarcity is likely to occur more frequently sooner or later” (Aleksandrova et al. 2014). The water conflict between upstream and downstream countries, is likely to be increased in the future scenarios of climate change and glacier melt and this conflict can reduce downstream water availability and quality for irrigation and crop production (Aleksandrova et al. 2014). Many experts suggests that to resolve this problem and achieve long term sustainability in the agricultural sector, Central Asia can switch from low-return crops to less water-intensive crops in the dry irrigated land but this recommendation does not cover the issue of the excessive cost of drainage, distribution and irrigation.” (Hamidov, Helming and Balla 2016). Alternative crop rotation techniques in the countries can also be used but proper analysis of the land, water availability and climatic parameters are needed to be analyzed for taking any kind of steps regarding this.

While the demand for food keeps growing in the region, the reorganization of the agricultural sector of Central Asia is creating uncertainty in the food security situation of the region. At the pre-independence era of soviet union, each of the countries of Central Asia specialized in specific agricultural strategies and practices such as Kazakhstan had grain production, Kyrgyzstan had alfalfa, maize and sheep production and Turkmenistan, Uzbekistan and Tajikistan had cotton and karakul sheep for pelts (Hamidov, Helming and Balla 2016). But after that during the transition period the crop production began in many countries that included food legume production with some level of cotton production. The wheat area was doubled during this period but that had low yield. Kyrgyzstan which had alfalfa before started to specialize in potatoes and maize, Turkmenistan at bread wheat and monoculture wheat production began at Kazakhstan although the cropland area was reduced there (Hamidov, Helming and Balla 2016). The livestock and forage production has decreased minimally at one hand but on the other hand the food and forage demand has increased in the region by many folds. The poor management of the rangelands, expanding desertification, loss of plant biodiversity and land degradation is aiding more to the food security problem of central Asia (Hamidov, Helming and Balla 2016). In this case, change in the climates or further degradation of the lands will most certainly impact the food security situation of the country and create an overall concerning situation.

2.3 Geospatial technologies for Climate Change and Land Degradation Analysis

2.3.1 Satellites overview and applications

Satellites are overhead objects that are used for data collection of different earth objects or different phenomenon/parameters of the earth itself. The satellite-based Earth observation started much later than airborne remote sensing, in only 1960s (Zhang and Kerle 2008). Since then, it has been proven as a crucial information source for data collection, analysis, emergency response and so on because of many reasons such as "(i) synoptic (i.e. large area) coverage, (ii) frequent and repetitive collection of data of the Earth's surface, (iii) diverse spectral, spatial and potentially three dimensional information, and (iv) relatively low cost for per unit coverage." (Zhang and Kerle 2008). The developed satellite technology is much more advanced now than the beginning and it is playing significant role to address and analyze many issues such as climate change, land degradation and food security.

Satellite technologies use different sensors to capture reflected electromagnetic energy from earth surface and create imagery (Figure 5). The optical remote sensing of the satellites uses the visible, near infrared and short-wave infrared sensors to detect the solar radiation reflected from the targets of earth's surface and the differences in these reflected wavelengths helps to distinguish the targets in the remotely sensed imagery of the satellite (CRISP 2001).

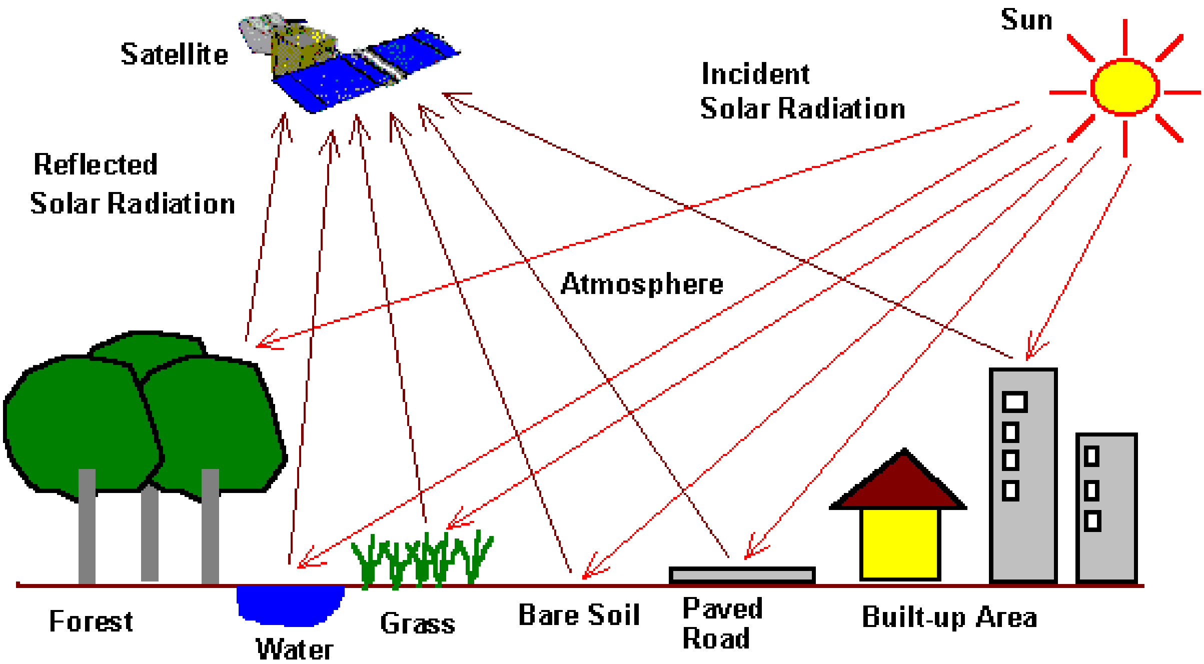


Figure 5:Satellite Data Collection Process (CRISP 2001)

There are two types of sensors which are active sensors and passive sensors. The passive sensors use an external energy source (i.e. Sun) while the active sensors provide their own energy source (i.e. Radar) (Baumann 2010). The active sensors are less common than the passive ones. Mostly the passive sensors are used to collect data which records the information from earth's surface "by measuring the transmission of energy from the surface in different portions of the electromagnetic (EM) spectrum" (Figure 6) (Baumann 2010). As the surface has diverse objects and different nature, the transmitted energy from the surface also varies which helps the creation of the surface imagery in the satellite (Baumann 2010).

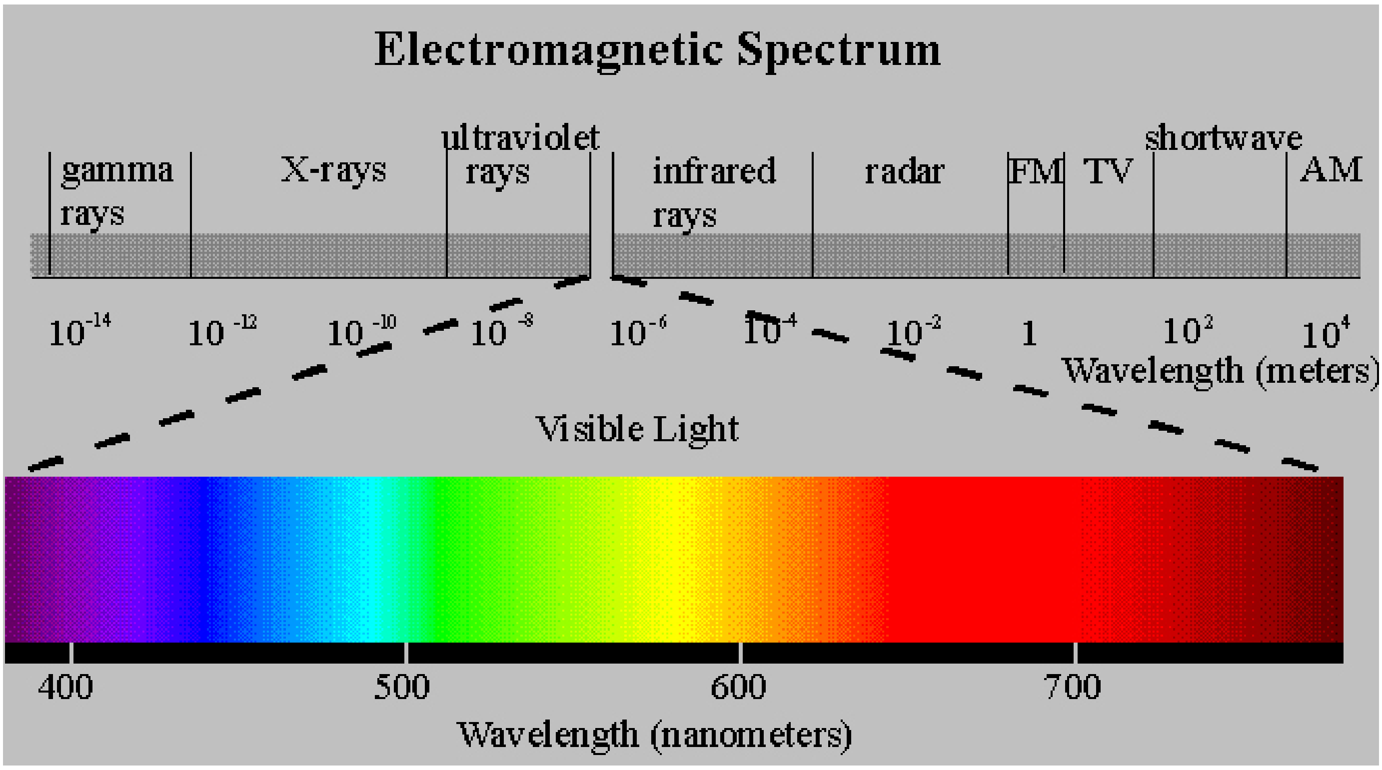


Figure 6: Electromagnetic (EM) Spectrum Wavelengths (Baumann 2010).

The sensors of the satellites record different regions of the spectrum and creates multiple images at the same time and these regions of spectrums are called "Bands" which are measured by nanometers(nm) (Baumann 2010). There are different range of spectrum regions for different lights (Figure 7).

Spectral region	Range of wavelength in nm	Subregion
Ultraviolet	100-280 280-315 315-380	UV-C UV-B UV-A
Visible	380-430 430-500 500-520 520-565 565-580 580-625 625-740	Violet Blue Cyan Green Yellow Orange Red
Infrared	740-1400 1400-10000	Near IR Far IR

Figure 7: Regions and subregions of the electromagnetic spectrum (Malacara 2011)

The bands can be composed in different ways to create different kind of color composites that focuses on different objects or characteristics of the surface. A single band image displays the features in different grey tones, but these can form color composites when combined with other different bands (Baumann 2010). The natural or true color composite of bands, which shows what the usual human eyes seeing range, uses the visible region of the electromagnetic spectrum and uses the red, green and blue (RGB) potion. On the other hand, the false color composite, which uses the other band combinations, is used for enhancing particular features in an imagery that will not appear clearly in a true color composite (Baumann 2010). Figure 8 shows an example of these two types of composites. These different composites can be used for assessment of different natural resources such as, "vegetation and ecosystem dynamics, hazard and disaster monitoring, geological and soil analysis, land surface climatology, hydrology, land cover change, and the generation of orthorectified Digital Elevation Models(DEMs)." (Satellite Imaging Corporation 2017).

Figure 8: Natural/True color composite(left) and False color composite(right) (Baumann 2010).

2.3.2 Remote sensing techniques and applications

Remote sensing and satellite imagery analysis plays a very important role to assess many things such as climatic parameters, natural disasters, vegetation health, demographic situations and so on. Climate Change parameters and their effect on civilization, especially on food security issues. There have been many definitions of remote sensing from the beginning of imagery analysis and earth observation. One of the preliminary definitions denoted it as the acquisition of data of a physical object without touching it (Linz and Simonett 1976). According to the recent definition, "Remote sensing is the practice of deriving information about the Earth's land and water surface using images acquired form an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the Earth's surface." (Campbell and Winne 2011).

The history of remote sensing started from the discovery of infrared at 1800 and was developed by 1990 when the global remote sensing systems lidars was invented (Table 1) (Campbell and Winne 2011).

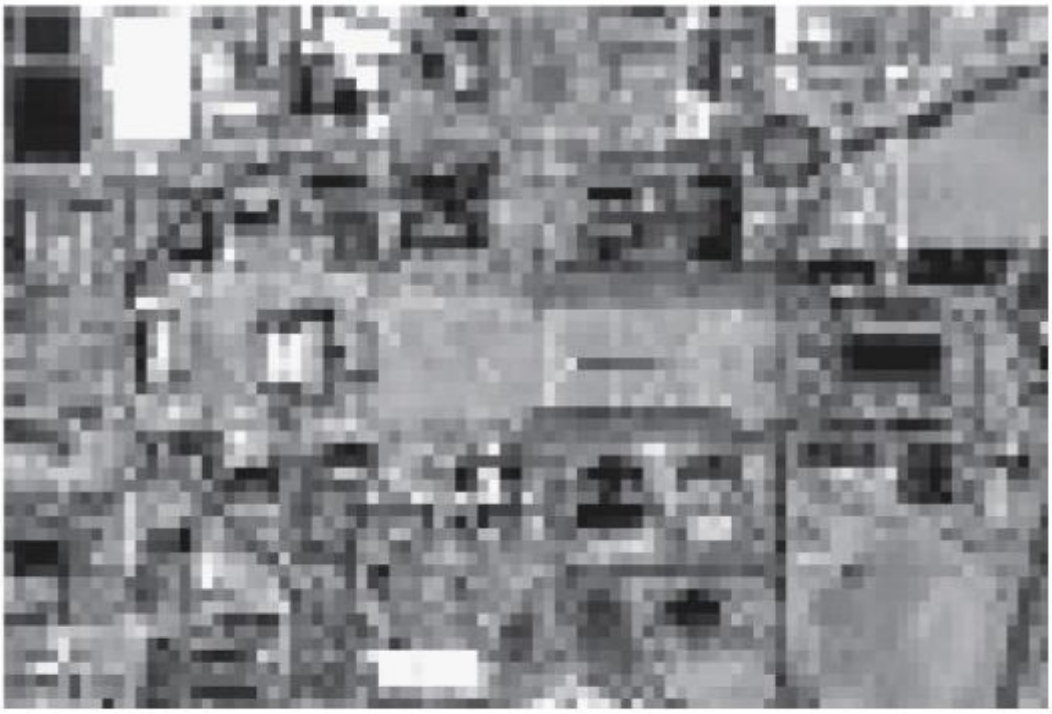
Table 1: Milestones in the history of remote sensing (Campbell and Winne 2011).

1800	Discovery of infrared by Sir William Herschel
1839	Beginning of practice of photography
1847	Infrared spectrum shown by A. H. L. Fizeau and J. B. L. Foucault to share properties with visible light
1850–1860	Photography from balloons
1873	Theory of electromagnetic energy developed by James Clerk Maxwell
1909	Photography from airplanes
1914–1918	World War I: aerial reconnaissance
1920–1930	Development and initial applications of aerial photography and photogrammetry
1929–1939	Economic depression generates environmental crises that lead to governmental applications of aerial photography
1930–1940	Development of radars in Germany, United States, and United Kingdom
1939–1945	World War II: applications of nonvisible portions of electromagnetic spectrum; training of persons in acquisition and interpretation of airphotos
1950–1960	Military research and development
1956	Colwell's research on plant disease detection with infrared photography
1960–1970	First use of term *remote sensing*
	TIROS weather satellite
	Skylab remote sensing observations from space
1972	Launch of Landsat 1
1970–1980	Rapid advances in digital image processing
1980–1990	Landsat 4: new generation of Landsat sensors
1986	SPOT French Earth observation satellite
1980s	Development of hyperspectral sensors
1990s	Global remote sensing systems, lidars

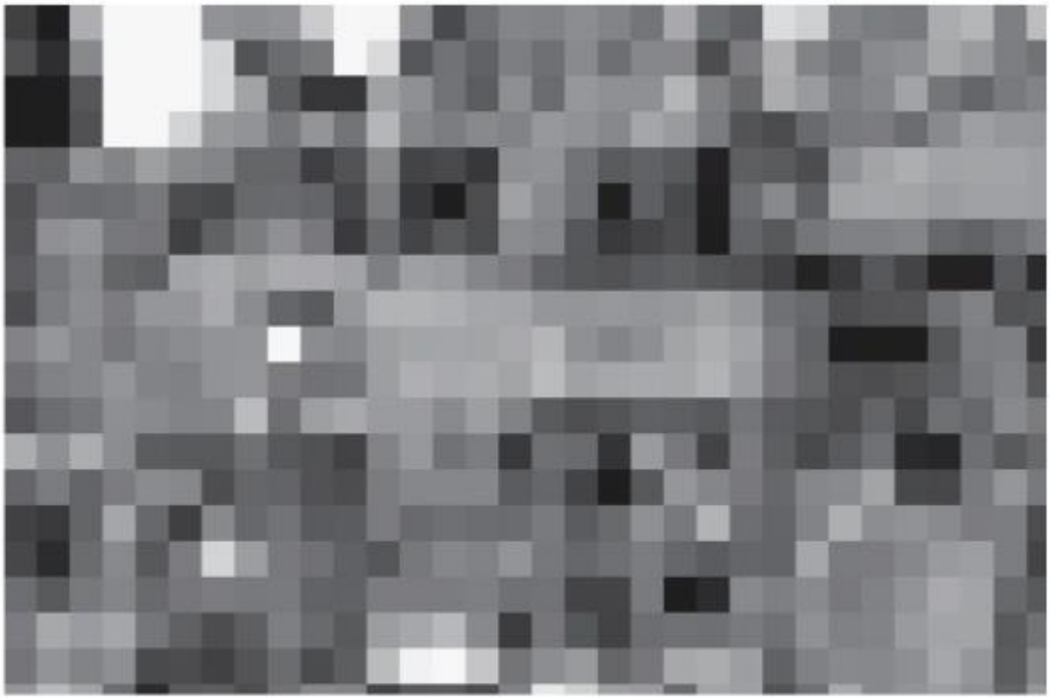
The modern remote sensing technologies are used for numerous purposes. Along with the availability enhancement of higher spectral and spatial resolution, it is very much possible to remotely monitor vegetation characteristics, land degradation, plant stress, climate change variability, contribution of different ecosystems to the balances in carbon and energy systems, canopy analysis and so on (Jones and Vaughan 2011). The analysis of global and national food security is also possible through remote sensing of different vegetation, waterbody and landcover of different regions.

It is important to know about data resolution while working with remote sensing. The 4 types of resolutions in remotely sensed data are spatial, spectral, temporal, and radiometric (Liang, Li and Wang 2012). Spatial resolution is referred to the measure of smallest objects which "can be resolved by the sensor, or the ground area imaged for the instantaneous field of view (IFOV) of the sensor, or the linear dimension on the ground represented by each pixel." (Liang, Li and Wang 2012). Different pixels have different clarity and purposes. For example, different resolution imagery of University of Maryland at College Park is shown in Figure 9 which can give idea about the resolutions and pixels. The clearer the imagery is, the smaller is the pixel size in it and that means the higher the resolution is. On the other hand, bigger pixel size refers to lower spatial resolution which can lack precision of smaller objects. Low resolution imagery tends to have lower file size than higher resolution imagery due to the lack of details. Each of these categories has their own purposes when it comes to research and remote sensing.

1m



10m



30m

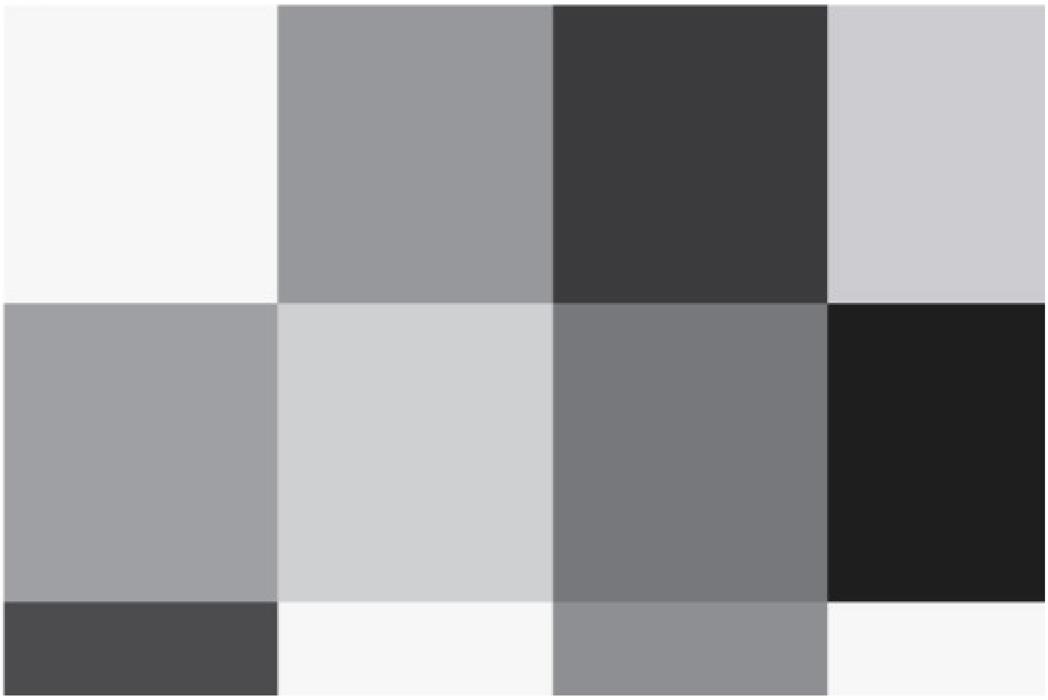

250m

Figure 9: Campus of the University of Maryland at College Park at four spatial resolutions (Liang, Li and Wang 2012).

The high-resolution imagery is proving to be assets for environmental monitoring and many scientific research. The multispectral sensors and the different composite imageries can increase spectral resolution which can be used for assessing different things such as, urban growth, transportation development, land cover change, climate change impact detection and so on(Figure 10) (Satellite Imaging Corporation 2017).

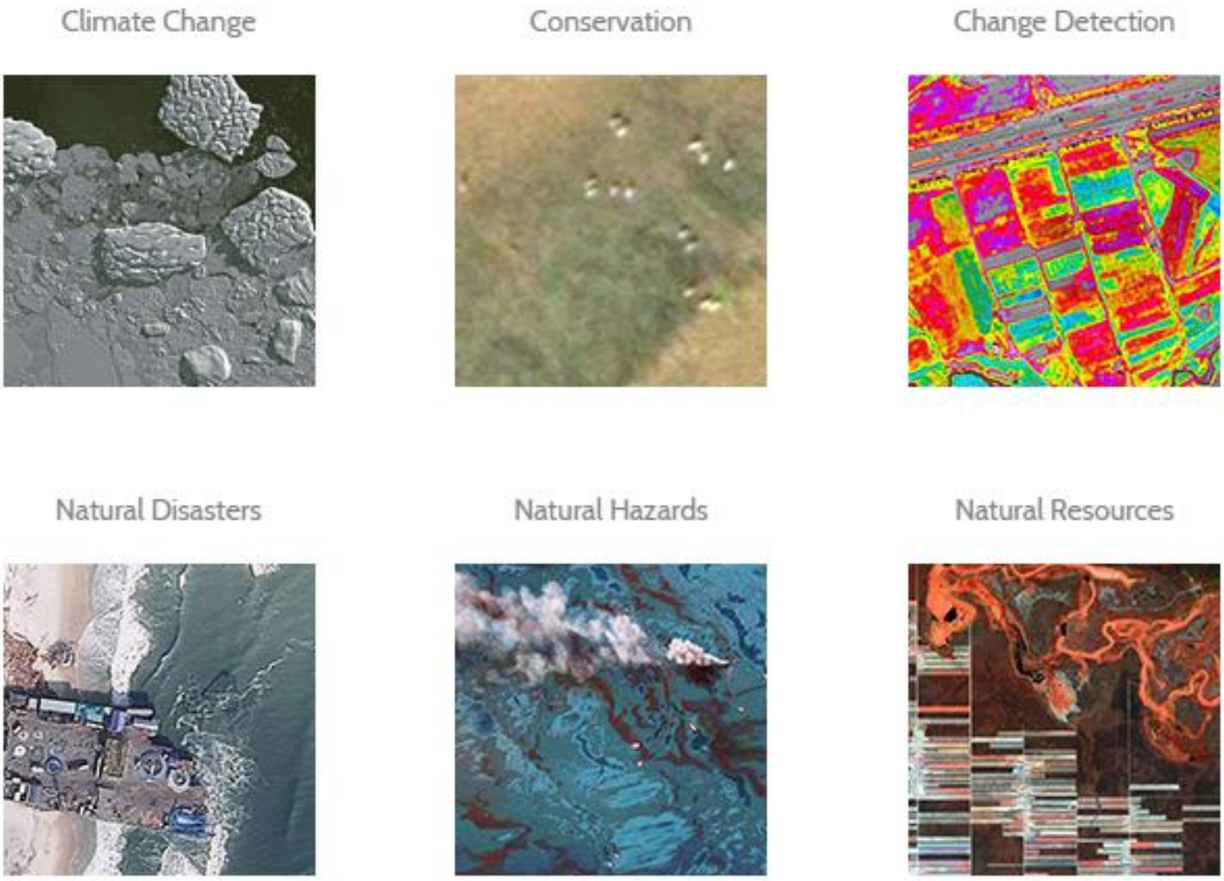


Figure 10: Different uses of remote sensing (Satellite Imaging Corporation 2017).

2.3.3 Geographic information systems (GIS) and data processing

GIS Systems are widely used nowadays for data processing and environmental analysis. For assessing the climate change and food security problems, remote sensing and mapping of the vegetation cover, vegetation health, land cover, soil contents and land degradation are widely used as credible research tools. The natural vegetation cover, which is a crucial mean for getting global and regional eco-information, can be remotely sensed through the satellite sensors (Li et al. 2010). There are more than hundred vegetation indices from which vegetation can be analyzed. Each of the index is a specific combination or formula of the sensor measure reflectance properties such as pigment, chlorophyll, water content and so on. at 2 or more wavelengths that describes certain characteristics of the vegetation (Earth Observing Systems). Out of many vegetation indices, normally NDVI (Normalized Difference Vegetation Index) and EVI (Enhanced Vegetation Index) are the most widely used indexes around the world for vegetation analysis and satellite monitoring (Li et al. 2010). According to the definition of Earth Observing Systems, the NDVI acts as an "indicator of photosynthetically active biomass or, in layman's terms, a calculation of vegetation health." (Earth Observing Systems). It helps to distinguish landcover from vegetation and to visualize the vegetated regions with its normal or abnormal process of growth (Earth Observing Systems). NDVI is calculated using NIR(Near Infrared) Band and visible Red Band (Figure 11).

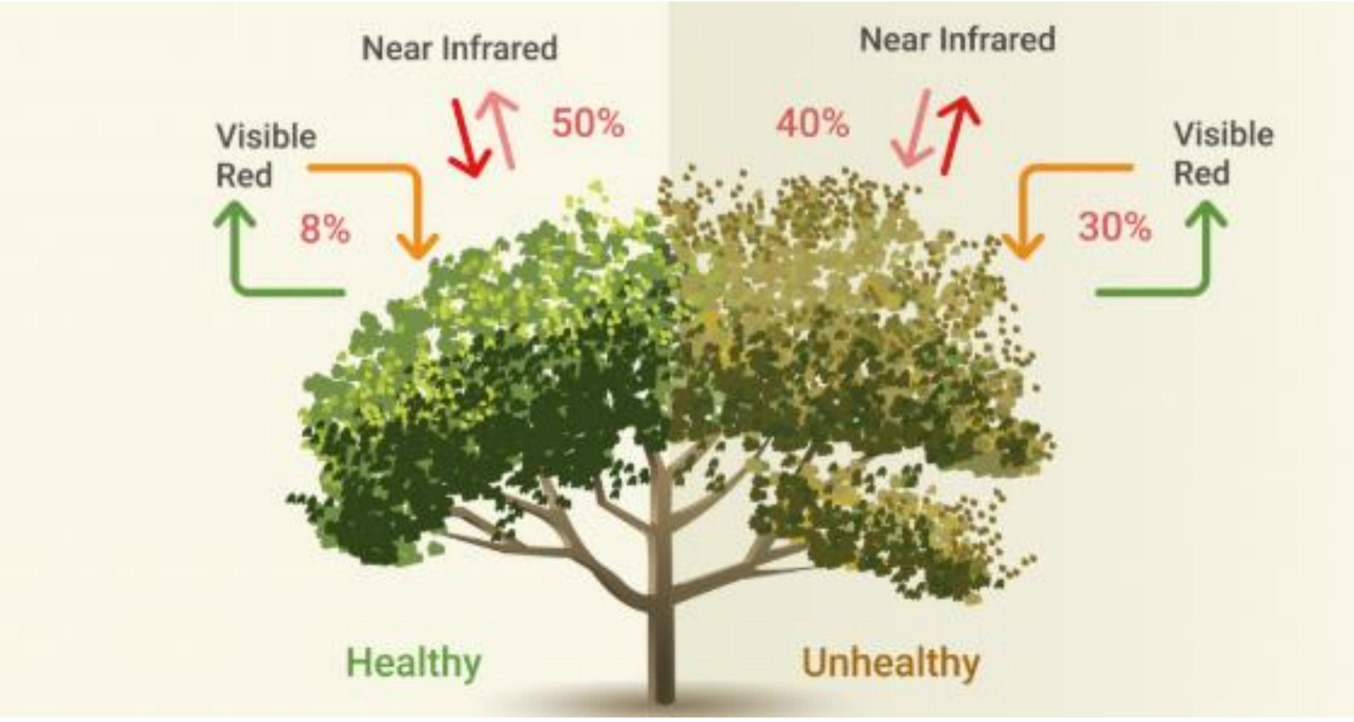


Figure 11: NDVI Calculation Bands (Earth Observing Systems)

The equation of the NDVI calculation is:

NDVI = (NIR-Red) / (NIR+Red)

This equation of NDVI is the most commonly used formula to assess vegetated areas with remotely sensed data. NDVI occupy higher sensitivity range that can detect the crown density change than other indices and satellites. For example, Landsat 8 has the band range capacity to produce NDVI (Zaitunah et. Al. 2018). The value of NDVI ranges from -1 to 1 and values closer to -1 refers to unhealthy to dead vegetation where value closer to 1 refers to healthy vegetation (Figure 12).

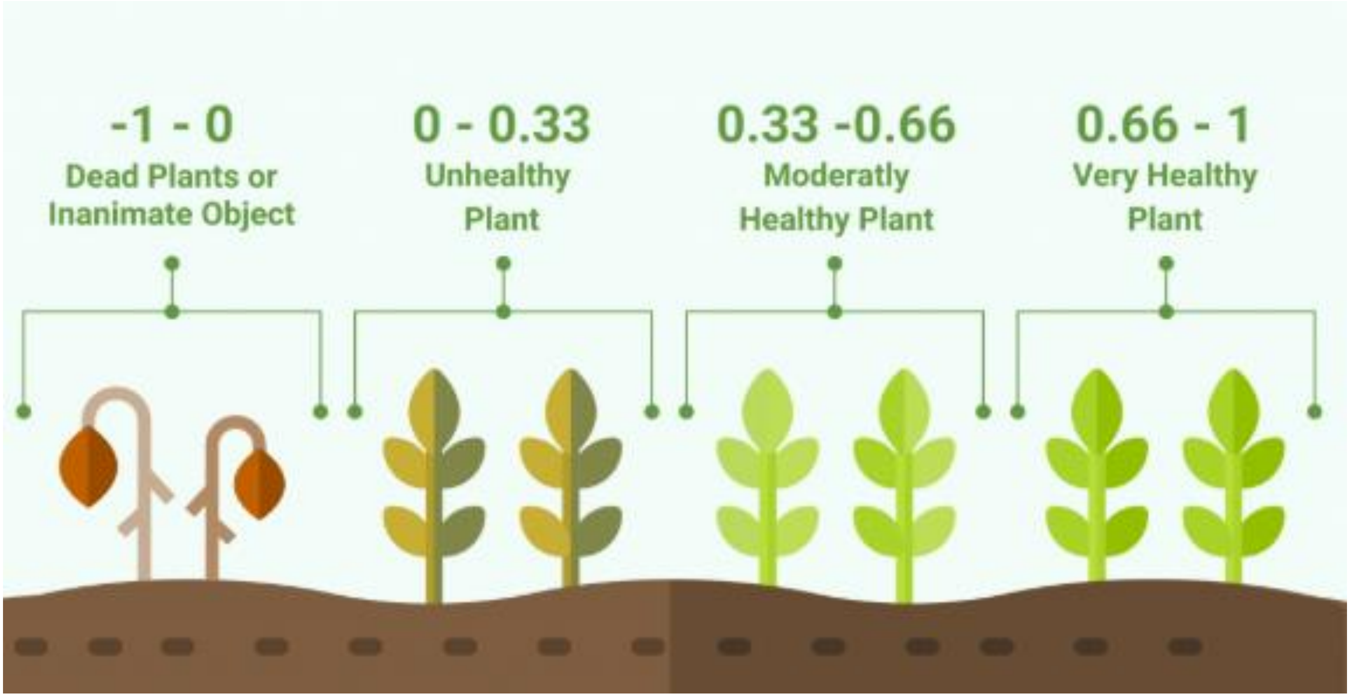


Figure 12: Different NDVI value range and their interpretation (Earth Observation Systems)

Another commonly used index is EVI (Enhanced Vegetation Index) which can provide greater and dynamic range than NDVI by eliminating soil background impact and atmospheric aerosols and improving sensitivity over high biomass area (Li et al. 2010). The equation for EVI calculation is:

EVI = 2.5 * ((NIR – Red) / ((NIR) + (C1 * Red) – (C2 * Blue) + L)), where NIR is Near Infrared, Coefficient C1 and C2 is used for correcting aerosol scattering present in the atmosphere and L is used for adjusting Canopy Background (USGS).

The EVI value also ranges from -1 to 1 and usually the healthy vegetation value varies between 0.2 and 0.8 (Earth Observation Systems).

The short-wave infrared (SWIR) is another part of the electromagnetic spectrum which is used for different geospatial analysis materials identification such as soil moisture content, salinity and vegetation moisture content which can be used to assess food security condition of a region (Thenkabail et. Al. 2009). As through the SWIR analysis surface water and moisture can be identified, more assessment and prediction regarding the crops and landcover health can be determined easily from that (Figure 13).

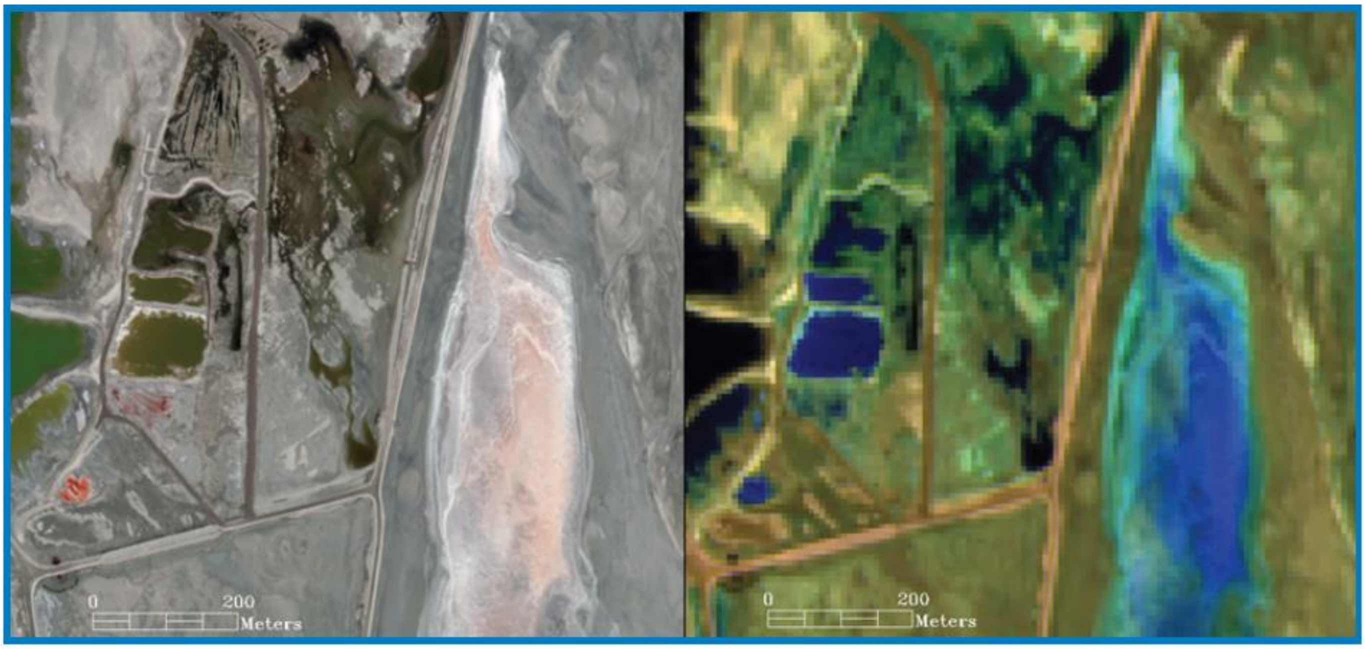


Figure 13: Natural color imagery vs SWIR moisture detection (DigitalGlobe).

3. Research Methodology

3.2 Selection of study area

From all the countries of Central Asia, Kyrgyzstan was selected as the main research area for the research. Geographically the boundary of the area was acquired from "Natural Earth Data" website based on which all the further geoprocessing was done within the area for the research parameters.

3.3 Data collection

3.3.1 Remotely sensed data

The remote sensing technologies are developing through passing of years and there is vast amount of geospatial data available now for researchers. Each kind of spatial data product has their own use and can be tailored to different kind of research. Depending on the satellite, its path, time of sensing and the resolution of the imagery, the usage of the data varies. Following datasets can be used for this research of Climate Change and Food Security analysis of Kyrgyzstan (Table 2).

Table 2: Potential Remote Sensing Data Resources

Data	**Source**
MODIS	https://lpdaac.usgs.gov/products/mod17a2hv006/
Sentinel-2	https://scihub.copernicus.eu/dhus/#/home
Landsat	https://glovis.usgs.gov/app

3.3.2 Open source datasets

Many open data resources can be used for this kind of researches which will not only minimize the cost of the researcher but also can provide high level variation in the gathered data which can definitely add new dimension to the researches. Some potential open data sources for this study are listed in Table 3.

Table 3: Potential Open Data Resources

Data	Source
OSM(OpenStreetmap)-The Humanitarian Data Exchange	https://data.humdata.org/dataset
FAOSTAT(Food and agriculture data)	http://www.fao.org/faostat/en/#home
Kyrgyzstan Spatial	http://www.kyrgyzstanspatial.org/
FAO AquaStat	http://www.fao.org/aquastat/en/climate-info-tool/

3.4 Data analysis Tools

Different geospatial tools are used for the analysis of demographic, climate and landcover data of Kyrgyzstan. These tools are ArcGIS Desktop, NASA Giovanni, Beta Earth Map, Google Earth Explorer, and Google Earth Pro. These tools were used based on analysis need and data availability of each parameters. Below the description of the tools are given for clearer understanding (Table 4).

Table 4: Description of Potential Tools for the Research

Name	Source	Description
ArcGIS Desktop	https://www.esri.com/en-us/arcgis/products/arcgis-desktop/overview	
	ArcGIS Desktop is powerful and cost-effective desktop geographic information system (GIS) software. It is the essential software package for GIS professionals. ArcGIS Desktop users create, analyze, manage, and share geographic information so decision-makers can make intelligent, informed decisions. Author maps, perform spatial analysis, and manage location data with ArcGIS Desktop.	
NASA Giovanni	https://giovanni.gsfc.nasa.gov/giovanni/	
	Giovanni is a Web-based application developed by the GES DISC that provides a simple and intuitive way to visualize, analyze, and access vast amounts of Earth	

	science remote sensing data without having to download the data. Giovanni is an acronym for the GES-DISC (Goddard Earth Sciences Data and Information Services Center) Interactive Online Visualization and Analysis Infrastructure.
Beta Earth Map	https://Earth Map.org/
	Earth Map is a tool for quick historical environmental and climate analysis based on Google Earth Engine and developed with the support of the Government of Germany through The International Climate Initiative (IKI) from the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety.
Google Earth Engine Explorer	https://explorer.earthengine.google.com/#workspace
	Earth Engine Explorer is a free and advanced tool that lets the users search, visualize and thoroughly analyze geospatial data employing the google cloud infrastructure.
Google Earth Pro	https://www.google.com/earth/versions/#download-pro
	Google Earth Pro is a desktop software that operates on desktop and is free for all the users who are in need of advanced feature mapping such as importing and exporting GIS data, analyzing historical imagery and so on.

3.5 Geospatial data processing

3.5.1 OSM Agricultural Data Processing

The land use data was found in "The Humanitarian Data Exchange" platform. This platform is a place where different governmental and non-governmental organizations provide different types of data that can be used for humanitarian purposes and research.

The data which was used for this research had many types of land use polygons. The land use data related to Agriculture was separated through "Select by attribute" in ArcMap and was exported as a new polygon layer to use in other parameter's analysis (Figure 14).

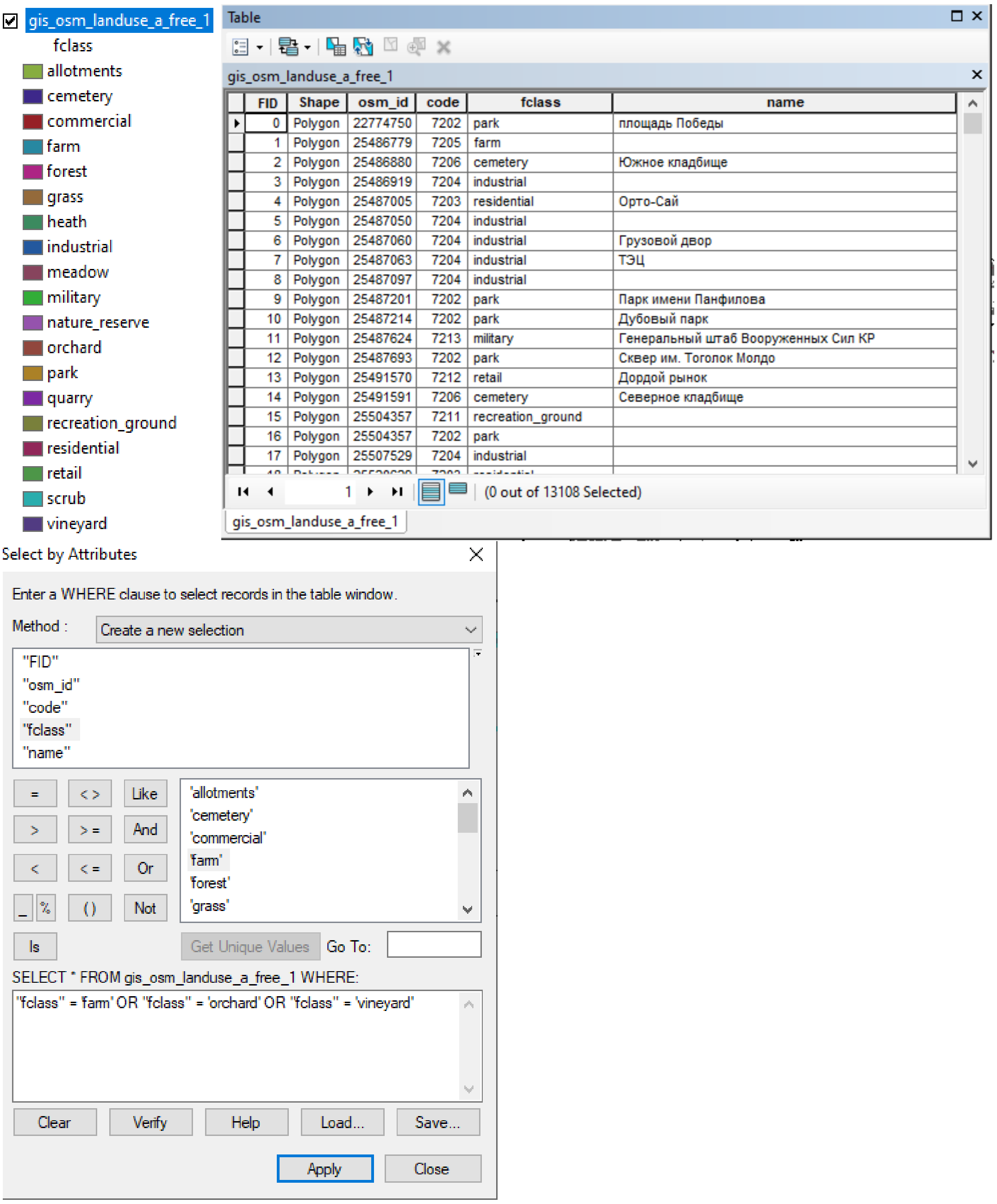


Figure 14: Agricultural Data selection from OSM Data

This data was some scattered polygons in Kyrgyzstan from which it is not possible to detect the area of most agricultural activities. For solving this problem, the polygons were clustered using the “Aggregate Polygon” Function of the “Generalization” tool of “Cartography Tool” (Figure 15).

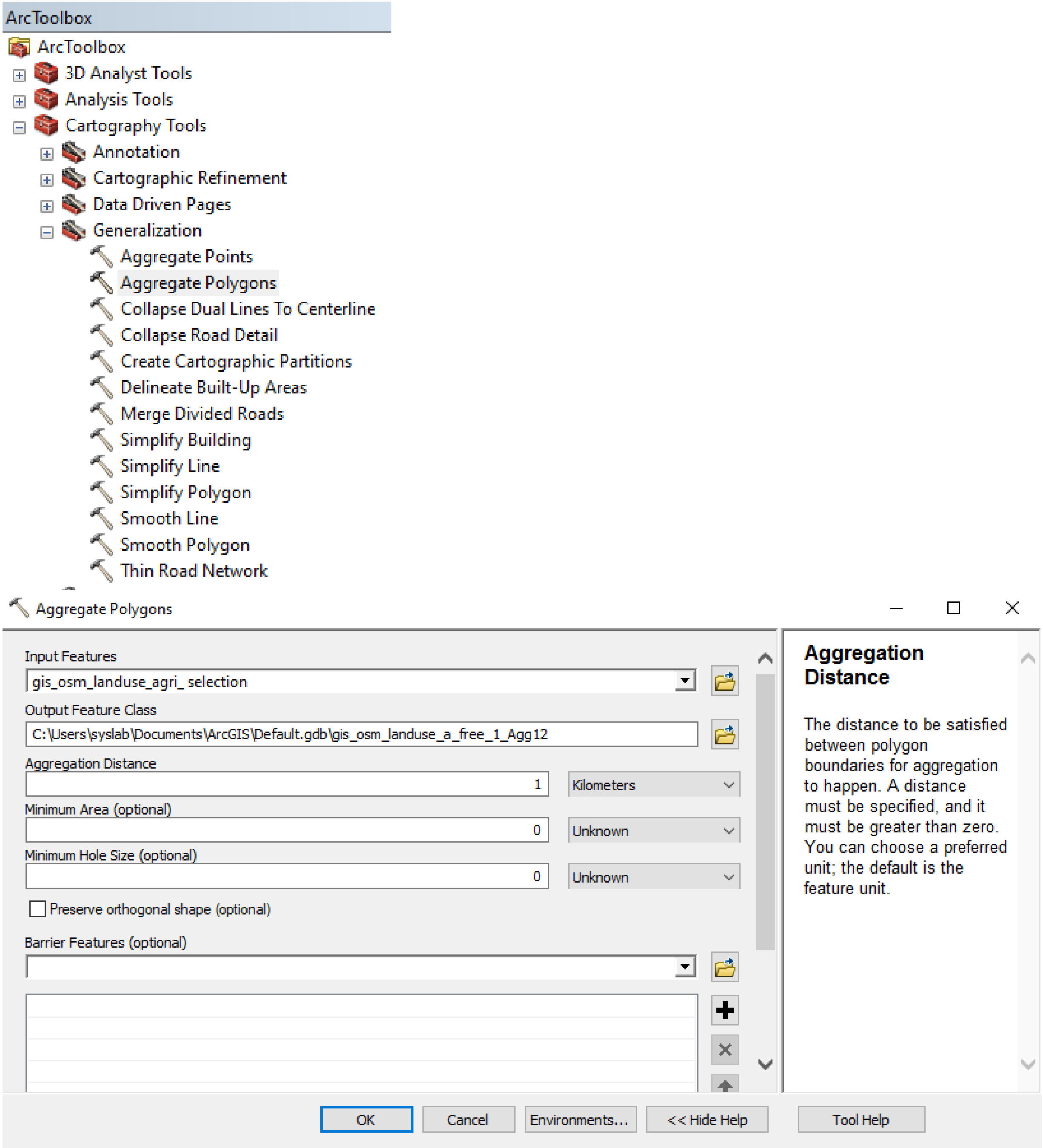


Figure 15: Aggregating Agriculture Polygons using Cartography Tool

The aggregated layer was added to the ArcMap Data Frame for further comparison and analysis. Also, it was compared with the updated satellite imagery of the country in Google Earth Pro for better understanding of the geolocation, nearby elevation and snow covered mountains.

3.5.2 Temperature analysis

For temperature analysis of Kyrgyzstan NASA Giovanni and Earth Map were used. Both these tools are online and has a credible cloud-based repository of remotely sensed data.

NASA Giovanni Workspace-

The NASA Giovanni workspace needs registration and upon login shows the window in Figure 16. It has many options for data plot and for this research “Monthly and Seasonal averaged” option is chosen where the summer time (June, July, August) will be averaged by 4 time periods within 2000-2020, each period having 5 years.

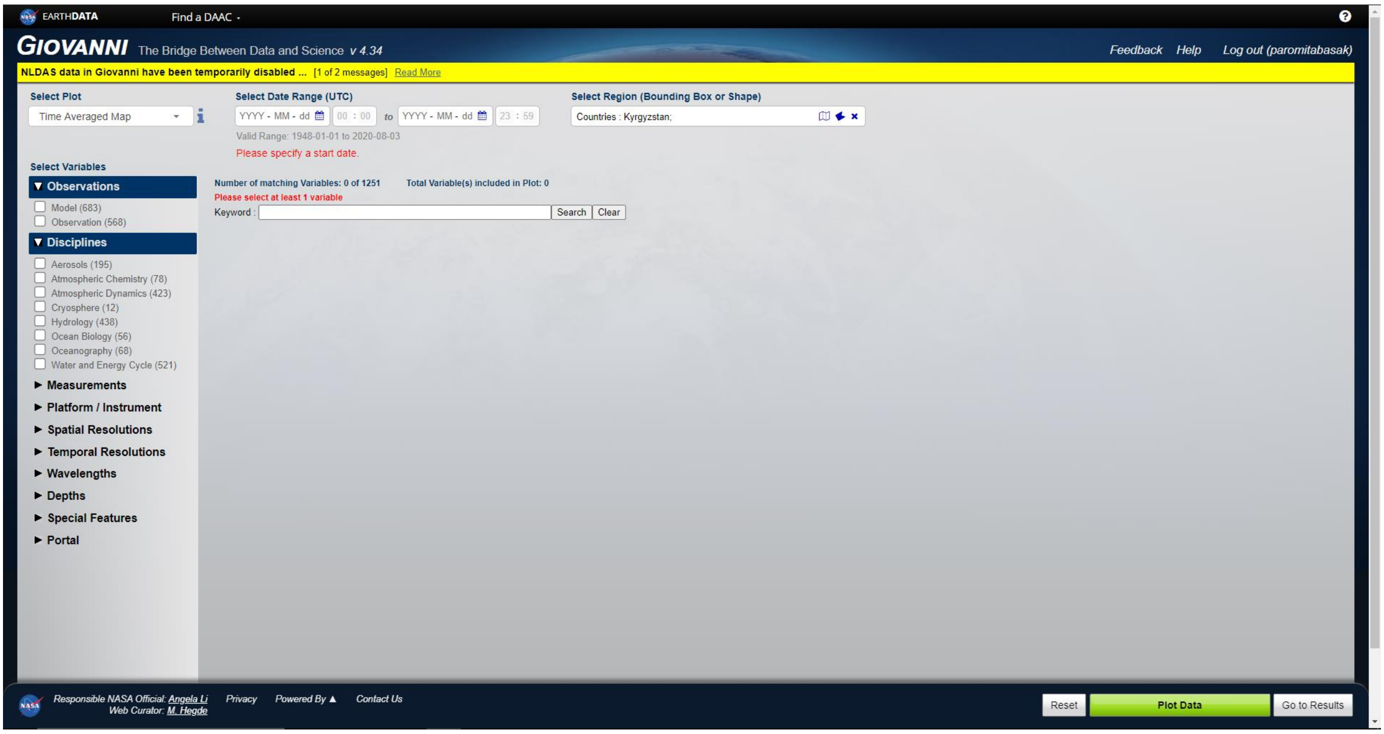


Figure 16: NASA Giovanni Workspace

NASA Giovanni has many parameters of different credible remote sensing and satellite-based data resources that can be plotted in the Giovanni workspace. For the Temperature analysis, NASA Global Land Data Assimilation System Version 2.1(GLDAS_NOAH025_M v2.1) and this version combines model and observation data from 2000 to present which can be a valuable source of this century’s climate change trend researches. The time frame of the data is from

2000-01-01 to 2020-04-30, temporal resolution is “Monthly” and the spatial resolution is 0.25 °. The country boundary is selected in the “Select Region” tab and the initial date range is selected from 2000(June-August) to 2005(June-August). After defining all the range, the “Plot Data” is clicked and the result window shows the progress of the creation first and then finally the seasonal average map is created (Figure 30).

As Kyrgyzstan is a small country and this is a Global Dataset, the map is very pixelated.

But further analysis cannot be done in Giovanni, so this map data was downloaded. There are three format options for that which are GeoTIFF, KMZ and PNG (Figure 17). As the further analysis will be done in ArcGIS Desktop, the GeoTIFF option was chosen for convenience (Figure 17).

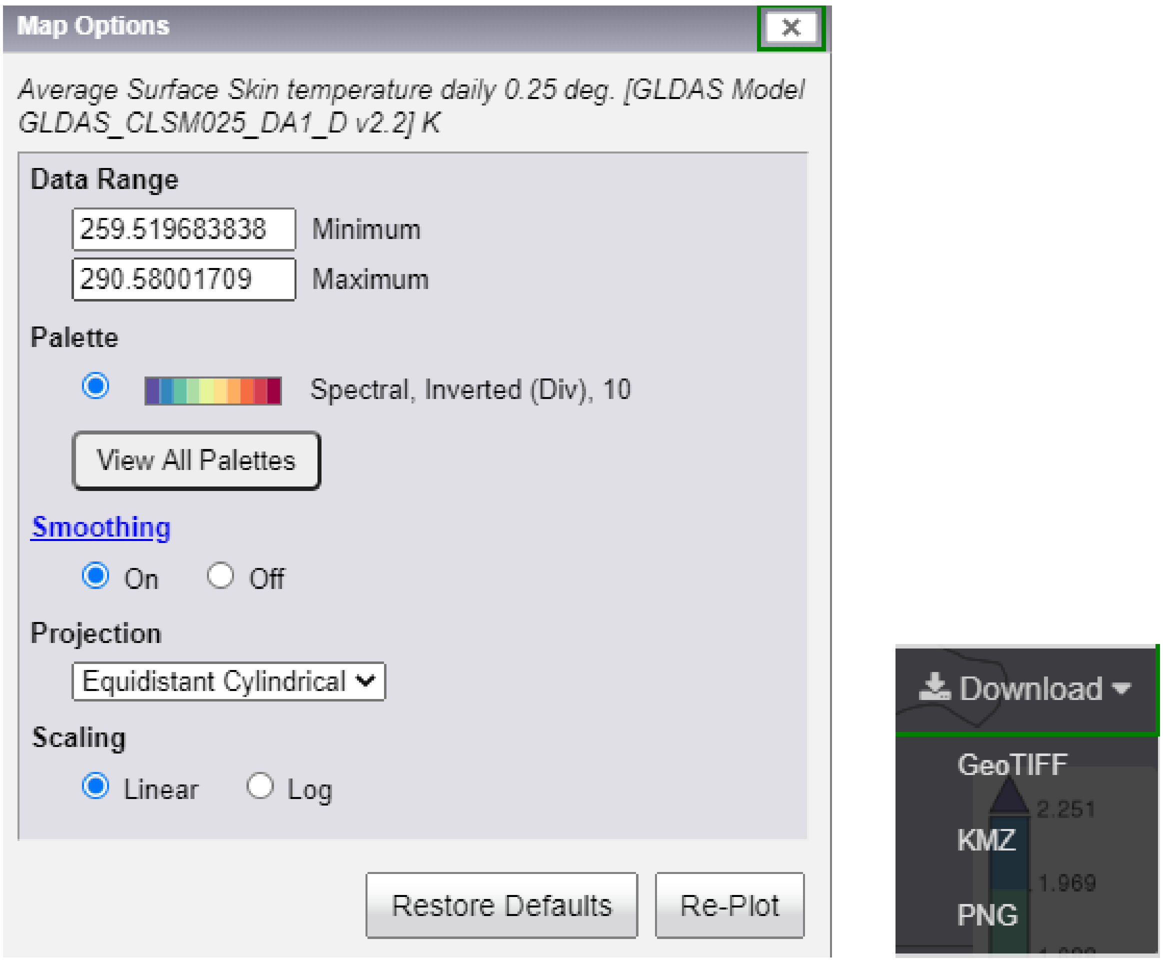


Figure 17: Giovanni results map options window and Download window

The downloaded GeoTIFF was processed in ArcMap after that. GeoTIFF files are geotagged so when they are added in the ArcMap, they match the existing boundary of Kyrgyzstan. But as the file was too pixelated proper comparison and analysis is challenging to be done. Because of that at first the raster GeoTIFF imagery was converted into points using the Conversion tool from the ArcToolbox (Figure 18).

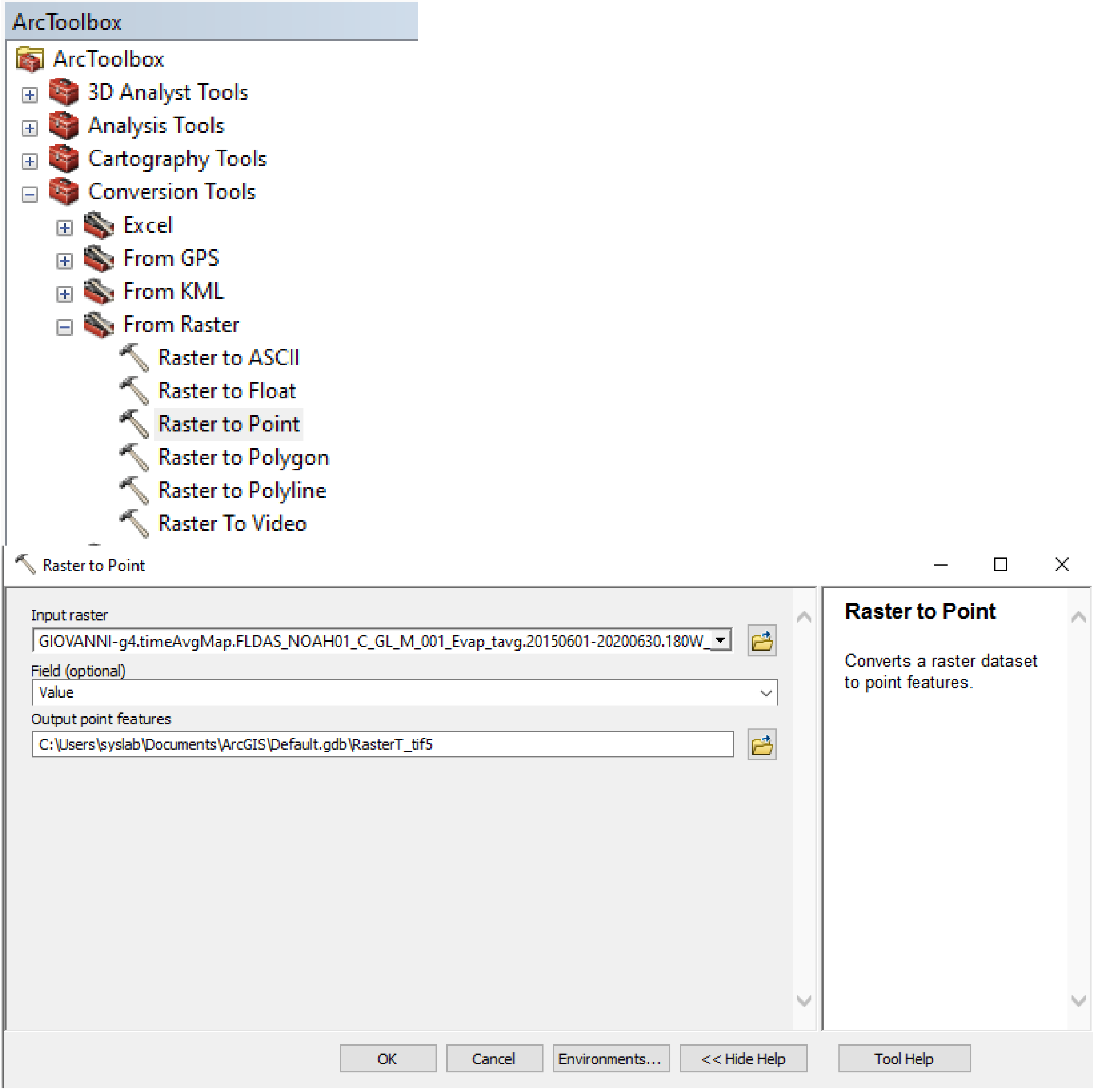


Figure 18: Giovanni Raster to Point Conversion in ArcMap using Conversion Tools

This created a point vector data layer where each of the points were centroids for each raster pixel and contained the temperature value of that pixel. After that, the point layers were interpolated using Spatial Analyst Tool from the ArcToolbox and smooth interpolated map was created after the geoprocessing (Figure 19).

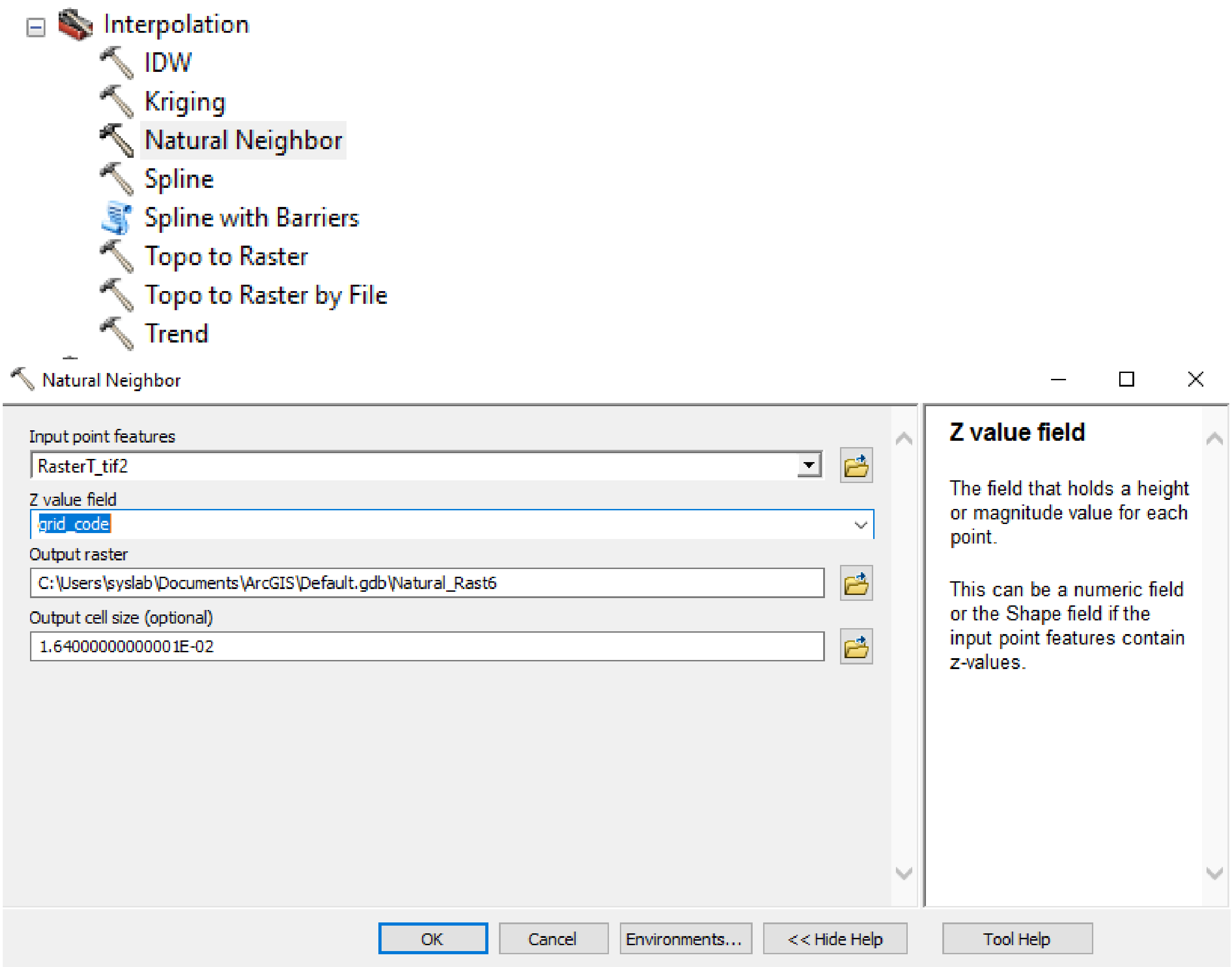


Figure 19: Point Interpolation using Spatial Analyst Tool

Here "Natural Neighbor" interpolation method was used. The Natural Neighbour method is a geometric estimation technique that uses natural neighbourhood regions generated around each dataset point. This is a weight-averaged interpolation method which creates a Delauney Triangulation of the points that were given as inputs and selects the closest nodes which produce a convex hull around the interpolation points. After that, their values are weighed by proportionate area. Here in the Z value field the ‘grid_code’ field was carefully chosen which contained the average temperature value.

After the geoprocessing was done, the interpolated file was clipped based on National Boundary of Kyrgyzstan and the final map was produced with values.

The seasonal averaged map of (June-August) for 2005-2010, 2010-2015 and 2015-2020 classes were produced using the same procedure as described above.

Earth Map Workspace-

Compared to NASA Giovanni, Earth Map online tool is easier to operate. It has many main parameters of environmental and climatic aspects that can be utilized for analysis. At first, Kyrgyzstan was chosen as the area of interest. And the boundary appeared in the workspace after that where the calculated parameters will be shown (Figure 20).

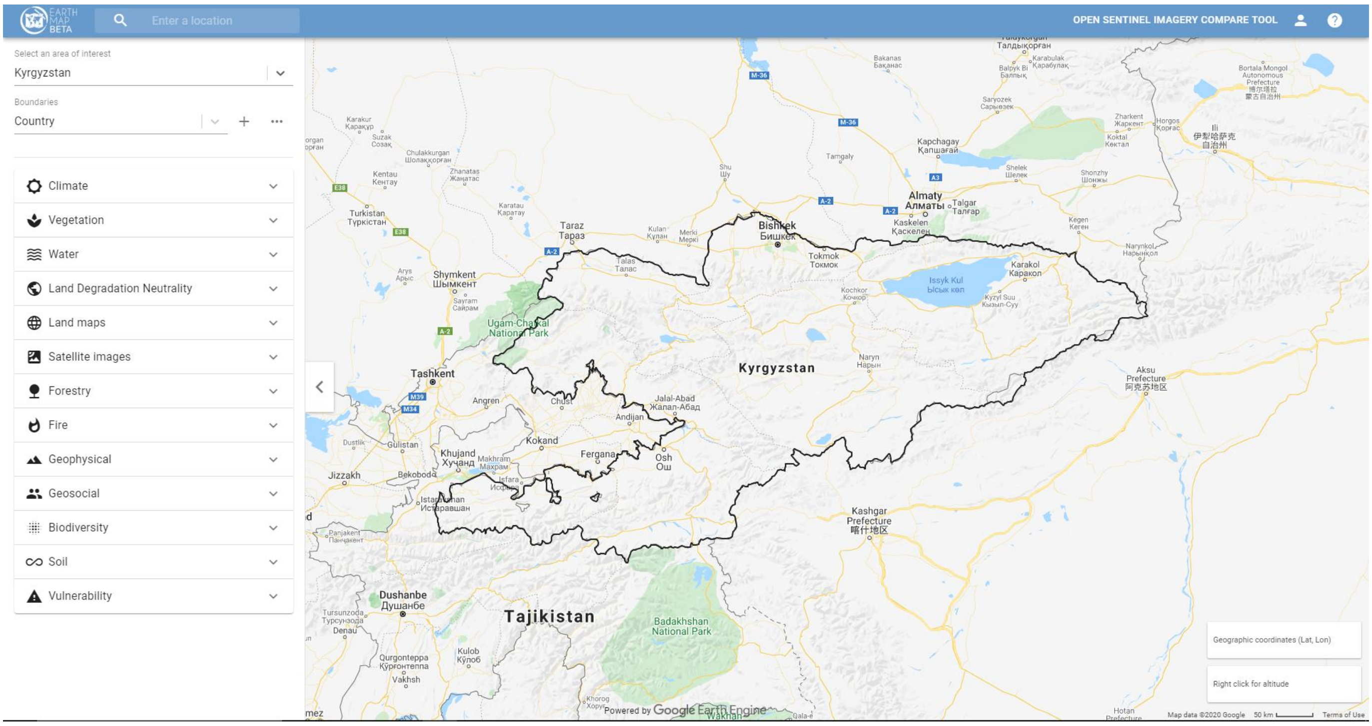


Figure 20: Earth Map Workspace

Upon clicking on the boundary of Kyrgyzstan, the parameter metrics analysis window opens in Earth Map which has many types of data that can be analyzed and downloaded. The

Maximum and Minimum Temperature for all the months from 2000-2020 was calculated using this tool (Figure 21).

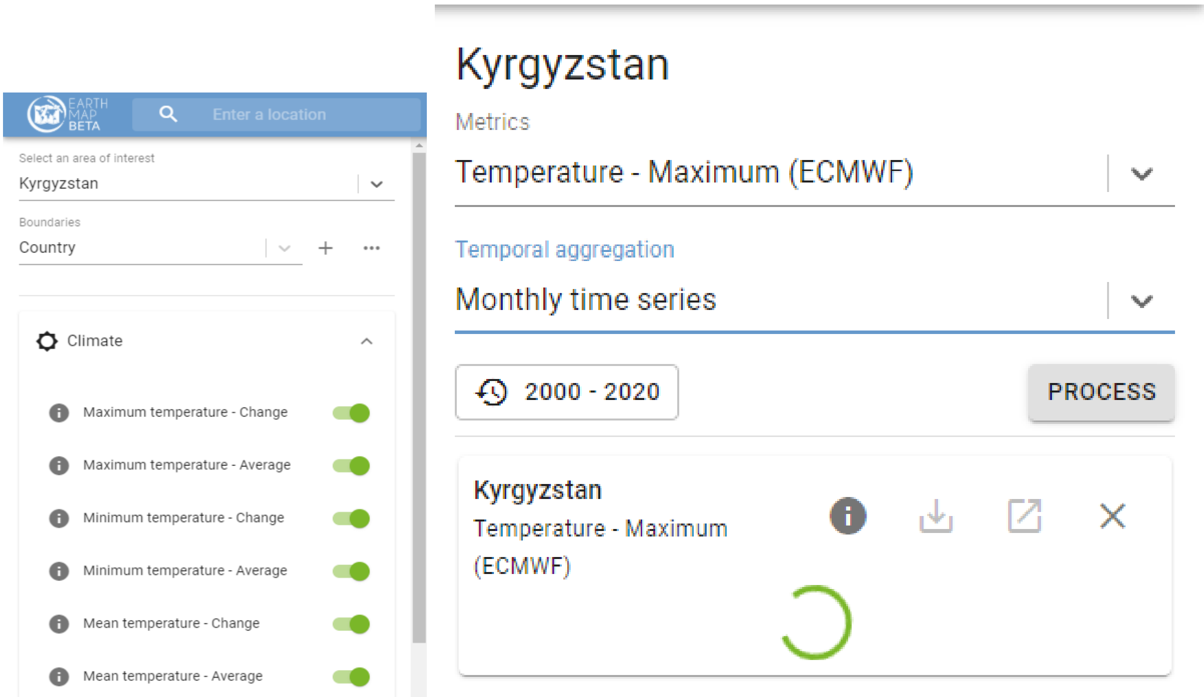


Figure 21: Temperature Parameters in Earth Map

3.5.3 Precipitation analysis:

Following the same procedure and steps of Temperature Analysis, the Precipitation Analysis was done in both Giovanni and Earth Map. The Giovanni parameter was Total surface precipitation (M2TMNXFLX v5.12.4) by "MERRA-2 Model" where the data time period was from 1980-01-01 to 2020-06-30, temporal resolution was "Monthly" and spatial resolution was 0.5 x 0.625 °. As the research timeline is from 2000-2020, the average was calculated in the platform based on the 4 time periods, that was done for the temperature analysis. Later, it was processed in the ArcMap following the same steps of Temperature analysis.

3.5.4 NDVI Analysis

For the Normalized Difference Vegetation Index(NDVI) MODIS satellite imagery was downloaded from the Earth explorer USGS(U.S. Geological Survey) government website (Figure 22).

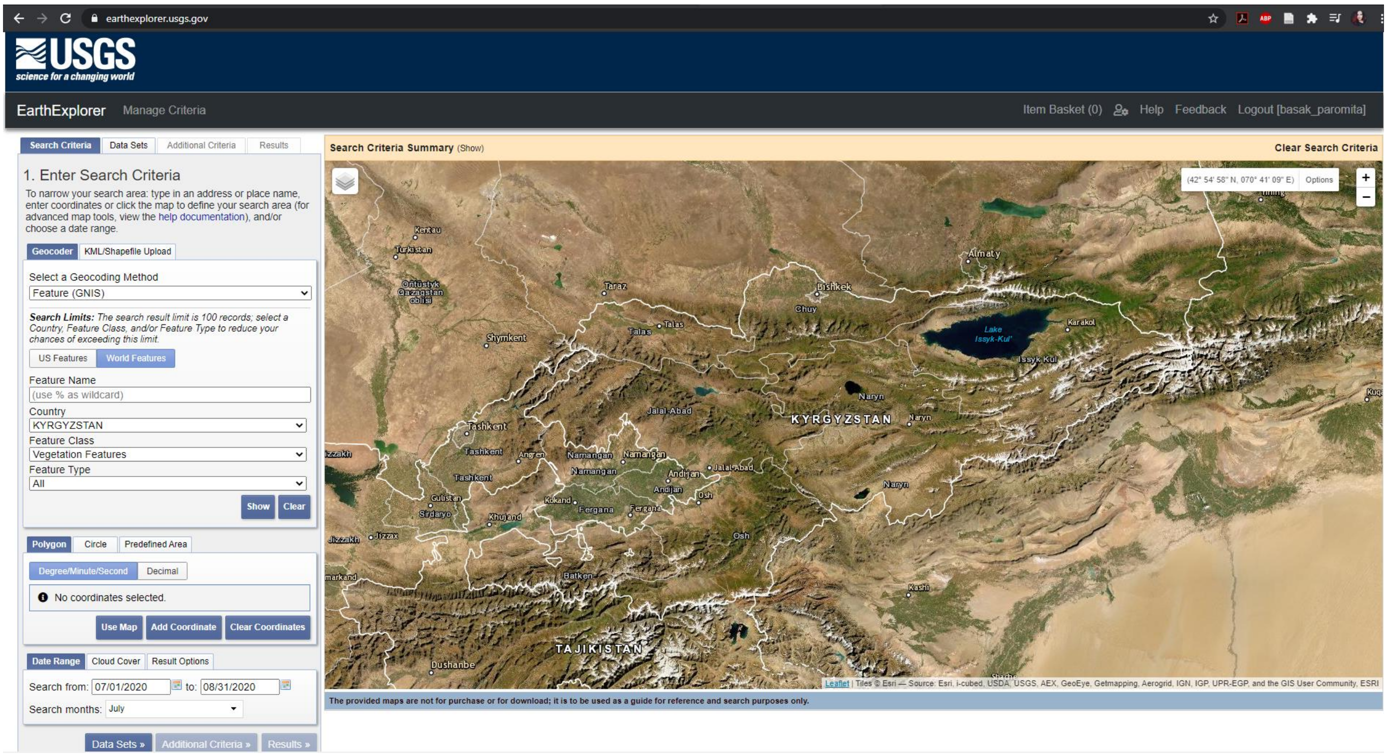


Figure 22: USGS Earth Explorer workspace for data search

The EarthExplorer site of USGS contains great number of datasets that can be used for different research purposes. Using this platform MODIS NDVI imagery was downloaded for the month July for 2019 and 2020 for comparison. The problem was the imagery was not continuous for the entire region of Kyrgyzstan. Two imagery had to be downloaded for each year. The imageries were loaded in the ArcMap and was merged using Data Management Tool. The process path was ArcToolbox > Data Management Tools > Raster > Raster Dataset> Mosaic to New Raster (Figure 23).

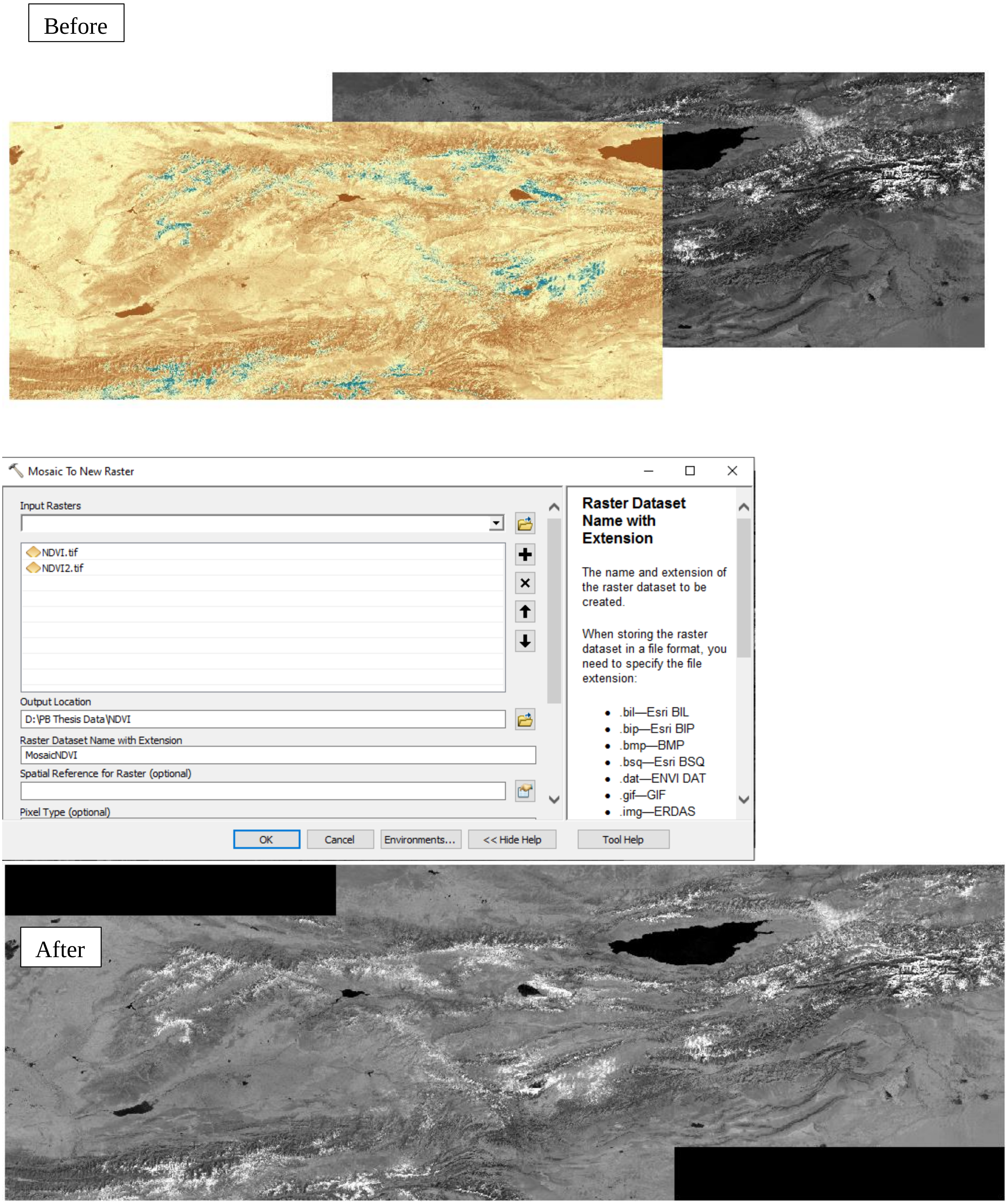


Figure 23: NDVI seperate Mosaic union to new combined raster file

After the file was combined for both 2019 and 2020, they were clipped according to the boundary file of Kyrgyzstan and divided in classes that can show the vegetation condition of the country in different regions. Then the raster difference was calculated using the raster calculator which showed the vegetation gain and loss between the two years.

For calculating the average NDVI difference between two decades, Giovanni Seasonal Average (June- August) was calculated for 2000-2010 and then 2010-2020. They were downloaded in GeoTIFF format and using raster calculator from Spatial Analyst tool of ArcMap, the difference between the layers were calculated(Figure 24).

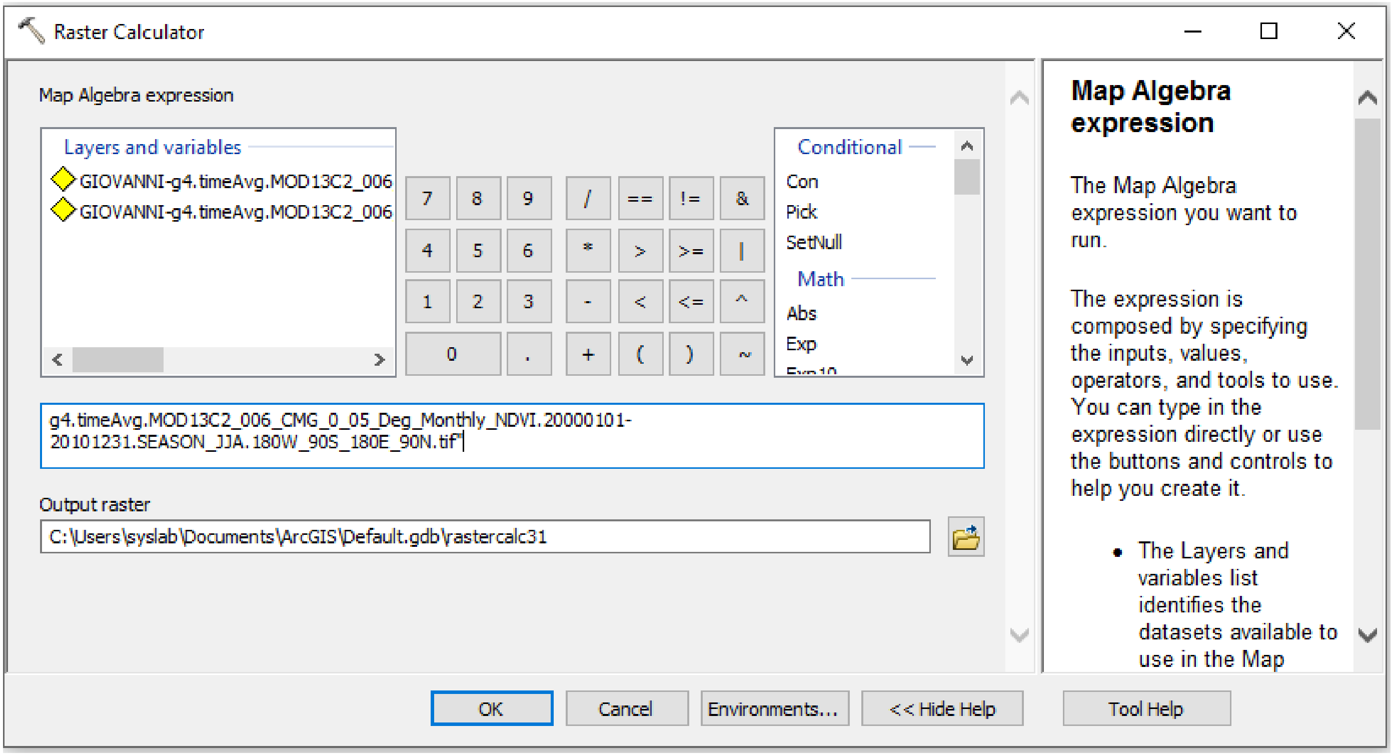


Figure 24: NDVI Difference using Raster Calculator(Spatial Analyst Tool)

3.5.5 Plant Root Level Soil Moisture Analysis

Following the same procedure and steps of Temperature Analysis, the Potential Root level soil moisture was mapped in first Giovanni and then in Earth Map.

3.5.6 Land Productivity Dynamics Analysis

The land productivity dynamics (LPD) were mapped using Earth Map platform. The LPD data was derived from NDVI product of MODIS/Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid V006 which shows persistent stress or decline of productivity, gain and stability of land productivity from 2001 to 2018. It was generated based of 3 NDVI-based indicators which are initial standing biomass, standing biomass at change and steadiness.

This data will help to identify the productivity of the lands in Kyrgyzstan, especially in the agricultural areas.

3.5.7 Drought and Flood occurrence and Crop production data Analysis

The data for aridity and elevated area of Kyrgyzstan was downloaded from "Kyrgyzstan Spatial" website by The University of Central Asia & IFPRI (International Food Policy Research Institute). This website contains data regarding food availability, accessibility, stability, utilization, nutritional status of individuals, governance; population, access to services, poverty, nutrition and disease and factors that affects development and food security of the country (Figure 25). The data that corelates the most with this research was downloaded and mapped in ArcMap. The maps created from this step will be crucial for the analysis of Kyrgyzstan food security.

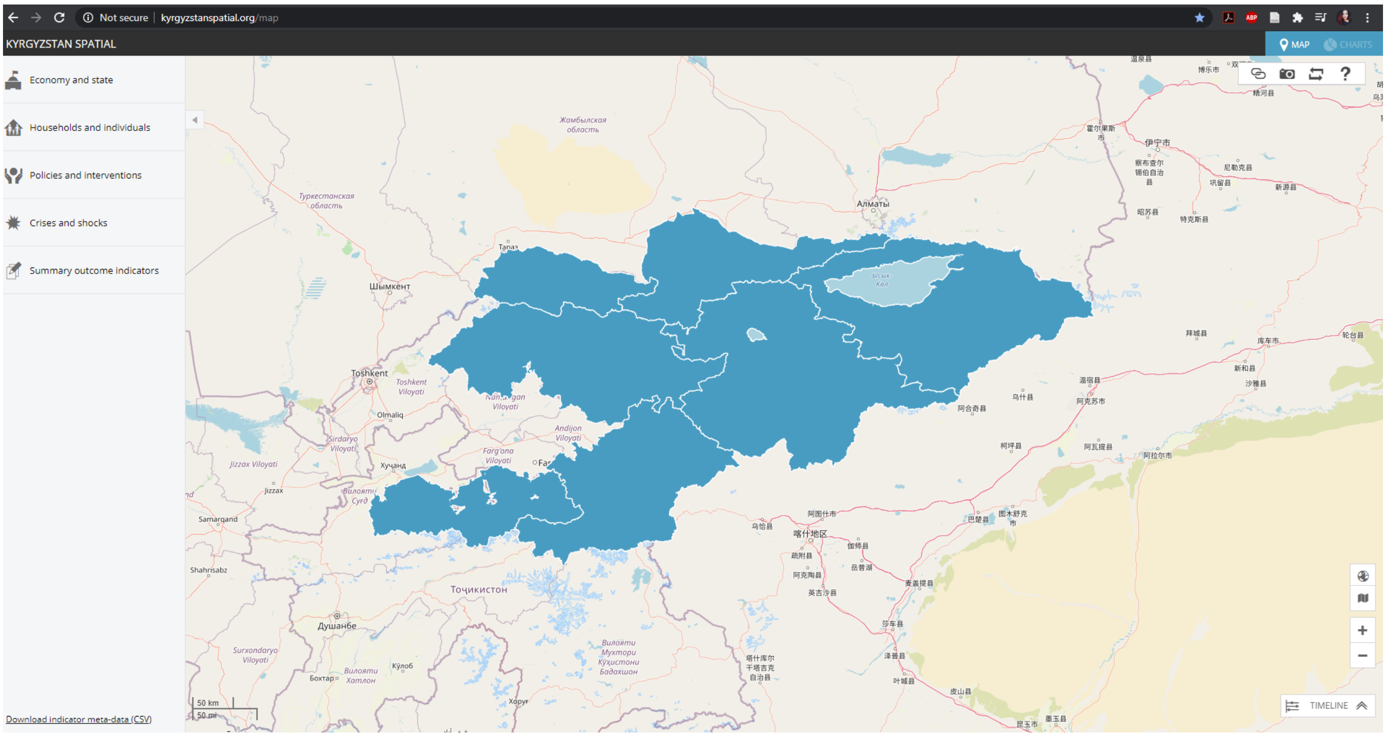


Figure 25: Kyrgyzstan Spatial Data Platform

4. Kyrgyzstan Area Selection and Its Food Profile

Even though the entire Central Asian region is facing the repercussions of Climate Change and food security issues, Kyrgyzstan is chosen as the case study area for this research (Figure 26).

Figure 26: Geographical Position of the Study Area Kyrgyzstan

The justification behind choosing Kyrgyzstan for the research lies in the history of food security situation of the country. Kyrgyzstan's transition to market economy from Soviet-era centralized command economy has resulted in severe food security problems in the country. From early 1990s, the drop in incomes and overall economy has resulted into sharp decline in food absorption and the usage of grain feeds for the livestock production also reduced significantly. Even though there are some recovery of the problem through expansion of grain production, especially wheat, the other nutritional needs such as protein and additional micronutrient intake is remaining deficient for the population (FAO 2016). In 2015, it was estimated in global nutrition report that that 36.2% of women of reproductive age have anemia, and 10.8% of adult women and 9.9% of men have diabetes, 18.6% of women and 14% of men have obesity (Global Nutrition Report 2019). Also, 6% of the citizens were undernourished and 7.9 percent of children suffered from weight deficit (National Statistics Committee of Kyrgyzstan 2016).

The geographic location and features of the country is also responsible for the food security issues it has been facing. Kyrgyzstan is located between two major mountain systems of Central Asia which are the Tian Shan and the Pamirs and 80% of the country falls under Tian Shan mountain range and about 4% of the country is always under snow and ice (World Bank 2020). Most of the population is living under the foothills of the mountains which are extremely vulnerable to climate change induced hazards such as flood, landslides and so on. The agriculture of the country contributes to one-third of the national GDP employing 65% of the population and is the most important livelihood activity of the country (World Bank 2020). But this extremely weather dependent sector of Kyrgyzstan has been facing constant climatic obstacles which is totaling up to a loss of almost US $30-35 million/year (World Bank 2020). Therefore, it is extremely important to quantify the climate change parameters of the country which is not only affecting the country's food security scenario now but has high potential to alter it in the future.

5. Analysis of Agricultural Areas, Climate Change and Landcover Change

5.1 Agricultural Areas

It was difficult to find all the agricultural areas of Kyrgyzstan. After doing all the processing of the data in ArcMap, the aggregated clusters were then added to Google Earth Pro overlaying with the satellite imagery that can show the snow cover and land elevation (Figure 27, Figure 28, Figure 29).

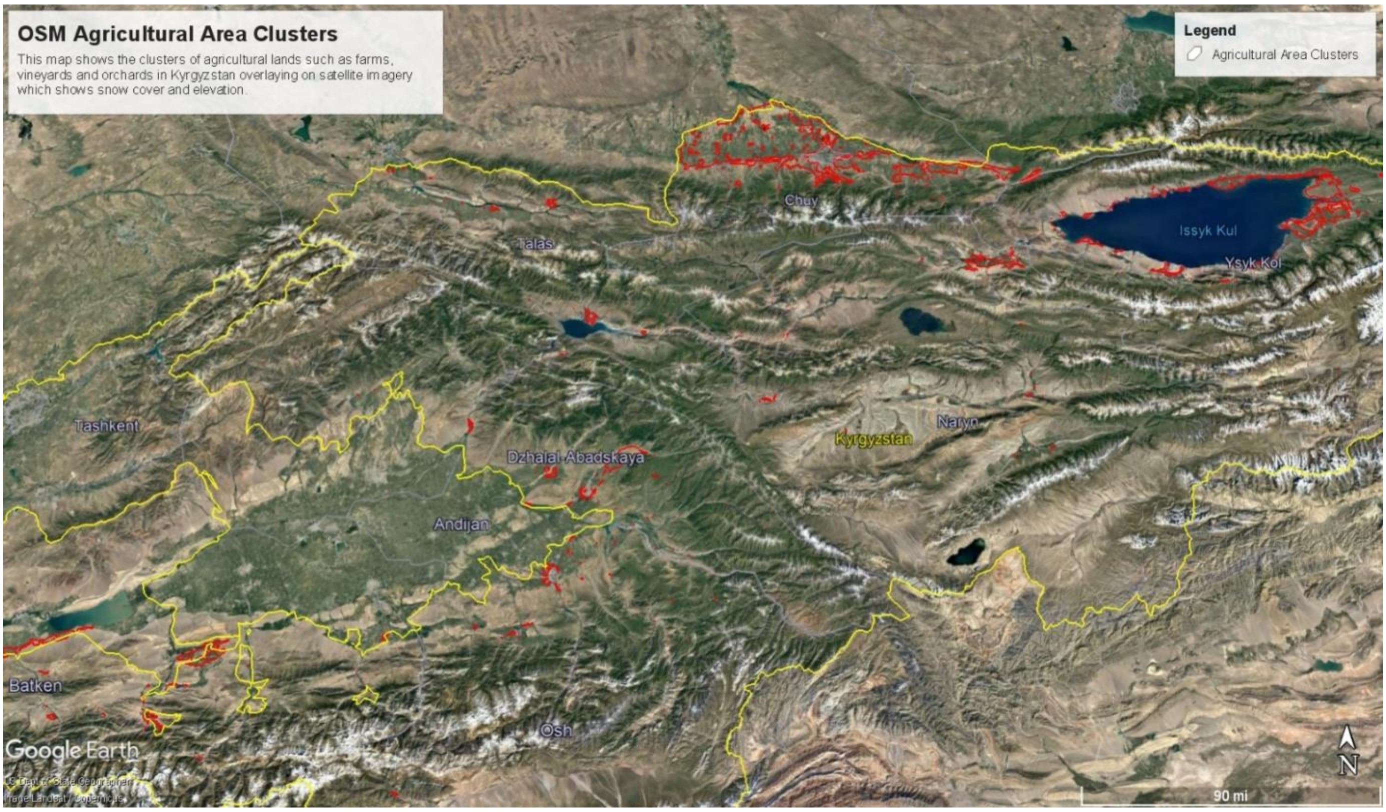


Figure 27: Google Earth Pro Satellite Imagery Comparison to Overall OSM Agricultural Areas

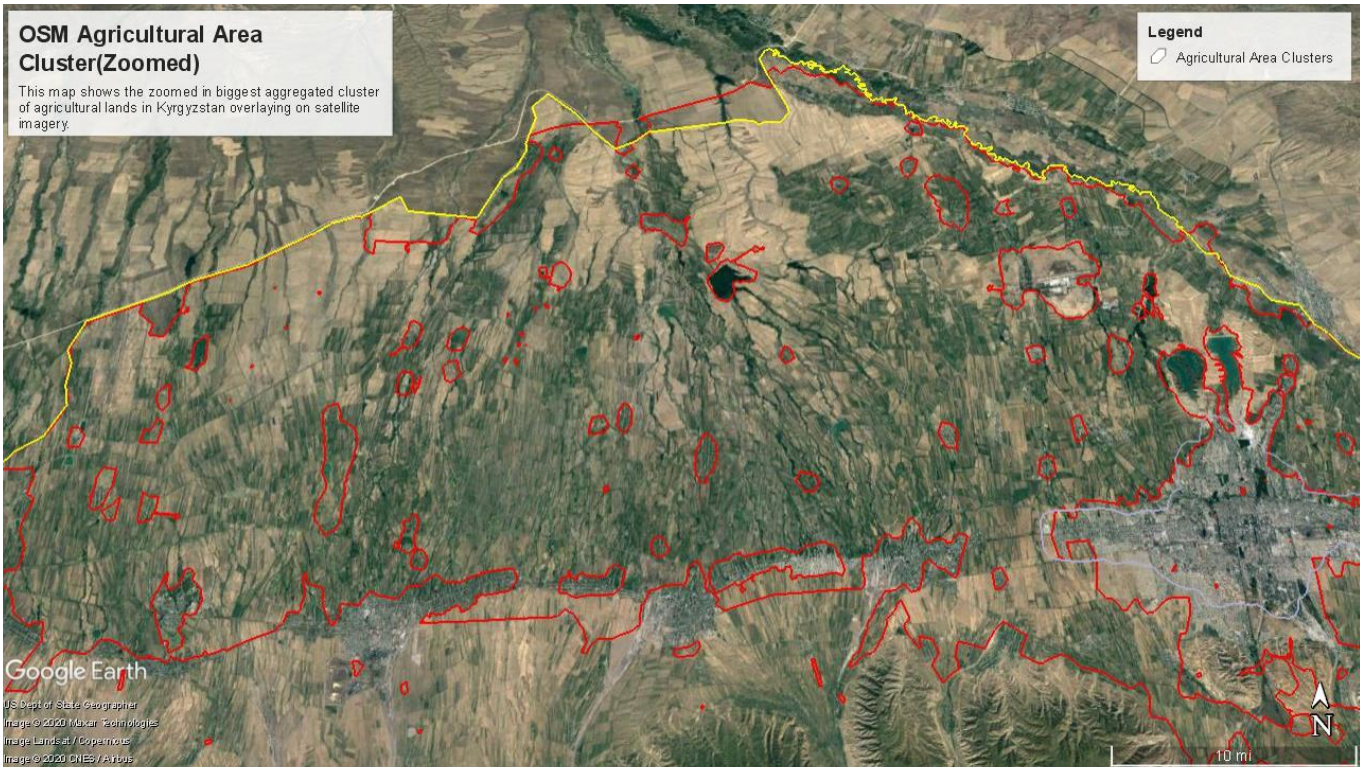


Figure 28: Google Earth Pro Satellite Imagery Comparison to Agricultural Areas around Bishkek Region.

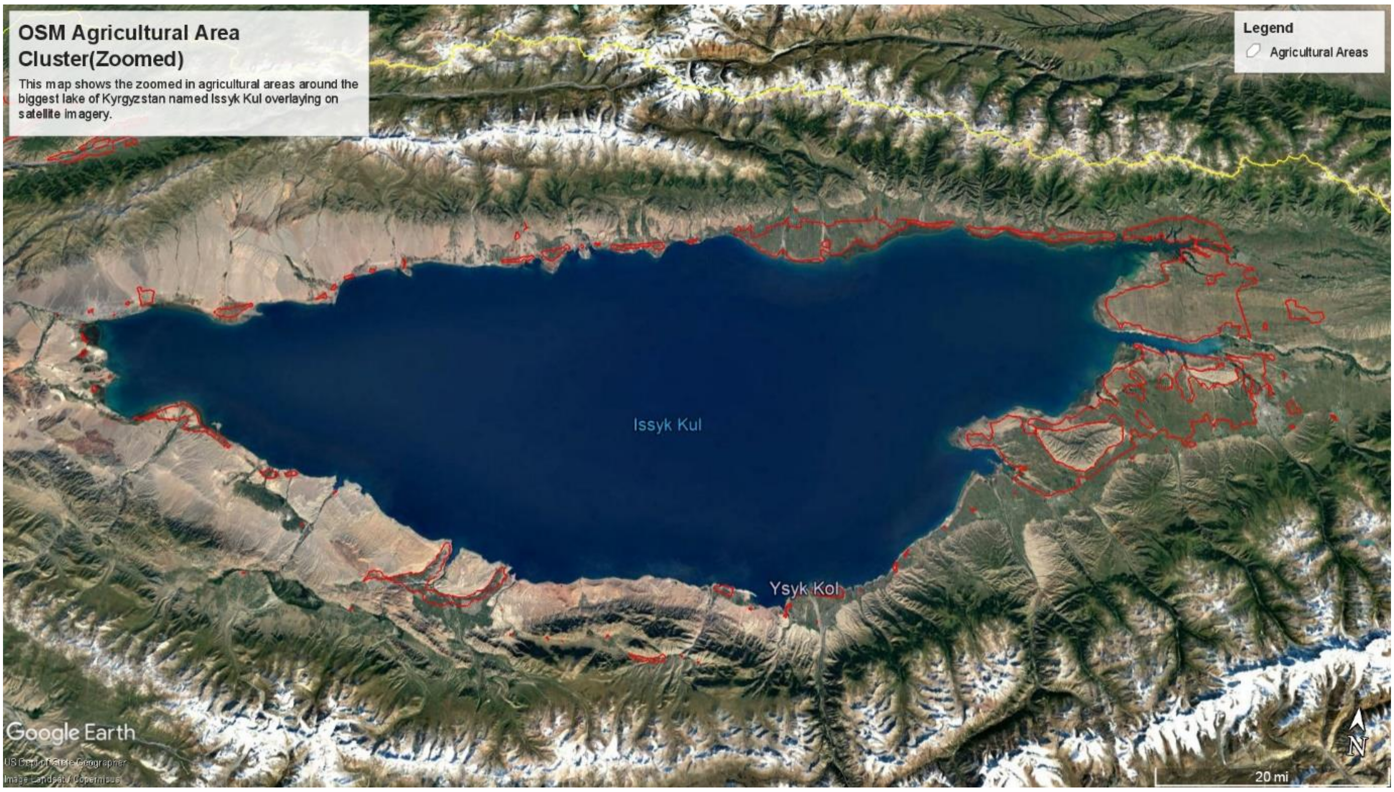


Figure 29: Google Earth Pro Satellite Imagery Comparison to Agricultural Areas around Issyk Kul Lake Region.

From the above maps, the land areas where the agricular areas are located can be seen with respect to updated satellite imagery of the country. It is evident from the maps that the agricultural areas are located only in the low elevation places of Kyrgyzstan. This shows that the limitation of suitable places for crop production in the regions, especially the agricultural zones, such as Bishkek(Figure 28) and Issyk Kul(Figure 29). These places needs more attention from the authorities for implementation of new technologies and policies for maximizing crop production.

5.2 Temperature

Temperature is the first climatic parameter that was analyzed in Giovanni and ArcGIS Desktop(ArcMap). The seasonal average was counted for JJA (June, July, August) for 5 years average in 4 periods from 2000 to 2020. The first pixelated map of Giovanni showed higher temperature in upper northern part and north-western part of Kyrgyzstan (Figure 30). When same calculation was done for other periods(2005-2010, 2010-2015, 2015-2020), same kind of maps were produced with similar regions having higher temperature values (Figure 31, Figure 32, Figure 33)

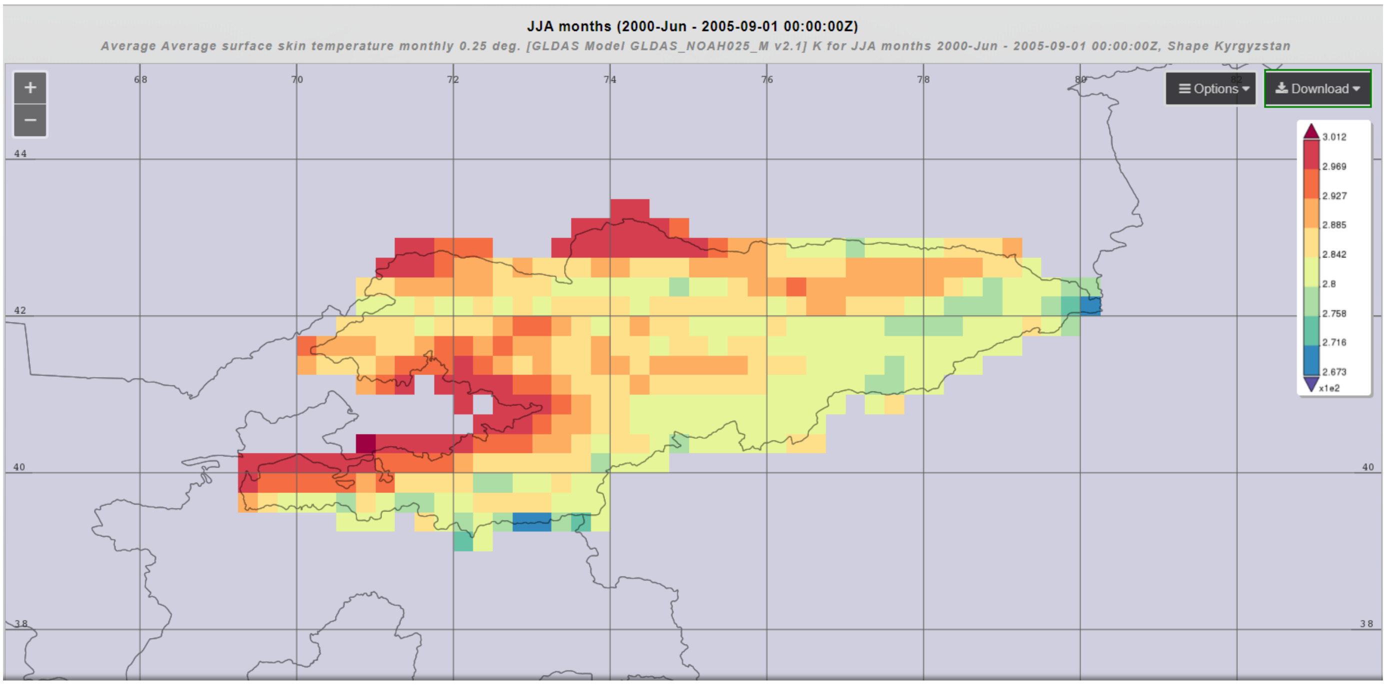


Figure 30: Giovanni Seasonal(June-August) Averaged Temperature Map (2000-2005)

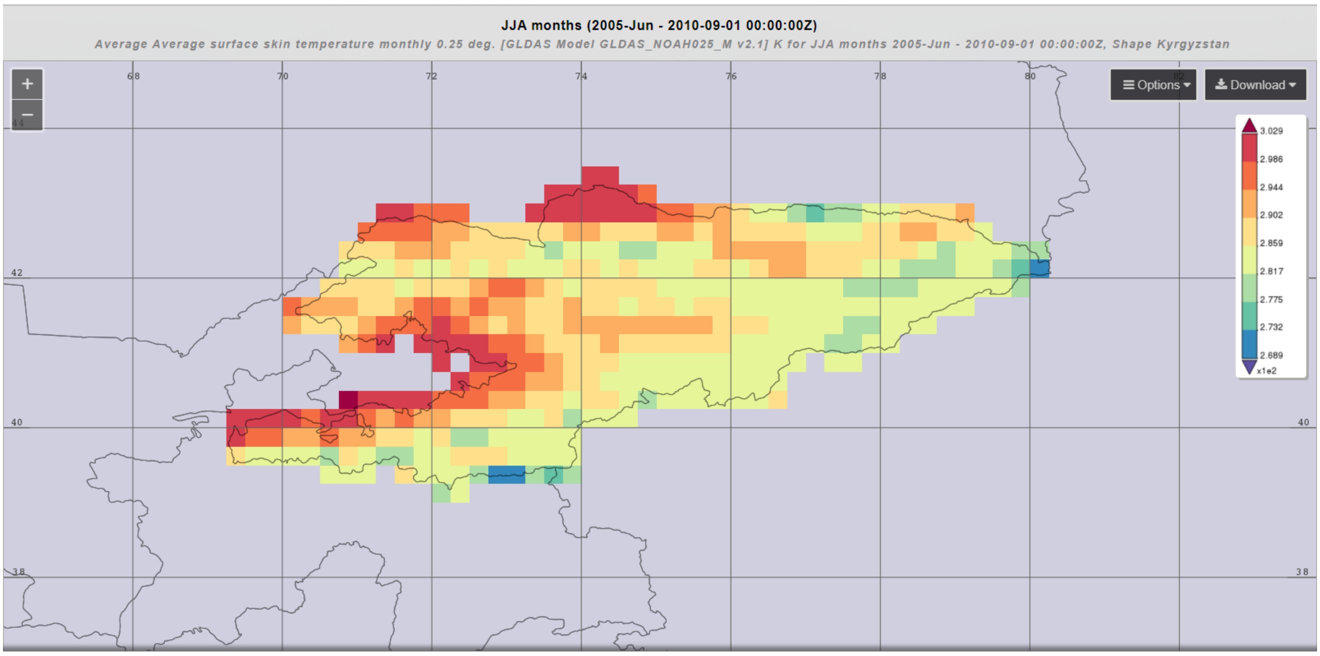


Figure 31: Giovanni Seasonal(June-August) Averaged Temperature Map (2005-2010)

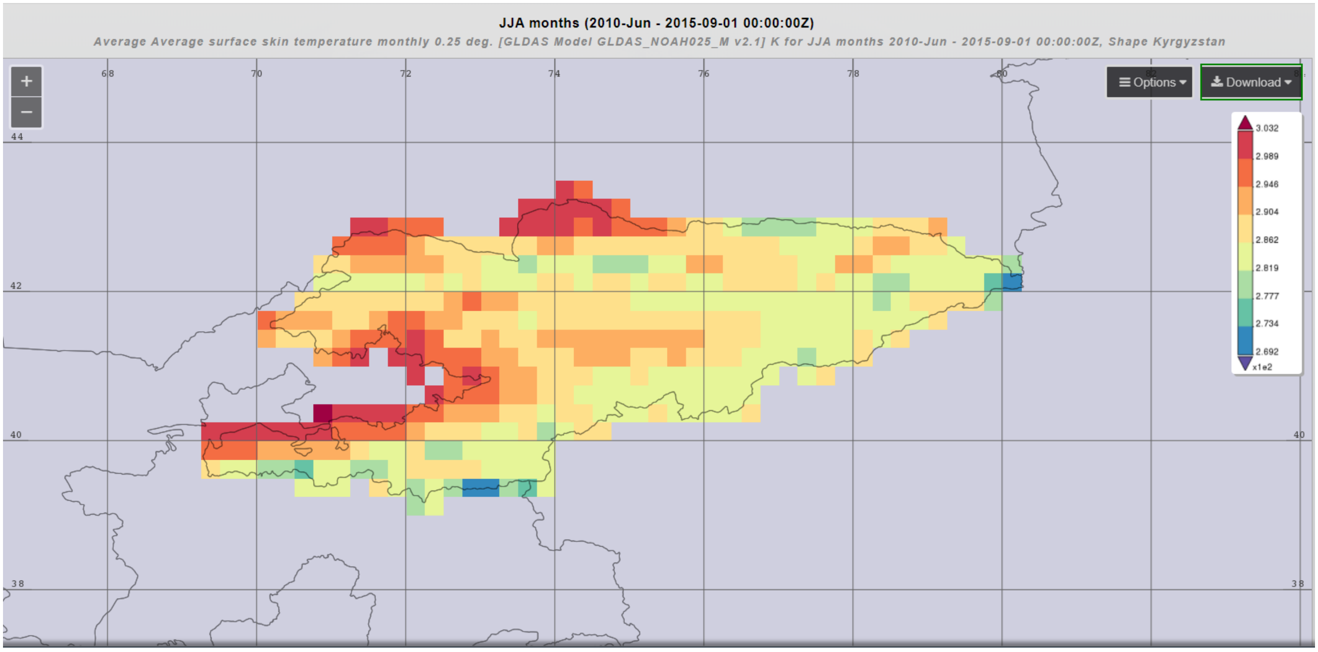


Figure 32: Giovanni Seasonal(June-August) Averaged Temperature Map (2010-2015)

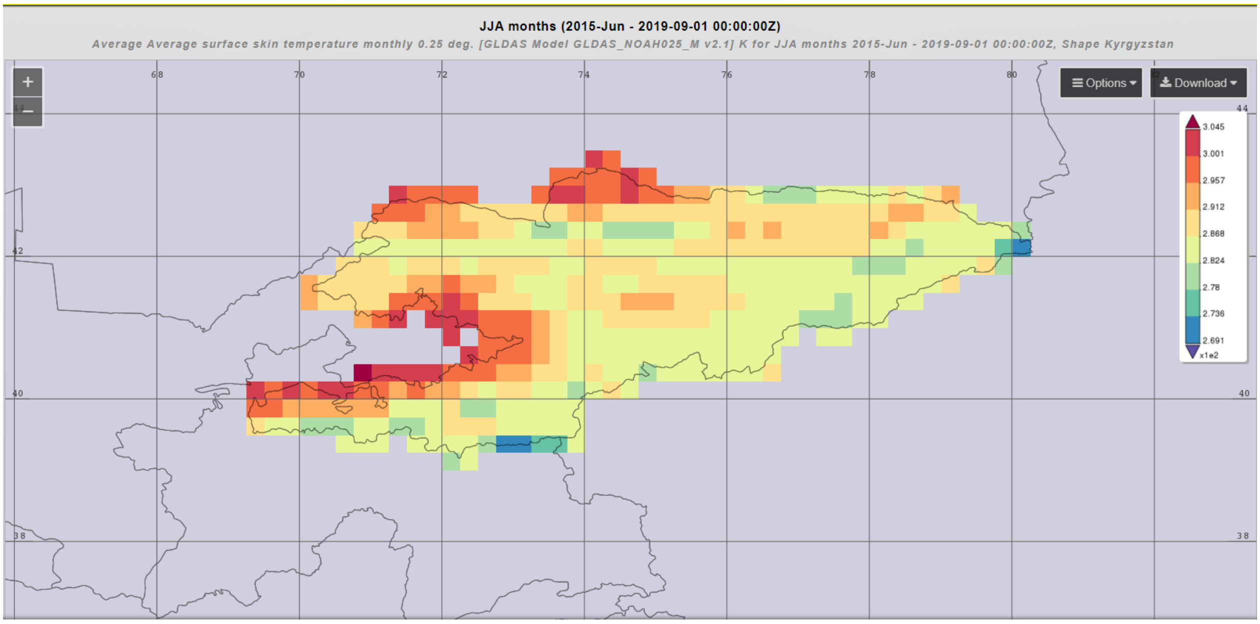


Figure 33: Giovanni Seasonal(June-August) Averaged Temperature Map (2015-2020)

Pixelated maps in Giovanni although can provide an overall idea, cannot show the exact comparable trend within the periods. For understanding the actual temperature change within these periods, the data was interpolated in ArcMap software.

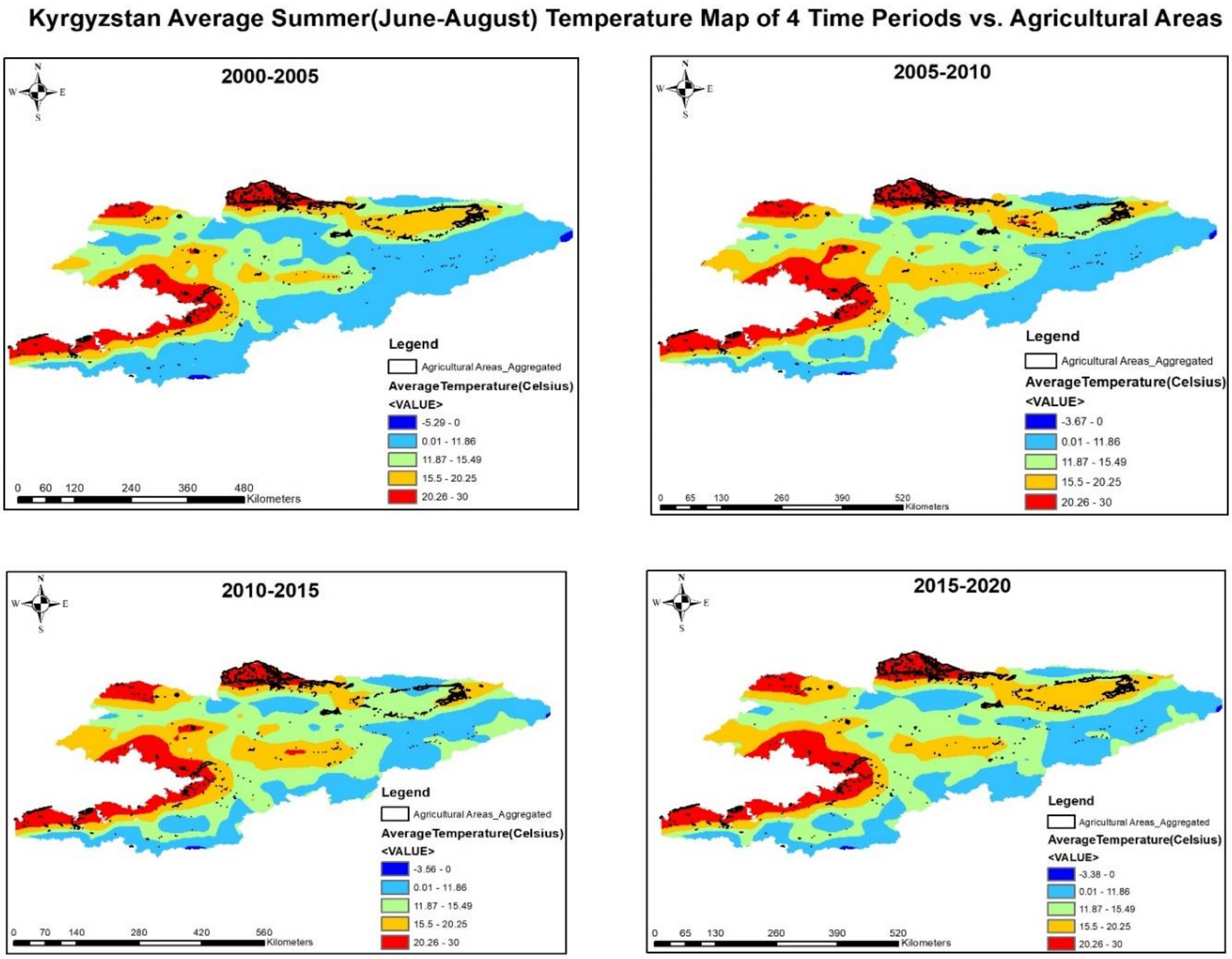


Figure 34: Four Time periods' interpolated map of Average Summer Temperature with respect to the OSM Agricultural Area.

The Interpolated comparison map in Figure 34 shows that the clustered Agricultural areas of Kyrgyzstan is overlapping with the higher temperature regions throughout all the four classes. The highest temperature area with 20.20- 30 degrees Celsius stays almost consistent in the agricultural areas in the north and north-western side. The orange region is increasing gradually throughout the entire country as the years progress. On the other hand, the lower temperate region with light and dark blue is seemed to get lower from 2000 to 2020. This shows a consistent increase in temperature at the area which confirms that climate change induced temperature increase is happening in Kyrgyzstan from 2000 to present.

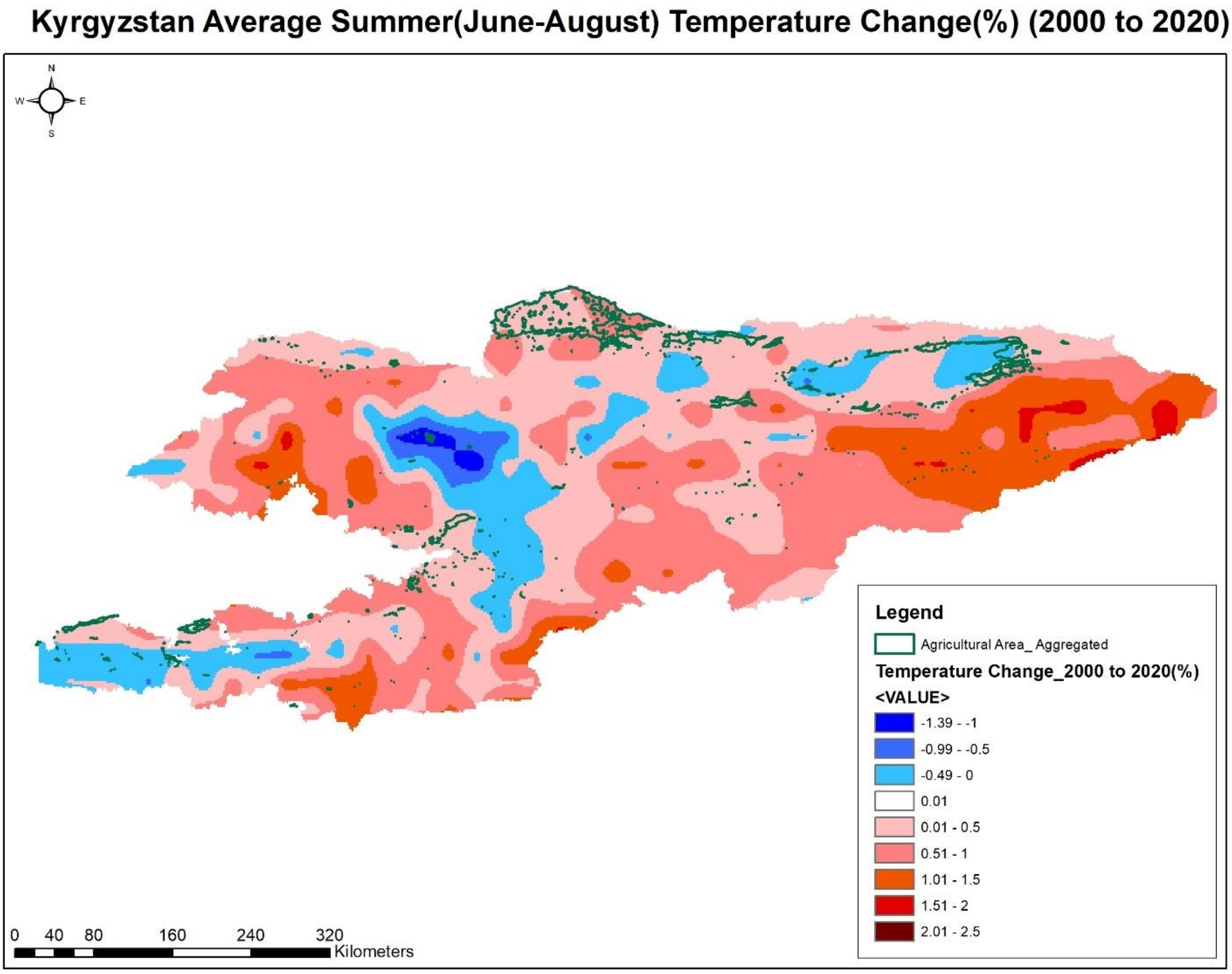


Figure 35: Summer Temperature Change(%) Map of Kyrgyzstan between two decades("2000-2010" and "2010-2020"

To quantify the temperature change of the entire country, further analysis was done with the seasonal average temperature data. For calculating the average, the percentage was calculated with the Spatial Analyst Toolbar that lets the users do complex raster imagery calculations. The mathematical percentage formula that was used for the raster calculation was:

$((X- X_0)/ X_0)$ *100; X= Seasonal average of 2020, X_0= Seasonal average of 2000

The final interpolated map showed the overall temperature increase and decrease percentage of Kyrgyzstan. High color contrast was used for the two kind of changes so that the areas with higher increase or decrease can easily be detected (Figure 35). The map demonstrates a color gradient from blue to red. The blue areas are indication of percentage decrease (below 0% class) in temperature of the region and the red areas indicate percentage increase (above 0%). The map clearly shows temperature increase in most of the regions of Kyrgyzstan through the domination of red colored areas. The compared clustered agricultural areas in this change map shows that most of these regions are facing temperature increase. While this has the probability of increment in yields and growth of higher temperature crops, the existing crops of the region which is accustomed to lower temperature may show a decline in production. To have an idea of the overall statistical temperature trend of Kyrgyzstan, Earth Map was used. The changes of maximum and minimum temperature for all the months(2000-2020) is shown with monthly average and deviation in Figure 36 and Figure 37 below.

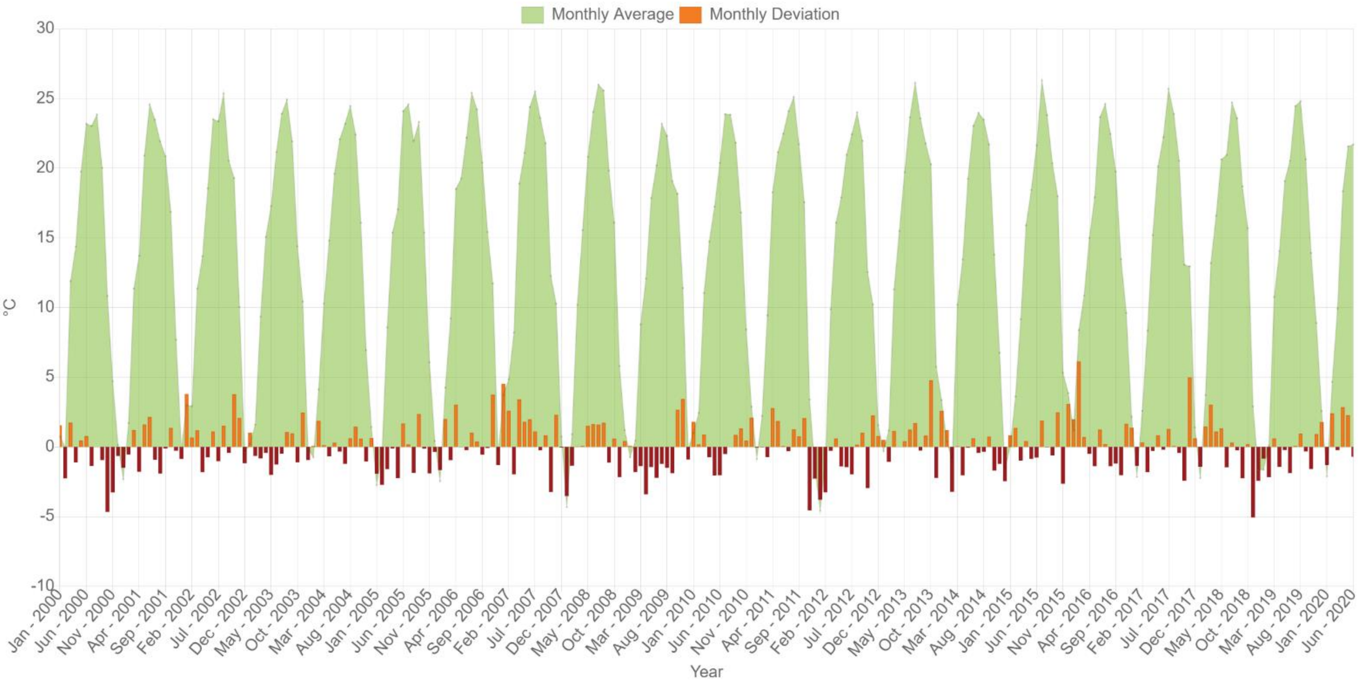


Figure 36: Kyrgyzstan Maximum Temperature Monthly time series(2000-2020)

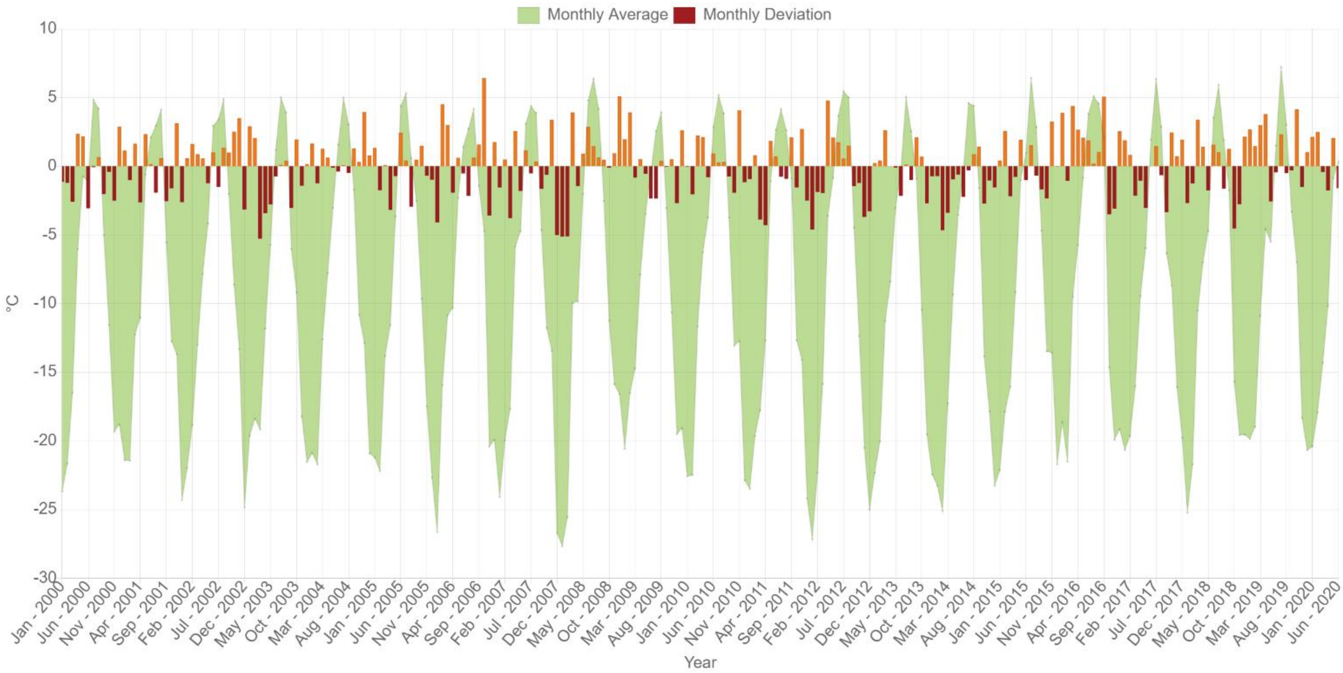


Figure 37: Kyrgyzstan Minimum Temperature Monthly time series(2000-2020)

These time series statistics data are derived from the ECMWF (European Centre For Medium-Range Weather Forecasts) which is an independent and intergovernmental organization. The organization functions regularly working with data from different global meteorological model, various remotely sensed data from satellites and earth observation systems and weather forecast assimilation system which can help to identify climate change trends. This temperature data source was shown to be a collaboration between ECMWF and Copernicus Climate Change Service which shows the credibility of the data. In the Maximum temperature time series (Figure 36), it is clearly seen that although the average does not show significant change, since 2012, the maximum deviation, which is compared to the average temperature value, is on the rise. The minimum temperature time series (Figure 37) shows the increase in recent years lowest temperature and high deviation which indicates that the minimum temperature threshold is going up that can impact the snow-cover, glaciers and the crop productivity of the region.

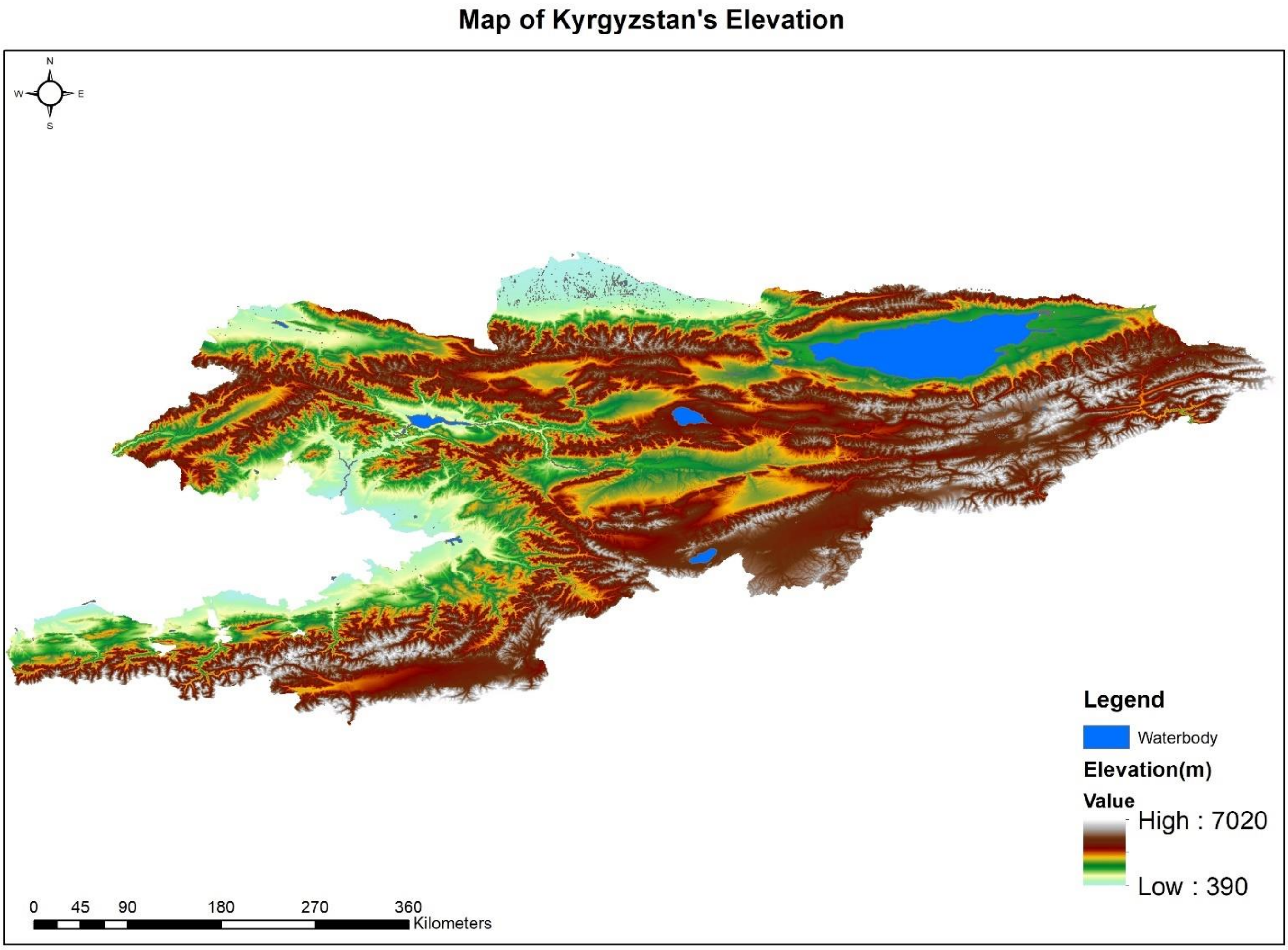


Figure 38: Elevation Map of Kyrgyzstan

It is also important to remember here that this landlocked country has mostly higher elevation areas including the big Tian Shan Mountain range at the south-eastern side of the country where any kind of agricultural activity is not possible (Figure 38). So, the existing low land areas of agriculture overlapping with the increasing temperature areas is indeed a concerning matter for food security and policy making situation for the country.

5.3 Precipitation

The next analyzed climatic parameter which can heavily impact the food security of the region was surface precipitation. Surface precipitation plays a very important role in determining crop productivity, pasture health and therefore food security. Following the same steps of

Temperature analysis, seasonal surface precipitation for summer (June-August) was mapped in the NASA Giovanni workspace. The produced map was more pixelated that the temperature maps (Figure 39).

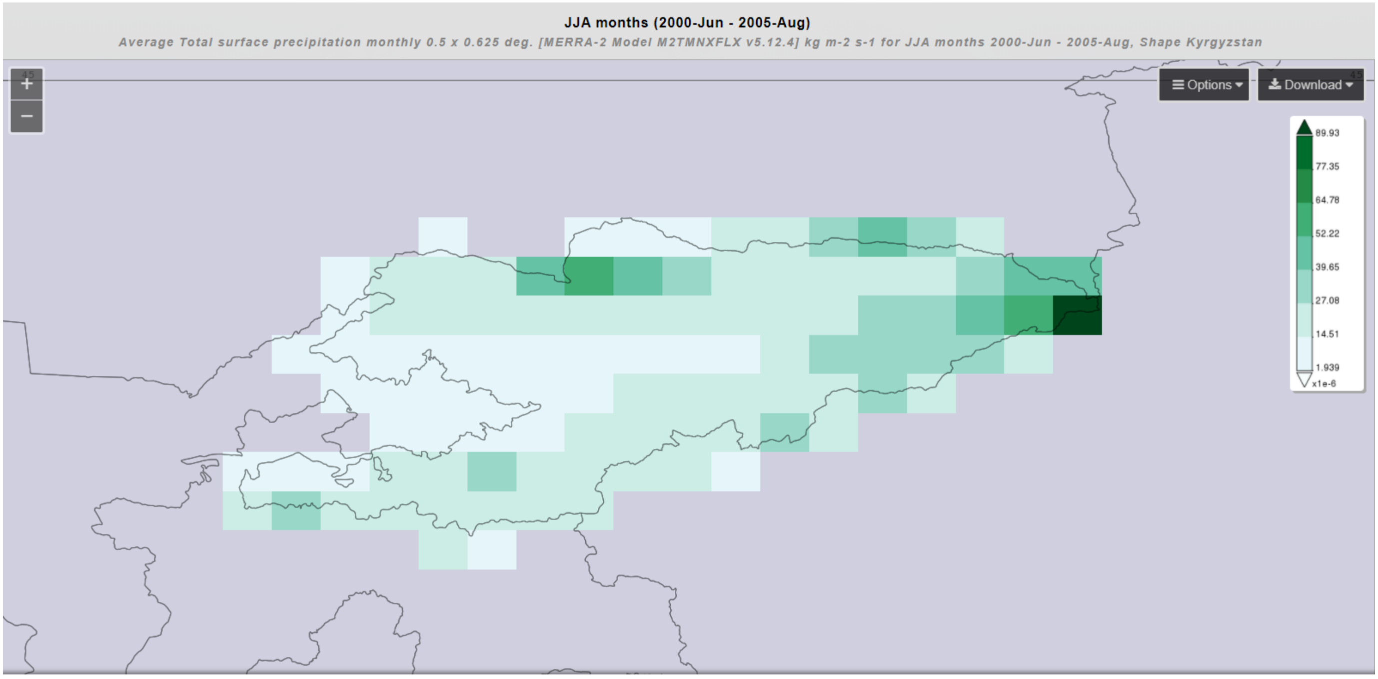


Figure 39: Giovanni Surface Precipitation Map(June-August) from 2000-2005

The data was then interpolated in the ArcMap. The problem with this data was that the pixel size was too big and some of the areas could not be covered in the interpolation method. But based on the initial pixel values, those values could be assumed. Similar type of 4 time periods map was produced from the Giovanni data.

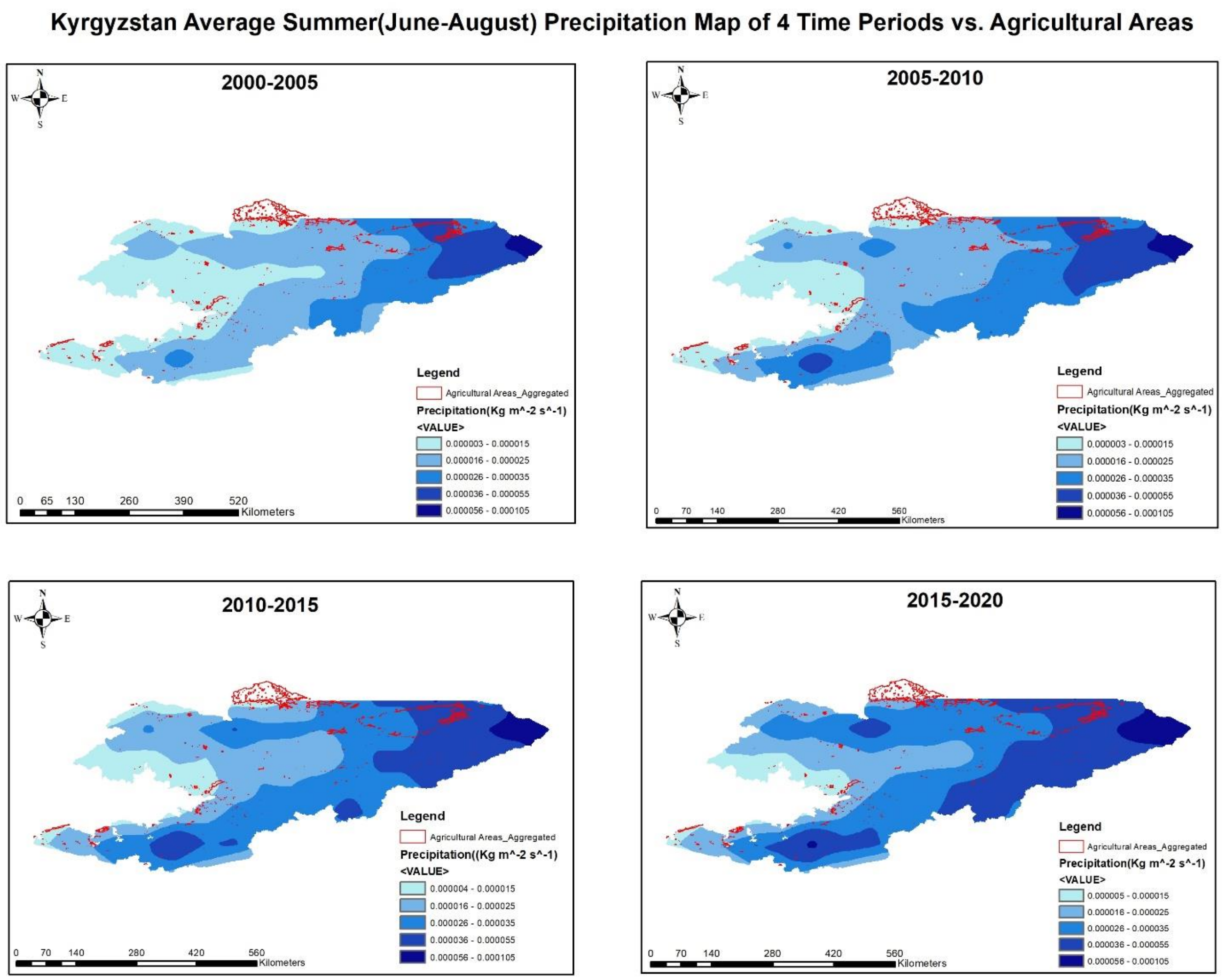


Figure 40: Four Time periods' interpolated map of Average Summer Precipitation (Kg/m^2/s) with respect to the OSM Agricultural Area.

The precipitation data of the 4 periods' maps show a significant amount of change with the passing years (Figure 40). It is important to state here that the interpolation of the data did not cover the Bishkek agricultural area due to the pixels being too large and the centroids only interpolated till the extent showed in the map. Because of this, it shows white color rather than the blues in precipitation legend values. The value for that area was presumed from the nearest area's value. Here, the Giovanni maps also confirm that those areas have similar pixel value.

The data visualized through the map (Figure 40) contained total precipitation of the region which includes both rain and snowfall. In the lower temperate regions, both of these precipitation matters a lot in case of crop production as the crops not only use the water from rain, but also the melted water of the snow after the passing of winter. The interpolated maps here draw a hopeful scenario where the precipitation is seen to increase with passing years. In the first map (2000-2005), the area of the lower precipitation area is significantly high at the northern and western region with lightest blue color. But in the next period this colored region seems to be smaller while the upper classes of average precipitation percentage dominated the map frame. This is indicating as overall scenario of precipitation increase in Kyrgyzstan from 2000 to 2020.

To reevaluate the assumption made from Giovanni data, the average precipitation of Kyrgyzstan from 2017 to 2019 was visualized in Earth Map platform. The average precipitation map(Figure 41) reconfirms the Giovanni result and shows that the areas with higher precipitation matches with the interpolated areas of Giovanni(2015-2020) periods map. Although, the Earth Map’s map is pixelated, it shows that the south-eastern part where the Tian Shan mountain range is, is having lower precipitation while the mid part, north-west and south west part of the country is showing higher values of average precipitation (Figure 41, Figure 42).

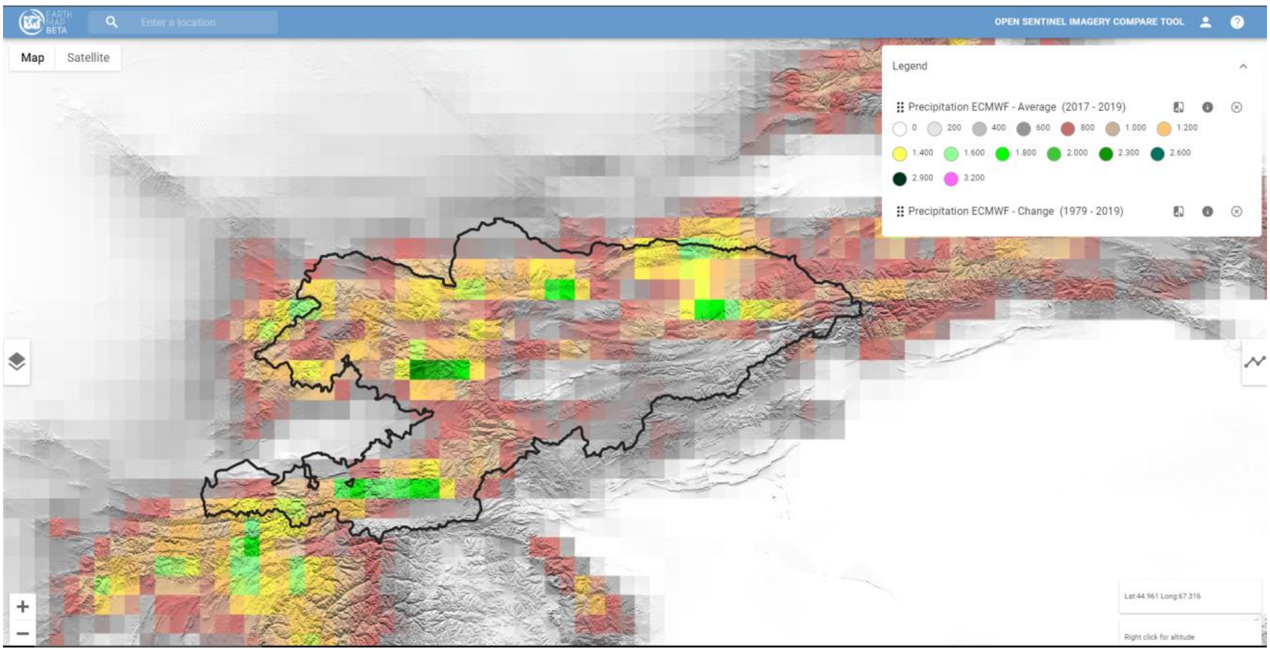


Figure 41: Earth Map Precipitation Average map(2017-2019)

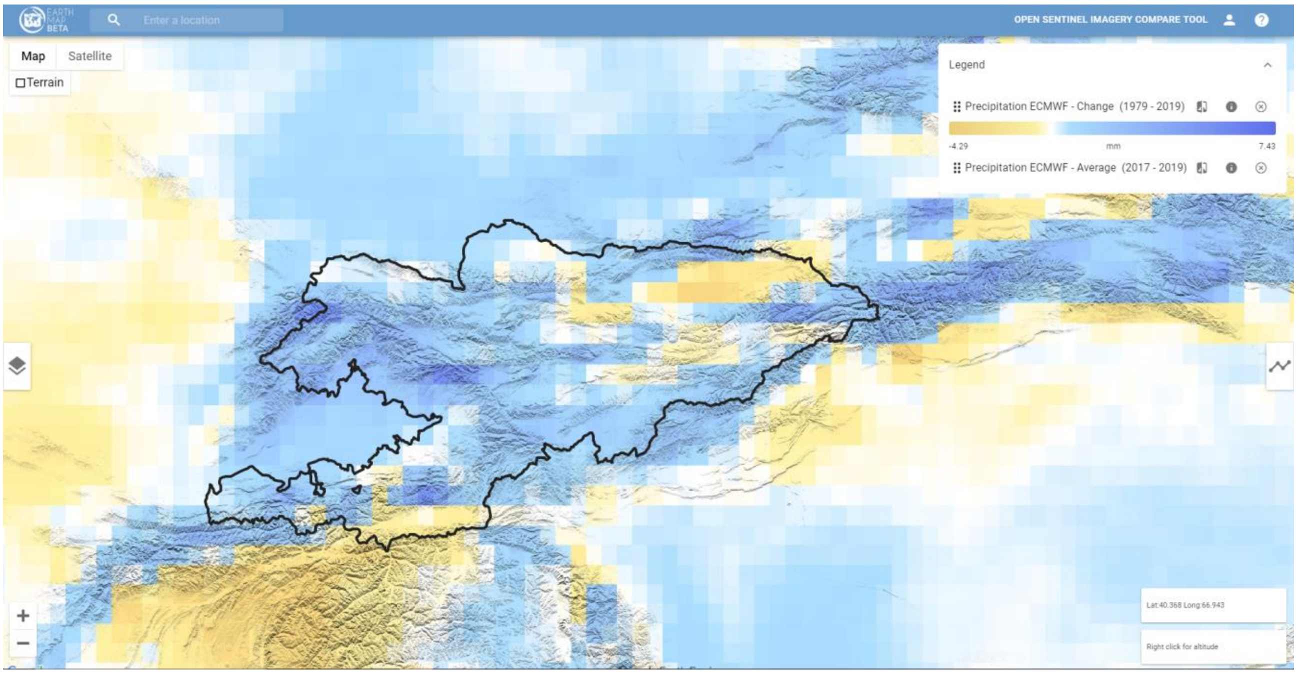


Figure 42: Earth Map Precipitation change map (1979-2019)

The Precipitation change map of Earth Map also shows that the precipitation is increasing in most of the areas of Kyrgyzstan except north-eastern part (Figure 42). According to the white pixel values in the legend, the white pixels are denoting low to no significant precipitation changes in the areas they appear. Although some decrease value pixels can be seen in the map at the areas where agricultural lands are at (Figure 29), the overall dominance of the increasing values portrays a upward increase graph for precipitation. This can be a great news for the crops and the food security scenario. But this increase combined with high temperature caused snow melt can also result into occasional flooding which can significantly affect the overall yields and productivity of the crops.

5.4 Evapotranspiration

Evapotranspiration refers to the combination of evaporation and plant transpiration. The evaporation process is an activity where liquid water is converted to vaporized form and eliminated from the evaporating surfaces such as different types of waterbodies, pavements, wetlands, soils, and wet vegetation. This phenomenon is affected by a lot of factors such as location of the evaporating surface, the amount of water available in the evaporating surface, crop canopy shading degree, rain, irrigation, water transportation within soil layers and so on. When the water supply to the surface is absent, the evaporation amount decreases significantly. On the other hand, transpiration process refers to the vaporization and extraction of liquid water contained in the plant tissues to vapors in the atmosphere through plant stomata. This process emits most of the water obtained by the plant from soil leaving a tiny fraction which is used by the plant (Allen et. al 1998).

As the transpiration and evaporation process occurs concurrently, it is very hard to distinguish between these two processes. Because of this reason, "Evapotranspiration" concept combines them and determines the overall scenario of evaporation and transpiration in the atmosphere. Evapotranspiration can differ based on time and plant age. When the crops are sowed, almost 100% percentage of evapotranspiration is the evaporation value of the soil but when the plants or crops are matured, more than 90% of evapotranspiration depends on plant transpiration rather than soil evaporation (Allen et. al 1998).

The Evapotranspiration data was analyzed in Giovanni first(Figure 43) and then was analyzed in ArcMap following the same interpolation steps of previous parameters (Figure 44).

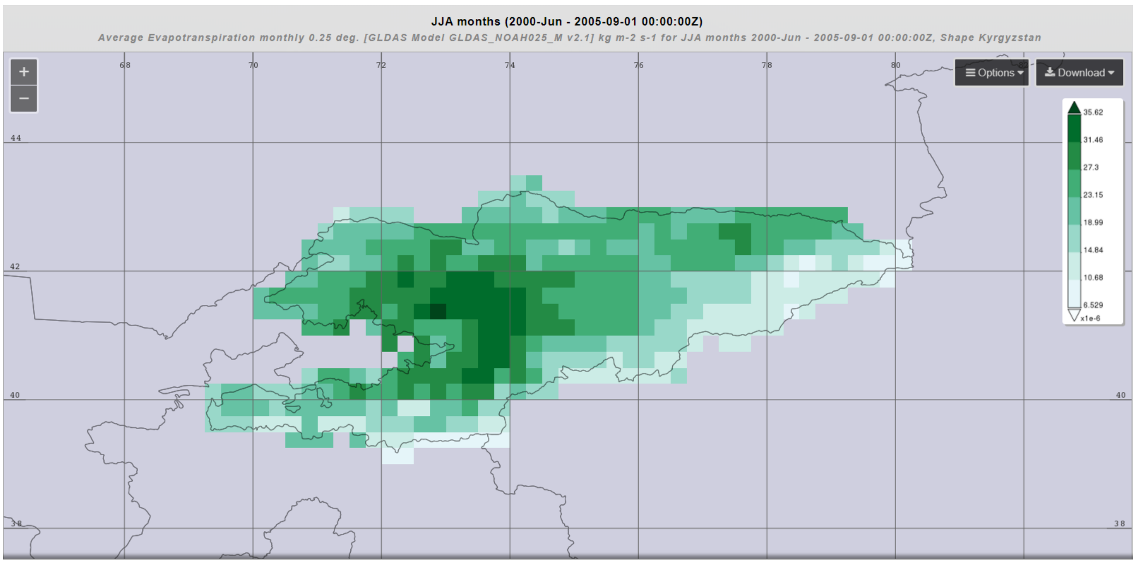


Figure 43: Giovanni Average Evapotranspiration Map(June-August) from 2000-2005

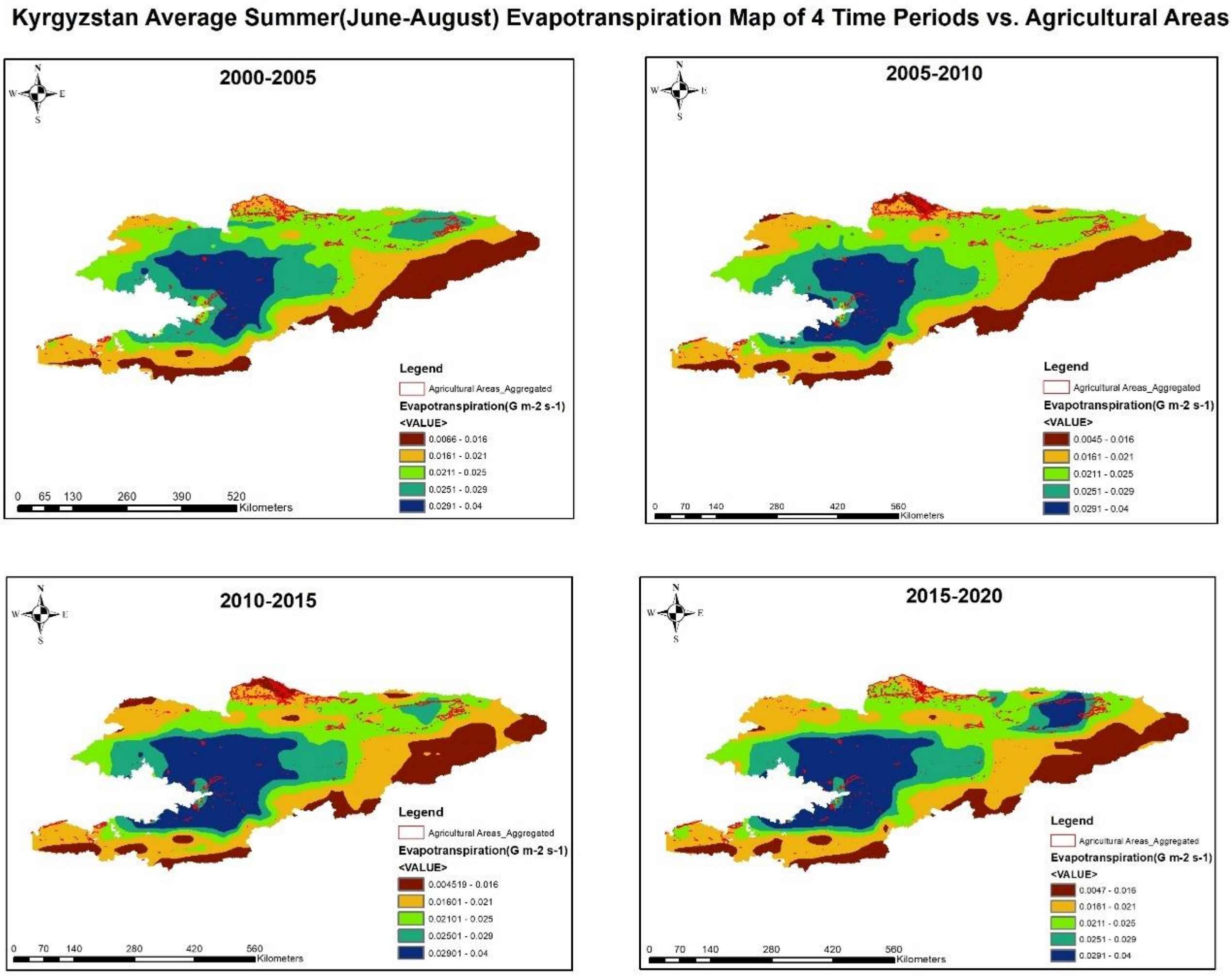


Figure 44: Interpolated average Evapotranspiration Maps for 4 time periods(2000-2020)

The interpolated evapotranspiration shows a lot of change in evapotranspiration throughout the 4 periods (Figure 44). The lowest class having value until 0.016(G m^-2 s^-1) is decreasing in the south-eastern part where the Tian Shan mountain range is, which means evapotranspiration is increasing there. This can indicate high evaporation rate due to temperature increase in the mountain areas which can also mean increased melting of snow covers of the mountains. The largest agricultural cluster at the north part of Kyrgyzstan although shows lower class evapotranspiration value in 2 middle time periods (2005-2010, 2010-2015), the evapotranspiration value again increases in 2015-2020 average map. Relating to the precipitation maps(Figure 40), it may also indicate to higher precipitation value led evaporation rate in those areas than increased plan transpiration rate. For determining that, the plant condition of the areas needs to be analyzed which will be done in the vegetation analysis part.

The PET(Potential Evapotranspiration) change was also mapped in the Earth Map platform from 2001 to 2017 (Figure 45). High change was observed in the south eastern region, north western upper and lower part which matches with the ArcMap interpolated maps average evapotranspiration change pattern over times.

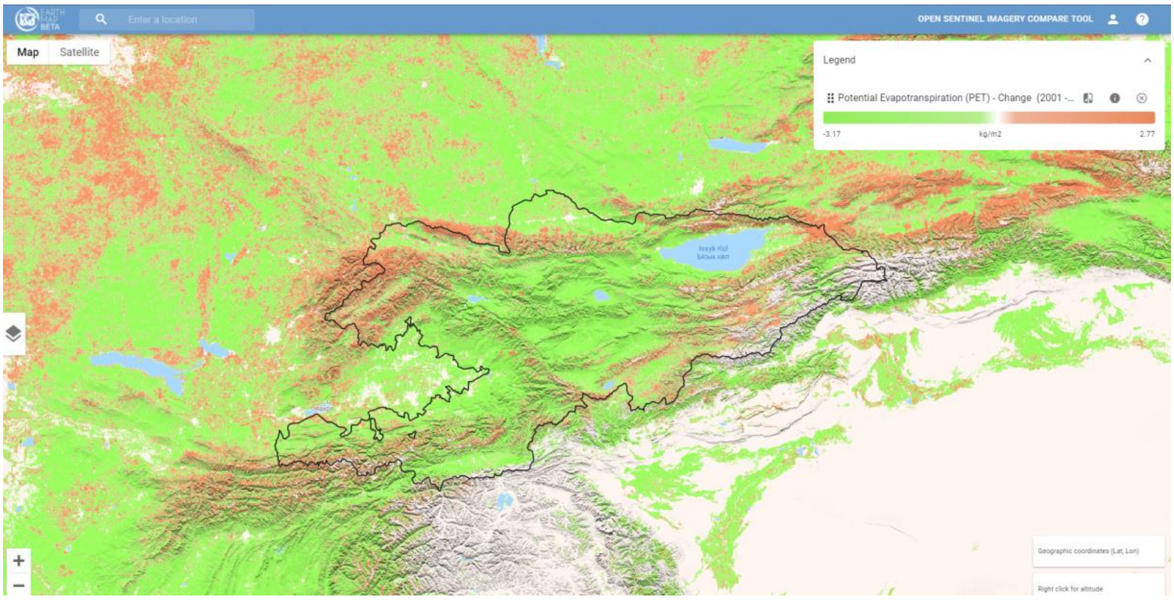


Figure 45: Earth Map Potential Evapotranspiration Change Map(2001-2017)

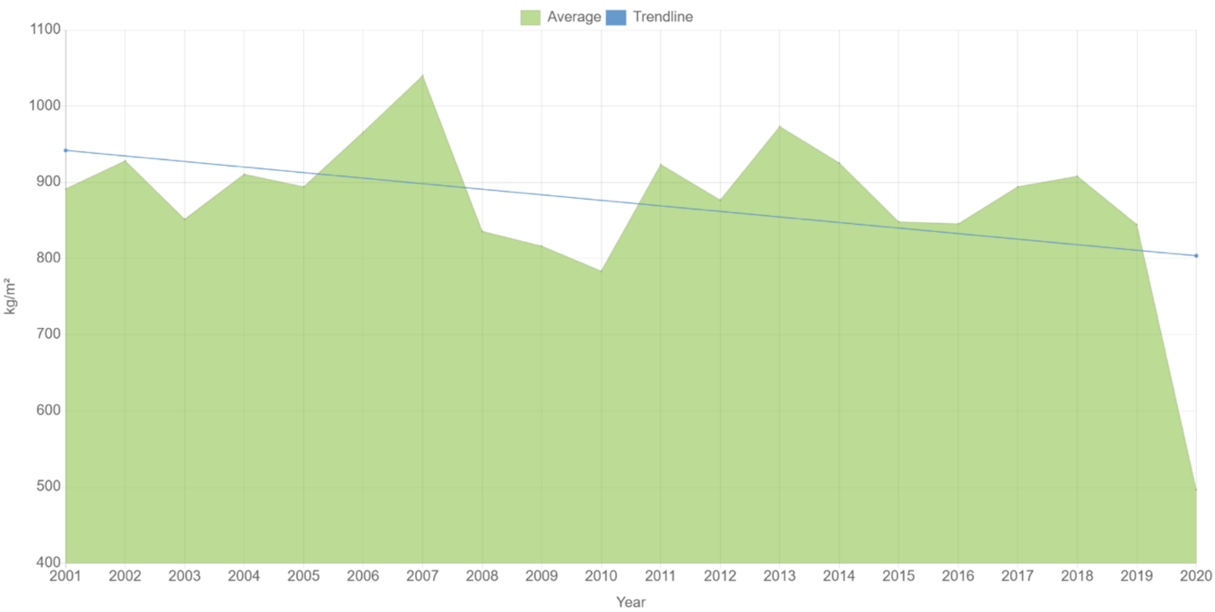


Figure 46: Earth Map Potential Evapotranspiration Statistics and overall Trend(2001-2020)

To see the statistical trend of the evapotranspiration, Earth Map data calculator was also used for the annual average PET. Although the previous maps show evapotranspiration value increase in many places, this calculation shows the overall decrease in evapotranspiration values through a downward trendline (Figure 46). This portrays a scene of low plant or crop productivity in the country as the evapotranspiration value is proportional to productivity of the vegetation.

5.5 Root Level Soil Moisture

The root level soil moisture is a very important parameter for the crop productivity and yields. This parameter determines how much water is available for the plant to intake from the soil. Due to lack of soil level moisture during droughts, many crops either die or produce poor yield.

The average root zone soil moisture in summer was first mapped in Giovanni for 2000-2005 (Figure 47). After that the same was done for other periods and the raster was downloaded and interpolated in the ArcMap (Figure 48).

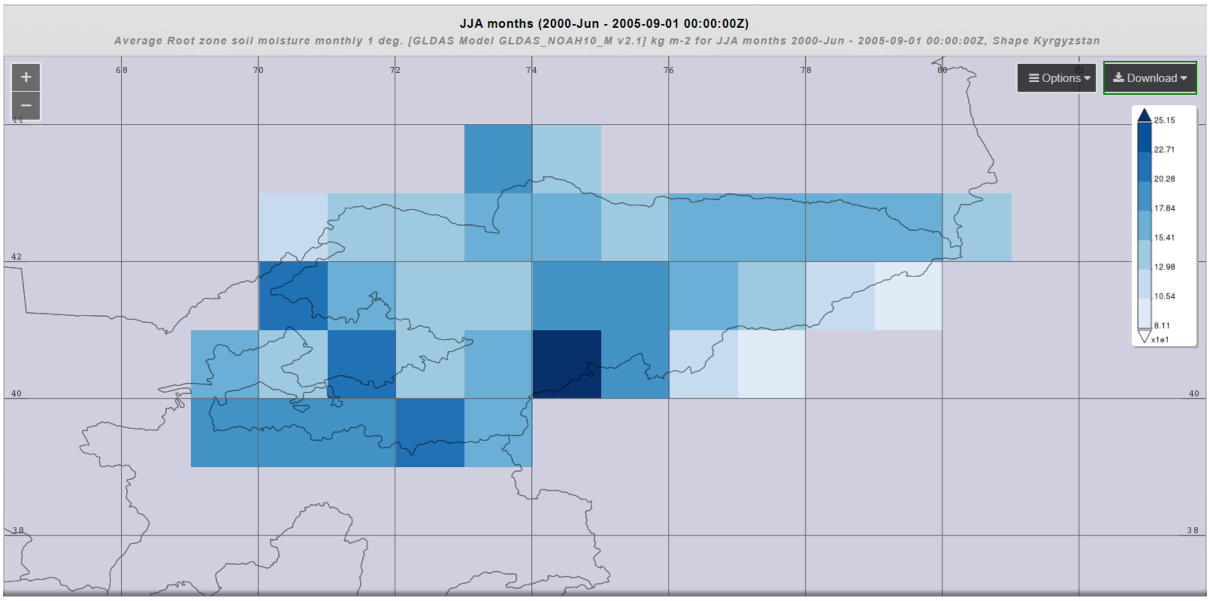


Figure 47: Giovanni Average Root Zone Soil Moisture Map(June-August) (2000-2005)

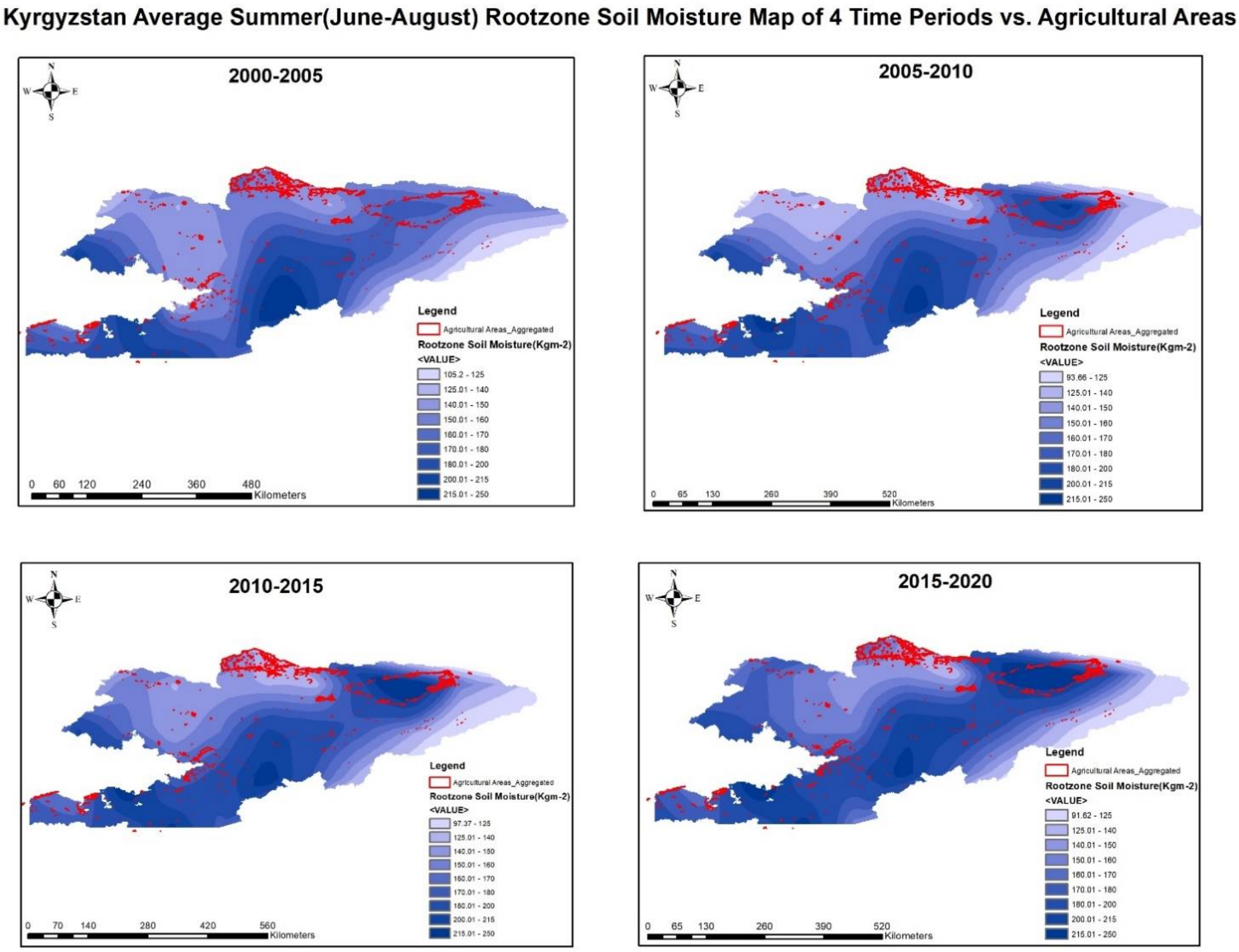


Figure 48: Interpolated average Root Zone Soil Moisture Maps for 4 time periods(2000-2020)

The root zone soil moisture is seen to increase throughout the region as the darker blue regions take more areas that previous year averaged classes (Figure 48). The maps show that north-eastern and south-western region of agricultural areas are having the highest amount of soil zone moisture where the moisture is still low at the most productive agricultural areas of Kyrgyzstan. The final map of 2015-2020 shows that this particular zone is having soil moisture from 91.62 kg/m^2 to 150kg/m^2 which is still lower than the other regions. Most of the high moisture zones are is the higher elevation areas where it is unsuitable for crops and snow cover is usually present. So, the low moisture content in the limited agricultural areas are a matter of concern for the food security situation of the country. The rate is although seen to be increasing in 2015-2020 period, the amount is still lower than other areas.

5.6 Vegetation Analysis (NDVI)

The NDVI value was calculated using the MODIS Terra Satellite's Daily imagery from USGS website of the clearest image from the month of July in 2019 and 2020. The Terra satellite is a multi-national NASA scientific research satellite which can obtain higher resolution imagery. The produced comparison NDVI map is more detailed than the previous maps because of this high-resolution raster (Figure 49).

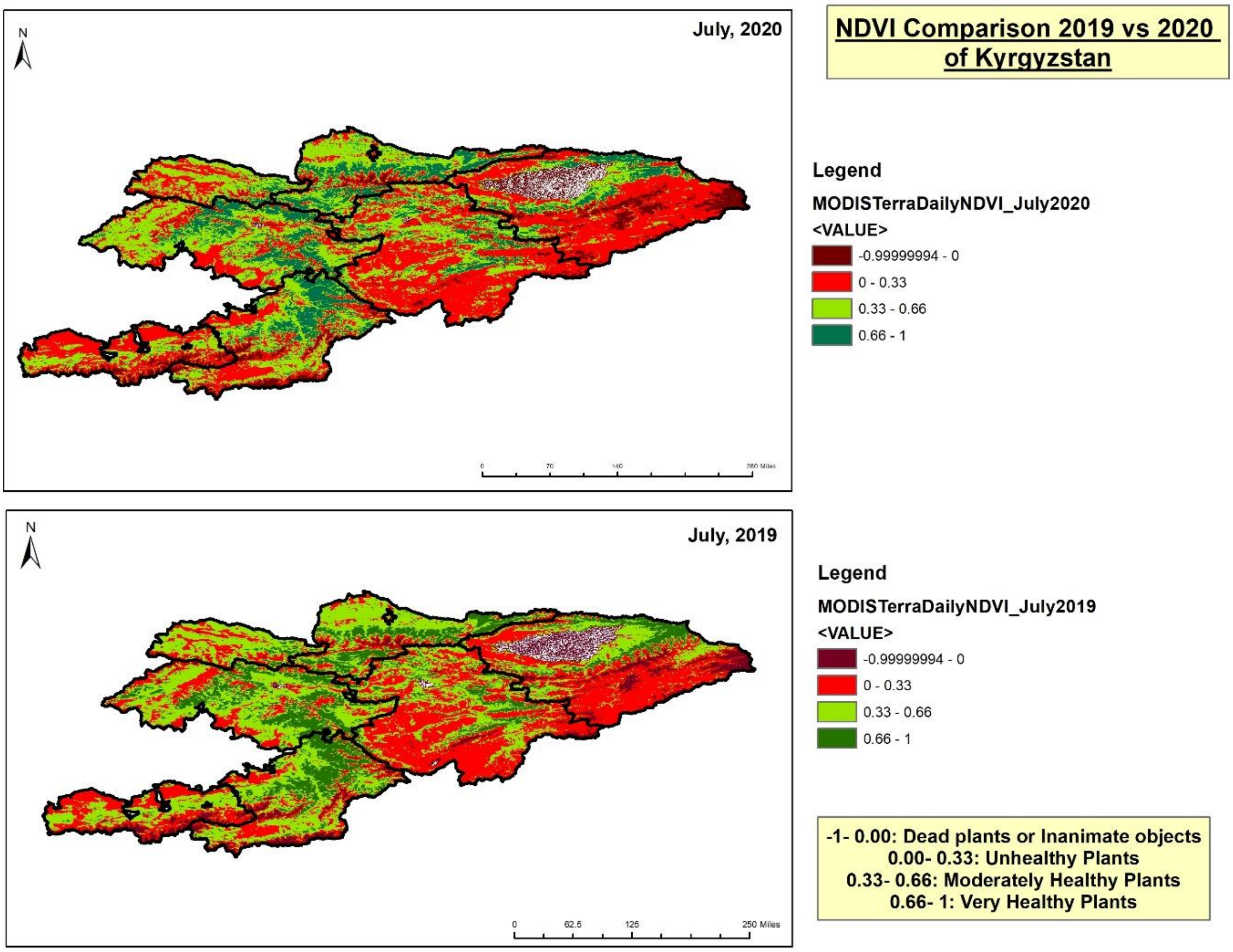


Figure 49: MODIS Terra Satellite's NDVI Map of July 2019 vs 2020

From the two maps, the lower and higher NDVI value regions can be identified (Figure 49). The red colored areas are referring to the unhealthy vegetation in Kyrgyzstan. The values also contain the inanimate objects values such as water or snow. Both maps, although looks very similar, the red areas increase in July 2020 from 2019. This can be seen from the difference map of two of these years where the yellow to orange values show NDVI decrease and the green to blue palette shows NDVI increase (Figure 50). The zoomed agricultural area of the north-side shows significant NDVI decrease through the yellow color. This indicated that the vegetation cover and productivity is decreasing in the area.

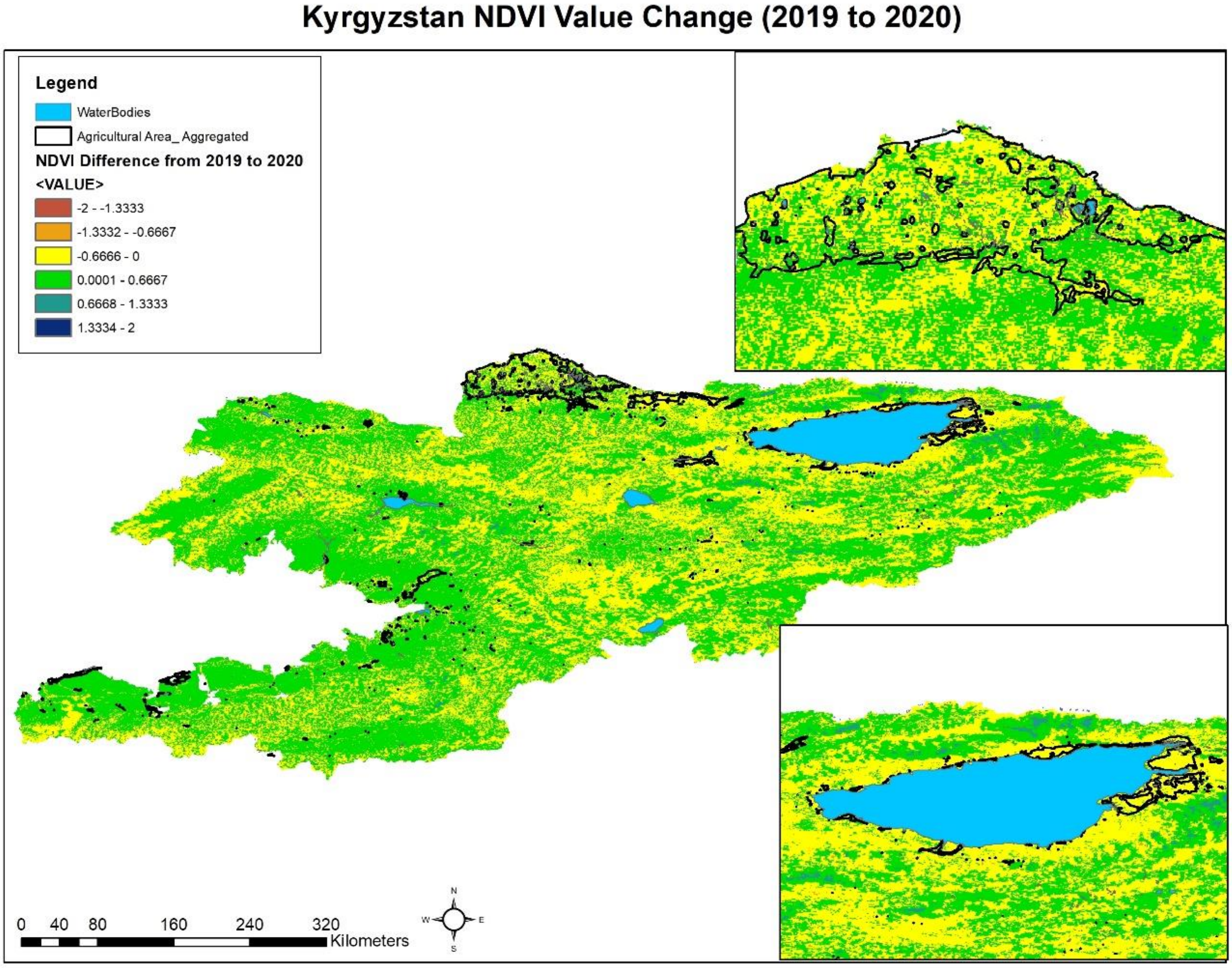


Figure 50: NDVI Change between 2019 and 2020

The decade average and change for NDVI value was also calculated using Giovanni and ArcMap Raster Calculator.

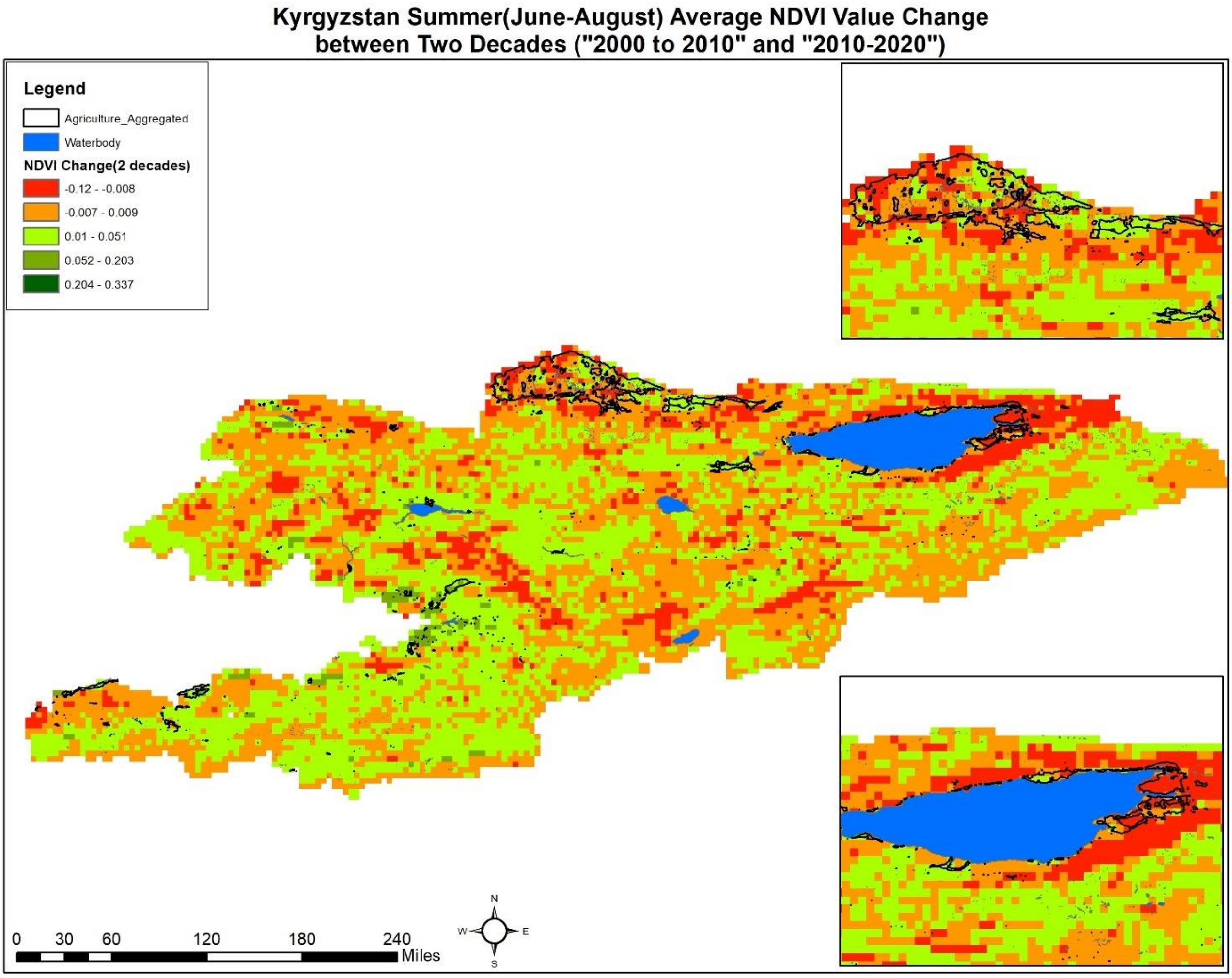


Figure 51: Summer NDVI Change between Last Two Decades("2000-2010" and "2010-2020")

The decade change map shows that the NDVI value has decreased in most of the areas of Kyrgyzstan, especially in the agricultural zones of Bishkek and Issyk Kul (Figure 51). The dominance of red colored class (-.12 to -.008) and orange class (-.007 to -.009) in the agricultural areas signifies that the vegetation cover value is decreasing which is very concerning for the crops. The increasing NDVI class is also seen throughout the region denoted by the Peridot Green color(0.01-0.051), most of those areas fall into the non-agricultural regions(presumably in the mountains). This map signifies that the health of the vegetation is deteriorating with time, especially in the agricultural areas, which can impact the production and therefore food security.

5.7 Land Productivity

The land productivity dynamics of Kyrgyzstan was mapped in Earth Map. The map shows the areas of declining productivity(red), early signs of decline(pink), stable-but stressed(yellow), Stable not stressed and increasing productivity (Figure 52, Figure 53, Figure 54).

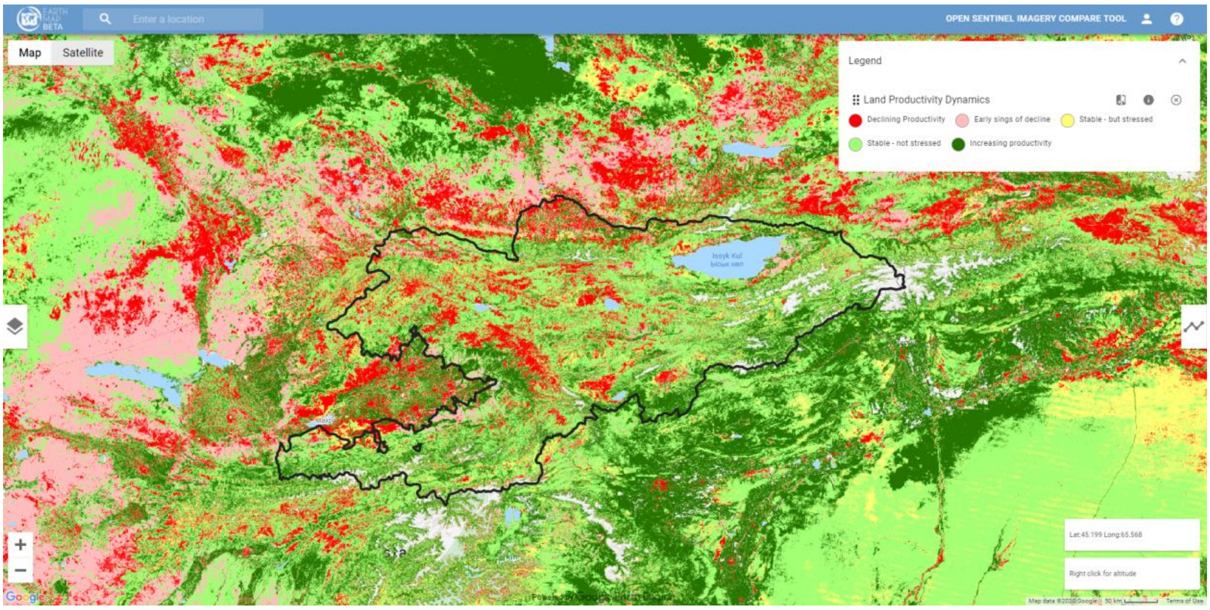


Figure 52: Earth Map Land Productivity Dynamics in Overall Kyrgyzstan (2001 to 2018)

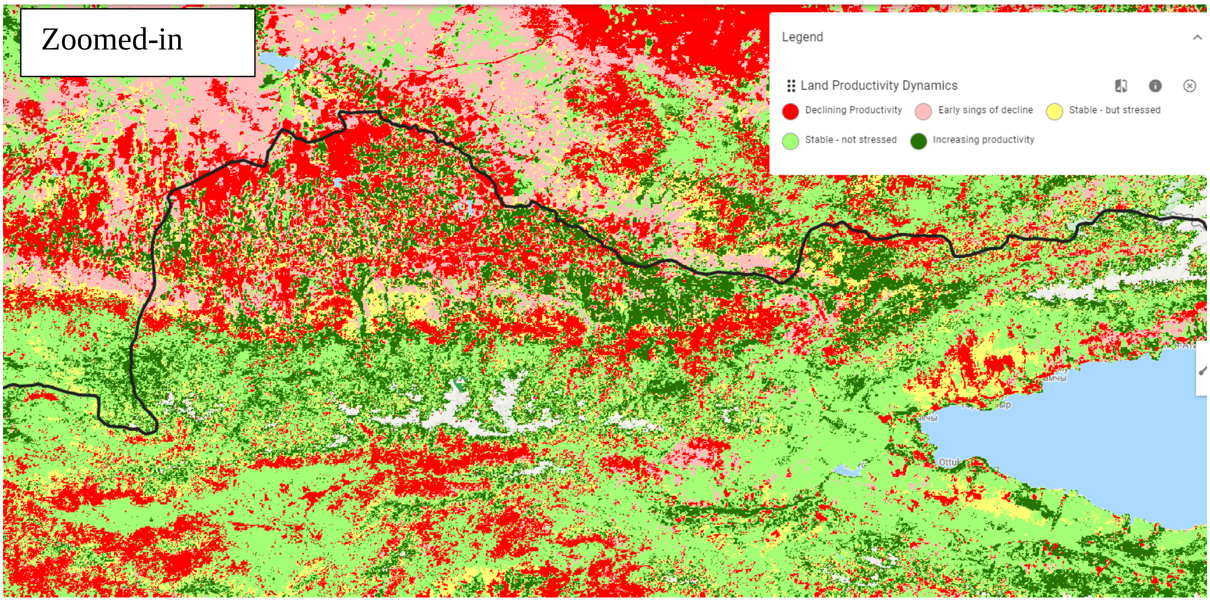


Figure 53: Earth Map Land Productivity Dynamics in Bishkek Area (2001 to 2018)

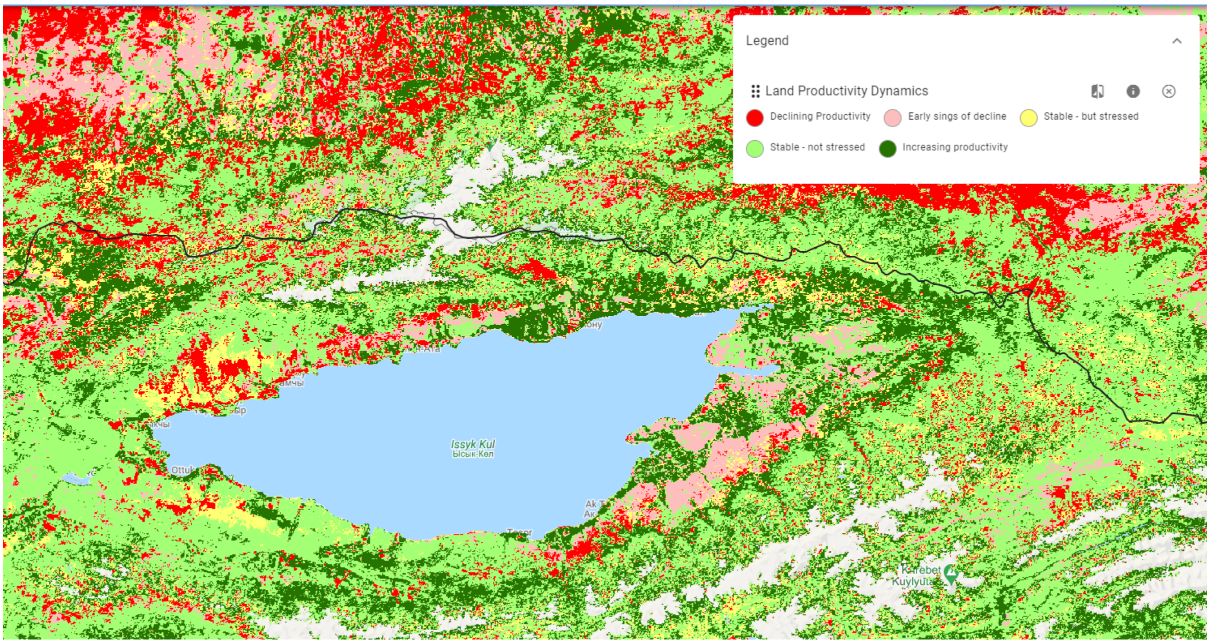


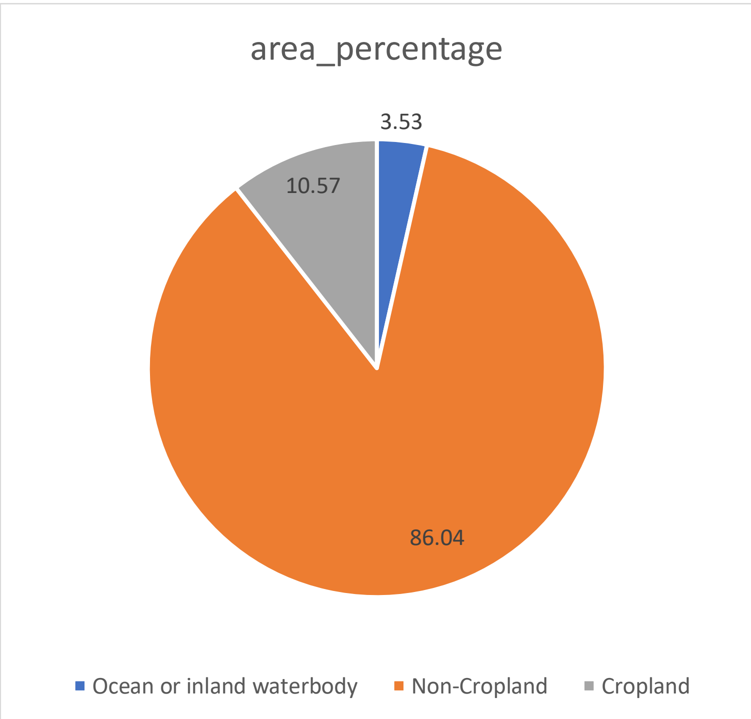
Figure 54: Earth Map Land Productivity Dynamics in Issyk Kul Area (2001 to 2018)

The first map of Figure 52 shows the overall scenario of Kyrgyzstan land productivity and Figure 53 shows the northern area Bishkek where most of the agricultural activities happen. The dominance of Red and Pink color in that area indicates that most of the agricultural land are in the "Declining productivity" and "Early Signs of Decline" zone. Some areas although shows dark green color of Increasing Productivity, compared to the declining zones, they are very less. Figure 54 shows lake Issyk Kul area which also has some agricultural areas around the lake (Figure 29) where the land Productivity is also declining. This can refer to the fact that the lands due to being overused for agriculture and pastures are losing their productivity. Climatic factors such as temperature and precipitation also play an important factor here. It is important to notice here that although the climatic factors such as precipitation and root zone soil moisture may seem to increase drawing a positive scenario for the food security, the soil nutrition can be on the decline which declines the overall productivity of the lands suitable for agriculture.

6. Analysis of Food Security Threats and Implications

It is very crucial to understand the implication of the mapped parameters in the overall food security issues of Kyrgyzstan. As food security is a multi-dimensional complex term that integrates different explorable parameters, this research is focusing on the production parameter's relation to climate change.

Due to the geographical location and feature of the country, suitable lands available for agricultural activities are very less. According to Earth Map USGS data, the percentage of cropland in Kyrgyzstan is only 10.57% where the inland waterbody is 3.53% and non-cropland is 86.04% (Figure 55). Most of these non-cropland areas are falling under the high elevated mountain zones of Kyrgyzstan. The agrarian lands can only exist in the lowland and valleys of the mountains.



Class name	Area(ha)	Area(%)
Ocean or inland waterbody	702,643.21	3.53
Non-Cropland	17,126,108.17	86.04
Cropland	2,104,225.62	10.57

Figure 55: Earth Map USGS GFSAD30 Global Food Security-Support Analysis Data of Kyrgyzstan Cropland(2017)

Due to the low percentage of available land, the existing lands are extensively used for agricultural activities which are decreasing the nutrition contents hence the productivity of the land. According to World Bank annual dataset, the agricultural area of Kyrgyzstan is on the decline from 2000 to 2016 (Figure 56).

Figure 56: Agricultural land (% of land area) of Kyrgyzstan (World Bank)

From the trendline graph of Figure 56, it can be seen that the percentage of agricultural areas increased from 55.9% at 2000 to 56.5% at 2003 which is the highest peak of the graph. After that, the percentage is gradually declining till 2016. From the analysis of the research, we can see the small number of agricultural areas in Kyrgyzstan (Figure 27). If the percentage of these areas lower, then the food security condition of the country will definitely be negatively impacted. The agricultural sector accounts for 38% of GDP in Kyrgyzstan which is the highest in Central Asia (Bobojonov and Aw-Hassan 2014). Any negative impact on the production of the crops will therefore definitely impact the overall GDP of the nation.

The change in climatic parameters can affect the production side of the food security. The first parameter that can the high possibility of affecting the crop production of the region From the average temperature map (Figure 34) and temperature change map(Figure 35), it is evident that the temperature is increasing in the country. Upon focusing on the agricultural areas, it was observed that they were falling under significantly higher temperature than the other areas of the region. This occurrence can induce drought in this area. Datasets from Kyrgyzstan Spatial was mapped in this research for detecting the areas which were arid from 1950 to 2000, which expressed a generalized function consisting precipitation, temperature, and potential evapotranspiration (PET) in terms of aridity index (Figure 57).

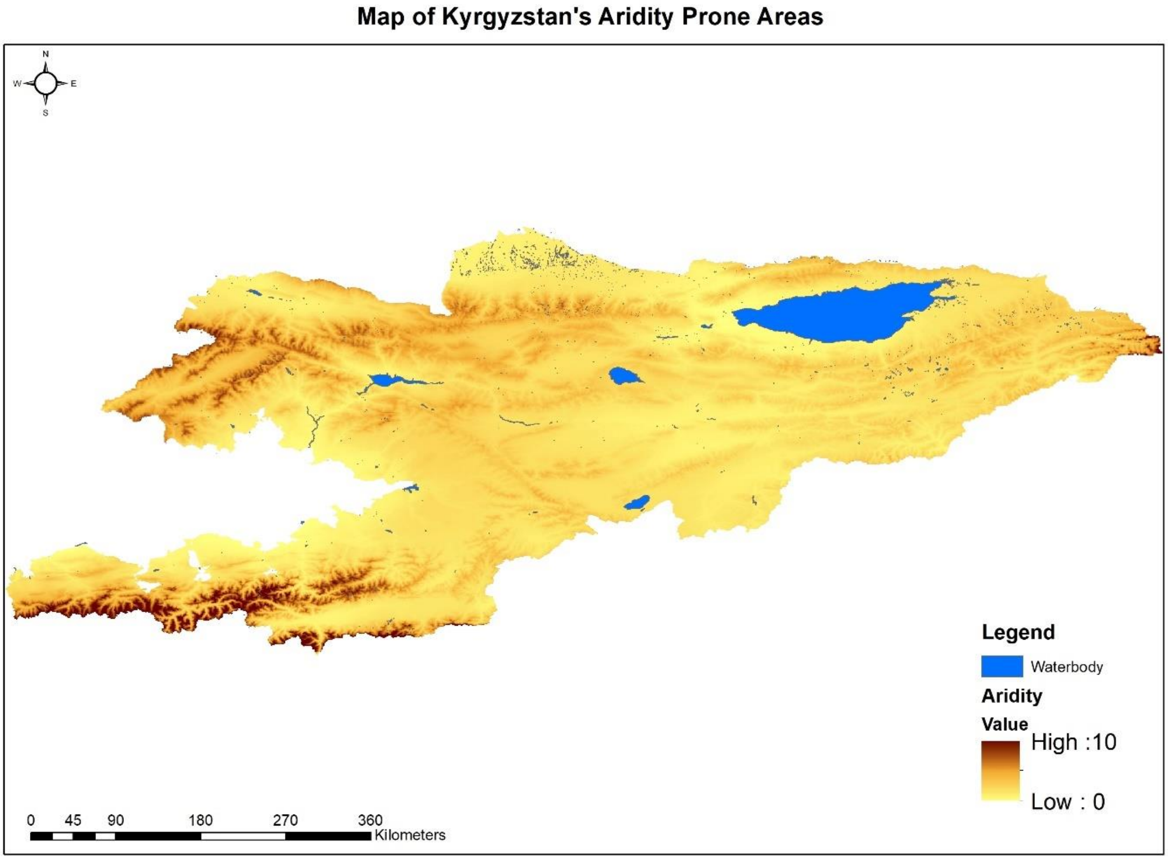


Figure 57: Arid Areas of Kyrgyzstan from (1950-2000)

The significance of this aridity map is that it can be compared with the temperature and precipitation maps of this research which showed the change in different areas of the nation from 2000 to 2020 (Figure 34, Figure 40). If these areas are compared, the climate change can be visibly noticeable as new areas, especially the agricultural ones, are becoming more and more temperate with gradual increase of precipitation that might aid to fill the climatic water deficit.

To determine how this change has affected the crop production it is important to see the production of some of the crops and if they are facing any deficit in the climate for growth and yields. For this, World Bank datasets were used first to see the overall growth of crops (Figure 58, Figure 59, Figure 60).

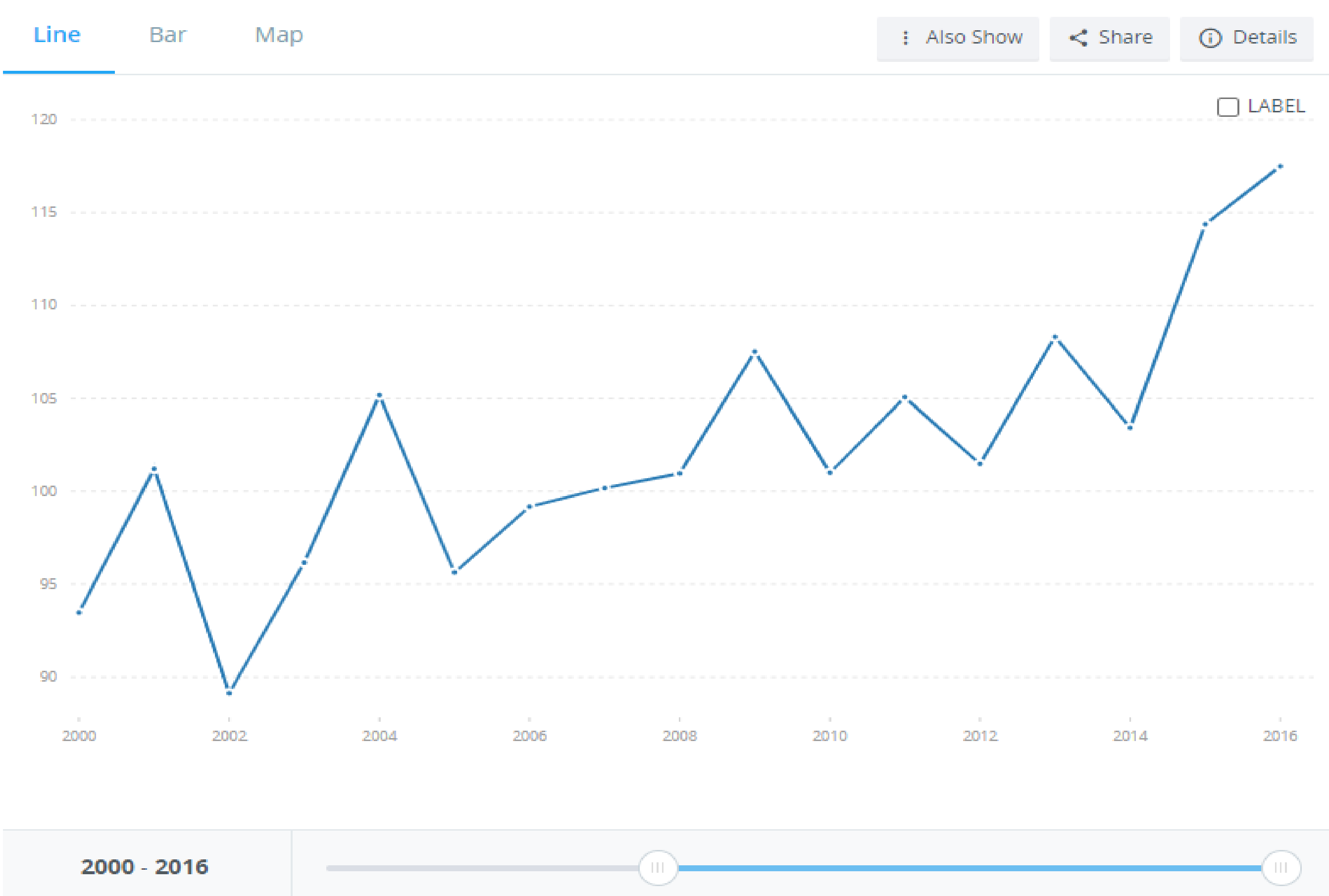


Figure 58: Kyrgyzstan Crop production(weighted average) index (2000-2016) (World Bank 2016).

The overall annual crop production index shows that the production has gone up from 2000 to 2016 (Figure 58). The crop production index in this figure is showing every year's production comparing it to base period 2004-2006 and includes all the crops of Kyrgyzstan except the fodder crops for pasture (such as, Alfalfa). The problem with this kind of overall datasets is that it is weighted average in kind, is compared to one base period and mostly do not consider the crop nutrition and climatic variability.

The annual cereal and livestock production trend was also available in the World Bank data site from where it can be seen that the cereal production is showing an irregular trend (Figure 59). The production had an overall downward trend from 2000 till 2007(approximately 1.42 metric ton) and then it shows an irregular upwards for the next years till 2016 when the last datapoint(1.71 metric ton) indicated a downward trend onwards (Figure 59).

Figure 59: Annual Cereal production (metric tons) (2000-2016) (World Bank 2016)

On the other hand, the livestock production shows an increasing trend graph from 2000 to 2016 which denotes that the production of livestock is increasing compared to the base production class 2004-2006 which was determined for these graphs (Figure 60). As Kyrgyzstan's food production system has livestock production obtaining a significant percentage, the increasing trend of livestock is an indication that the farming system is focusing more on livestock growth.

Figure 60: Annual Livestock production(weighted average) index(2000-2016) (World Bank 2016)

While the World Bank database graphs show increase in weighted average production increasing in many crops and livestock, it is needed to assess the climatic parameter's effect on the crops to ensure they are getting enough nutrients from the climate. The FAO AQUASTAT tool was used for determining the crop evapotranspiration and climatic water deficit.

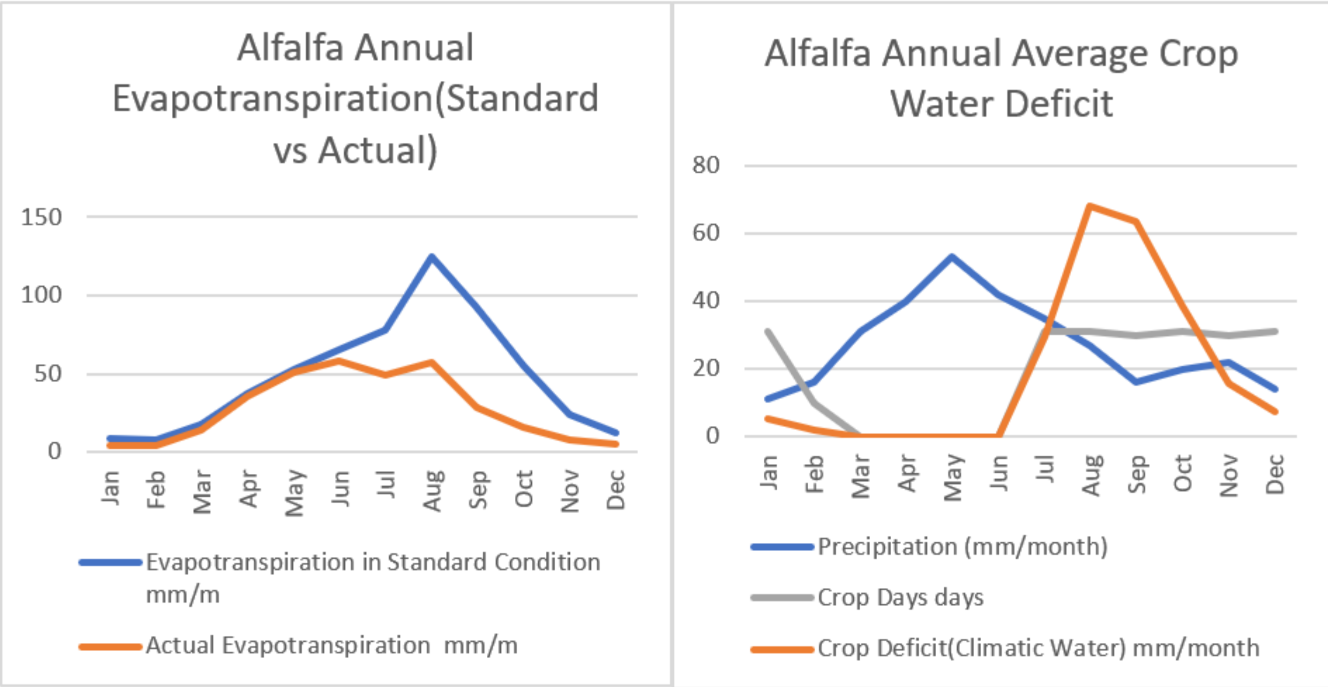


Figure 61: Alfalfa(Pasture Feed) Evapotranspiration and Crop water Deficit(FAO AQUASTAT)

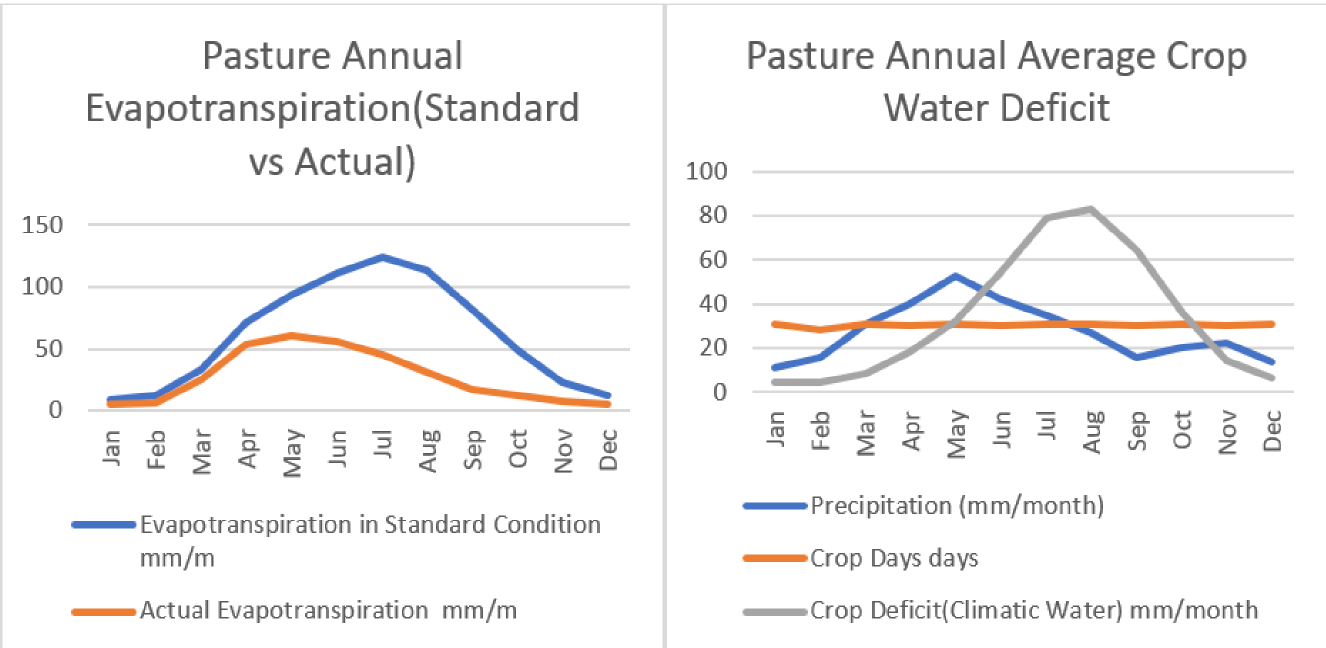


Figure 62:Pasture Evapotranspiration and Crop Water Deficit(FAO AQUASTAT)

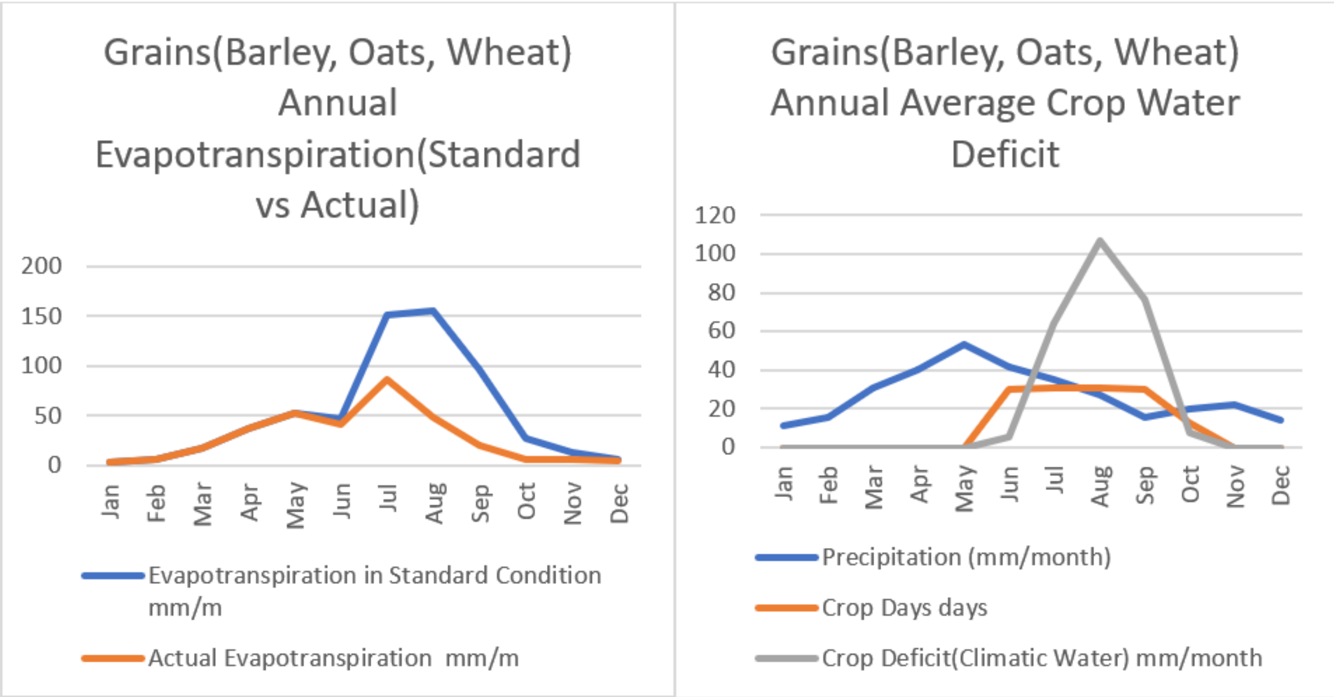


Figure 63: Grains(Barley, Oats, Wheat) Evapotranspiration and Crop Water Deficit(FAO AQUASTAT)

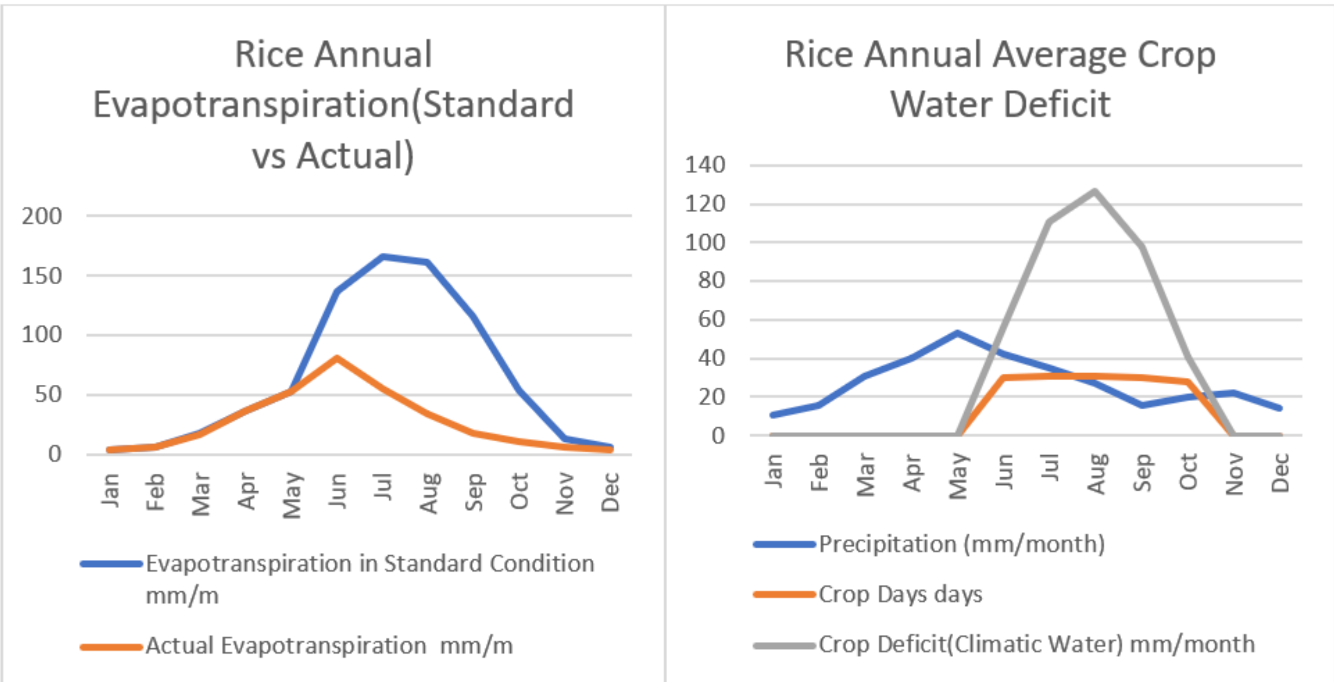


Figure 64: Rice Evapotranspiration and Crop Water Deficit(FAO AQUASTAT)

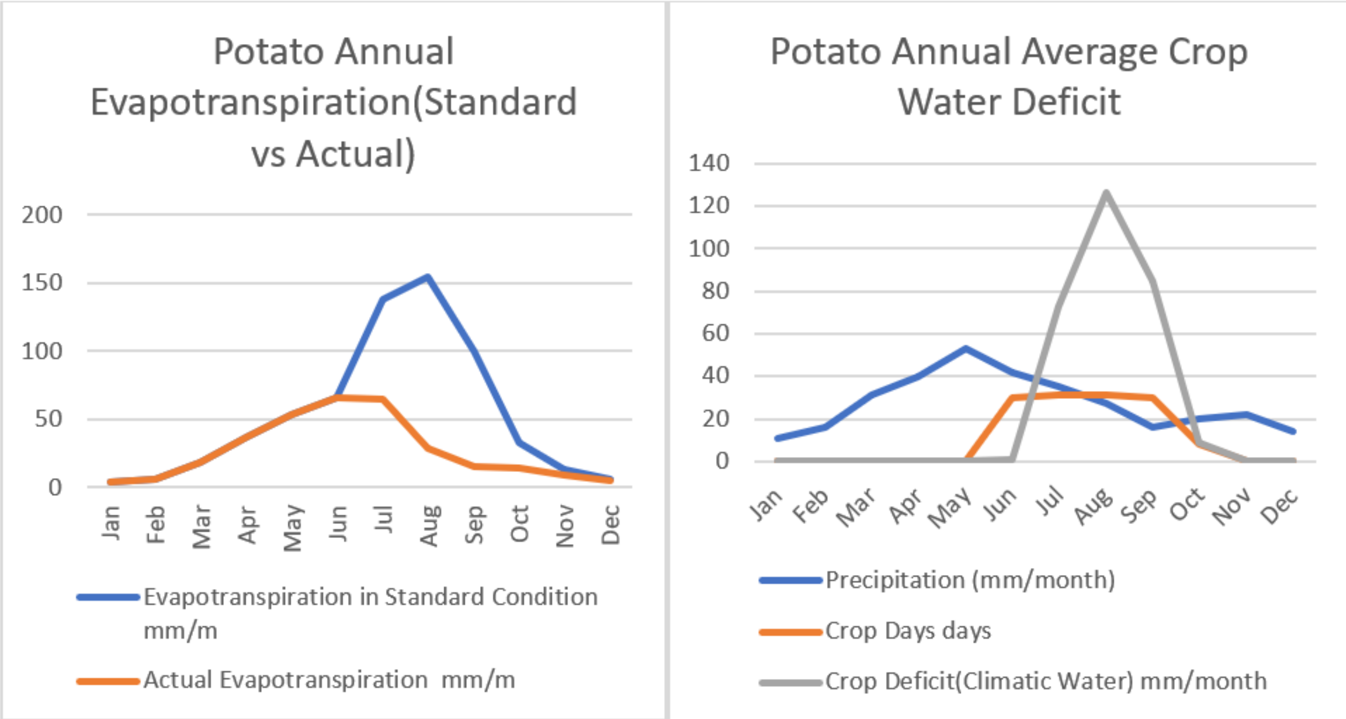


Figure 65:Potato Evapotranspiration and Crop Water Deficit(FAO AQUASTAT)

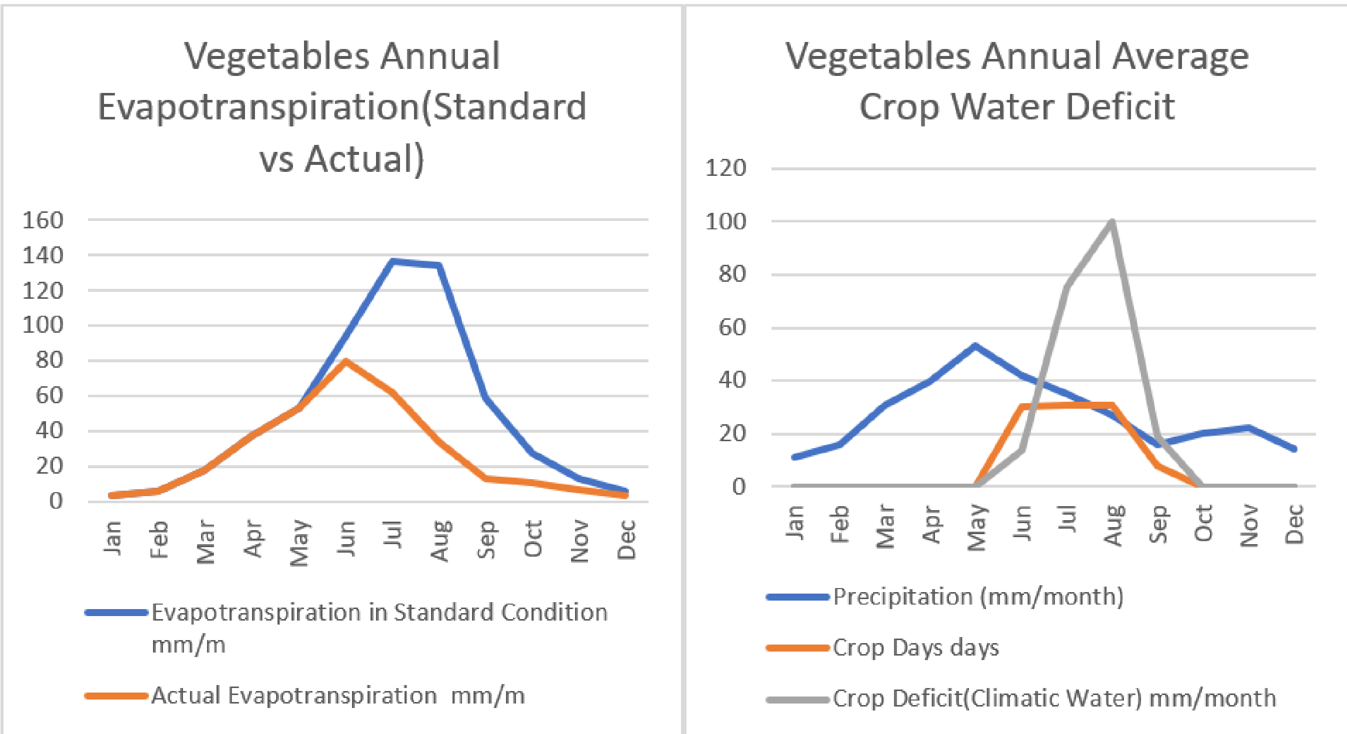


Figure 66: Vegetables Evapotranspiration and Crop Water Deficit(FAO AQUASTAT

From the graphs of the FAO AQUASTAT data, the pasture feed Alfalfa(Figure 61), Pasture Land (Figure 62) and crops(Barley, Oats, Wheat, Rice, Potato, vegetables) (Figure 63, Figure 64, Figure 65, Figure 66) can be seen highly deficient of climatic water even though the precipitation is high. If this is related to the interpolated precipitation maps of this research (Figure 40, Figure 42), the amount of precipitation increase through last decade is not still fulfilling the climatic water demand of the crops and pastures. Also, the evaporation graphs show that the actual evapotranspiration is much lower than the standard evapotranspiration values for all the crops and pastures. This can be related to the evapotranspiration map(Figure 44) where the evapotranspiration rate is seen to go higher but it is evident upon comparing with the graphs that the crops are not meeting the standard evapotranspiration values. So the average evapotranspiration value must contain higher percentage of surface evaporation value than plant transpiration. The evidently increasing temperature(Figure 34, Figure 35) can be another very significant factor here for the climatic water deficit and the low value of actual evapotranspiration.

Impact of climate change on Food Security is a multi-dimentional factor. It not only affects the availability(production) but also the accessibility, utilization and stability of food. Although the growth of production is seen to have grown since 2000, the population and food demand has also increased. While lack of lowland for agriculture was already an issue, the degradation of those existing land (Figure 52, Figure 53, Figure 54) is an added obstacle for the food security. Overuse of fertilizers, soil nutrients, salinization and desertification of the suitable agricultural areas make the food generation system extremely vulnerable. This is currently deemed as one of the main reasons to affect the production growth of agriculture around the world. Soil degradation can be both human or climate induced and usually refers to the state of soil bein eroded by wind or water, nutrient depletion, decline in organic matter, salinization, leaching and so on (Bindraban et al. 2012). As the realization hits that soil as a resource needs to be treated as a non-renewable resource, the need of more quantitative research on the impact of this land degradation upon the food systems and the loss brought by it, increases. It is estimated that land erosion and degradation is causing around 700 to 14.000 million Euros annually in Europe (Bindraban et al. 2012). To avoid such kind of economic loss, the degradation of the lands in Kyrgyzstan should be taken into serious consideration and proper measures should be taken for preserving the soil of the country while ensuring the food security.

While talking about the production of crops for addressing the food security issues in Kyrgyzstan, it is also very important to take into account the recent events. The food security of Kyrgyzstan as most other Central Asian countries depend upon the economic condition, logistics of the whole food system, incomes, natural disasters and so on. When the COVID-19 pandemic crisis hit the world at the beginning of 2020, all the systems collapsed including the economy and food security. The recession, which is predicted to be worsened in the future, has been resulted in unemployment and unaffordability for food. The lockdown due to the virus affected logistics of the crop production systems around the world. This phenomenon will definitely affect the already challenged food security of Kyrgyzstan as the country is yet not self-sufficient in food production. The recession of workers in Russia is creating an inbound migration of workers in Kyrgyzstan which will increase the demand for food in the country but also the lack of income due to unemployment.

The inter-connectedness of climate change parameters and food production with other factors such as global pandemic like COVID-19, persuades that all these issues need to be addressed together for proper policy and management measures to ensure food security for the population. The changing parameter's sensitivity to crops should be carefully researched to determine the limiting factors and maximizing the productivity.

7. Conclusion

The principal aim of this research was to explore the extent of climatic parameters change in Kyrgyzstan and their relation to the existing food security problems of the country. The problem statement oriented around the relation between climate change parameters and their impact on the production side of the food security system in Kyrgyzstan. The objective was to spatially analyze these climatic parameters that has direct relationship to crop production using open data sources.

The research analyzed and explored many statistical and remotely sensed data for determining the crop production areas in Kyrgyzstan and the climatic parameters average change for last 2 decades. These climatic parameters were surface temperature, precipitation, evapotranspiration, root level soil moisture, vegetation index and land degradation. While performing analysis on these parameters, different tools were used such as ArcMap, Google Earth Pro, Earth Map, NASA Giovanni and so on. Datasets were derived from OpenStreetMap, humanitarian data site, USGS(United States Geological Survey), MERRA Model, GLDAS(Global Land Data Assimilation System), ECMWF(European Centre For Medium-Range Weather Forecasts), FAO(Food and Agricultural Organization), World Bank and so on. The reason for using different data platforms was to avoid data bias and doing a research that had combination of multiple datasets.

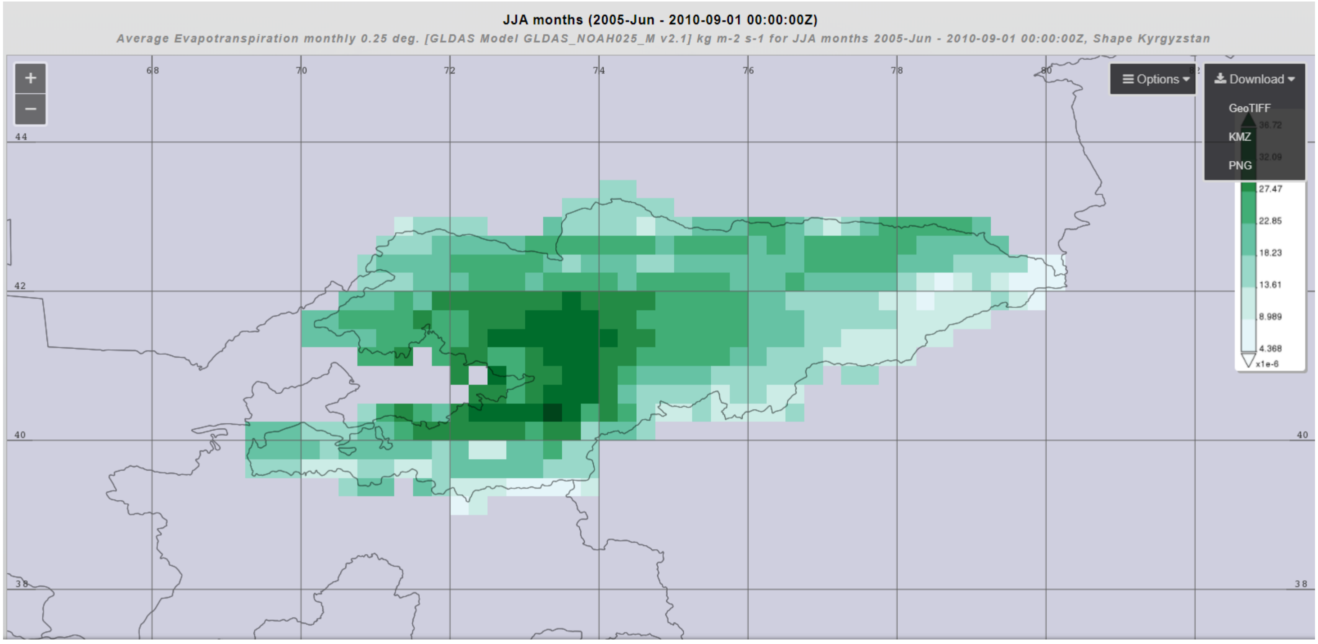
Complex geospatial analysis was done in different software for making the maps and detecting the change. Most of the analysis was firstly done in the online platforms such as Giovanni and Earth Map and was later these products were analyzed more in the offline platforms (i.e., ArcMap, Google Earth Pro). For calculating and comparing the results, years between 2000-2020 was divided into 4 time periods each having five years. The results of the climatic parameter analysis showed average values of different time periods which were compared with each other. The temperature is seen to increase from 2000 to 2020, especially in the agricultural areas of Kyrgyzstan. The precipitation, evapotranspiration and root level soil moisture are also seen to increase when the periods were compared. On the other hand, the land degradation maps confirmed the declining quality of the agrarian lands in Kyrgyzstan which poses a serious threat for the crop and pasture production.

The parameter analysis maps were later compared with credible food security related datasets form World Bank and FAO which graphed the progression of crops and pasture production since 2000. That comparison showed that that although the trend for overall average precipitation, soil moisture and evapotranspiration was seen to increase, the crops were having significant amount of climatic water deficit in the cropping days. The actual evapotranspiration value was also seen to be much lower than the standard value. This result proclaims that even though some agriculture related parameters are going up, this is not yet fulfilling the crop nutrient needs.

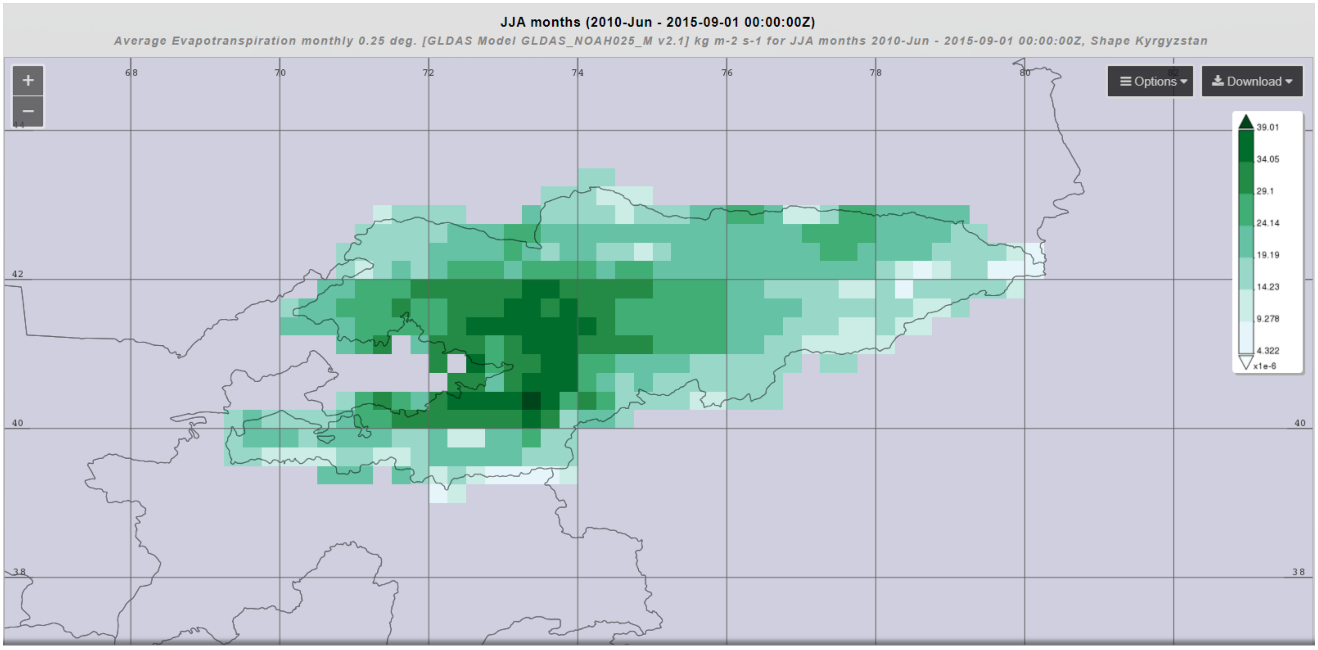
The results of this study can aid in the climate change and food security related research on Central Asia. This study shows how open data can be used for visualizing different parameters affecting food security which is a very cost-efficient way. The findings of this study in different areas can become a base for on field studies which can confirm the direct impact on the crop growth and yields. The vulnerable areas of the maps can be chosen as study areas for further in-depth food security and climatic analysis of parameters such as soil, temperature, precipitation, vegetation, and evapotranspiration. Moreover, policymakers of the countries can also benefit from the study as the maps identify the areas that need more emphasis and agricultural technology development. Additionally, the study can be a template for analyzing climate change and impact on crop production for any other vulnerable countries of the world.

To address the issues of food security in a region, many sides are needed to be considered. Although this study only focused on the production of crops and pastures, other parts of food security can also be connected with these results for avoiding risks of production failure and maximizing the yields. All the visualized maps using open data and accessible satellite imagery demonstrated the potential of GIS, remote sensing, and open data platform’s usability for addressing the threats of agriculture and food security.

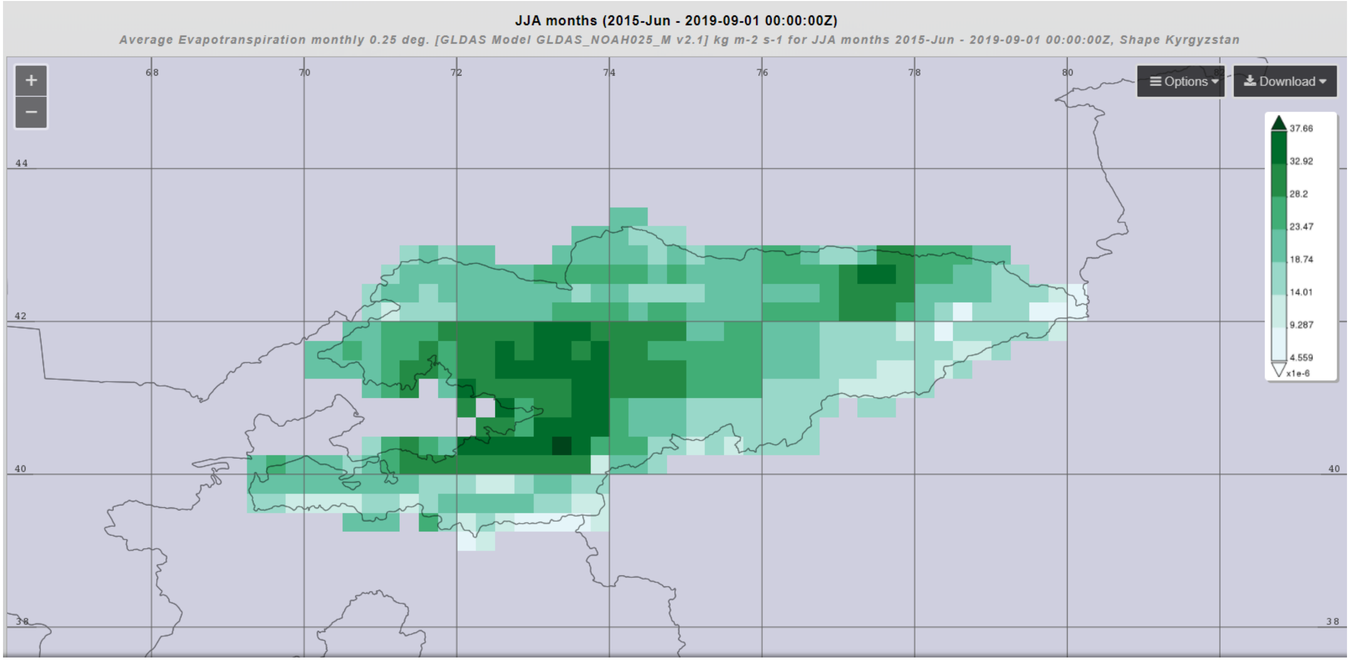
Appendix



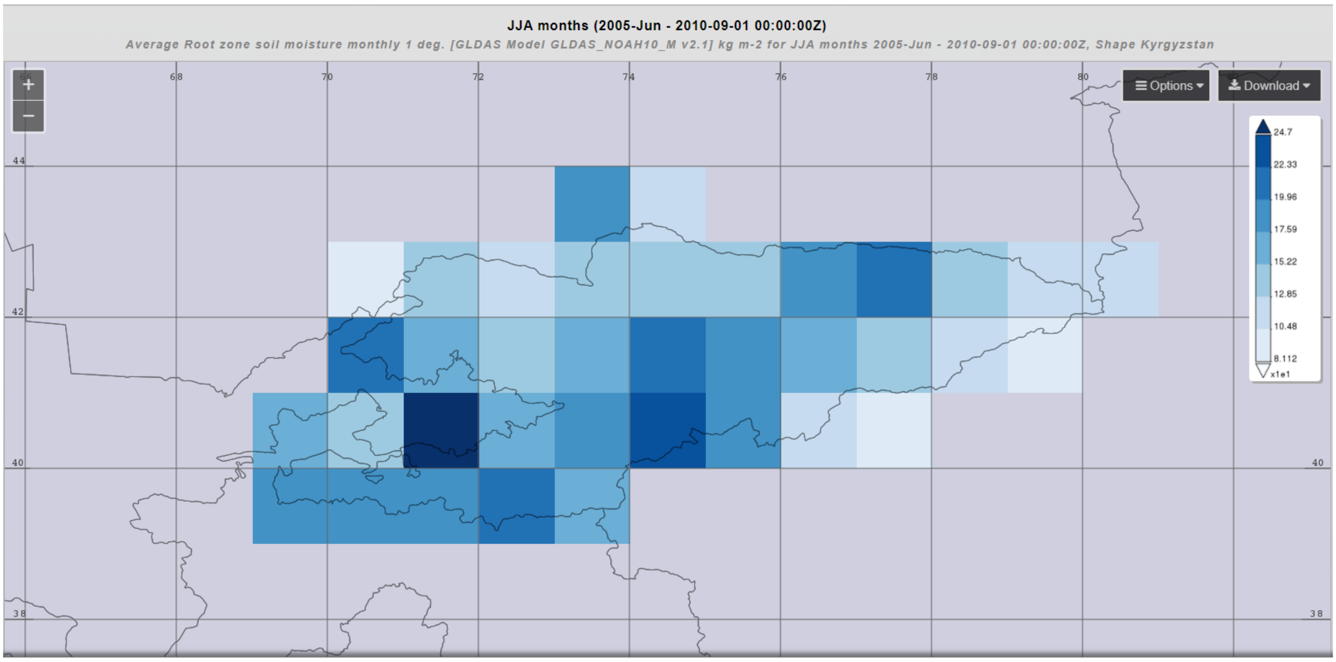
Appendix 1: Giovanni Summer (June- August) Average Evapotranspiration (2005-2010)



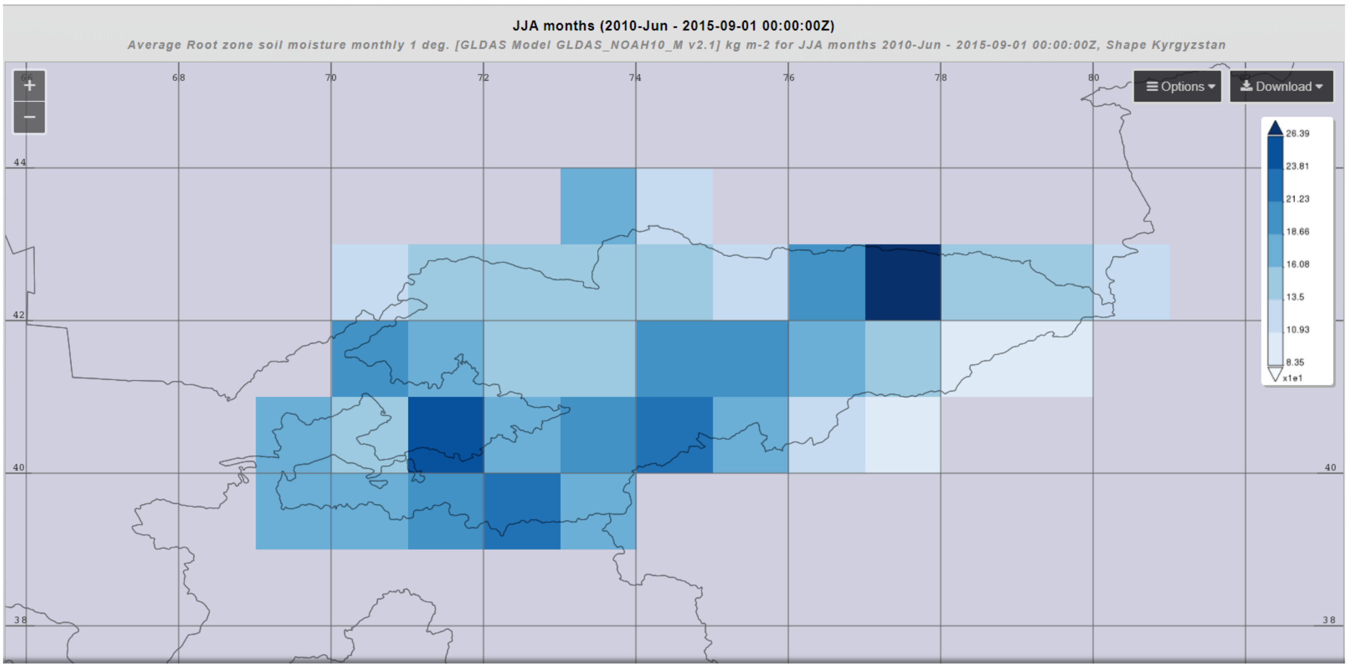
Appendix 2: Giovanni Summer (June- August) Average Evapotranspiration (2010-2015)



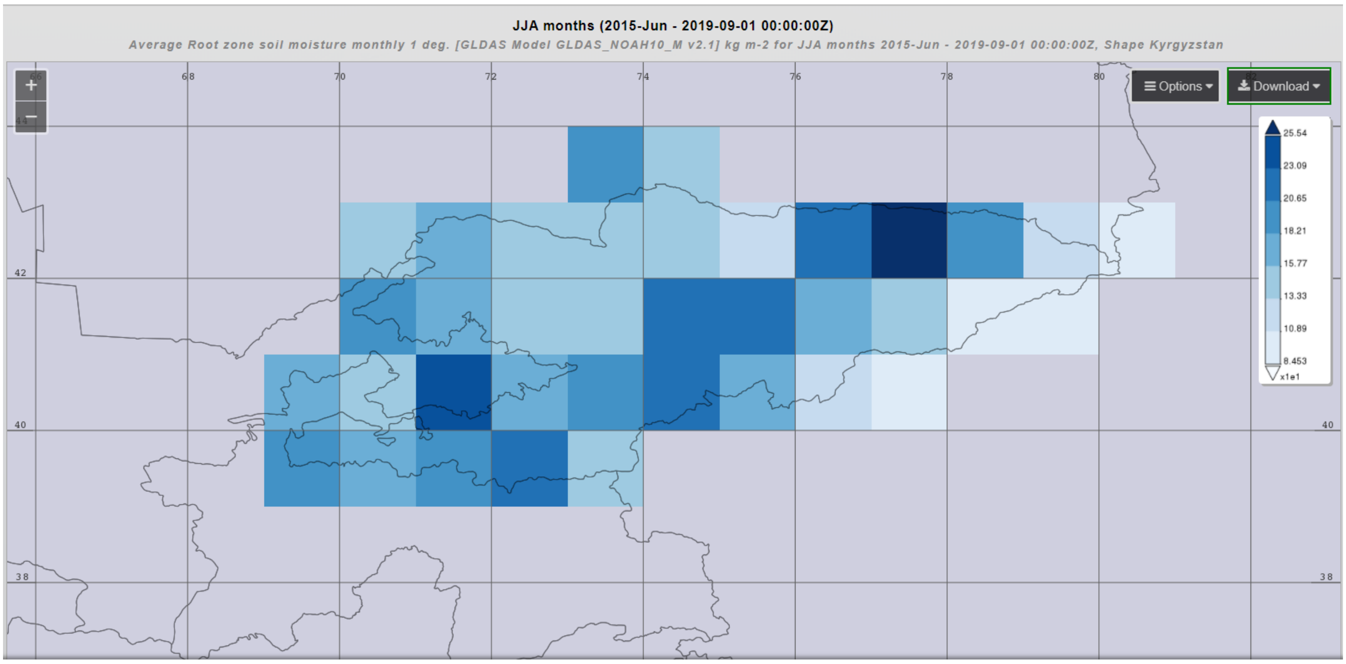
Appendix 3: Giovanni Summer (June- August) Average Evapotranspiration (2015-2019)



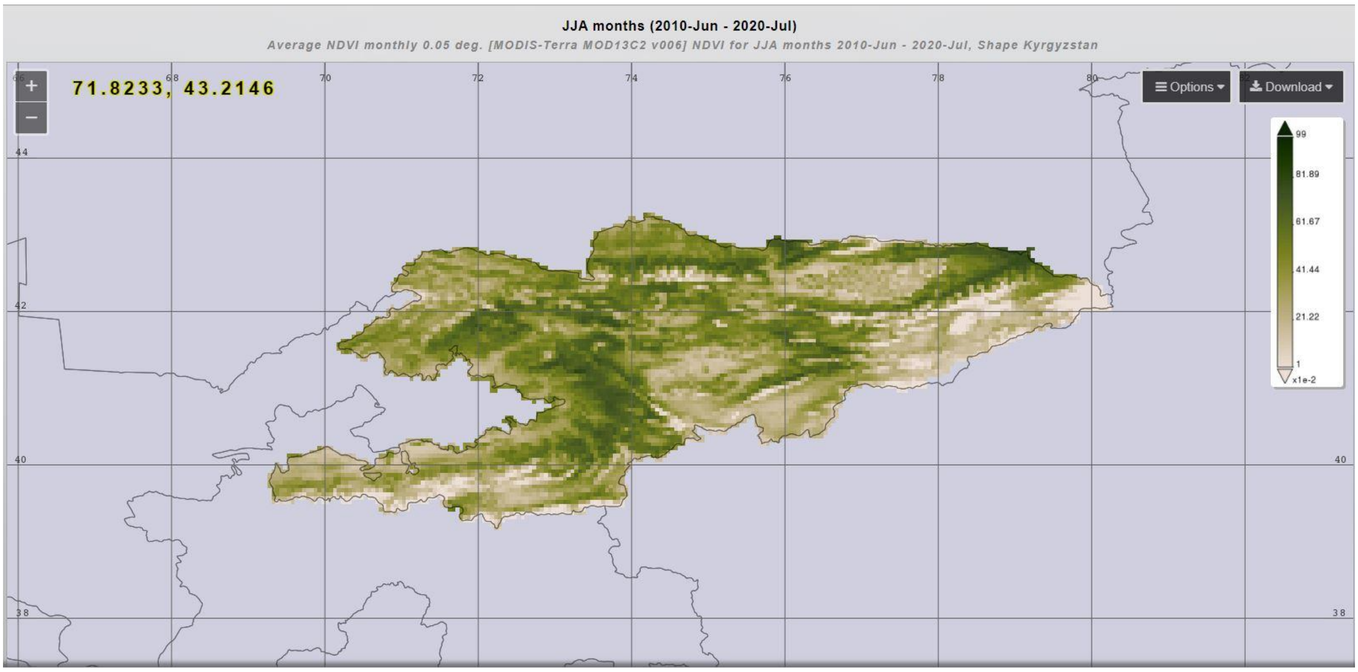
Appendix 4:Giovanni Summer (June- August) Average Root Zone Soil Moisture (2005-2010)



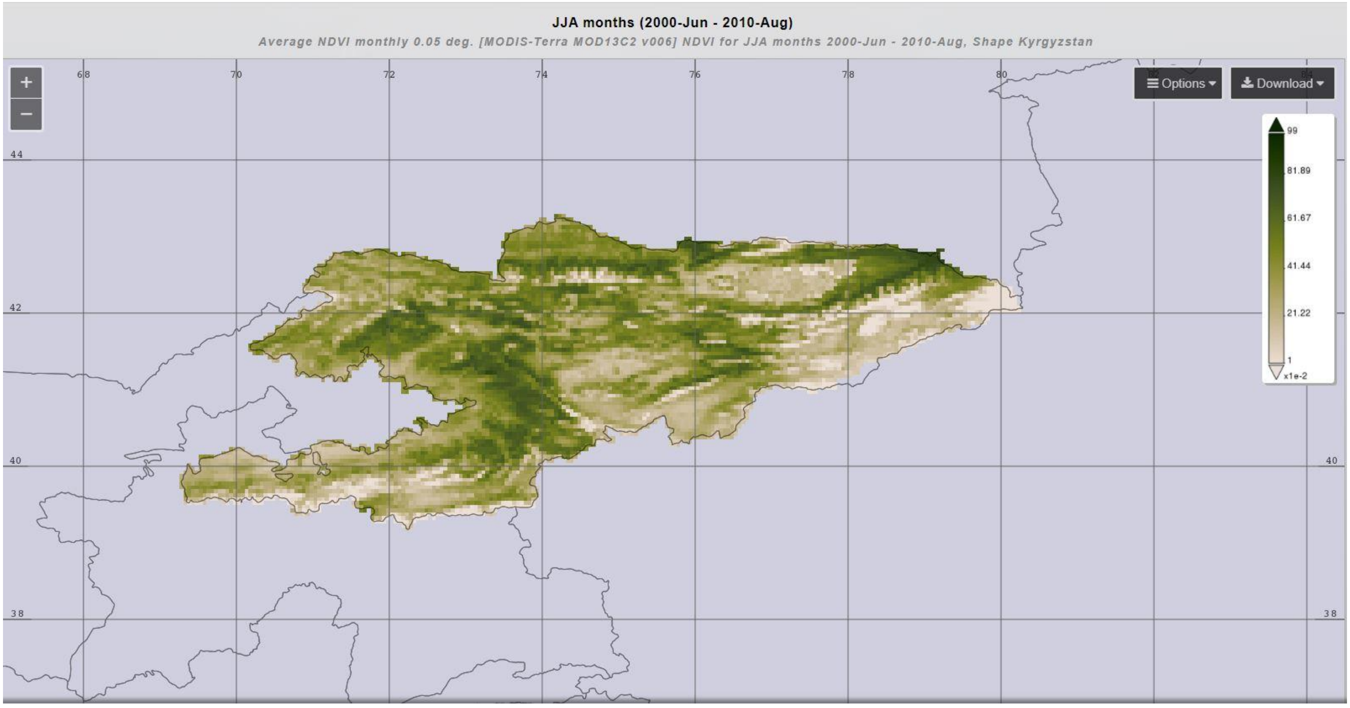
Appendix 5: Giovanni Summer (June- August) Average Root Zone Soil Moisture (2010-2015)



Appendix 6:Giovanni Summer (June- August) Average Root Zone Soil Moisture (2015-2019)



Appendix 7:Giovanni Summer (June- August) Average NDVI monthly (2000-2010)



Appendix 8:Giovanni Summer (June- August) Average NDVI monthly (2010-2020)

References

Aleksandrova, Mariya, Lamers, John PA, Martius, Christopher and Tischbein, Bernhard .2014. *Rural vulnerability to environmental change in the irrigated lowlands of Central Asia and options for policy-makers: a review*. Journal of Environmental Science and Policy. 41:77–88. doi:10.1016/j.envsci.2014.03.001.

Bindraban, Prem S, Marijn van der Velde, Liming Ye, Maurits van den Berg, Simeon Materechera, Delwendé Innocent Kiba, Lulseged Tamene, 2012. "Assessing the Impact of Soil Degradation on Food Production." *Current Opinion in Environmental Sustainability* 4 (5): 478–88. https://doi.org/10.1016/j.cosust.2012.09.015.

Bobojonov, Ihtiyor, and Aden Aw-Hassan. 2014. "Impacts of Climate Change on Farm Income Security in Central Asia: An Integrated Modeling Approach." *Agriculture, Ecosystems & Environment* 188 (April): 245–55. https://doi.org/10.1016/j.agee.2014.02.033.

Allen, Richard G., Luis S. Pereira, Dirk Raes, and Martin Smith. 1998. "FAO Irrigation and Drainage Paper,". Food and Agricultural Organization (FAO). Rome, 1998.

Campbell, James B., and Randolph H. Wynne. 2011. *Introduction to Remote Sensing, Fifth Edition*. Guilford Press.

Clay, Edward. 2002. *Food Security: Concepts and Measurement*, Paper for FAO Expert Consultation on Trade and Food Security: Conceptualizing the Linkages Rome, 11-12 July 2002. Published as Chapter 2 of *Trade Reforms and Food Security: conceptualizing the linkages*. Rome: FAO, 2003

CRISP (Centre for Remote Imaging, Sensing and Processing). 2001. "Principles of Remote Sensing - Centre for Remote Imaging, Sensing and Processing, CRISP.". https://crisp.nus.edu.sg/~research/tutorial/optical.htm.

DigitalGlobe. n.d. 'Short Wave Infrared Imagery (SWIR)'. Accessed 1 July 2020. https://www.digitalglobe.com/products/short-wave-infrared.

Earth Observing Systems. n.d. '6 Spectral Indexes on Top of NDVI To Make Your Vegetation Analysis Complete – EARTH OBSERVING SYSTEM'. Accessed 1 July 2020. https://eos.com/blog/6-spectral-indexes-on-top-of-ndvi-to-make-your-vegetation-analysis-complete/.

FAO (Food and Agriculture Organization). 1983. *World Food Security: A Reappraisal of the Concepts and Approaches.* Director General's Report. Rome.

FAO (Food and Agriculture Organization). 1996. Rome Declaration on World Food Security and World Food Summit Plan of Action. World Food Summit. 13-17 November 1996. Rome.

FAO (Food and Agriculture Organization). 2002. *The State of Food Insecurity in the World 2001*. Rome.

FAO (Food and Agricultural Organization). 2016. "Food Security and Nutrition Programme for Kyrgyzstan," November 6, 2016.

FAO (Food and Agriculture Organization). 2020. "Suite of Food Security Indicators." FAOSTAT. The Food and Agriculture Organization. Accessed June 2, 2020. http://www.fao.org/faostat/en/#data/FS/visualize.

FAO AQUASTAT. n.d. AQUASTAT Climate Information Tool. Accessed August 10, 2020. http://www.fao.org/aquastat/en/climate-info-tool/.

FAO, IFAD, UNICEF, WFP and WHO. 2019. The State of Food Security and Nutrition in the World 2019. *Safeguarding against economic slowdowns and downturns*. Rome, FAO. Accessed June 8, 2020.

Fischer, Gunther, Shah, Mahendra, Van, Velthuizen Harrij, 2002. *Climate change and agricultural vulnerability*. Preprints. World Summit on Sustainable Development, Johannesburg, p 160.

Gregory, P.J, J.S.I Ingram, and M Brklacich. 2005. “Climate Change and Food Security.” *Philosophical Transactions of the Royal Society B: Biological Sciences* 360 (1463): 2139–48. https://doi.org/10.1098/rstb.2005.1745.

Global Nutrition Report. n.d. “Kyrgyzstan Nutrition Profile.” Global Nutrition Report. Accessed June 1, 2020. https://globalnutritionreport.org/resources/nutrition-profiles/.

Hamidov, Ahmad, Helming, Katharina, and Balla, Dagmar. 2016. ‘Impact of Agricultural Land Use in Central Asia: A Review’. *Agronomy for Sustainable Development* 36, no. 1 (March 2016): 6. https://doi.org/10.1007/s13593-015-0337-7.

IPCC (Intergovernmental Panel on Climate Change). 2001. Climate Change: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge Univ Press, Cambridge, UK.

IPCC (Intergovernmental Panel on Climate Change). 2007a. Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge Univ Press, Cambridge, UK.

IPCC (Intergovernmental Panel on Climate Change). 2007b. Climate Change: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge Univ Press, Cambridge, UK.

Jones, Hamlyn G, and Robin A. Vaughan. 2011. Remote Sensing of Vegetation. Vol. 22(6). Journal of Vegetation Science.

Li, Zhongfei, Xiaobing Li, Dandan Wei, Xu Xu, and Hong Wang. 2010. 'An Assessment of Correlation on MODIS-NDVI and EVI with Natural Vegetation Coverage in Northern Hebei Province, China'. Procedia Environmental Sciences 2: 964–69. https://doi.org/10.1016/j.proenv.2010.10.108.

Liang, Shunlin, Xiaowen Li, and Jindi Wang. 2012. Advanced Remote Sensing. Elsevier. https://doi.org/10.1016/C2010-0-67304-4.

Linz, Joseph, and David S. Simonett. 1976. *Remote Sensing of environment*. Print. Addison-Wesley Publishing, 1978.

Lioubimtseva E, Cole R, Adams J, Kapustin G, 2005. Impacts of climate and land-cover changes in arid lands of Central Asia. Journal of Arid Environments.62(2):285–308. doi:10.1016/j.jaridenv.2004.11.005

Malacara, Daniel. 2011. Color Vision and Colorimetry: Theory and Applications, Second Edition. 1000 20th Street, Bellingham, WA 98227-0010 USA: SPIE. https://doi.org/10.1117/3.881172.

National Statistical Committee of Kyrgyzstan, 2016. Information bulletin of the Kyrgyz Republic on food security and poverty. Accessed July 30, 2020. http://stat.kg/media/publicationarchive/a088fb17-45ea-4cf2-9e70-e253d44ea998.pdf).

Ohio State University(OSU), Miami University. n.d. "Article Maps & Charts | Origins: Current Events in Historical Perspective." Origins: Current Events in Historical Perspective. Accessed August 25, 2020. http://origins.osu.edu/article/69/maps.

Rosenzweig, C., F. Tubiello, R. Goldberg, E. Mills, and J. Bloomfield, 2002: Increased crop damage in the U.S. from excess precipitation under climate change. Glob. Environ. Change A, 12, 197-202, doi:10.1016/S0959-3780(02)00008-0.

Satellite Imaging Corporation. 2017. “Satellite Images for Natural Resources.” Satellite Imaging Corporation. 2017. https://www.satimagingcorp.com/applications/natural-resources/.

Schmidhuber, Josef, and Tubiello, Francesco N. June 2007. “Global Food Security under Climate Change.” Proceedings of the National Academy of Sciences 104, no. 50: 19703–8. https://doi.org/10.1073/pnas.0701976104.

Thenkabail, Prasad, John G. Lyon, Hugh Turral, and Chandrashekhar Biradar. 2009. Remote Sensing of Global Croplands for Food Security. CRC Press.

UNDP, 1994. *Human Development Report 1994.* Oxford and New York: Oxford University Press

United Nations. 1975. Report of the World Food Conference, Rome 5-16 November 1974. New York.

USGS (The United States Geological Survey). n.d. ‘Landsat Enhanced Vegetation Index’. Accessed 1 July 2020. https://www.usgs.gov/land-resources/nli/landsat/landsat-enhanced-vegetation-index?qtscience_support_page_related_con=0#qtscience_support_page_related_con.

World Bank. 1986. Poverty and Hunger: Issues and Options for Food Security in Developing Countries. Washington DC.

World Bank. 2016. “Crop Production Index (2004-2006 = 100) - Kyrgyz Republic | Data.” 2016.https://data.worldbank.org/indicator/AG.PRD.CROP.XD?end=2016&locations=KG&start=2000.

World Bank. 2020. “Kyrgyzstan Country Profile.” World Bank Climate Change Knowledge Portal. August 2020. https://climateknowledgeportal.worldbank.org/.

Zaitunah, Anita, Samsuri, Ahmad, Gulraiz and R A Safitri. 2018. ‘Normalized Difference Vegetation Index (Ndvi) Analysis for Land Cover Types Using Landsat 8 Oli in Besitang Watershed, Indonesia’. *IOP Conference Series: Earth and Environmental Science* 126 (March): 012112. https://doi.org/10.1088/1755-1315/126/1/012112.

Zhang, Yun, and Kerle, Norman. 2008. *Satellite Remote Sensing for Near-Real Time Data Collection*.https://www.researchgate.net/publication/230674340_Satellite_remote_sensing_for_near-real_time_data_collection.