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Wildfires in Kazakhstan: Investigating Wildfire Dynamics in Kazakhstan between 2001 and 2022

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Abstract

The study investigates the wildfire dynamics in Kazakhstan, comparing the burned areas between the two decades: 2001-2011 and 2012-2022. The wildfire literature in the context of Central Asia is scarce. So, the aim of the study is to fill the gap and explore if there were any changes in the wildfire patterns in Central Asia in the past 20 years. To accomplish this, satellite data were used, namely, the data from Fire_cci v5.1 and MODIS MCD64A1. Two different satellite imagery products were used to cross-verify the results. The results showed that when comparing the two decades, the overall burned area decreased by almost half. Moreover, when it comes to vegetation types, grasslands were the one that burned the most. The study gives two reasons behind these trends. It suggests that greater burned area in the first period might be explained by massive outmigration from the rural areas and the rapid decrease in livestock numbers in the 1990s. It further claims that stricter land management policies and fire management initiatives taken in the second decade might explain, why the burned area decreased in the second decade. The findings show that land management plays crucial role in wildfire management, and that effective policies can reduce fire hazard in the steppes.

Keywords: wildfire dynamics, wildfires in Kazakstan, fire management, fire regimes, Kazakhstan, Central Asia, grassland fires

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Table of Contents

List of Figures

1. Introduction

1.1 Background

Did you know that one of the largest wildfires in the world occurred in Kazakhstan? In June of 2023, a fire erupted in one of the ancient pine forests of Eastern Kazakhstan claiming the lives of 15 people and destroying more than 60,000 hectares of pristine ribbon forest in the protected area (Orda 2025). News like this are surely devastating, and the wildfires are becoming more and more prevalent around the world. When it comes to Kazakh steppes, wildfires have also become a source of serious danger and phenomenon that needs closer attention. Considering the impact of global warming and that Central Asia will experience longer drought periods and water shortage as it has never before, investigating the wildfire dynamics in the region is vital.

To understand what contributed to the wildfire dynamics we see today in Kazakhstan, one needs to delve deeper into the history of region. For the past several centuries, Kazakhstan overcame several crucial historical events that shaped everything from people's socioeconomic well-being to how the landscape was used over time. Kazakhstan's steppes went through four distinct historical shifts: pre-colonial nomadic times, sedentarization during Russian colonialism, collectivization and overexploitation of the lands during the Soviet era, and privatization of the lands after the independence. As nomads Kazakhs wisely used the pastures grazing the herds and rotating the grazing periods, so, the steppes do not burn out. Controlled burning was practiced for military or hunting purposes also (Chibilev and Bogdanov 2009). The number of livestock that Kazakhs owned made it possible for biofuel not to build up in the steppes, which decreased the possibility of large wildfires.

The Russian colonialism brought about some changes to the steppe. As slavic settlers arrived, some Kazakhs were sedenterized. Nevertheless, while social and economic structures changed, the majority of Kazakhs still remained to be nomadic. As Kerven, Robinson, and Behnke (2021) noted, there was a synergy between Kazakhs' lifestyle and the steppes' environment: apart from rotational grazing, there was also no overgrazing as every 10-12 "dzhut" (harsh winters where livestock numbers declined) occurred. So, the ecological capacity of the steppes was not reached as it took a long time for the livestock numbers to recover, and then the "dzhuts" would happen again (Kerven, Robinson, and Behnke 2021).

However, with the rise of Soviet Union Kazakhs were brutally sedenterized losing their livestock and homes. As the Soviets aimed at maximizing the production going far beyond the environmental limits of the steppes, the livestock numbers were maximised as much as possible with them grazing on territories where vegetation did not fully recover (Kerven, Robinson, and Behnke 2021). Later as the Virgin Lands campaign took over the vast steppes of Kazakhstan, the summer pastures and huge patches of fertile land was plowed, which caused the erosion and salinization of the lands (Kerven, Robinson, and Behnke 2021). The land degradation and the change in the vegetation cover all later contributed to the wildfire dynamics we see today.

After the dissolution of the Soviet Union, mass outmigration from the rural areas occurred. Previous collective farms were dismantled, the lands and the livestock were privatized, and previous agricultural management schemes were dismantled. As a result the biofuel build-up took place, which enabled destructive wilfires in the steppes. The economic crisis and the absence of appropriate policies in the newly independent state led to wildfires not being a priority on the government's agenda until the early 2010s. Nevertheless, wildfires need to be explored taking into account the effects of global warming that are becoming more apparent year by year. There is a scarcity in the literature when it comes to the wildfire research in Kazakhstan and Central Asia as a whole. However, research on wildfires in Kazakshtan will shed the light on wildfire dynamics not only in the region but in the world in general since it reflects how climate change is affecting different parts of the world. Thus my study fills the gap by exploring the fire trends in Kazakhstan showing the patterns and discussing what might explain those patterns.

1.2 Research Question and the aim of the study

The research question that I will try to answer in this study is "How have wildfire dynamics changed in the past two decades in Kazakhstan, and what explains those changes?". The aim of the research is to investigate the wildfire patterns in the country by comparing the burned areas between the two decades (2001-2011 and 2012-2022) and seeing if there has been any change. If there is a change or conversely a lack of any change, the reason behind the results will be explained. To achieve this, I will first use sattelite data provided by Fire_cci v5.1 sensor to obtain the images and information regarding the burned areas and affected vegetation classes in two decades. Then I will cross-verify the results I obtain using the data provided by MODIS MCD45A1 sensor. After comparing the burned area data over two decades, I will conduct further policy and literature and policy review to understand the results I gathered.

1.3 Thesis outline

In chapter 2, I will introduce the key literature in the wildfire research connecting it to what has been investigated so far globally and in the region. In chapter 3 of the thesis, I will explain in detail the data sources I used and their limitations and delve into the details of the research process . The chapter 4 will be dedicated to the results that I obtained. Chapter 5 will be the discussion section, where I will explain the results and their implications in

Kazakhstan. Finally, the last chapter will conclude the thesis outlining the major points yet again and suggesting the future directions of the research in the wildfire research.

2. Literature Review

2.1 Theoretical lenses of wildfire research in the literature

Scholars have been researching wildfire dynamics partly because fire is an important factor in the development of ecosystems and partly because increasing frequency of wildfires have had devastating effects on human lives and the planet in general. The research on wildfires goes as far back as to the middle of the 20th century, when fire considered to be a source of threat and most scholars focused on fire suppression and monitoring. Earlier works by (Albini 1976) and Rothermel (1972) were mainly aimed at introducing various mathematical models to predict fire behaviour and enhance suppression mechanisms. Countryman's (1972) article, however, stands out from his peers. He acknowledged human contribution to wildfires stating that grazing, timber harvesting, construction work, and other anthropogenic activities have influence on fire activity by changing the quanitity and properties of fuel (Countryman 1972). Though the article was still aimed at enhancing the understanding of fire eruption and its control.

In 1980s and 1990s, the focus gradually shifted towards understanding the fire as an essential ecological process that also forms ecosystems. One of the foundational pieces in wildire research from this period was a book called "Fire and Plants" by Bons and Wilgen (1996) who popularized the understanding of fire as a part of ecosystem which affected the distribution and evolution of plants. Fire was no longer considered as a complete source of danger that should be suppressed and fought against but as a naturally reoccuring phenomenon that shapes the vegetation on the planet.

Then starting from the 2000s as the impact of climate change started becoming more apparent its influence on the wildfire dynamics also became a prevalent theme in the literature. Bowman (2009) was one of the authors that acknowledged the warming of the weather and the extension of fire-prone periods. The article provided by Syphard et al. (2007) was also crucial in understanding how human activity affected the frequency of fire events and the size of the burned area. All in all, fire literature can be divided into three different lenses: ecological, climatic and land management. Today's scholar's try to use interdisciplinary approach, when investigating wildfires and their impact.

2.2 Fire as an ecological phenomenon

One of the most prominent theoretical lenses used in fire research is the ecological lense, which has become a separate branch of fire-related research called fire ecology. As the scholarship moved past the understanding of fire as a source of danger, authors started viewing wildfires as a part of ecosystems. In fact, wildfires are closely linked to biodiversity and vegetation, where both the fire and plants reinforce each other. Wildfires occurred far before the humans populated the Earth, and fire regimes formed today's land cover. As McLauchlan et al. (2014), Simon at al. (2009), and (Bond and Keeley 2005) stated wildfires serve as the drivers of natural selection of plants and other living creatures. For instance, the C4 grasslands were found to have spread thanks to fires that cleared woodlands and created favourable environments (Keeley and Rundel 2005; Pausas and Keeley 2009). Some plants adapted with some trees growing thicker barks and smoke triggering germination, i.e. the reproductive process in some species (Pausas and Keeley 2009). At the same time a number of authors also explained how fire regimes are affected by the plants, and that change in vegetation cover influences fire regimes (McLauchlan et al. 2014; Platt et al. 2016).

This link becomes more evident when humans intervene and supress fires. When fire is suppressed in lands with naturally flammable vegetation the accumulated biofuel results in more intense fires, changing the usual fire regimes. While the authors debate about the exact link between plants and fire, there is a strong link between the formation of today's biomes and fire regimes. In his book, (Archibold 1995) described four biomes that frequently experience wildfires which are savannas, Mediterrenian shrublands, tropical and temperate grasslands, and boreal forests. Bond, Woodward, and Midgley (2004) in their turn conducted a study stimulating a world without fires. The authors found that tropical and subtropical savannas and grasslands are fire-dependant meaning that without fires, these biomes would not have existed on our planet (Bond, Woodward, and Midgley 2004). Instead the areas would have been covered with forests and woodlands.

2.3 Viewing fire through climatic lense

Apart from ecological origins of fire more and more scholars have started exploring the impact of climate of fire regimes and their variability. Especially as the effects of climate change are becoming increasingly apparent researching its influence on global fire patterns and prevention of fire-related disasters is an urgent need. It is evident that apart from vegetation climatic variables are equally important sources of fire. Seasonality and appropriate climatic conditions are critically important factors that contribute to the ignition of fires in the ecosystems (Pausas and Keeley 2009). Flanningan et al. (2009) agree with Pausas and Keeley (2009) arguing that weather and climate are the decisive components in fire activity. What sets these authors apart from the supporters of ecological perspective is that they recognize that wildfires today are not just necessary ecosystem mechanism but that they are becoming a major natural hazard concern.

A number of authors have shown that the recent fire events are not just the result of ecological "selective" process but an anomaly. Bowman and his colleagues (2017) reported that between 1979 and 2013 the increase in the length of the fire season constituted almost 19% due the climate change. The same results were also obtained by Jolly (2015), who also predicted that that area prone to burning will likely double. This means that the areas that have not experienced much fire activity may become much more succeptable. Predicting how climate change may actually affect global wildfire trends is tricky because many factors are involved in the ignition of fires such as the amount of fuel, precipitation, temperature, etc. Especially as Krawchuk and Moritz (2011) reported that sometimes when there were climatic anomalies (for example, long dry seasons) the correlation with fire activity was not straightforward due to human intervention (such as quick fire detection and supression). Nevertheless, the climatic lense broadened the understanding of wildfires as solely ecological events. Fire is not just a natural event it can also be a driver of natural disasters and a contributing factor to the carbon emissions and global warming. Such an outlook on wildfires urges the scholars and policymakers to make sound policies in fire management.

2.4 Integrated approach to fire management

Finally, the last school of thought that can be identified in the literature is the lense of land management and socio-political governance. What sets this school of thought apart from those that have been discussed so far is that apart from studying wildire as an ecological phenomenon, the scholars acknowledge a human contribution to wildfire eruption and changes of the landscape. From the beginning of the humankind people interfered with the fire burning lands on purpose and suppressing it when necessary. Nevertheless, with climate change and increasing frequency of wildfire that put millions of people in a risk, it is clear that certain policies and measures should be taken ro protect human lives and control the damage that can be made by the wildfires.

A debate erupted in the literature about the question of wildfire supression methods, and whether they are effective. There are various fire prevention methods such as fuel thinning or prescribed burning that are still in the use today. For instance, authors such as Stephens and Ruth (2005) supported such methods. Though they criticized the effectiveness of fire prevention policies in the US, they claimed that thinning of fuels helped decrease the severity of fires letting more forest vegetation to survive. The authors also reinforced the use of strategically placed area treatment (SPLAT), which is the treatment of fuels over the large forested areas with high lightning activity as an effective measure (Stephens and Ruth 2005). Cumming (2005) also noted the debate between the fire managers and fire ecologists in regards to the effectiveness of fire suppression. For instance, both Ward et al. (2001) and Martell (2007) agreed that fire suppression in boreal of forests of Ontario has been successful showing the reduced total burned area after the policy implementation.

Nevertheless, more recent literature has shown that fire suppression is not an ecologically viable methods of reducing wildfire threat. As Calkin et al. (2014) noted, while suppression methods are affective between 95-98% of the time, they usually lead to fuel build-up that is hard to manage if a larger fire erupts. What is even more interestung is that Johnson, Miyanashi, and Bridge (2001) and Keeley and Fotheringham (2001) both agrued that crown-fires are natural for boreal forests and chaparral shrublands, and that even the presciptive burning does not reduce the number of fire incidents that eventually happen. Fires in these eco-systems thrive on large scale desctructive fires after which new vegetation usually emerges.

More intergrative approaches are being argued for in the recent sholarship. While complete exclusion of fire may lead to fire buildup and more severe fires, fire management techniques should be applied according to the landscape. In places where fires are necessary for the ecosystems, humans and their assets can me moved to a less dangerous place, i.e. relocate (Gill, Stephens, and Cary 2013). The assets such as houses could be make more fire-resistant reducing the amount of damage that can result from fire (Gill, Stephens, and Cary 2013). What is important is that the fire management should be more nuanced, balancing ecological needs with human safety and acknowledging that coexisting with fire may, in some contexts, be more sustainable than attempting to fully suppress it.

2.5 Quantitative Research Methods

The use of satellite data in wildfire research is a relatively new and actively developing method of research. In the past the data regarding the wildfires including the burned area was generated from ground reports that were created by fire management teams and that were not reliable when conducting the examination of fire events on regional, continental or global scale (Chuvieco 2020). Sattelite imagery, on the other hand, gave the chance to scientists to observe fires from space and obtain much more accurate information. The products used for sattelite imagery collection evolved significantly today providing high-resolution enhanced products such as Fire CCI developed by European Space Agency and platforms such as Google Earth Engine that has been applied in as a research method in wildfire scholarship.

2.6 Historical evolution of sattelite imagery tools and what we have today

There are two indicators that can point to an active fire event, which are the light that is produced by the flames and the energy that is released (Chuvieco and Kasischke 2005). On the early stages of wildfire satellite data collection in the beginning of 1980s AVHRR (Advanced Very High Resolution Radiometer) was used, which detected fires using middle infrared lights generated from the released energy (Chuvieco and Kasischke 2005). AVHRR started gaining popularity among researchers and as Chuvieco et al. (2019) noted one of the pioneering works using AVHRR was by Setzer and Pereira (1991). They discovered 350 thousand independent fire events in the Amazon Basin using 46 images made with AHRR that was on NOAA-9 satellite (Setzer and Pereira 1991). While this was a breakthrough in wildfire research, the images generated by AHRR had low resolution and not very accurate since this sensor only had 5 spectral bands. In 2000's NASA launched its two satellites, Terra and Aqua, that had a new sensor named Moderate resolution Imaging Spectroradiometer (MODIS). Compared to AHRR MODIS had 36 spectral bands, which gave more accurate identification of active fire events and the sensor had much better spatial resolution with images being clearer. As the field developed many more satellite imagery products emerged, and are constantly being updated. Some of them include Fire CCI, MODIS MCD45A1, Copernicus Burnt Area, etc.

2.7 MODIS Fire_cci v5.1 grid product

Fire_cci Burned Area product that is used in this thesis was developed by European Space Agency's Climate Change Inititative. The product was developed with the goal of making more consistent observations and enhancing the algorithms of the detection of burned area (ESA Climate Office n.d.). Fire_cci v5.1, a version of Fire_cci products chosen for this thesis, provides global maps of burned areas at 250-300 m resolution, which gives clearer spatial details on fire events. The product is also advantageous for temporal studies since it spans from 2001 till 2022, and is constantly updated.

There are three reasons why Fire_cci v5.1 was chosen for this project. First, it's resolution that is better compared to many existing global BA products. As the project's focus was investigating the BA over the vast territory of Kazakhstan and examining the landcover that was affected, identification of small fires was not necessary, and Fire_cci was an appropriate choice for this. Both Oton et al. (2021) and Chuvieco (2019) stated that Fire_cci v5.1 is one the latest and most accurate BA products. Lizundia-Loiola et al. (2020) in their study compared the existing BA products including those from Fire_cci projects and NASA's MCD64A1 c6, and reported that Fire_cci 51 detected the amount of BA more accurately than

MCD64A1, which is the product that uses the sensors on Nasa's Terra and Aqua sattelites in combination.

Second, Fire_cci was chosen for it's temporal coverage which allowed to study two decades of wildfire BA trends in Kazakhstan. Fire_cci v5.1 provided monthly BA data over the span of twenty years, which gave a more accurate temporal representation of fire events. Though there are products such as MCD64A1 C6 that provide higher temporal data compared to Fire_cci v5.1 (Katagis and Gitas 2022), the former has a coarser resolution of 500m. Thus, Fire_cci v5.1 provides a better agreement between the resolution and temporal accuracy. As noted earlier MCD64A1 and Fire_cci are one of the latest products when it comes to BA identification, which is why the scholars chose them to compare their performance.

Third, it performs better in grassland biome that is particularly relevant to Kazakhstan. Grasslands in Kazakhstan are the most susceptible to fire and constitute the biggest share of the butned area. Since Fire_cci v5.1 captures the fires in grasslands particularly well makes it a good choice for the study. The number of studies that specifically assessed the performance of Fire_cci v5.1 in Central Asian grasslands is limited since most of studies have global focus or explore other regions. Nevertheless, the existing literature that showcases its performance elsewhere highlights the effectiveness of Fire_cci v5.1 in identifying burned areas in grasslands.

Chuvieco et al. (2018) and Huang et al. (2023) compared two recent fire products (MCD64A1 and Fire_cci v5.1) emphasizing that Fire_cci v5.1 showed more accurate information about the burned areas in grasslands. Chuvieco et al. (2018) stated that Fire_cci v5.1 showed more fire patches in grasslands and shrublands by 52% compared to its counterpart MCD64A1. Similarly, Huang et al. (2023), who mapped burned areas in Qinghai-

Tibetan Plateau, reported that while MCD64A1 had low commission error in forests, it performed worse than Fire_cci v5.1 in all other vegetation types including grasslands. In grasslands, Fire_cci v5.1 had relatively low commission error meaning that it showed fewer areas as burning compared to MCD64A1. Generally, it can be noted that Fire_cci v5.1 has its own flaws such as being ineffective at recognizing small-scale fires or having higher commission errors in forested areas. Yet, for the purpose of my study Fire_cci v5.1 is the most recent and appropriate tool for reseearching vast grasslands of Kazakhstan.

2.8 The Application of Google Earth Engine and MODIS Burned Area Dataset (MCD64A1)

Google Earth Engine is yet another tool that can be used to analyze wildfire dynamics. It is a widely used tool developed by Google that hosts petabytes of cloud satellite imagery and geospatial data. What makes Google Earth Engine particularly appealing is that it allows to use up-to-date satellite data to conduct time-series analysis and compute various indicators detecting changes on the Earth's surface such as vegetation health, burned area data urban mapping, etc. It also helps that Google Earth Engines stores the data in the cloud making it easily accessible and bypassing the need to load heavy data on local PC. Since the datasets are frequently updated over large areas Google Earth Engine is extremely helpful in wildfire research. Datasets such as MODIS Burned Area Dataset (MCD64A1) and Fire_cci v5.1 both of which were used in this study are available on Google Earth Engine platform.

In this study, MODIS Burned Area Dataset (MCD64A1) was used to verify the results generated by Fire_cci v5.1. The comparison of the results generated using two different datasets enabled comprehensive analysis of the burned area and overall increased the consistency of the results. MODIS Burned Area Dataset (MCD64A1) is one of the most frequently used BA products that was developed by NASA and the University of Maryland.

Its spatial resolution is 500 meters, and it captures the Earth surface daily making it suitable for the detection and analysis of wildfires.

Studies conducted by Giglio et al. (2018) and Roy and Boschetti (2009) confirmed the accuracy of MODIS BA products including MCD64A1 in identifying fire events with lower omission rates. Roy and Boschetti (2009) used MCD64A1 to map the burned areas in southern Africa and reported that the product effectively identified the seasonal fire dynamics in savannas, which are similar to temperate grasslands. Similarly, Tsela et al. (2014) investigated the occurrence of fire in different biomes of South Africa grasslands noting the reliability of MCD64A1 in capturing fires over larger areas. Humber et al. (2019) also used MCD64A1 as a benchmark to validate Fire_cci50 product due to its established reuptation for reliability and widespread acceptance as a BA tool. Although the number of studies that showed the use of MCD64A1 in Central Asian grasslands was limited, the research conducted in African savannas and grasslands indicated the effectiveness of this tool in identifying fires over vast territories. Despite its coarse resolution it proved to be effective in catching fire events over the vast lands similar to that of Central Asia.

2.9 The Gap in the Literature

All in all considering the region's vulnerability to wildfires and their impact on local biodiversity and human well-being researching the fire dynamics in Central Asia has a significant importance. Considering Central Asia's vulnerability to global warming and climate change the frequency of droughts and dry weather will only increase, which in its turn will prolong the fire season, make supression harder, and increase the overall possibility of fire eruption. Even though wildfires occur quite often in Central Asia and Kazakhstan's grasslands specifially, the area still remains to be understudied and the literature on the topic is limited. My research fills the gap in the literature introducing the wildfire dynamics in Kazakhstan for the past 20 years and explaining the reasons behind possible chang

3. Data and Methodology

3.1 Data Sources

This study analyzed the wildfire dynamics in Kazakhstan between two decades 2001-2011 and 2012-2022. To analyze the burned area data and gather information about the affected vegetation classes the primary data source that was used was MODIS Fire_cci v5.1 grid product provided by the ESA Fire Disturbance Climate Change Initiative (CCI) project. The information for this product is obtained by the MODIS sensor that is installed on Terra sattelite. It covers the global burned area data between 2001 and 2022 and has the resolution of 250 meters. To crossverify the burned area data, MODIS MCD64A1 collection-6 grid product was used. The data for it is obtained by both Terra and Aqua sattelites and contains data from November 2000 onwards. It's spatial resolution is 500 meters. To create maps and obtain shapefiles related to Kazakhstan open geospatial data sources were used such as the ones provided by Natural Earth website. The maps were created using a free GIS tool – QGIS. To cross-verify the data Google Earth Engine was used to access the MODIS MCD64A1 collection-6. It is a cloud-based platform, where anyone can obtain sattelite imagery and geospatial information through applying commands in Java-script.

3.2 Methodology for Data Processing

The data that was used in this study was processed using the code provided by the FLAM (Wildfire climate impacts and adaptation model) team at IIASA (International Institute of Applied Systems Analysis). With the help of the FLAM team at IIASA the code was adapted to extract information specifically about Kazakhstan. Two codes were used in this study: one, which extracted the total monthly burned area and the second, which extracted total monthly burned area for each vegetation class. All the codes were run using R-studio.

The idea behind the codes was similar. First, monthly burned area data from 2001 to 2022 was downloaded from the ESA Fire Disturbance Climate Change Initiative's website. Then using the first code the downloaded data was processed and stored as a separate CSV file with all the burned areas for each month from 2001 to 2022. The TIFF images were also generated and put in a separate folder showing the burned monlthy areas for the entire period of the study. I transformed the CSV file into Excel file, after which the data was checked, cleaned, and used for the creation of diagrams and figures. The second code also created a CSV file, but it included not just the total but a burned area for each vegetation class that covers the territory of the country.

The TIFF images with total burned areas for each month of the whole period were aggregated using a separate R-code. The burned area images for each month were aggregated into yearly TIFF files that were then aggregated into the decadal TIFF images that were used for creation of final maps on QGIS. All the codes were included in the Appendix section. The cross verification was done using the Google Earth Engine platform. The MODIS MCD64A1 collection-6 was accessed using a Java-script code, and the same information about the yearly burned areas in Kazakhstan for the whole period were generated. The layers with this information were then extracted as TIFF files on my local computer and then used to create the maps on QGIS.

3.3 Limitations of the Data

There are certain limitations of the data sources I chose. First, the spatial resolution decreased the accuracy since small fires can go undetected at 250 meter or 500 meter resolution. So, it is clear that not all fires were detected by the sensors on the sattelites. Moreover, clouds could have also decreased the accuracy, and the cloud-masking procedures might still lead to the dataset missing some fire events. Second, the land cover map assumed that the vegetation cover did not change between 2001 and 2022. However, it is clear that with the increase in population, economic development, new policies, etc. the vegetative composition might have changed. Third, while I was able obtain the overall burned area data, the sattelite products did not provide any information on fire frequency or the exact number of fires. So, I could not accurately access and compare the fire suppression efforts and the speed with which fires were spreading in both decades. Nevertheless, using Fire_cci v5.1 and MCD64A1 sensors I was able to extract valuable data that provided an overview of decedal fire trends in Kazakhstan.

4. Results

4.1 Trends in Burned Area Over Time

The analysis of the data showed that there have been signifant changes in the wildfire dynamics in Kazakhstan. Overall, between 2001 and 2022 the are burned by wildfire constituted around **203897957,8** m^2 of land. Out of this between 2001 and 2011 the total area affected by fires equated **135925566,3** m^2 and in the latter period between 2012 and 2022 the figure was **67972391,56** m^2. It is clear that comparing the two periods that my study focused on one may notice that the total area burned in the later period decreased almost twofold. Figure 1 shows the annual burned area statistics and the trend is downwards. Moreover, both the Fire_cci v5.1 and MODIS MCD64A1 spatial products follow almost identical pattern. It can be seen that wildfires have been especially rampant in 2002, 2010, and 2017. Nevertheless, besides the sudden peaks in certain years, the general trend is declining.

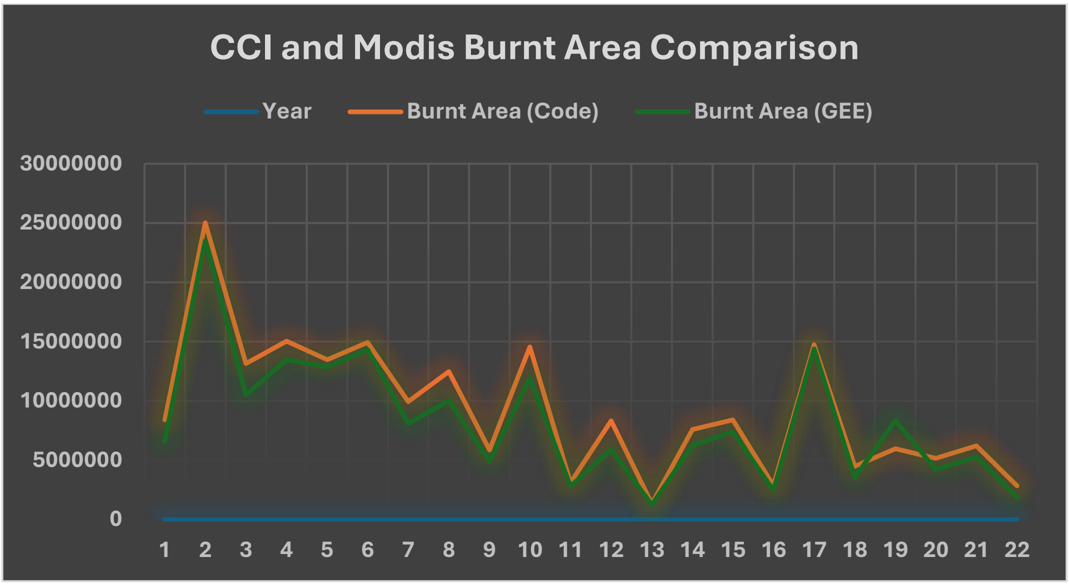

Figure 1. Comparison of BA detected by Fire CCI 51 and MODIS MCD64A1

4.2 Vegetation Types Affected by Fire

In this study the vegetation types were categorized according to those that are present in Kazakhstan's terrain. Fire_cci project divides vegetation into 18 land cover classes, however, some such as the ones located in tropical climate are not present in Kazakhstan and have been removed from the calculations. Moreover, forests have also been removed from the study. Fires do occur in the forests of Kazakhstan. 38% of tree cover was lost in Kazakhstan between 2001 and 2024 due to forest fires (Global Forest Watch 2025). Nevertheless, compared to other vegetation types forests cover only 5% of the territory, and the results geberated for the burned areas for forests were insignificant.

The vegetation types were mainly divided into 4 main ones: cropland, mosaic, grassland, and sparce vegetation. "Cropland" includes agricultural lands both rainfed and irrigated. Mosaics included lands dominated by small-scale farming plots interspersed with other land uses such as fallow fields, hedgerows, homesteads, or scattered trees and those that are natural ecosystems but are fragmented by patches of cropland or grazing areas. The grasslands included areas that predominantly have grasses and herbaceous (non-woody) plants with few or no trees at all. Finally, sparce vegetation was considered to be the lands where plants such as trees shrubs, and herbaceous plants covered less than 15% of the territory. Grasslands dominate Kazakhstan's landscape. More than half of the territory (69,3%) is covered by grasslands, lands with sparce vegetation and shrubs (Eisfelder et al. 2014).

Over the two separate periods examined in this study, the burning patterns of vegetation were similar. The most burned vegetation class was grasslands. The distribution of burned areas can be seen in Figure 2. Between 2001 and 2011 the burned area of grasslands constituted a little over 60,000,000 m^2, while between 2012 and 2022 the burned area for the vegetation class halved reaching a bit over 30000000 m^2. Yet, in both periods grasslands burned the most compared to other vegetation types. The next vegetation class that was vulnerable to wildfires in both decades was croplands. Around 25,000,000 m^2 of croplands were burned in the first period, whereas in the second decade, the number was about 17,000,000 m^2. The burned areas of mosaics and sparce vegetation were similar and burned the least in both periods. The area that was covered by burned mosaics and sparse vegetation added up to 20,000,000 ha between 2001 and 2011, and for 2012-2022 the number made up around 10,000,000 m^2. Figures 3 and 4 also show that during both periods the share of vegetation classes that burned due to wildfires was very similar. Around 46% and 47% of grasslands burned in the earlier and later periods respectively. The amount of croplands slightly increased in the latter period by 4% (from 19% to 23%) similar to croplands with 1% rise. The share of burned mosaics conversely decreased from 17% to 15% in the second decade. Despite some slight changes, the overall trend remained almost the same. What changed was the overall amount of burned area as I have mentioend above.

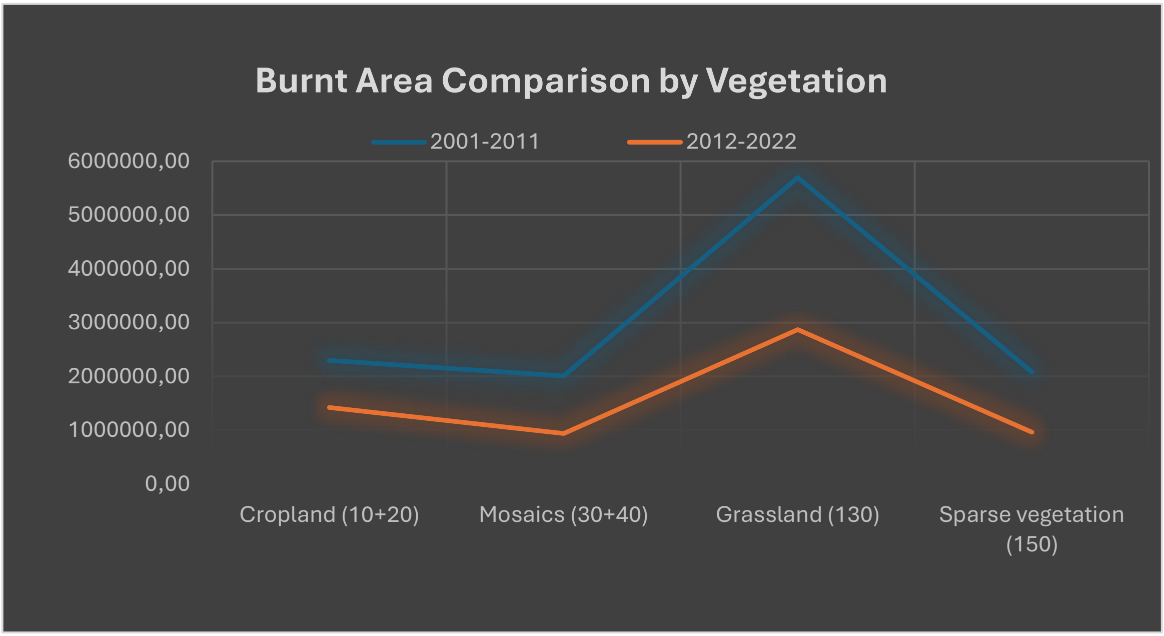

Figure 2. Vegetation that burned over the two periods (2001-2011 & 2012-2022).

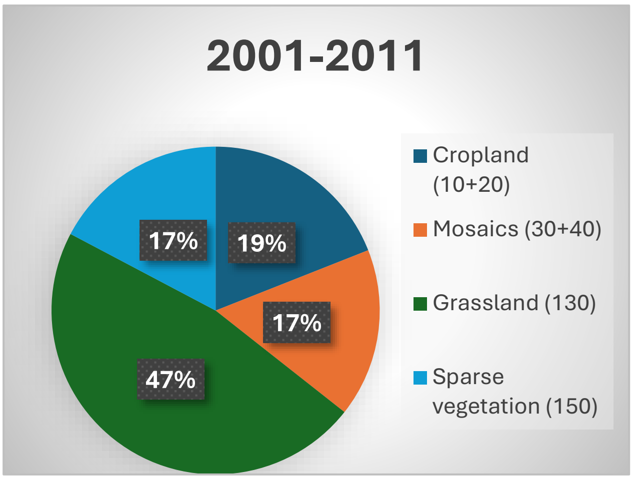

Figure 3. The vegetation classes that burned between 2001-2011.

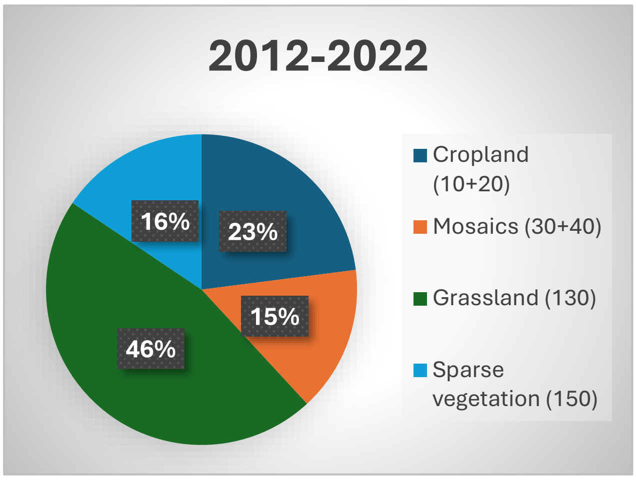

Figure 4. The vegetation classes that burned between 2012-2022.

4.3 Spatial and Temporal Patterns of Wildfires

The fire season in Kazakhstan starts from April and lasts until November summing up to around 7 months in total. As can be seen on figures 5 and 6 the fire season has remained the same over the two periods. Croplands burned in the first 2 to 3 months of the fire season, and the rest (grassland, mosaics, and sparce vegetation) burned in the later part of the season. As it was mentioned above the share of vegetation classes that burned in each decade

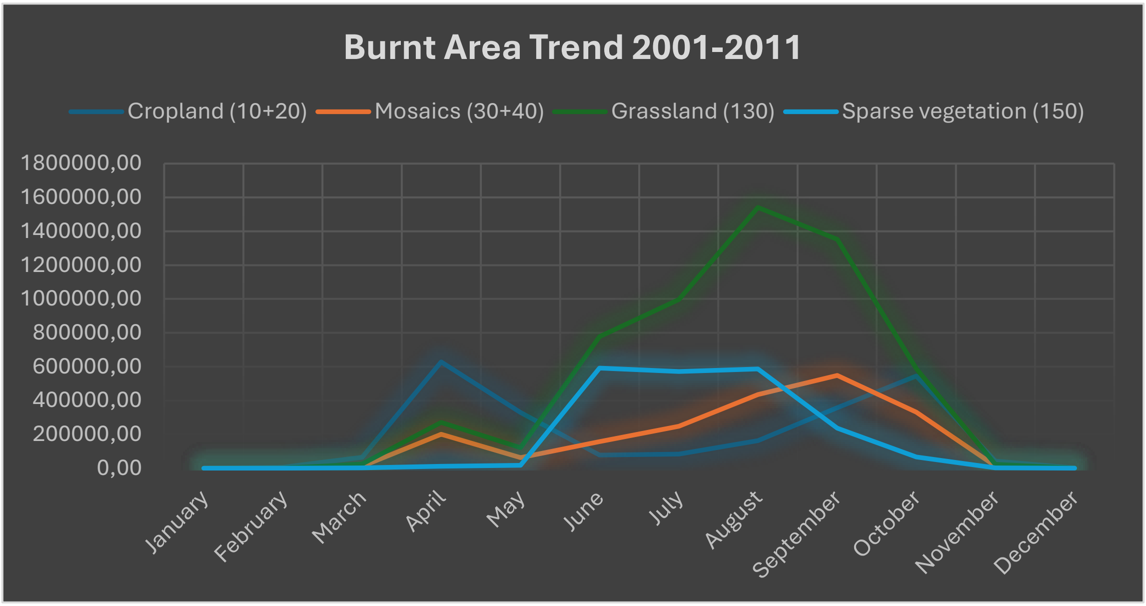

Figure 5. Fire season patterns in Kazakhstan between 2001 and 2011.

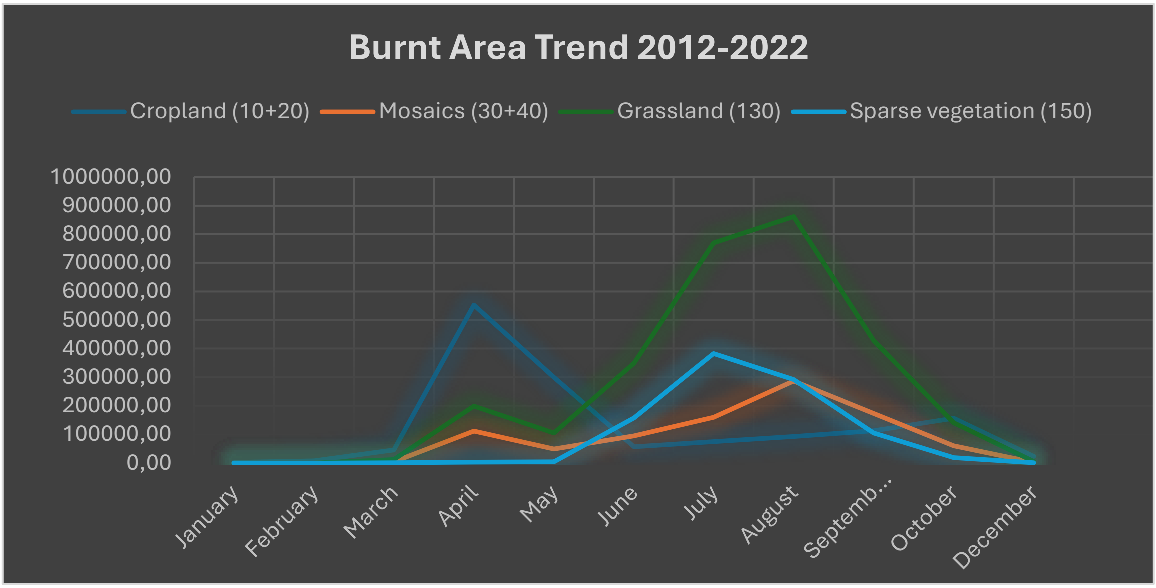

Figure 6. Fire season patterns in Kazakhstan between 2012 and 2022.

remained the same, and the overall amount of burned area per vegetation class halved. Nevertheless, while fire season remained to be unchanged, as the influence of climate change becomes more rampant, the length of the fire season and the severity of fires are likely to increase. It is forecasted that by 2050, Central Asia will experience severe water shortage and droughts, which will also likely impact the wildfire dynamics in the region.

When it comes spatial characteristics of wildfires in Kazakhstan most of the wildfires were concentrated in the central part of the country, forming a band that extended longitudinally from the western to the eastern regions. They also occured in the Northern part of the country. The South while experienced some wildfire activity had overall fewer

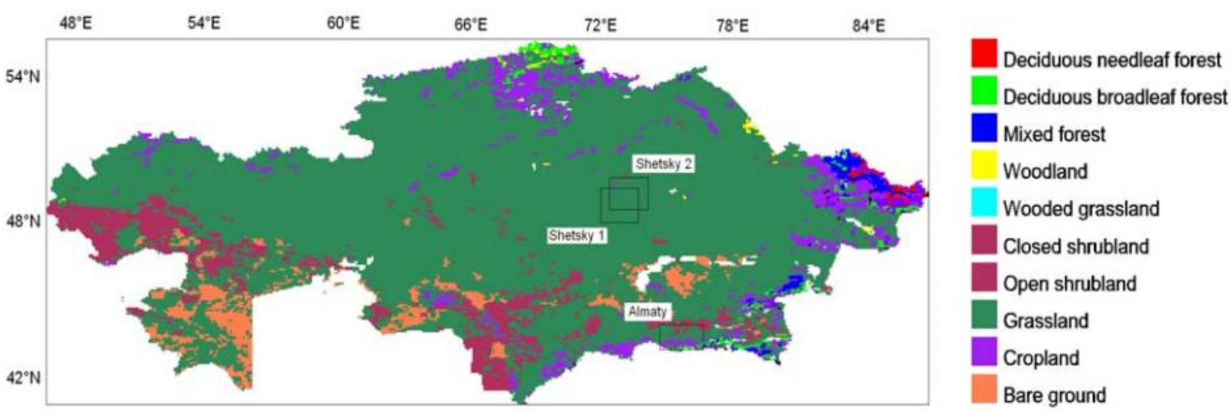

Figure 7. Kazakhstan's vegetation cover

instances of fire compared to other regions of the country. This spatial pattern can be explained through the vegetation that grows in these regions. As ilustrated in figure 7, most of the country and especially the North and the Center are covered by grasslands, which burn the most (Propastin and Kappas 2012). The Southern part of the country while also having some grassland, is covered by shrubs and bare lands (Propastin and Kappas 2012).This was clearly illustarted by Figures 8 and 9 show the wildfire hotspots detected by Fire CCI 51 sensor over the two decades. It can be seen that in the earlier period the fires were more frequent and intense. While the location of fires in both periods remained the same with more fires still occuring in the Northern and Central part of the country the maps show how between 2012 and 2022 the wildfires decreased in intensity and number. Very similar pattern can be observed from the maps in figures 10 and 11, where wildfire hotspots were identified using MODIS MCD64A1 sensor. Though fewer wildfire hotspots were recorded with this sensor likely due to its coarse resolution, it shows how the fires occurred in the same regions

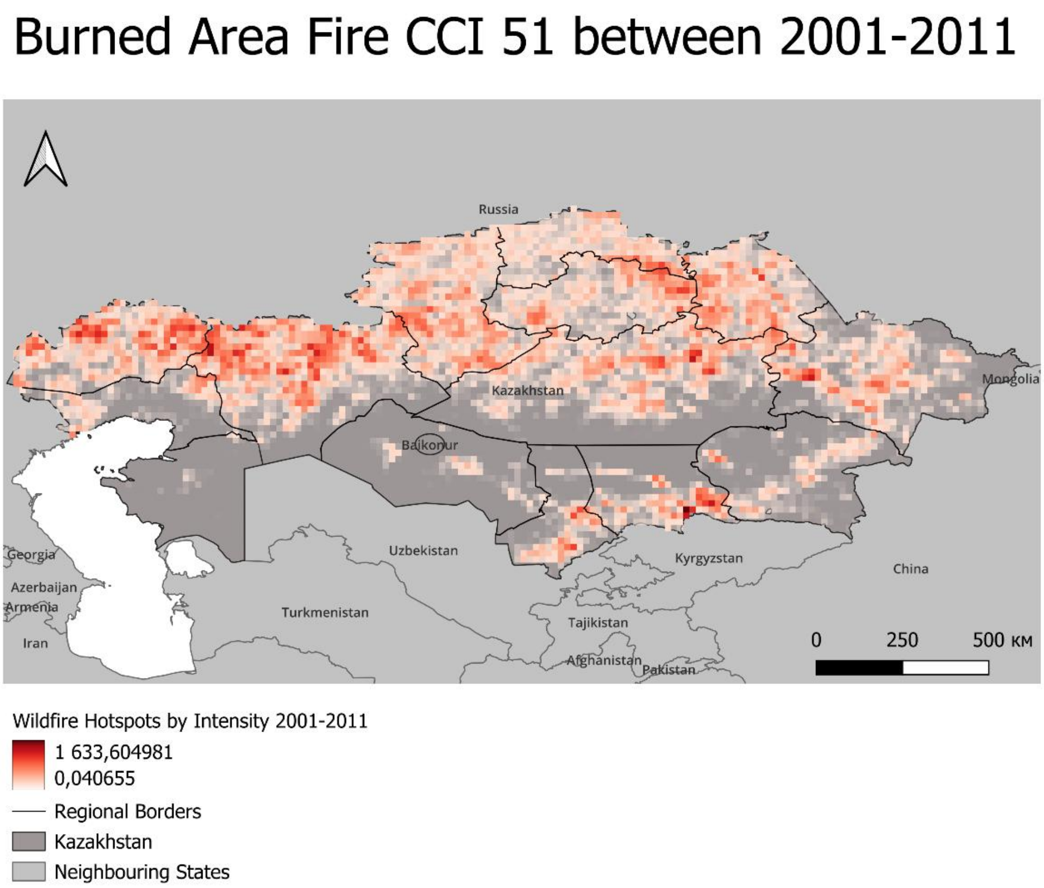

Figure 8. Wildfire hotspots between 2001 and 2011 (Fire CCI 51).

that were identified by Fire CCI 51 sensor. MODIS MCD64A1 also displayed a substantial decline in the number of fires that erupted in the decade between 2012 and 2022 compared to the decade between 2001 and 2011.

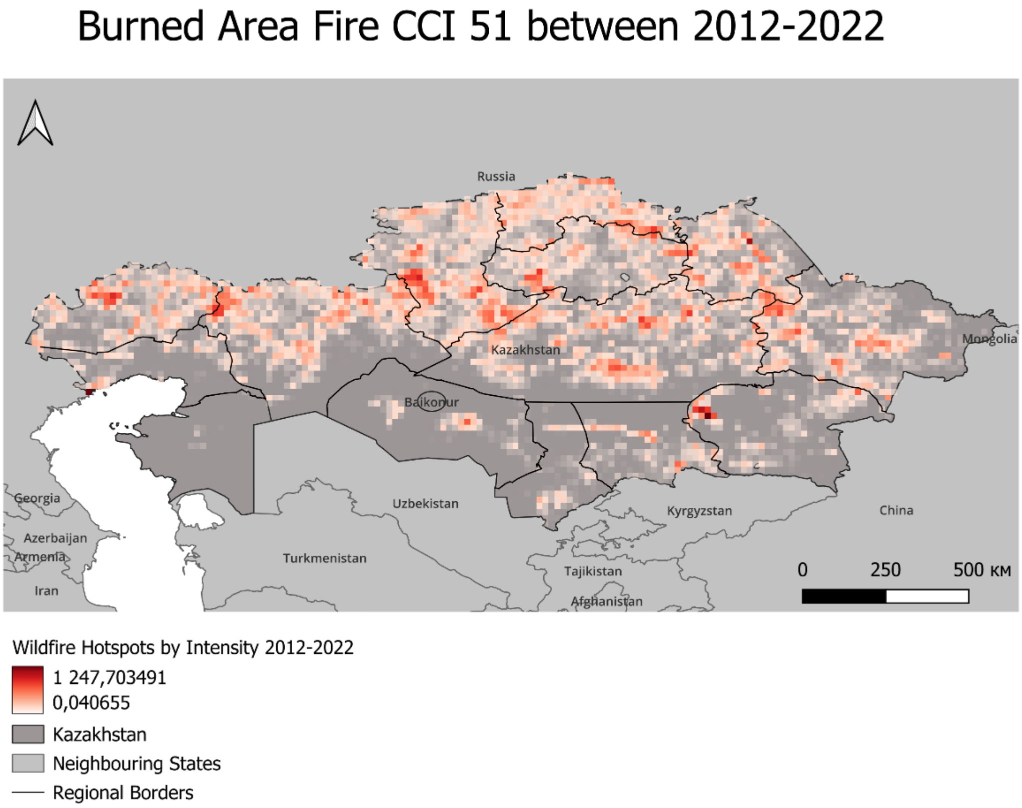

Figure 9. Wildfire hotspots between 2012 and 2022 (Fire CCI 51)

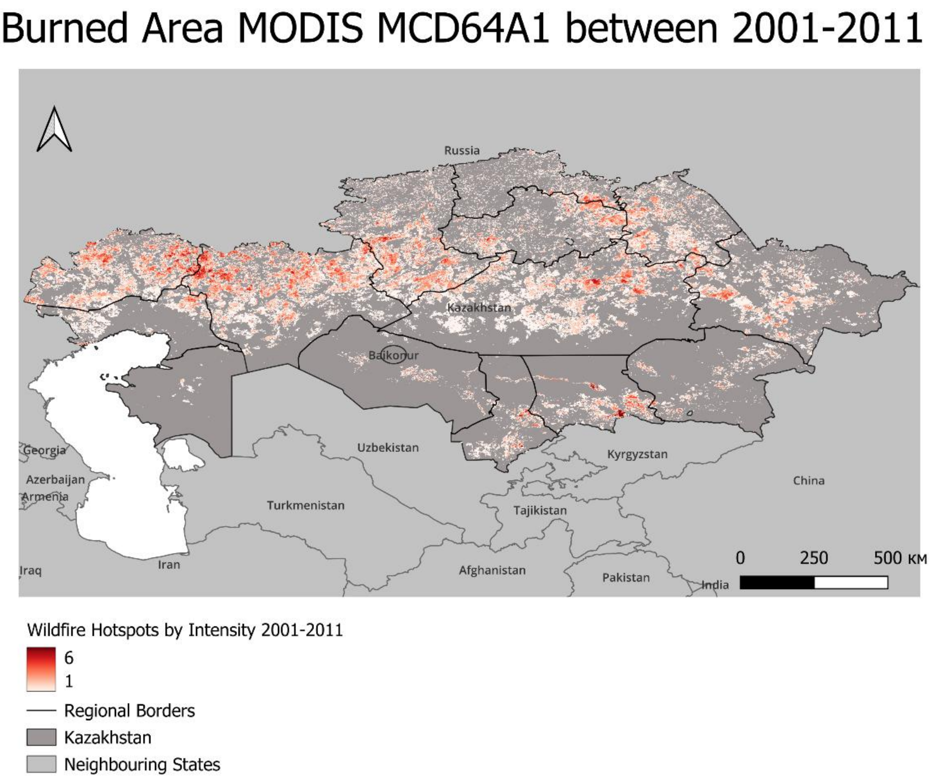

Figure 10. Wildfire hotspots between 2001 and 2011 (MODIS MCD64A1)

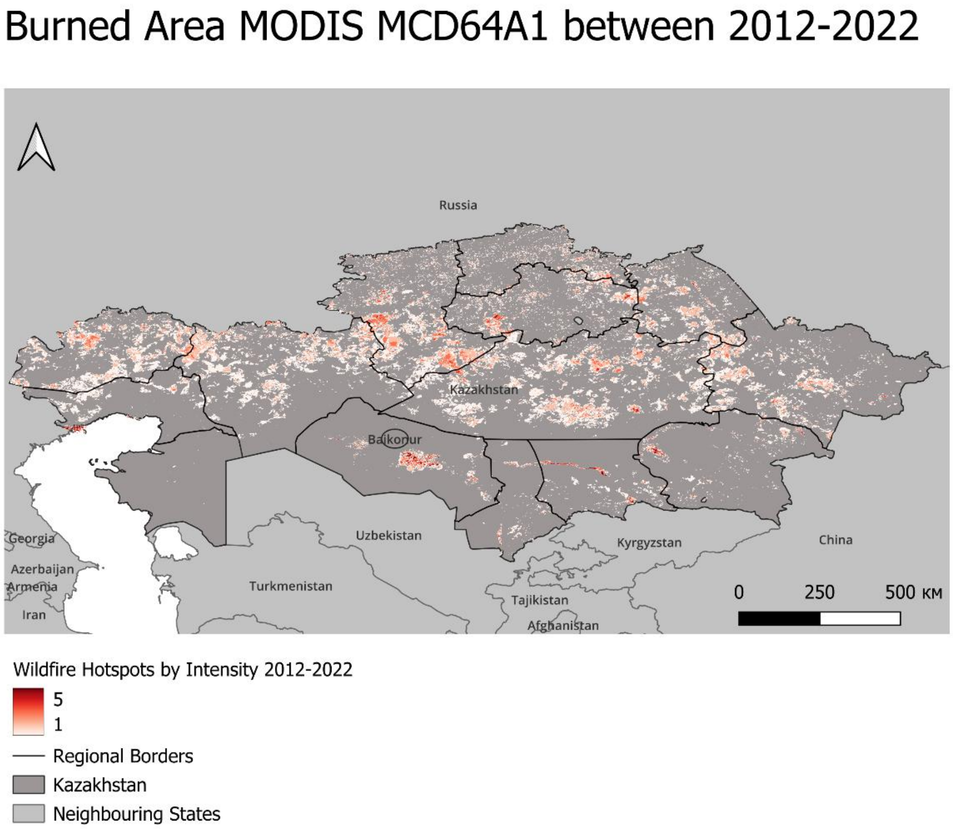

Figure 11. Wildfire hotspots between 2012 and 2022 (MODIS MCD64A1)

5. Discussion

5.1 Summary of the main findings

For the past twenty years wildfire dynamics in Kazakhstan changed drastically. In this study I compared the two time periods, 2001-2011 and 2012-2022, investigating wildfire patterns in Kazakhstan and observing changes in the burned area, location, affected vegetation classes, and temporal variation of fires. First, it was found that between 2001-2011 and 2012-2022 the total burned area decreased twofold. Both Fire_cci v5.1 and MODIS MCD64A1 showed this change with fewer fire hostpots covering the territory of the country. Second, when it comes to location of fires, they did not change significantly. In fact, fires occured in the same regions being more prevalent in the Central part of the country and up North. This can be explained by grasslands and croplands that mostly grow and cover these areas, and that burn the most. Third, the share of vegetation classes that burned in these two periods also did not change drastically. Grasslands topped the list of vegetation classes that were the most susceptible. The burning pattern of other three classes, which included croplands, mosaics, and sparce vegetation changed slighly over time. More areas covered by croplands burned in the latter period, and the areas affected by wildfires that included the latter two vegetation types burned less in the second decade.

Looking as the results of the study, one can clearly come up with the question of what could explain such a drastic change in wildfire dynamics. In fact, taking into account the climate change, where Central Asia is even more susceptible to dryer seasons, decreased precipitation, and prolonged droughts it is natural to expect the increase in fire frequency and burned areas. According to Hua, Zhao, and Zhong (2022), it is expected that Central Asia will have a rise in frequency and lengths of droughts due to constant evaporation which will be equal to amount of precipitation already by 2030. Nevertheless, the figures showed that the wildfire actually became less prevalent with smaller overall burned area an affected vegetation. What could explain these dynamics? There are different factors that play in how wildfire dynamics changed over the last two decades. These factors include change in the population, economic development, new land management or fire supression policies, etc.

Since my study is mostly aimed at exploring the dynamics rather than explaining what exactly happened, I will go over some of the major factors that might have affected the changed. Mainly, I will explore the two factors which are the population change and new land management policies in Kazakhstan. After the fall of Soviet Union in the 1990s people gradually started migrating between former Soviet republics and far abroad, which led to many abandoned territories and unmanaged rural areas with increased stocks of fuel. This could explain bigger share of burned areas in the first decade. Another more direct effect could be observed from the changes in the policies. In the latter period between 2012-2022, new land management policies were introduced in Kazakhstan, which also regulated and controlled fires. It can be seen that after the implementation of the new set of policies, the burned area decreased twofold. In the next section, I will explain in more details how these two factors affected the change in the wildfire dynamics.

5.2.1 Post-Soviet Recovery and Change in the Population, which left the stepped empty and unmanaged

After the collapse of Soviet Union in 1991, Kazakhstan experienced massive outmigration. The “kolkhozy” and “sovkhozy”, which were the collective farms during the Soviet era were dismantled, and people moved out from these farms leaving hectares of rural land alone. Such dynamics later contributed to increased biomass and succeptibility to fire eruption. Figures 12 and 13 show the change in the population and net migration trends. According to the data provided by World Bank (2023) (Figure 12), between 1991 early 2000s the population in Kazakhstan plunged, and the loss was evened out only closer to early

2010s. This can be seen even more clearly in Figue 13 that shows the net migration with more than a million people leaving Kazakhstan's steppes (World Bank 2024). Clearly, such a dramatic change in population density and shift in land management policies led to a rise of wildfires in the beginning of the new century.

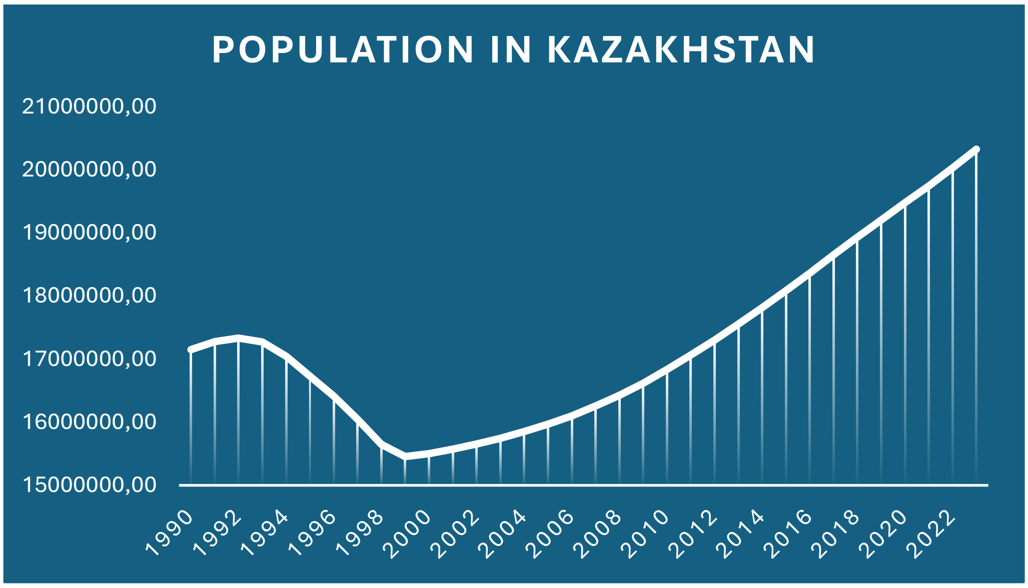

Figure 12. Kazakhstan's Population.
Source: World Bank. 2023. "Population, Total - Kazakhstan." World Bank. 2023. https://data.worldbank.org.

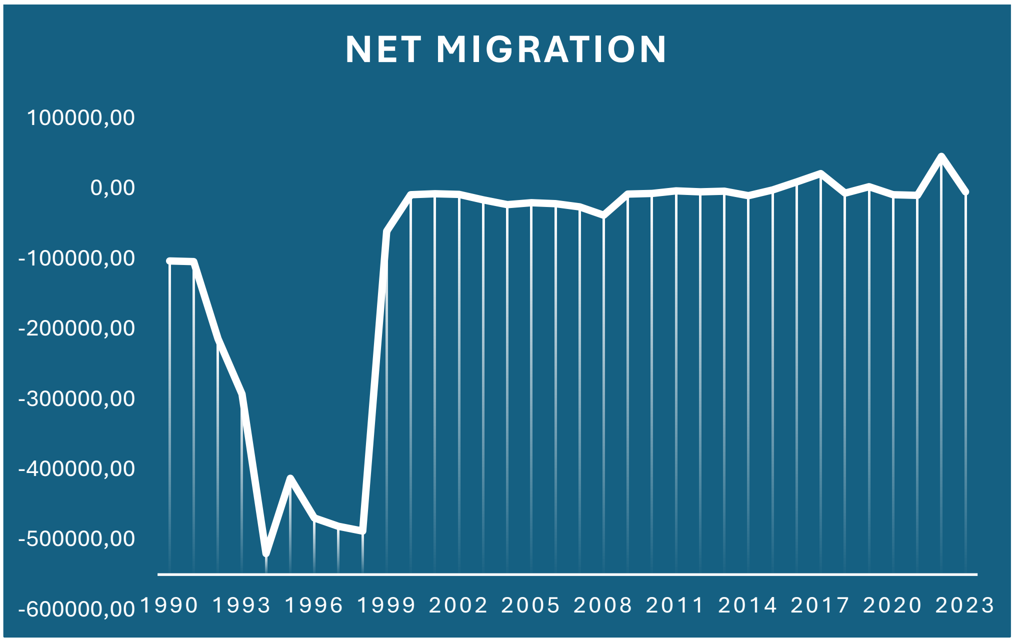

Figure 13. Kazakhstan's Net Migration.
Source: World Bank. 2024. "Net Migration - Kazakhstan." World Bank. 2024. https://data.worldbank.org.

The massive outmigration after the collapse of Soviet Union resulted in abandoned croplands and farmlands, which left hectares of land unmanaged. If we look at the figures, around 12 million hectares of croplands, which constituted around half of all Soviet croplands, were lefy unmanaged by early 2000s (Kamp et al. 2025). Much of abandonment occurred in the Central and Northern regions of Kazakhstan that have the most productive soils and that were extensively used for cultivation during Soviet times (Dara et al. 2018). And as it was shown in the maps above these are the primary areas that burn in both decades. The territories which were previously managed by plowing, cultivation, and fallow cycles during the Soviet times started rewilding with shrubs and grass growing in those places instead. The fire management practices that were at place in former communal farms no longer existed with firebreaks and regular monitoring being absent. This in its turn led to the accumilation of dead plants, which created fuel beds. The recultivation of the abandoned croplands in Kostanay region, which is in the Northern Kazakhstan, was substantially done only by 2013 (Dara et al. 2018). This can partially explain the difference in burned area between two decades. There is a strong correlation between formerly cultivated regions and the areas that burn the most even today.

Apart from abandoned croplands, livestock has also declined contributing to the problem. Livestock also plays a crucial role in managing fire regimes since grazing helps by getting rid of fuel build-up and vegetation growth. After 1991 the outmigration also resulted in rapid decrease of cattle, and it also had a substantial impact on increased fires in Kazakhstan. In fact a correlation between grazing intsensity and fire occurrence is surprising. Even the presence of small grazing intensity can put off large wildfires. Otherwise, when the grazing intensity falls below the threshold of around 250 dung piles/ha, the fires become 5 times more frequent (Freitag et al. 2021). As it was reported by Freitag at el. (2021) and Kamp et al. (2025) places with a lack of grazing started growing tall grass and thick litter layers, which are highly prone to wildfires. Kamp et al. (2025) claimed that homogeniuty of vegetation species, where only one or two grass species covered the steppe resulted in very intense fires in the early 2000s. And considering the fact that firefigting infrastructure and system was left unmanaged and underfunded, one can see how the consequences could be felt well after the beginning of 2000s (Smelyanskiy et al. 2015).

The cattle numbers improved after the 1990's, however, they did not reach the numbers that were during the Soviet times. The pastures for horses were brought back but sheep and other animals were still in decline, which is why fire regime response to these changes was delayed (Kamp et al. 2025; Kolluru et al. 2022). This is why we might see less burned areas between 2012 and 2022 since more fires still occurred in the early 2000s contributing to a larger burned area for the whole decade. Figure 14 from Kamp et al. (2025) shows the drivers of the intensification of the fire regime in Kazakhstan after the dissolution of the Soviet Union. The collapse of the governing structures and severe economic crisis led to policy failure, decrease in livestock and wildlife (due to poaching), and migration from rural areas, which all contributed to frequent and massive fires.

The consequences of abandonment not only resulted in more wildfires but they changed the fire regime and the landscape. As it was stated by Dara (2020) between 1990 and 2000 they discovered that the burned area increased seven times, and the overall number of wildfires increased by eight. While it was also the abandoned places that were burning, it is crucial to note that local vegetation also adapted in a way that supported the eruption of fires. Instead of the heterogenous landscape that was pre-fire, it was the species that were fire-adaptive that survived after repeated burning, which made the vegetation conducive to burning. This phenomenon was also confirmed by Freitag et al. (2021). These ecological feedbacks also affected the ecosystems and the biodiversity. According to Bhagwat (2024), the frequency of fires, their extent, and the areas affected by them all impacted the diversity of bird species in the steppe. As the cattle numbers have been recovering slowly, and have not yet reached previous levels, the fire frequency and intensity is still high, and the bird species diversity is also far behind from recovery (Bhagwat et al. 2024). The birds that consume shrubs and fire-prone vegetation are unable to survive, while the ones that are more adapted to new fire regime are dominating the steppe. And despite the introduction of new land management policies and the attempts of the government to alleviate the situation, the adverse impact of fires on biodiversity of species remains to be a problem as the areas with high fire activity became ecologically "locked-in", and current measures might not be enough to return to the previous state.

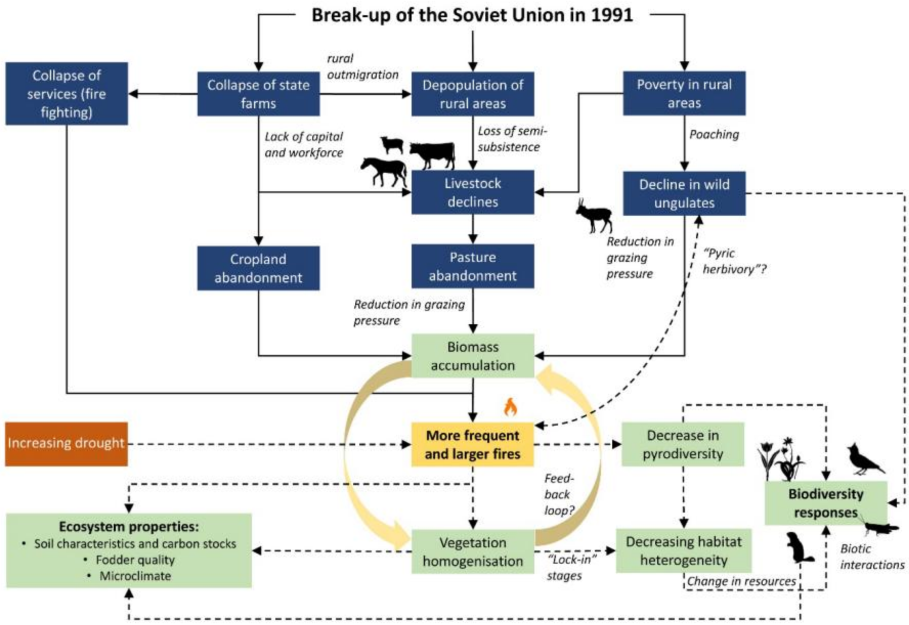

Figure 14. Drivers of increased wildfires in Kazakhstan.
Source: Kamp, Johannes, Tejas Bhagwat, Norbert Hölzel, and Ilya Smelansky. 2025. "Collapse and Recovery of Livestock Systems Shape Fire Regimes on the Eurasian Steppe: A Review of Ecosystem and Biodiversity Implications." *Philosophical Transactions of the Royal Society B* 380. https://doi.org/10.1098/rstb.2024.0062.

5.2.2. Tightning of the policies: better land management and stricter fines.

Another reason behind the drastic change in the fire regimes can be explained through different policies and measures that were taken in both periods. Between 2001-2011 there has not been any substantial legislation that would have controlled the spread of fire in the steppes. Suppressing and hindering the effects of wildfires did not seem to be on the government's agenda during the this decade. The Land Code (2003a) that was enacted in 2003 is aimed at regulating the administrative issues when it comes to land use such as resolving the questions of land ownership, land zoning, payments for the land use, etc. And while sustainable use was mentioned in the code, it did not elaborate further on it (Parliament of the Republic of Kazakhstan 2003a). Similarly, the Ministerial Decree (2003c) concerning the use of suburban areas near major cities in Kazakhstan zoned the territories and outlined the purpose of the suburban areas without any mention of fire hazards. While the Forest Code (2003b) talks about the measures that should be taken against the forest fires and aerial surveillance the code only focuses on forests and does not concern the steppe fires. So, agricultural burning and uncontrolled build-up of fuel remained in the territory of Kazakhstan, which contributed to continuation of wildfires.

Nevertheless, during the decade between 2012 and 2022 the situation with wildfires improved as the new law was introduced directly addressing the issue of wildfires in the steppes and new investments were made to combat the burning of the steppes. The groundbreaking law was implemented in 2011 regarding the rational use of agricultural lands with requirements such as prohibiting burning of crop residues and by-products on cultivated agricultural land, protecting agricultural land from degradation, including preventing overgrowth of flammable vegetation and ensuring proper waste management, etc. (Parliament of the Republic of Kazakhstan 2011). This law was updated in 2020 establishing clear liability mechanisms and punishment measures for improper care of agricultural lands such as confiscation of the territory (Ministry of Agriculture of the Republic of Kazakhstan 2020). This made the requirements regarding the wildfire prevention legally binding shifting the legal scene from vague sustainability goals to exact wildfire mitigation measures.

Apart from the new legislation technological investments were made to promote the prevention of wildfires. The Ministry of Emergency Situations is the one responsible for taking out the fires, and it acquired new technology to combat the erupted fires. In 2012, the Ministry purchased Ka-32A11BC helicopters, which had medical equipment and horizontal water cannons that were aimed at using for rescue activities and fire-fighting (Russian Aviation 2012). Though closer to the end of decade, by 2022, the Ministry of Emergency distributed 275 fire tank trucks to regional bodies, and 768 items of technical equipment was given to fire stations to enhance the fire supression efforts (Official Information Source of the Prime minister of the Republic of Kazakhstan 2023). Together with the provision of the equipment another important milestone that was achieved by Kazakhstan's government is the application of sattelite imagery and GIS products in early identification of fire spots, which helps to supress fires without letting them to spread.

Fire space monitoring system, though existed from early 2000s, started to develop in the latter periods. The system uses sattelite data from Aqua and Terra MODIS and NOAA AVHRR and helps identify fire spots in 6 regions of Kazakhstan (Spivak, Arkhipkin, and Sagatdinova 2012). Yet, the system only catches the existing fires, and the system for very early detection and forecasting has just began developing. The fire monitoring system also worked only in 6 regions of the country, which, of course, is not enough considering the vast territory the fire covers in Kazakhstan. The system that predicts possible fire eruption points and identifies thermal hotspots has just been implemented before the fire season in 2025 (Official Information Source of the Prime minister of the Republic of Kazakhstan 2025).

Nevertheless, training of professionals in identifying early fire hotspots has been at place since 2019 with the recent training taking place in May of 2022, where officers of the Ministry of Emergency Situations learned more about the application of GIS systems in fire management.

Nevertheless, there is still plenty of room for improvement when it comes to fire management in Kazakhstan. While the policy changes and the increase in population might have allevated the situation, problems with curruption and funding persist. While forest fires were not covered in this study, the corruption in forest fire management still represents the broader picture. As it was reported by Anti-corruption Agency of the Republic of Kazakhstan, 70 crimes that were connected to corruption in the forest sector have been identified in two and a half years (Anti-corruption Agency of the Republic of Kazakhstan 2025). The legal codification of fire management and the government’s attempt at improving the fire hazard related situation in the country showed successful results making the fire management more regulated in the country. Nevertheless, taking into account climate change and regional development inequalities, it is clear that much work still needs to be done. In spite of the decrease in the number and scale of wildifes, it is only a part of what could be ideally achieved with less corruption and better implementation of the policies.

5.3 Limitations and implications of my study

In my study, I conducted a comprehensive assessment of wildfire dynamics in Kazakhstan and explained possible reasons behind the change in the dynamics. However, there are still some limitations that I will go over in this section. First, I have primarily used Fire_cci v5.1 sattelite imagery product to detect burned areas in Kazakhstan, the results of which I then cross-verified using MODIS MCD64A1. While both of the products are widely used and known, their limitation is that they are unable to catch small fires, so, some data might have been ommitted and fires in early spring or late autumn might have been undetected. Second, as the scope of this study was primarily exploring the wildfire dynamics, investigating what exactly affected the decrease in burned area in the period between 2012 and 2022 was not conducted comprehensively. While shift in policies might had a significant impact on wildfire dynamics other variables such as socio-economic development, changing precipitation patterns, and other factors must have played a role in the difference of patterns we see today.

6. Conclusion

The wildfire dynamics in Kazakhstan remains to be an underexplored topic that needs closer attention from the scholars and environmentalists. The aim of this study was to investigate the wildfire patterns in the region over twenty years and examine the changes or their lack. It was found that there have been substantial changes in the wildfire dynamics over the study period. The burned area between 2012 and 2022 was twice as small as the burned area between 2001 and 2011. In addition, grasslands were the most burning vegetation type. Other vegetation such as croplands, mosaics, and shrublands burned at a similar rate. The results were crossverified, and almost the same dynamics were recorded both by Fire_cci v5.1 and MODIS MCD64A.

There were two possible explanations offered in this study. First, after the break-up of the Soviet Union mass outmigration from the rural areas occurred and the number of grazing livestock plummeted resulting in the layers of fuel build-up in the steppes that are highly succeptible to fire. The effects of outmigration were not evident instantly, however, greater areas burned in the first period might point at the delayed consequences of migration. Second, substantial policy changes happened in the second period with major land management and fire management laws being put in place. The government started putting the fight against the wildfires on its agenda, which was different from the first period when almost no regulations regarding the sustainable use of lands and prevention of wildfires existed. Stricter laws might show that there have been better suppression efforts or overall prevention measures taken against the wildfire eruption.

The study contributed by showing an important trend of decreasing burned areas in the last twenty years in Kazakhstan. The decrease in the burning area over the twenty year period might shed a light on important implications. In fact, the results of the study might seem a bit counterintuitive since considering the effects of climate change in the region, one might expect the opposite trend of increasing burned areas. However, the decrease in the burned areas mean that with effective policies and prioratization of wildfire prevention, it is possible to fight against the desctructive wildfires. While global warming and other factors that are condusive to the eruption of wildfires exist, mankind might be able to manage the situation if appropriate measures are at place.

Even though this study provided valuable insights on wildfires in Kazakhstan, there are some limitations to the study. First, the sattelite data that was used in the study might have not displayed a completely accurate information because at the available resolution small fires are quite hard to capture. Though the data sources that were used in the study are ones of the latests that are widely used and accepted in the scholarship. Second, while migration and policy strengthening might have explained the change in the wildfire dynamics, there are other possible explanation behind the change. For example, the economic development could also explain why the burned area was smaller in the latter period. Third, climate change and weather patterns have not been taken into consideration. Precipitation, for example, might also explain the dynamics we see today.

Further research needs to be conducted to thoroughly check and investigate the wildfire dynamics in Kazakhstan. The impact of social and economic factors on wildfire dynamics needs to be tested. To verify the impact of policies, suppression efforts need to be compared in both periods assessing the supression speed. Climate models might also need to be build to identify how wildfire dynamics might change in Kazakhstan in the future taking into account the impact of climate change. Policy recommendations will need to be drawn to identify further steps that should be taken to decrease the possibility of fire hazard in Kazakh steppes.

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