Evaluating options for implementing the Kazakhstan forest restoration targets

Master's thesis in Industrial Ecology

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Abstract

Kazakhstan is severely impacted by land degradation, where 70% of the land is considered to be degraded to some extent. Forest Landscape Restoration (FLR) is suggested as a measure to combat this process, but also to protect inhabitants of exposed areas. Goals to increase the forest area of Kazakhstan is expressed in both governmental and UN official documents, where the Republic of Kazakhstan has pledged to increase the national forest cover by 1.5 million hectares by 2030 [1]. The continental climate with hot and dry summers, together with land degradation and water stress, challenges forest growth and survival. Therefore, it is of interest to assess where efforts to re- and afforest will produce satisfying and long-lasting results.

In this study, we have evaluated the potential of already identified FLR options by assessing suitability and risks at current and projected environmental conditions. Moreover, opportunities have been identified in areas where forests restoration can benefit land degradation challenges. By analyzing a broad range of data, including land cover and water availability, using Geographical Information Systems (GIS), this study provides a unique focus on restored forests ability to withstand potential challenges caused by land degradation and water stress in the long-term perspective. The results highlight areas where forest restoration is suitable, likely to sustain and can address land degradation challenges. Such opportunities amounted to 0.92 million hectares, less than the pledged 1.5 million hectares. If this target is to be achieved, and at the same time generate benefits connected to land degradation, expansion into higher risk areas are necessary, consequently reducing chances of forest long term survival.

Natural regeneration is the FLR-option with the largest opportunity area associated with low risk. This is due to beneficial environmental conditions in the eastern and south eastern Altai and Tien Shan mountains, where protective measures can generate successful attempts. Furthermore, this study concludes that some targeted FLR options, such as protective tree lines and shelterbelts, have very limited potential to be sustained due to unfavorable environmental conditions. As vast areas of the country are in need of efforts to combat land degradation, this study suggests that other means, such as reducing water consumption, are necessary to complement the limited contribution that forest restoration can serve to reverse land degradation trends.

Keywords: Kazakhstan, forest restoration, forest landscape restoration, reforestation, afforestation, Bonn Challenge, tugai, saxaul, agroforestry, tree plantations

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Martin connected us with the first interview respondents, namely Tobias Kuemmerle, professor at HU Berlin University, Johannes Kamp, professor at University of Goettingen, and Matthias Baumann, Post-doctoral researcher at HU Berlin University. Tobias, Johannes and Matthias supported our development of relevant research questions by providing their expertise perspectives and experiences of local studies in land use change, biodiversity, rewilding, forest restoration attempts in Kazakhstan, land degradation, methodology and data availability. Moreover, we greatly value our local contacts Dani Sarsekova and Sara Kitaibekova from the Forest resources and forestry Department at the S.Seifullin Kazakh Agrotechnical University in Nur Sultan, Kazakhstan, who shared their valuable time during two interviews, and expressed generous hospitality and appreciation towards collaborations with Chalmers University of Technology. During the two interviews, fast growing tree variants, efforts, water needs and usage as well as historical forest restoration efforts were discussed.

Alisher Mirzabaev, Senior Researcher at the University of Bonn, was interviewed where current forest and irrigation practices, data recommendations were the main points of discussion. Akmal Akramkhanov, regional manager for Central Asia and the Caucasus at ICARDA and recommended by Alisher Mirzabaev, was interviewed covering topics such as soil salinity, irrigation and natural water supply. Anastasia Shyrokaya, Research Assistant at University of Bonn and also recommended by Alisher Mirzabaev, was interviewed where assessment of land degradation through GIS analysis was the main focus. Lastly, Niels Thevs, Senior Scientist and Coordinator Central Asia Programme at CGIAR and author of many publications used in this study was interviewed. Forest distribution, potential and suitability were discussed, as well as plausibility of different data sets and preliminary results of this study were discussed and validated. Moreover, additional data sets from the Soviet Union time were shared by Niels Thevs as a consequence of this interview.

Lastly, we would like to thank the employees at the Department of Space, Earth and Environment for inspiring discussions during the Land use seminars, and Chalmers University of Technology for making this thesis possible.

Linnea Annderssen Elsa Ardfors, Gothenburg, June 2021

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1
Introduction

During the last decades, Kazakhstan has been severely impacted by land degradation [2]. During the time when the region was a part of the Soviet Union, degradation was mainly caused by agricultural expansion. When the Soviet Union collapsed, Kazakhstan experienced a deficiency of energy and illegal logging of trees for fuel wood became the main driver of land degradation. Today, 70% of the country's area is considered degraded to some extent and salinization and overgrazing continuously drives degradation further [3]. To combat desertification and to increase resilience to climate change, the Republic of Kazakhstan has pledged to increase the national forest cover by 1.5 million hectares of land by 2030 [1]. In order to maximize the benefits from the high costs of establishing and maintaining plantations, a proper understanding of conditions that supports growth and regeneration of forests is vital [4]. Arguably, forests restoration that are self-governing and delivers multiple benefits in a long-term sustainable way should be desirable, rather than only maximizing the amount of tree plantations [5].

Deserts areas are growing and becoming more arid, jeopardizing agriculture and water availability in a country that is already dependent on neighboring countries for almost 50% of water provision [6][7]. Despite the water resource deficit, national demand for water required by cities, industries and agriculture is currently increasing. This causes water reserves to constantly decrease, threatening life quality, the country's food security and ecosystems. The Aral Sea provides a horrifying example of this, where 90% of the sea's water reserves were lost in just 40 years due to large scale irrigation practices. If the current level of water consumption is maintained, the second largest remaining sea, Lake Balkhash, could face the same destiny [8]. Even though water management is a recognized priority of the government, in *UN World Water Development Report 2020* it was highlighted that the links between climate change and water availability were not considered in the climate and economic strategies of Kazakhstan [9]. Water availability, impacted by irrigation and climate change, is a crucial factor for forest restoration, and yet not specifically addressed in forest restoration documentations [3]. It is therefore of importance to assess how forest restoration attempts can be optimized to both withstand challenges of water stress and also support the preservation of water resources.

1.1 Aim and research questions

Since most of the country is in the need of reversing land degradation, a process which forest restoration can support, it is of interest to locate areas where forests have a high likelihood to sustain in the long-term perspective. By expanding the consideration of additional environmental factors, trends and projections in a risk assessment of the areas in need of restoration, this study enables the possibility of weighting risks and benefits of successful attempts against each other. In this way, prioritization can be supported by focusing on areas associated with high benefit and low risk, thereby maximizing the impact of forest restoration attempts. Moreover, in areas where potential benefits outweigh risks, the restoration attempts can be performed with measures mitigating these risks.

This report aims to evaluate risks and potentials for sustainable forest restoration in Kazakhstan, including consideration of environmental factors, trends and projections. The results intend to serve as a guidance for initiatives by the republic of Kazakhstan and UNDP to successfully reach the reforestation targets and to avoid unsuccessful attempts, by highlighting risks and benefits of forest restoration. The questions we aim to answer in this report are:

- What is the extent and location of areas targeted for forest restoration as identified by the Government of Kazakhstan and the UNDP?
- Which of the targeted areas are suitable for forest restoration based on existing environmental conditions, such as water availability and land cover?
- How are these areas' suitability for forest restoration affected if trends in land degradation proceed and projections in water stress are realized?
- In what areas are forest restoration likely to sustain and at the same time generate benefits that can support combating land degradation?

1.2 Delimitation

This report assesses forest restoration within the borders of Kazakhstan, but can also be used as guidance for forest restoration planning in similar environments. Restoration areas and approaches assessed are those prioritized by the Government of Kazakhstan and UNDP. Since the primary focus is forest restoration, other nature restoration practices, such as rewilding of steppe, are not considered. The study was performed remotely from Sweden during the covid-19 pandemic, which impacted the possibility for study visits. Moreover, consideration of socio-economic factors was delimited from the report. Instead, environmental conditions were the main focus of the assessment.

2
Background

In central Asia, the country of Kazakhstan covers an area of 2.73 million km^2, comparable to the size of western Europe. Kazakhstan has a continental climate with high temperature shifts over the course of the seasons. In general, the solar radiation increases and precipitation levels decrease towards the southern regions. With the exception of the mountain areas located in east and south-east, the annual precipitation levels are many times smaller than potential evaporation levels, generating a moisture deficit and dominating arid areas [10]. Out of 14 different biomes found globally, Kazakhstan holds four biomes, including vast grasslands, deserts, temperate forests and high altitude vegetation, as shown in Figure 2.1. The forest cover share of the total area of Kazakhstan differs depending on the definition of forest. According to FAO's definition, 1.2% of the total land cover are forests, whilst according to the National Committee of Forestry and Wildlife, forest *and* shrub land cover reaches 4.7% of total land [3]. The main species that forms forests are conifers (e.g. pine, spruce, larch), softwood broad-leaved (e.g. birch, aspen), hardwood broad-leaved (e.g. oak, elm), black saxaul and white saxaul. However, the climatic conditions limits the potential area of forest cover in Kazakhstan [3]. Forests areas in Kazakhstan are often in mosaic form together with other types of vegetation covers, for example grassland in mountain forests or steppe and cropland in the steppe forest [3].

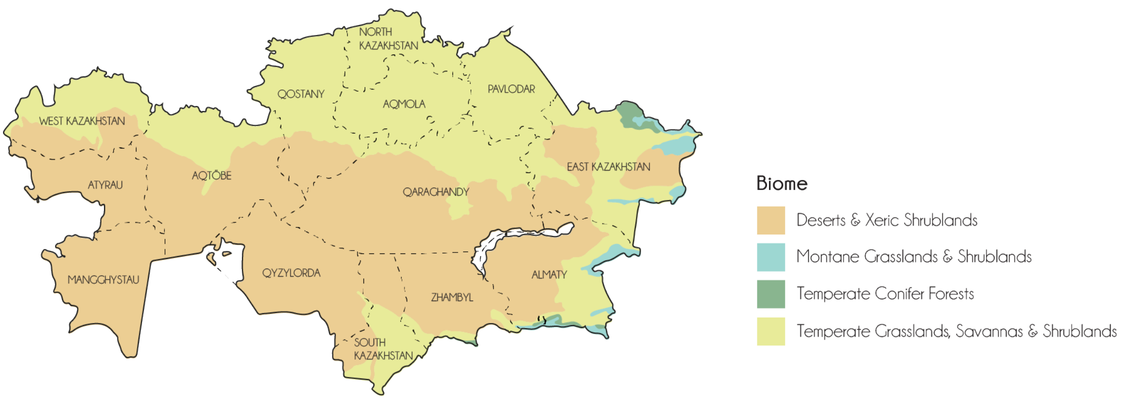


Figure 2.1: Biomes in Kazakhstan [11]

Forest Landscape Restoration (FLR) aims at regaining ecological functionality and supporting human well-being in a long term perspective in deforested or degraded forests landscapes [12]. Forest restoration can be achieved in multiple ways, such as regeneration of forests, commercial tree plantations and agroforestry systems [5]. Restoration efforts can be divided into wide-scale forest restoration and mosaic restoration, where both opportunities are present in Kazakhstan [12]. Mosaic restoration focuses on multi-functionality of the landscape [12], with multiple objectives such as improved land productivity, production of wood products, rural development, livelihoods, support environmental services (mainly water and soil), carbon sequestration and climate change resilience [13]. The intended forest restoration efforts in Kazakhstan are mainly targeting the forests ability to reduce wind erosion on sandy soils, protect the water function and reduce flood risks [7]. By achieving these objectives, forest restoration will contribute to combating desertification and increase resilience to climate change [1].

2.1 Drivers of land degradation

Kazakhstan is impacted by desertification, which is the soil degradation in arid, semi-arid and dry subtropical areas. Unlike "desert", that is a description of a static landscape, "desertification" a dynamic process where landscapes such as grasslands and arable land is ecologically degraded towards desert-like landscapes [14]. Approximately three quarters of the country is assessed to have moderate or high sensitivity to potential desertification [14][8]. The process of desertification is influenced by a variety of factors, including climate change and human activities, and results in loss of resource productivity, increased atmospheric dust and disruption of the water cycle [15]. When desertification reaches mountain areas, there is an increased risk of landslides, rockfalls or mudslides [8].

Salinization is described as one of the main drivers of desertification in Kazakhstan [3]. River deltas are naturally exposed to salinity drivers and disruption of processes that sustain the natural balance results in increased salinity. Although salinization is driven both by natural and anthropogenic causes and the local relative influence of these drivers are often poorly understood [16], it can be assumed that irrigation practices that reduce freshwater inflow is a strongly contributing factor to salinization around the river deltas in southern Kazakhstan [16][17][18]. Irrigation practices are dominant in the southern regions due to lower levels of precipitation [19] and the dominant irrigation practice is surface irrigation [20]. Agriculture is the major water consuming sector, and many rivers in southern Kazakhstan are surrounded by agriculture [20], creating competition of water use between agriculture and natural ecosystems [19]. Forest degradation, specifically of tugai forests along rivers and saxaul bushes, are not only a consequence of large-scale clearance and development of irrigated agricultural land, but also by soil salinization and river runoff reduction [3]. The current demand for water required by agriculture, but also by industries and cities, are causing the water basins resources to decline [8]. Moreover, reduction of river runoff to river basins is commonly identified as a consequence of climate change in Kazakhstan [20][19], amplifying this trend further.

In the north, irrigation practices are not as common due to possibilities of rain-fed agricultural production. However, these rain-fed agricultural systems have relatively low yields compared to the irrigated agriculture of the south [19], and therefore grazing is often applied [15]. Overgrazing is identified as a driver of desertification in Kazakhstan [3]. Although the overall grazing pressure in Kazakhstan has reduced during the last decade [21], large-scale intensive agricultural activities is still the main cause of land degradation in the northern regions Kostany and Akmola[14].

Climate change is expected to lead to an increase of the annual temperature in Central Asia with 0.6 - 1.1 degrees Celsius [22]. Although there is no consensus within the research field on what effects climate change will have on precipitation in Central Asia [19], some studies implies that precipitation will increase in the north and decrease in the south and west [22][14]. The changes in climate are predicted to have seasonal volatility effects, delaying peak river discharge timing in mountain areas, reducing snow accumulation and discharge in summer [22][19]. With increased temperatures, some regions might see positive prolonged vegetation periods. However, water availability might also be reduced as a consequence of increased evapotranspiration and less snow-originated water supply for river runoff during vegetation period and for irrigation [22]. There have already been notable agricultural productivity decreases in Kazakhstan as a consequence of climatic changes [22]. One study that analyzed desertification in Kazakhstan based on precipitation and temperature concluded that climate change is a driver of desertification in the western regions Aktobe, West Kazakhstan, Mangystau and Aturau [14].

2.2 Forests role in combating land degradation

Desertification control can be archived by integrating forests in many different ways, for example through plantations, reforestation, regeneration, agroforestry, tree nurseries and wind breaks [15]. Even though forests play an important role in reversing desertification trends, the cultivation in these arid areas are problematic with lower growth rates, lower survival rates and difficulties in maintenance [15]. Forests play an important role in areas prone to salinization since forest loss brings salts closer to the top layers of the soil, contributing to salinization [23]. *Populus euphratica*, which tolerates salinity and accumulates salt in its tissues, are often used for afforestation in saline deserts to stabilize sandy lands and used as shelterbelts. Attempts are being made to generate breeds that have enhanced salinity tolerance to reduce the difficulties of planting in very saline areas [24][17]. Even though excessive salinity have some commonalities with drought, *Populus euphratica* is far from drought resistant [17]. Therefore, saline resistant species does not necessarily mean that they are drought resistant.

Forests both regulates and impacts water availability [23], and its effect on water provision needs to be carefully studied in arid climates with water deficiency [25][23]. Recent studies have focused on more accurately evaluating forest impacts on water availability, shifting from overestimated and simplified assumptions such as the more forest, the more water [23]. Water resources can be divided into green and blue water [25]. During afforestation, the allocation of green water, plant used water, and the blue water, human used water, changes. Water consumption of trees can be higher than other shorter vegetation, potentially leading to a short-term reduction of blue water supply [25]. For this reason, upstream forests are not always increasing downstream water yields [23]. Other positive effects, such as forest regulation of hydrological flows, which leads to increased river flow, reduced risks of floods and seasonal dry out, are also occasionally overestimated [23]. Climate, forest and soil types are factors that influence the water use [23]. Therefore, it is important to consider context-specific factors of countries, regions, watersheds, forest types and management practices when planning reforestation [23]. While it is important to consider differences in water consumption between different plants, in areas that are prone to salinization, forests plays an important role in regulating salinity and should therefore not be deforested [23].

As forests contribute many different functions, such as erosion control, improved quality of water and soils, change resilience, carbon sequestration, biodiversity, land productivity, generation of forest products, recreation and rural development [23][26][25][13], there are trade-offs to consider. An example of this is utilization of fast growing trees for bio-fuel, where the high water demand of fast growing trees results in a local trade-off between energy supply and water depletion risk [23]. Moreover, forests act as an effective barrier to reduce soil erosion on sloping lands by stabilization trough the roots and thereby reducing landslides [23]. Restoring previous forests on slopes or old mining sites would reduce these risks in Kazakhstan [3]. Forests along rivers, riparian forests, reduces the domestic, industrial and agricultural pollution and provide shade that reduces thermal stress by a warmer climate [23].

Inclusion of trees as shelterbelts around crop production fields to reduce wind erosion and thereby reduce water consumption in crops, one type of agroforestry, has proved to be effective in many global drylands [20][15]. The water consumption of the trees themselves are often neglected when assessing their impact on the crop water consumption, but one study has assessed the total water consumption of the whole crop-shelterbelt system in South east Kazakhstan [20]. Wind speed and water consumption reductions of these systems can reach 36% and 30% respectively [20], but many factors influence this. Also, the trees trap snow, generating slightly lower temperatures and higher air humidity. The size of the crop area that are surrounded by the protective tree lines has proven to determine if the total water consumption will increase or decrease. The assessment study from the south-east of Kazakhstan showed that 500x500m fields had more success in reducing total water consumption for different crops compared to 200x200m fields [20]. Nevertheless, as increased field size generates less wind erosion protection, larger fields are not by default preferable. Moreover, the type of crop also influences the success of the reduction of water consumption that the tree lines have. Water demanding crops, such as corn or cotton, are crops that can benefit from these tree lines to improve water management [20]. Hence, in the structural choice of agroforestry system, crop and tree variant as well as tree intensity are important to consider when assessing the water resource impact. Agroforestry system also generates other benefits, such as increased crop yields and income from tree products such as timber or fuel wood [20].

2.3 Targeted areas and approaches for forest restoration

The national viewpoint of forests role in Kazakhstan is not that of a provisioning industry but as a supporting ecosystem protecting soil and water [7]. In 2013, Kazakhstan adopted "the Concept of transition of the Republic of Kazakhstan to a green economy" with the aim to "harmonize relations between people and the nature". Within this concept, conservation is specified as a priority, resulting in extensions of protected areas as well as establishment of new protected areas [8]. In 2004, the government prohibited felling and use of conifer and saxaul stands at land controlled by the State Forest Fund [7], corresponding to 10.6% of the country area in 2013 [8]. Previous conservation and restoration activities also includes forest ranges of ribbon wood in Priirtyshie in the north-east of Kazakhstan and saxaul plantations in the southern region Kyzylorda [8]. Moreover, a recent incentive allows for private tenants to rent land for 49 years to be used for forest restoration, bee farming, and farming of medical plants and herbs [24].

This section introduces the forest restoration options and their relevant areas that are targeted to increase the forest cover in Kazakhstan. Targeted areas refer to the descriptions of areas that would benefit from forest restoration, such as arid climates or areas around rivers, and are derived from documentation by the Government of Kazakhstan and the UN. Moreover, relevant forest restoration options (FLR-options), such as agroforestry or natural regeneration, are also derived from these documentations. This section intends to summarize the relevant FLR-options and their associated targeted areas.

2.3.1 Protective land and buffers

Tugai is the term used to describe forests that grow along riverbanks in Central Asia. In arid climates, tugai forests are composed of species such as *Populus euphratica*, that have adapted to the low precipitation by extending their root-systems into the groundwater [3][27]. **Tugai forests** in Kazakhstan are restricted to narrow margins along rivers where the groundwater levels are high enough [3]. As tugai forests provide vital ecosystem services in dry lands and work as a barrier to desertification, restoration of tugai forests are considered to be of priority [3]. Tugai forests are naturally and regularly exposed to fires and their rehabilitation and regeneration depends on floods during the spring to replenish the groundwater [10][27]. As tugai forests has previously been cleared for agriculture [3], restoration might be hampered by competing interests. Reduction of river runoff, for example due to irrigation practices, also drives degradation of tugai forests [3].

Arid zones are considered to be in greatest need of restoration [3]. Limited availability of freshwater, moisture deficit and a dry climate limits the numbers of tree species suitable for forest restoration in southern Kazakhstan. *Haloxylon ammodendron*, or the **Black Saxaul**, is often used to reduce desertification and in rehabilitation attempts due to its adaptability to desert environments [4]. These attempts target wind speed reduction, reducing soil erosion, drift sand catchment, air temperature reduction and biodiversity enhancement [4]. Saxaul vegetation have been severally degraded in the desert areas of Kazakhstan, with an estimate of 61,9% loss of saxaul vegetation area from the 1950's and forward [28]. This indicates a large potential in saxaul restoration [28]. The black saxaul derives its water from groundwater, whereas the white saxaul derives water from rainwater [28].

Saxaul plantations on the dry beds of the Aral Sea is identified as a targeted restoration practice [3], although previous plantations in the area have had limited success. From 1988 onwards, 54000 ha of artificial plantings of saxaul have been established on the dry bottom of the Aral Sea. Survival rates of these plantations have been 5-10% and regeneration is compromised by strong wind and dryness that disables seeds to root [10]. Furthermore, the drying out of the Aral Sea has provoked a drop in the groundwater levels to the extent that black saxaul is no longer fit for growing in the Kyzylkum desert, located south of the river Syr Darya and towards the border of Uzbekistan [7].

Figure 2.2: Left: Saxaul shrub [29] Right: Tugai forests in Uzbekistan [30]

Protective tree lines along roads and railways as well as **shelter belts** around cities are identified as a measure to improve health of citizens and protect infrastructure in windy landscapes [3]. Kazakhstan has a history of planting forest for protective purposes [7]. The green city belt of the capital Nur-Sultan (previously Astana) has been underway since 1997 and reached 78 000 ha of forest by 2018. Although the full impact of the belt is yet to be seen, wind speeds as well as fog and snowstorm occurrence has dropped in the capital since establishment. In addition, the area is now habitat for wild animals and visited for recreational purposes by the citizens of Nur-Sultan. Work has begun on the creating of green belts around other regional centers in Kazakhstan [31].

2.3.2 Agricultural land

Agroforestry, the integration of trees on active agricultural and/or livestock land [32], is identified by the UN as an opportunity to expand forested areas [12] and protect agricultural land from wind erosion[3]. Agroforestry practices aims at improving soil fertility, yields, water retention, protection, reducing erosion and generating valuable wood products [12]. Agroforestry can mitigate the risks associated with irregular and unpredictable precipitation levels as the large root-systems of trees hold water and reduce runoff. A diversified harvest of fruits, nuts and wood is also a way to mitigate risks of economic fluctuations in markets [15].

All though UN promotes agroforestry in Kazakhstan, there is less emphasis on it in the national documentations and none of the documentations reviewed within this study specifies any areas that are targeted for agroforestry. In the irrigated agriculture areas, tree shelter belt systems, where trees are planted around cropland, are the most prominent form of agroforestry system. These systems were diffused during the Soviet Union, but after the collapse the trees were often cut down for of fuel wood [20]. Culture has a great influence on the extent to which agroforestry systems are applied [33][34]. In mountain areas and along the boarder to Uzbekistan, there is a tradition of integrating trees into agricultural practices [34].

The suitable trees types for agroforestry differs across the country due to climatic differences [34]. In the south, Mulberry trees for silk production [33] and Poplar [34] are common tree species used. Poplars are specifically common as shelter belt trees in rainy or irrigated areas in the south east [20], and have adopted to the prevailing environmental conditions in the form of resilience to salinity [17]. In the north, elm, birch and acacia are more common as they have adopted to less water availability and colder climates [20][34]. The climatic conditions in the north creates difficulties in the form of limited tree growth [34].

2.3.3 Forest land

Natural regeneration of forest is effective when desirable tree species and tree seedling are still present [13]. It is more challenging without the native species when lacking seed sources and loss of topsoil, and planting might be necessary. When planting in bare areas, integration of nurse crops, in the form of fast growing trees, can provide support. Natural regeneration is supported if there are fragments of forests close to the site and the larger areas, the better. The success of these attempts is determined by long-term commitment in the form of maintenance [13]. In Kazakhstan, forests on slopes and near settlements have suffered degradation from grazing and tree felling [3]. Removal of pasture is suggested to support natural regeneration of broadleaf and conifer forests in the Tian Shan and Altay mountains that have more recently suffered from degradation [3]. When restoring forests on slopes, the risks of landslides are reduced [3]. Conservation of landscapes is also believed to support ecotourism that identified as one of the most promising tourist products [8].

Developing production of forest products on currently unproductive sites is an opportunity of forest restoration, generating products such as lumber, fiber, wood-fuel and non-wood products (e.g. food or medicine). In this way, forest restoration costs may be covered by financial returns [13]. There are many examples of intentions to strengthen the forest sector in Kazakhstan. The government is developing a legal framework of private ownership of forests to stimulate private investments in forests, with specific focus on afforestation [3]. This can increase the adoption of sustainable forest management and the utilization of wood as a renewable material and fuel. Moreover, the Kazakhstan-2050 strategy includes targets of a development towards a green economy [3]. **Planted forests and woodlots of fast-growing tree plantations** is highlighted as an approach to stimulate wood processing industries and a way support the transition to a green economy [3]. Furthermore, Kazakhstan has been involved in a UN funded capacity building project for Sustainable Forest Management, partly with the intention to strengthen the involvement of regions and businesses in the forest sector [35]. The intention to stimulate private engagement in the forestry sector is still at an early stage, but the development has been described as promising [8]. Nevertheless, the documentations reviewed in this study does not include any description of specific areas where these efforts will be targeted.

Northern Kazakhstan holds 80% of the timber resources, where more than half of the coniferous forests are located in the eastern parts [36]. Poplar and willow are suitable fast growing tree species for the climate of Kazakhstan [36]. These can be used for environmental protection at the same time as they are economically important, with potential of bio-energy resources and timber production [36][17]. In contrast to annual mono-culture crop systems, the use of short rotation coppice plantations on agricultural land generates benefits in reduction of water and wind erosion and for biodiversity [36].

3

Methods and data

This study was conducted in four steps, partly supported by the Restoration Opportunities Assessment Methodology (ROAM). ROAM is a framework developed by the International Union for Conservation of Nature (IUCN) and the World Resource Institute (WRI). ROAM offers tools to locate and analyze areas suited for Forest Landscape Restoration (FLR) and aims at providing guidance for where to start and how to proceed with FLR [12]. The background description of targeted areas for forest restoration, described in Chapter 2.3, covers some of the ROAM methodological steps, such as identification of what areas that are in the need of forest restoration, suitable types of FLR-options and what needs they address. The aim of forest restoration is to increase resilience to climate change, reduce desertification, land degradation, soil erosion and flood risks. There are also other benefits from forest restoration such as biodiversity support, carbon sequestration and development of a green economy. The FLR options and the associated benefits of each option are described in Chapter 2.3. This study complements existing literature by summarizing an consolidating national as well as international documentation, translating and assessing the potential of the FLR options into geographical representations.

This study was performed by compiling and analyzing data from both secondary sources, such as databases and literature studies, and primary sources, in the form of interviews. Interviews with international and local researchers were performed to integrate local knowledge and increase relevancy. In total, seven interviews were conducted, including the respondents Tobias Kuemmerle, Johannes Kamp, Matthias Baumann, Alisher Mirzabaev, Akmal Akramkhanov, Anastasia Shyrokaya, Niels Thevs, Dani Sarsekova and Sara Kitaibekova. Tobias Kuemmerle, professor at HU Berlin University, Johannes Kamp, professor at University of Goettingen, and Matthias Baumann, Post-doctoral researcher at HU Berlin University, were collectively interviewed with the intention to shape relevant research questions. Historical land developments and forest restoration attempts, land degradation and its drivers, biodiversity as well as methodology and data availability were discussed. Alisher Mirzabaev, Senior Researcher at the University of Bonn and the author of Climate Volatility and Change in Central Asia (2013), was interviewed where current forest and irrigation practices, data and contact recommendations were the main points of discussion. Akmal Akramkhanov, regional manager for Central Asia and the Caucasus at ICARDA and recommended by Alisher Mirzabaev, was interviewed covering topics such as soil salinity, irrigation and natural water supply. Anastasia Shyrokaya, Research Assistant at University of Bonn, also recommended by Alisher Mirzabaev, was interviewed where assessment of land degradation through GIS analysis was the main focus. Niels Thevs, Senior Scientist and Coordinator Central Asia Programme at CGIAR and author of many publications used in this study were interviewed. Forest distribution, potential and suitability were discussed, as well as the accuracy of different data sets and preliminary results of this study were discussed and validated. Moreover, additional data sets from the Soviet Union time were shared by Niels Thevs as a consequence of this interview. Lastly, two different interviews with Dani Sarsekova and Sara Kitaibekova from the Forest resources and forestry Department at the S.Seifullin Kazakh Agrotechnical University in Nur Sultan, Kazakhstan, were held. The interviews included fast growing tree variants, water usage as well as current and historical forest restoration efforts. All citing referring to the interviews were verified with the interview respondent to assure quality.

Based on gathered information, a set of criteria were developed for assessing risks of forest restoration attempts, with a specific focus on long term forest survival. By integrating geospatial data using the Geographical Information Systems (GIS) software QGIS, geographical representations of the targeted areas from Chapter 2.3 were created and evaluated through the assessment criteria described in this chapter. To serve the purpose of generating a national overview of potential risks and opportunities for forest restoration, a wide range of data sets were used. However, the chosen approach to use a wide range of data sets came with the compromise of using data sets with different pixel sizes. Therefore, the results generated from this methodology should not be used for the purpose of identifying exact areas for forest restoration, but rather as highlighting risks and opportunities in different areas when planning forest restoration. Lastly, to identify opportunities, the risks were compared with the benefits that the restored forest can generate. The overall approach is illustrated in Figure 3.1 and described in detail in this chapter.

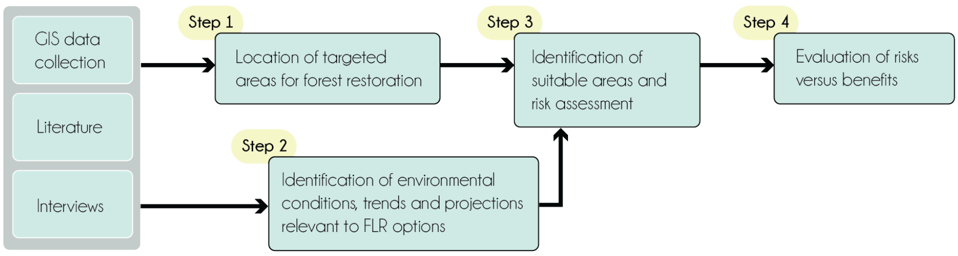
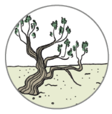


Figure 3.1: Illustration of the method

3.1 Step 1: Location of targeted areas for forest restoration

In the first step, the areas targeted for restoration, as described in Chapter 2.3, were translated into geographical areas using QGIS software. The targeted FLR options are summarized in Table 3.1, where they are categorized according to the ROAM methodology and the corresponding targeted areas are described. Geo-spatial data was used to translate the descriptions, e.g. arid climates, closeness to river channels or degraded forests, into maps visualizing these objectives. When geo-spatial data in applicable formats for QGIS integration were missing but were available in other forms, new layers were created in QGIS to represent this data. For example, the *dry beds of the Aral Sea* targeted for plantation of saxaul was represented in this way. The data used for locating the targeted areas are summarized in Table 3.1.

Table 3.1: Summary of FLR options and targeted areas

Land areas	FLR option	Targeted areas for FLR	Data used for identification
Protective land and buffers Land that is vulnerable to desertification or in need of safeguardig against extreme weather and erosion control	1. Tugai forest restoration 	*Riverbanks in arid climates with a focus on areas prone to desertification*	FAO (1997;2014), Dinerstein (2017) Trabucco & Zomer (2018) Wenqiang (2015)
	2. Saxaul restoration 	*Arid climates with the aim to combat desertification, focus on the dry beds of the Aral sea*	Trabucco & Zomer (2018) Wenqiang (2015) Ministry of Environment Protection (2009)
	3. Protective tree lines and shelter belts 	*Along roads and railway lines and around regional centers in windy regions*	Meijer (2018), FAO (1997) WorldPop (2018) Davis (2019)
Agricultural land Land which is managed to produce food and/or fibre	4. Agroforestry 	*Agricultural land*	Cropland - ESA
Forest land Land where forest is, or is planned to become, the dominant land use	5. Natural regeneration 	*Restoration of degraded or deforested land*	Forest cover change - ESA
	6. Fast growing tree plantations 	*No information on targeted areas*	

3.1.1 Protective land and buffers

Riverbanks in arid climate targeted for **tugai forest restoration** were located by combining spatial data on river distribution and aridity. The data on river distribution was processed by including perennial and excluding intermittent rivers [37] [38] and arid zones were represented by areas defined as arid in the generalized climate classification scheme for Aridity Index values [39]. The distance to river channel supporting high diversity tugai forests is 1.5km (±0.4) [27]. Therefore, a distance of 1.5 km to river channels was marked as potentially existing, degraded or deforested tugai forests with objective for restoration. Furthermore, translated geospatial data of tugai forests from the Sovjet Union were shared in the interview with Niels Thevs [34]. This data was used for complementary purposes. As tugai forests functions as a barrier to desertification, tugai forests located in areas exposed to desertification [40] was marked as objective for restoration.

Targeted areas for **restoration and plantations of saxaul** was located based on areas defined as arid based on generalized climate classification scheme for Aridity Index values [39]. The area around the Aral Sea was manually marked based on information derived from Governmental documentation [7]. Moreover, as saxual is often used to address and rehabilitate desertification, areas that are subject to desertification [40] were also considered to be objective for restoration and plantations of saxaul.

Areas for **protective tree lines and shelter belts** were mapped by combining data of average wind speed [41] with road-nets [42], railways [43] and settlements. Settlements were identified by using population density [44]. In the dataset of road nets, there are five classifications of roads, where category 1 and 2 were used to represent the largest roads. To identify roads, railways and cities in need of wind protection, the wind map was filtered with wind speeds that were above or equal to the average wind speed around Nur Sultan. This reference area, with approximately 5 m/s in average wind speed [41], was chosen as protective tree lines have already been established around the city for this purpose. Roads, railways and settlements that are subject to at least this average wind speed were thereby mapped.

3.1.2 Agricultural land

To locate areas targeted for **agroforestry**, cropland was identified by using ESA land cover data [45], where all four categories including cropland was used, namely, Cropland: rainfed, Cropland: irrigated or post-flooding, Mosaic cropland/vegetation with cropland >50% and Mosaic cropland/vegetation with cropland <50%. This was chosen to capture all the potential areas for this initial step.

3.1.3 Forest land

Degraded forests are objective for restoration by **natural regeneration**. Several data sources of forest cover were used within this study. In some cases, these were conflicting, and therefore a comparative evaluation was performed. FAOSTAT evaluates the forest cover of Kazakhstan to be 1.2% of the total land cover and the National Committee of Forestry and Wildlife evaluates the forest *and* shrub land cover to be 4.7% of total land [3]. With this information as guidance, different data sets were evaluated in QGIS for accuracy [46][45][47]. Through an area analysis, it was concluded that the MODIS data set provided by NASA [46] includes a forest cover of 0.7% and shows no presence of tugai forests in arid climates. In the same way, the land cover data provided by ESA[45] includes a forest cover of 1.7% and Hansen (2013) a forest cover of 1.85%. The additional forest cover in Hansen (2013) is located around rivers in arid climates[47]. This dataset was reviewed in an interview with Niels Thevs, who has experience in working with forest restoration in Kazakhstan [34]. The additional forest cover were identified as incorrect as the Ili river in Almaty is not surrounded by forests but with different reed beds and tree lines of Elaeagnus angustifolia along river branches [34]. Since the land cover data from ESA included the largest areas with evaluated accuracy and the longest time frames, it was used to locate degraded forests as potential targeted areas for forest restoration.

This was achieved by an analysis of forest cover change between the years 1992 and 2019 [45], were all natural forest excluding those already included in the Saxaul or Tugai forest category were considered. Pixels showing forest cover in 1992 but not in 2019 was classified as loss of forest and pixels showing no forest cover in 1992 but in 2019 was classified as gain of forest. To simplify interpretation of the results, a zonal statistic of forest land was performed. For this, forest land was divided into zones based on connectivity. Larger connected forest areas were further subdivided for similar area representation of the zones. Although smaller subdivisions would have produced more detailed results, the chosen approach was considered to be sufficient since the study does not intend to provide detailed site specific indications. Moreover, identifying areas with high connectivity of forest pixels were considered to be more likely of representing actual forest cover. A mean value of each zone was calculated. Loss was given a value of -1 and gain was given a value of +1. Forest zones showing a negative mean value were classified as degraded forests and marked as objective for restoration.

To complement this analysis, other sources of land degradation [40] and descriptions in forest restoration documentations [3] were used to capture larger potential areas with objective for restoration. Using the data set on land degradation, all land classified as degraded to some extent, represented as category 1 to 4 out of 5 categories, was considered degraded land. Zonal statistics on forest zone level were performed, and forest zones having 2/3 or more of pixel cover indicating degraded land was classified as degraded as thereby as objective for restoration. Moreover, overgrazing in the Altai and Tien Shan mountains has resulted in over-mature forests due to continuous removal of seedlings, inhibiting regeneration. These areas are described to benefit from natural regeneration [3] and were therefore marked as objective for restoration based on geographical location. The need of reducing the risks of landslides by forest restoration was assumed to be covered in the criteria of Altai and Tien Shan mountains, since mountain areas are defined by slopes. Degraded forests near settlements in need of restoration, as described in 2.3, were assumed to be covered in the degradation analysis. For **fast growing tree plantations**, no specific areas or conditions were mentioned in the reviewed documentations as targeted for this purpose.

3.2 Step 2: Identification of environmental conditions, trends and projections relevant to FLR options

When evaluating forest restoration options and areas, important considerations are assessing the current status of forests, forest functions, agricultural areas, land degradation, environmentally protected areas and road accessibility [13]. Moreover, a strong connection to desirable benefits of the attempts and current environmental conditions are of importance [13]. The ROAM methodology uses assessment criteria to evaluate potential areas for forest restoration. For example, current land cover and competing interests for land will affect the feasibility of forest restoration [12]. This study has, according to the ROAM methodology, used a set of assessment criteria describing the **environmental conditions** in Kazakhstan, with the intention to support the risk assessment in Step 3. In Step 3, environmental conditions were used to exclude unsuitable areas for each restoration option. The conditions mapped were (i) water availability, (ii) land cover and (iii) other relevant conditions. Water, together with nutrients, temperature and sunlight, is one of the most vital factors affecting forest growth [48]. It was chosen as a criteria based on the dry climate that limits forest growth. Land cover was chosen as an assessment criteria to locate relevant land classifications, for example topography, current agricultural land, forests, shrubs and barren areas. Other relevant conditions that were mapped were wind speed, accessibility to markets and existing protected areas.

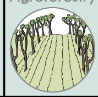
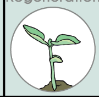
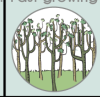
In addition to the ROAM methodology, this study broadened the set of criteria, with a focus on long term sustainability of the restoration attempts, by identifying **trends and projections**. The intention of the additional criteria was to support the risk assessment in Step 3 of the remaining suitable areas. The risk assessment in Step 3 assesses the restored forests ability to withstand ongoing changes in terms of land degradation and water availability. Factors driving land degradation could be a potential threat to forests survival in the long-term perspective. To assess where these drivers are most significant, trends in (iv) land cover changes were identified. Lastly, in a country were water is deficit and water reserves are both impacted by water use and climate change, integrating (v) projections in water stress which includes impacts of both water withdrawal and climate change were considered relevant. The assessment criteria and used data are summarized in Table 3.2 and described in this chapter.

3.2.1 Environmental conditions

Water availability was mapped with four indicators, namely, precipitation, soil type, irrigation systems and baseline water stress. In terrestrial ecosystems, trees are provided with water from precipitation [48]. Hence, yearly precipitation was mapped by using data from CHELSA [49], where a yearly average was calculated using the monthly average over the years 1979-2013. In arid climates, some trees have adapted by extending their root system into the groundwater [3]. Rivers in arid climates recharge the groundwater, but dependent on the topography around the rivers, this groundwater is only accessible to trees within a few kilometers of radius from the river channel [34]. A distance of 1.5 km from river channels was mapped in Step 1. To complement data on water availability around rivers in arid climates, soil types [50] were used as an indicator as fluvisols are soils that are occasionally flooded and gleysols are soils with a high moisture content [51].

Irrigated areas were identified through a combination of datasets. The areas equipped

Table 3.2: Summary of criteria used for assessment of targeted areas for forest restoration

General description	Assessment criteria	Data used for representation	Data used for assessment of FLR options: Tugai 	Saxaul 	Shelterbelts 	Agroforestry 	Regeneration 	Fast growing 
Environmental conditions 	(i) Water availability	Soils	■					
		Precipitation			■	■	■	■
		Irrigation			■	■		■
		Current water stress			■			■
	(ii) Land cover	Land cover	■	■		■		■
		Forest cover					■	■
		Elevation			■	■	■	■
	(iii) Other relevant conditions	Mean wind speed		■				
		Accessability to markets						■
		Protected areas						■
Trends and projections 	(iv) Land cover trends	Land degradation	■	■	■	■	■	■
		Vegetation cover change	■	■	■	■		■
		Forest cover change					■	
	(v) Water availability projections	Projected water stress	■	■	■		■	■

for irrigation and the actual use of these irrigation systems were retrieved from FAO [52]. Irrigation systems are used for different sectors, and the two main water consuming sectors are agriculture and industry. Agricultural irrigation systems were identified through ESA 2019 land cover data by extracting the category "Cropland Irrigated or post-flooding" [45], and verified by interviews [34][24]. All of these areas were assured to be actually irrigated by using FAO data [52]. Aqueduct Global Maps 3.0 Data produced by WRI was used to indicate risk of physical quantity of water availability [53], where Baseline Annual was chosen to indicate current water stress levels. The baseline water stress is a representation of the current status without anomalies based on historical data. Water stress, the ratio between water withdrawal and available renewable surface- and groundwater supply, is relevant for Kazakhstan as it both have a deficit of water availability and extensive water use systems with historical negative impacts. The baseline water stress, indicates as Current water stress in Table 3.2, were used to eliminate unsuitable areas for FLR options that require additional water use through plantations, as a high baseline water stress level indicates high water usage competition [53]. Areas that were used to extract unsuitable areas were those having High (40-80%) or Extremely high (>80%) current baseline water stress.

Land cover was mapped to both exclude unsuitable areas and locate suitable areas. For example, exclusion of existing healthy forests or shrub-land and identification of bare land suitable for saxaul restoration and plantations. Elevation was mapped

[54] to exclude areas above the forest zone of 3000 meters [34].

Two commonly used land cover data sets provided by ESA [45] and NASA [46] were reviewed to determine the most useful classifications for the purpose of this study. Since the dataset by ESA includes a more detailed classification of sparsely vegetated land compared to the one by NASA, ESA [45] was used to identify cover of shrub land and bare land. The ESA data set were also used for its relevant classification of croplands, namely, *Cropland: rainfed, Cropland: irrigated or post-flooding, Mosaic cropland/vegetation with cropland >50% and Mosaic cropland/vegetation with cropland <50%.* The cropland data was used both to determine suitable areas, for example in the case of agroforestry, but also unsuitable areas, in the case of planted trees for commercial purposes, where these areas have conflicting interest.

As mentioned in the previous chapter, different land cover data shows different distribution of forests due to different ways of classifying land. The two land cover datasets considered as most accurate, by NASA and ESA, was combined in order to visualize forest cover. This data was combined by using NASA data, corresponding to a lower total area, to represent dense forest cover, and ESA dataset, corresponding to a larger area, was used to represent other tree cover when not overlapping with NASA forests.

Other relevant conditions were wind speed, accessibility to markets and existing protected areas. Wind exposure were mapped by retrieving the mean wind speed at 50 meters during a 10 year period [41]. This data was chosen as strong winds are identified as one of the factors that inhibits regeneration of saxaul in the area around the Aral Sea [10]. Accessibility to markets in Central Asia created by ICARDA [55] was mapped with the intention to identify suitable areas in the case of commercializing tree resources. Due to lack of available geo-spatial data formats, areas located within a 4-hour travel time to city was manually translated into a new layer in QGIS. Lastly, protected areas [56] in Kazakhstan were mapped with the intention to exclude these areas for the option of planting trees for commercial purposes.

3.2.2 Trends and projections

For identification of **trends in land cover**, changes in vegetation index and forest cover between 2001-2019 were analyzed. Since a major part of the land has been degraded prior to 2001, these analyses over time were complemented and combined with data on degraded land [40]. Thereby, historically degraded land prior 2001 was represented. The same approach for identifying degraded land as used in Step 1 was applied, using category 1-4.

Changes in *vegetation index* was analyzed between the years 2001-2019 by using the NASA data on Land Cover Dynamics [46], which includes vegetation index. Pixels showing vegetation cover in 2001 but not in 2019 were classified as negative trend and pixels showing no vegetation in 2001 but in 2019 were classified as positive trend. To simplify interpretation of the results, a zonal statistic was performed, where

Kazakhstan was divided into zones according to the political districts. The political districts were considered to be of reasonable size to divide zones of vegetation. This, as vegetation is widely distributed all over Kazakhstan in comparison to the distribution of forests. A mean value of each zone was calculated were loss was given a value of -1 and gain was given a value of +1. Zones showing a negative mean value were classified as negative vegetation trend and zones showing a positive mean value were classified as positive vegetation trend. By combining the two analyzed data sets on degraded land [40] and vegetation index [46], long term trends in vegetation were derived. Positive trends were identified as zones/districts not classified as degraded and showing an overall positive vegetation cover trend 2001-2019. Negative trends were identified as zones/districts classified as degraded and showing an overall negative vegetation cover trend 2001-2019.

For analyzing changes in *forest areas*, the zonal divisions created in Step 1 was used. The size of these zonal areas was considered suitable since forests are only existing in smaller areas of the country. Using the same method as to analyze vegetation change, forest cover change between the years 2001-2019 was analysed and combined with a zonal statistic of land degradation. The forest data used was a combination of the MODIS/Terra+Aqua Land Cover Type Yearly L3 Global 500 m SIN Grid data set from NASA [46] and land cover data from ESA [45] as described in section 3.2.1. Pixels showing any of the two categories, dense forest or other tree cover, in 2001 but no forests cover in 2019 was classified as forest loss and was given a value of -2. Pixels showing dense forest cover in 2001 but other tree cover in 2019 was classified as forest degradation and was given a value of -1. Pixels showing other tree cover in 2001 but dense forest cover in 2019 was classified as upgraded forests and were given a pixel value of +1. Lastly, pixels showing no forest cover in 2001 but some of the forest categories in 2019 was classified as gain of forest and was given a pixel value of +2. A mean value of each zone was calculated, and zones with a negative mean value was classified as negative trend while zones with a positive value was classified as positive trend. By combining the two analyzed data sets on degraded land [40] and forest cover [46][45], long term trends in forests were derived. Trend was identified as positive in zones not classified as degraded and showing an overall positive forest cover trend 2001-2019, and negative in zones classified as degraded and showing an overall negative forest cover trend 2001-2019.

For identification of **projections in water availability**, Aqueduct Global Maps 3.0 Data produced by WRI [53] was used. The Aqueduct Future Projections [57] of water stress was used to indicate future risks of physical quantity of (v) water availability. Already developed projections of water availability was used, rather than trends, due to high complexity of estimating water flows, influenced by both natural and anthropogenic forces. The baseline period used to develop the projected indicators were 1950-2010 [57]. The projections combine scenarios of climatic and socioeconomic changes by using Coupled Model Intercomparison Project (CMIP) Phase 5 project and Shared Socioeconomic Pathways database from International Institute for Applied Systems Analysis [57]. The scenarios used were Representative Concentration Pathways (RCP), including RCP 8,5 and RCP 4,5, and Shared Socioeconomic Pathways (SSPS), including SSP2 and SSP3. These projections were considered relevant as Kazakhstan has a history of direct societal impacts on water availability, in the form of irrigation, and are projected to be impacted by climate change. To serve the purpose of this study to highlight potential risks, the combination of the most expansive scenarios, RCP8,5/SSP3, representing the high emission and high socioeconomic development, were used. The projections with the longest time frame, 2040, were used to serve the aim of reaching successful restoration attempts in longer time perspectives.

Water stress, or the ratio between water withdrawal to supply, was chosen as an indicator as both influencing factors are relevant for water availability in Kazakhstan. The change in water supply was represented by total blue water, meaning renewable surface water [57], and climatic changes are estimated to have impacts on the water runoff supply. The projections of water withdrawal include country characteristics such as GDP, population, urbanization, likelihood of expansion (industry, irrigation, etc.), and water consuming sectors, e.g. agriculture and industry [57]. In the case of agricultural irrigation, factors such as irrigation efficiency and impacts that climate change will have on the size of water withdrawal by the sector were considered. The projections of water stress can both be driven by increased water demand and reduced water supply [57]. A majority of the areas in Kazakhstan are expected to increase in terms of water demand. Expected reduction in water supply are restricted to fewer areas, specifically western and to some extent central and southern regions. To indicate high risk areas, projected increase of water stress 2 times current level or higher were used, and to indicate low risk areas, projected decreases of water stress 1,4 times current status or higher were used.

3.3 Step 3: Identification of suitable areas and risk assessment

In this step, the targeted areas identified in Step 1 were evaluated through the assessment criteria developed in Step 2. The intention of this analysis was to answer the guiding question *What intervention types would be suitable where?* from the ROAM-methodology [12]. The considered environmental conditions, trends and projections for each FLR option, summarized in Table 3.2, are elaborated on in this chapter. Firstly, the targeted areas from Step 1 were assessed for suitability by using the environmental conditions identified in Step 2. Subsequently, these suitable areas were classified into low, medium or high risk areas for long term sustainability based on the trends and projections from Step 2. Thereby, this assessment indicates restored forests ability to withstand ongoing and future changes in environmental conditions. Low risk indicates a higher probability of long-term successful restoration attempts and high risk indicates that ongoing trends or future projections challenge the sustainability of that option. These assessments were performed separately for each FLR option as needed supporting conditions differ between the options. Suitable areas that were neither of high nor low risks were classified as medium risk. The same classification of medium risk was given in areas where different trends or projections were indicating conflicting risks, for example positive vegetation trends and high projected water stress.

3.3.1 Risk assessment of protective land and buffers

Tugai forests require occasional flooding and are highly positively associated with soil moisture content [10][27]. Therefore, areas suitable for tugai forest restoration was mapped based on soil type, where areas with fluvisols (flooded) or gleysols (high moisture content) were assessed as suitable for tugai forest restoration. Existing cropland [46] was assessed as unsuitable for tugai forest restoration due to the conflict of competing interests. The remaining areas after the exclusion of unsuitable soil types and existing cropland were the basis for the risk assessment, which included trend of vegetation cover and projected water stress presented in Chapter 3.2.2.

Saxaul is the most water resilient FLR option and often used to combat desertification in the most arid areas. The black and white saxaul derives its water from different sources, groundwater and rainwater respectively. Data on groundwater levels in Kazakhstan was not found and excluding areas only based on precipitation levels was considered inappropriate as it may exclude areas suitable for black saxaul. Instead, areas located adjacent to existing shrub land was assumed to have sufficient water resources for saxaul growth. A distance of 0.1 degrees or 11.1 km from existing shrub land was used for this analysis. As afforestation is mentioned as potential for saxaul plantations, bare land within this distance was assessed for suitability for restoration and plantations of saxaul. Areas showing historical coverage of saxaul [28] but no present shrub land cover was also assessed for suitability. Strong winds are one factor that inhibits regeneration of saxaul in the around the Aral Sea [10]. The collected data on mean wind speed shows that some areas around the Aral Sea are exposed to more extreme winds. Based on the mean wind speed in those areas, all areas showing a mean wind speed above 7 m/s were marked as unsuitable areas for saxaul restoration and plantations.

Since bare land in arid climates are potential areas for restoration and plantation of saxaul, these areas are already stressed in both vegetation cover and available water resources. Therefore, both trends in vegetation cover and projections in water stress were assumed to have a potential impact on the long-term sustainability of the restoration attempts and were hence included in the risk assessment.

Sufficient water availability was considered as a crucial environmental condition to identify suitable areas for **protective tree lines and shelter belts** since plantations of protective tree lines along roads in the 1950s resulted in low success rates due to non-sufficient precipitation levels [18]. A average yearly precipitation 300 mm/year may be sufficient water supply for trees in Kazakhstan if complemented with irrigation the first five years [24]. If no irrigation systems are in place, at least 400 mm/year is needed [34]. Therefore, the targeted areas from Step 1 were classified as suitable if either having yearly precipitation levels of >400 mm/year or at least 300 mm/year and supporting irrigation structures, by using average precipitation levels [49] and irrigation systems [52]. To avoid competing interest of irrigation systems, an analysis of actually used irrigation systems were performed. The lowest interval, corresponding to <28%, of five classifications were chosen to represent low utilization of irrigation structures. Not utilized irrigation systems with a minimum yearly average precipitation levels could thereby be combined to identify suitable areas. Current water stress, indicating a high water usage competition [53], was used to eliminate unsuitable areas as planting trees along roads, roads and around cities where there have not been trees before may require additional water use.

Moreover, the targeted areas were assessed through elevation [54], and none of the targeted areas from Step 1 were overlapping with unsuitable elevation levels above 3000 meters [34]. Wind speed was not used for determining suitable areas as no threshold limit were found, and protected areas were not used as the targeted areas from Step 1 are those where already established roads, rails and settlements are. The risk assessment was performed by using vegetation cover trends and future projected water stress.

3.3.2 Risk assessment of agricultural land

To identify suitable areas for **agroforestry**, all croplands identified in Step 1 were assessed through the environmental conditions average yearly precipitation [49], irrigation structures [52], and elevation [54]. One motivation for implementing agroforestry is its potential to improve total water consumption. To capture this potential, this analysis was performed with the assumption that the agroforestry systems are implemented in an appropriate manner, such as using suitable tree and crop variants or optimized system size. With this assumption, a high current water stress is not considered as a unsuitable environmental condition. Existing irrigation systems utilized by agriculture are concentrated to the southern regions [34][24]. This is visible in the classification *Cropland, irrigated or post-flooding* in the ESA land cover data [45]. Cropland that is not supported with irrigation, but with an average precipitation levels of 400mm/year or above [34], were also classified as suitable. Suitable areas for agroforestry therefore corresponds to irrigated cropland or croplands with precipitation level 400 mm/year or above, that are within the tree elevation line of below 3000 meters [34]. The trees used in the agroforestry systems may be utilized for commercial purposes, however, including accessibility to markets was not considered necessary as sufficient support was assumed to be available through the crop production. The risk assessment of the remaining suitable areas included trends in vegetation index and forest change. Projections in water stress were not included with the same rationale of current water stress.

Not including current water stress will generate larger areas identified as suitable for agroforestry, and not including projected water stress will affect the results by generating larger areas associated with medium risk through reducing the classification basis for high and low risks. The use of agroforestry in Kazakhstan as a mean to reduce water consumption is currently being evaluated [20]. Therefore, assessing risks using assessment criteria connected to water availability was considered not to be sufficiently supported by existing research. The generation of larger medium risk areas were considered sufficient to capture the potential of the option.

3.3.3 Risk assessment of forest land

Suitable areas for **natural regeneration** of forests were based on sufficient levels of precipitation, 400 mm/year. Cropland was excluded from the areas with objective for restoration as for the competing interest of land, and dense forest cover was excluded based on no assumed need for restoration. The remaining areas were considered suitable for restoration by natural regeneration. The risk assessment was performed using trends in forest and vegetation cover as well as projected water stress.

Fast growing tree plantations is an area under development in Kazakhstan and there were no descriptions of potential targeted areas were found. Tree species are being bred to tolerate precipitation levels as low as 300 mm/year [24]. Yet, irrigation is needed during the first 5 years of plantation of these breeds. Areas suitable for fast growing tree plantations were therefore mapped based on either a average yearly precipitation of minimum 400 mm/year [34] or 300 mm/year with connection to irrigation systems that were classified as not used [52] in the same manner as done for protective tree lines and shelter belts. All cropland classes [45], were excluded to avoid competing interest. Moreover, protected areas [56], areas with high current water stress [53], elevation above 3000 meters [54] and areas with existing forests [45] were excluded from suitable areas. Lastly, accessibility to markets as described in Chapter 3.2.1 were used to locate suitable areas by excluding all areas not located within four hours of travel time to a city. This is especially of importance in the case of biofuels, as long logistic distances may potentially result in a net loss of energy.

3.4 Step 4: Evaluation of risks versus benefits

Whilst risk awareness is important, highlighting trade-offs between risks and benefits of forest restoration generates a more holistic picture. To enable this trade off assessment, areas that would benefit of forest restoration was mapped based on the presence of factors connected to land degradation in Kazakhstan. Opportunities of forest restoration were then identified in areas were low risk are coupled with high benefits. This was achieved by combining the results of the benefit mapping in this step and the results of Step 3.

3.4.1 Mapping of areas that would benefit from restoration

As described in Chapter 2.3, there are several benefits of forest restoration, since it can address problematic land developments. To generate an overview of areas that would benefit from restoration, data representing different problematic conditions connected to land degradation in Kazakhstan were combined, namely desertification, land degradation, salinization, salinization due to irrigation, landslide risk, flooding risk and high wind exposure. Each data was analyzed separately to identify areas that are most severely affected. The selection of the number of categories used to represent these areas were based on the area distribution of the categories for each data set. For example, a majority of the land in Kazakhstan is degraded to some extent, and therefore only the highest category of degradation was chosen to represent areas with the greatest challenges. A combination of all data sets was then performed to indicate areas that would benefit the most of any kind of restoration, potentially to be addressed by forest restoration.

Desertification, being a large threat in Kazakhstan, can be addressed through forest landscape restoration. The National Tibetan Plateau Data Center provides data on desertification in Kazakhstan [40] where the distribution of sandy land, vegetation degradation and salinized land are included as influencing factors, which were used to indicate areas with high needs of restoration. Distribution of sandy land [40] only contained one category, which were used to indicate areas that would benefit from restoration. The data on land degradation [40] was chosen to represent historically degraded land in the same manner as done in Step 1 and 2, which clearly shows how most parts of the country has suffered from land degradation. Only the top one degraded category out of five available classes were chosen to avoid including almost all area of Kazakhstan. The salinization [40] data included seven categories, where areas classified with category four or above where chosen. Since salinization is one of the main drivers of desertification in Kazakhstan [3], these processes are partly driven by anthropogenic water withdrawal and irrigation pressure is high in Kazakhstan, salinization due to irrigation [58] was also used. As this dataset, *Proportion of land salinized due to irrigation (Global)*, was only available in Web Map Service (WMS) URL version that is non-modifiable, a manual translation into polygons was performed to represent this data and enable further analysis in QGIS. The original dataset includes three categories, <2%, 2-5% and >5%. To reduce complexity, the classifications were not considered, and instead all areas containing any pixel were mapped as an area with salinization due to irrigation.

A specific challenge described in the documentation reviewed within this study is the risk of landslides that forest restoration can address. To represent these challenges, a combination of the topographic dataset [59] and land degradation [40] were used. The topographic data was divided into seven categories, 0-2%, 2-5%, 5-8%, 8-16%, 16-30%, 30-45% and > 45%. Areas with moderate slopes, >15% [12] and below the tree line, that are exposed to land degradation of the two highest categories out of five [40], were then mapped to identify areas that would benefit from forest restoration. To represent flooding risks, data of Riverine flood risk from Aqueduct Global Maps 3.0 Data produced by WRI [53] was used. This data indicates the portion of the population that is anticipated to be impacted by flooding in an average year, including considerations of available flood protections. Areas classified as Extremely high, more than 1 per 100, out of total five classifications, were used chosen. Lastly, wind erosion was mapped by using on mean wind speed [41]. Since high wind exposure is common in most parts of Kazakhstan, only mean wind speeds above 7m/s were chosen to represent areas most exposed to wind erosion.

3.4.2 Mapping opportunities

By combining the map of areas that would benefit from restoration with the risk assessment in Step 3, forest restoration opportunities were identified. To enable this analysis, areas that would benefit from restoration were defined as at least one pixel cover in the map created in the previous section. By including a large amount of different problematic conditions, large areas were captured, with the intention to minimize risks of losing potential areas in the spatial overlap analysis to identify opportunities. Two different opportunities mapping were performed, resulting in two different categories of opportunities, low risk opportunities and medium risk opportunities. Low risk opportunities were derived by identifying areas that would both benefit of restoration and are associated low risks from Step 3. In the same way, medium risk opportunities were identified through locating areas that would benefit from restoration and are associated with medium risks. These analyses were performed for each of the different FLR-options.

4

Results

4.1 Step 1: Location of targeted areas

This chapter presents the results of the translation from the targeted area descriptions to geographical visualizations. Results are shown in Figure 4.1. Areas fulfilling a single restoration objective are marked with turquoise and areas meeting multiple objectives are marked with blue in the figure.

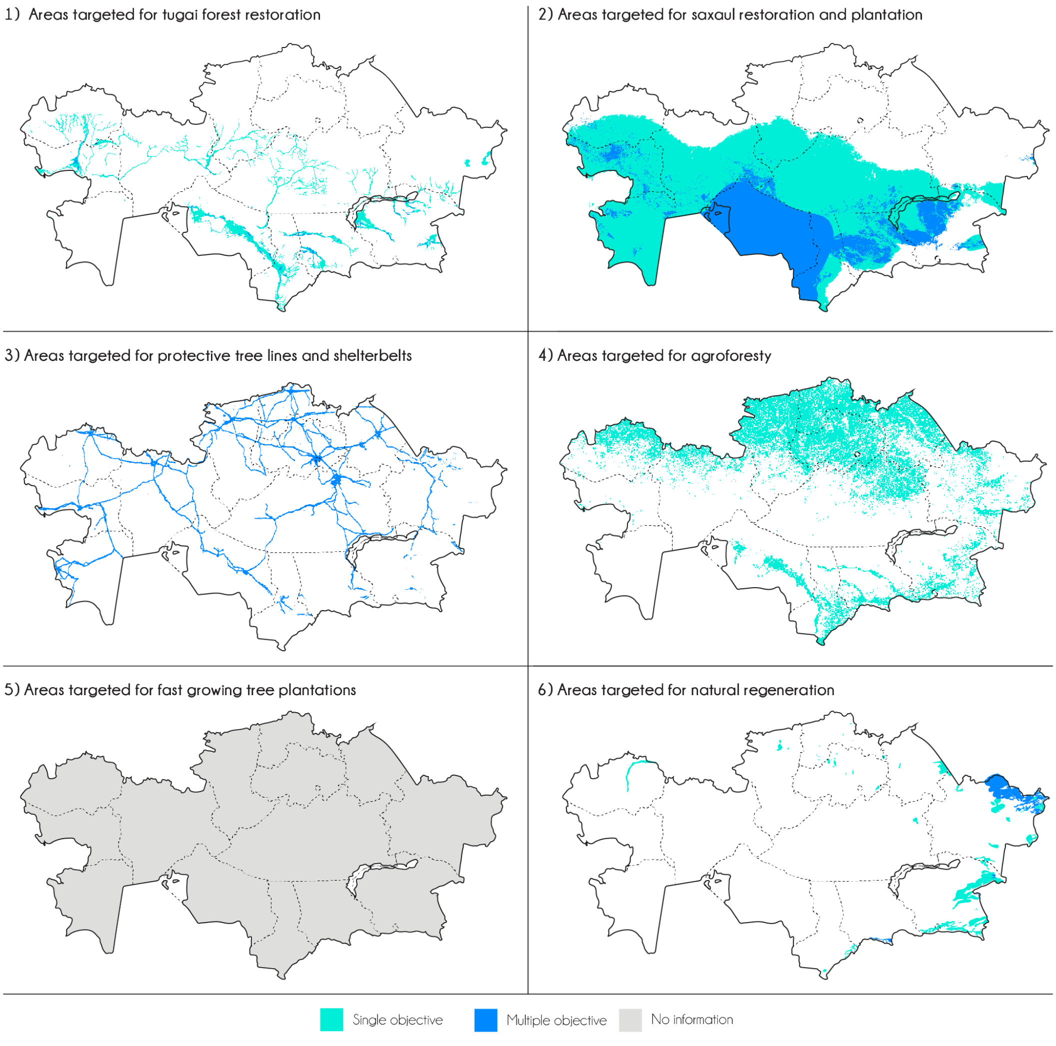


Figure 4.1: Targeted areas

As the descriptions of the targeted areas for forest restoration are broad, the results show that more than 80% of the total area of Kazakhstan, have one or more objectives for restoration, addressed by at least one FLR-option. The resulting vast areas were considered reasonable for the purpose of highlighting potential areas for restoration, which will be narrowed down in the following steps.

4.2 Step 2: Identification of environmental conditions, trends and projections relevant to FLR options

This section presents the results of identified environmental conditions, trends and projections. The environmental conditions that were mapped are (i,a) water availability from precipitation, (i,b) water availability from other sources, (ii) land cover and (iii) other relevant conditions. The results are presented in Figure 4.2 and shows that high water availability, current forest cover and beneficial wind speeds are mainly found in the Altai mountains of East Kazakhstan and in the Tien Shan mountains in the southeastern regions of Almaty and Zhambyl. Irrigation systems in east and south east are mainly connected to agriculture, and the irrigation systems in the central, west and north are mainly for drinking water and industry. At national level, agriculture accounts for 66% of the total water withdraw and industry accounts for 30%. The water origin of this withdraw which 90% origins from surface water and 5% from groundwater [60].

The trends and projections assessed were (iv) land cover trends and (v) projected water stress including effects from climate change and anthropogenic water withdrawal. Results are shown in in Figure 4.3, indicating that the western and southern regions are the most exposed to negative trends and projections that can pose challenges for forest restoration in the long term perspective. Central Kazakhstan, specifically the region of Qaraghandy, shows conflicting trends and projections, where the vegetation trend is positive and the projected water stress is negative. The eastern regions of East Kazakhstan and Almaty shows a decline in projected water stress and/or a positive trend in vegetation and forest cover.

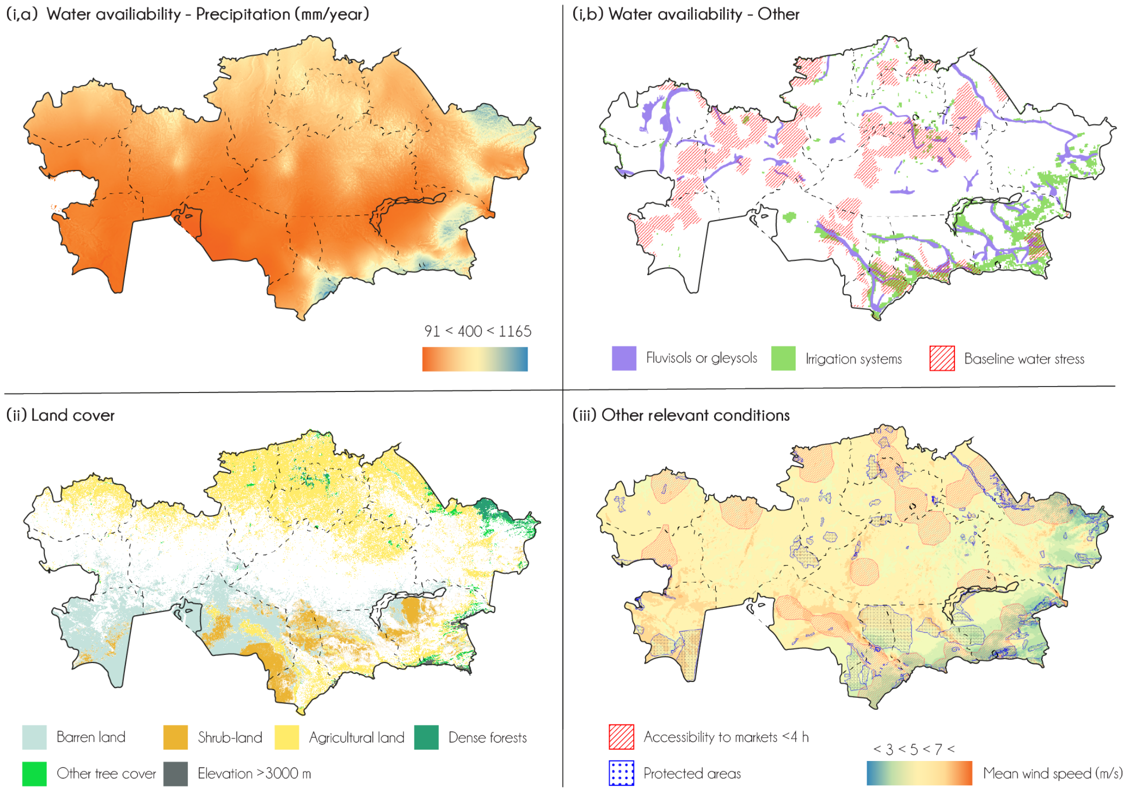


Figure 4.2: Environmental conditions in Kazakhstan affecting the feasibility of forest restoration

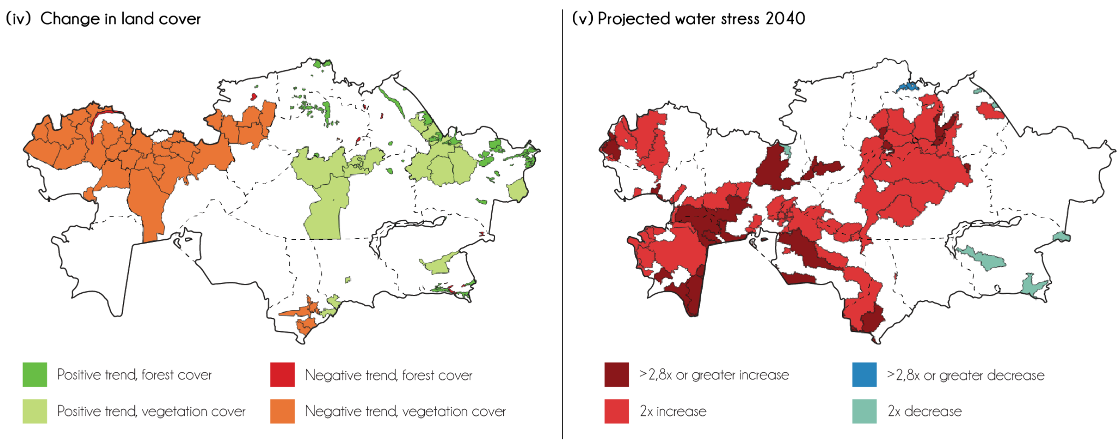


Figure 4.3: Identified trends relevant for sustainable forest restoration

4.3 Step 3: Identification of suitable areas and risk assessment

The results from the risk assessment performed in Step 3 are presented in Figure 4.4. Grey areas correspond to targeted areas that were classified as unsuitable. The remaining areas, assessed as suitable for restoration, was classified into low, medium and high risk areas, represented in green, yellow and red respectively.

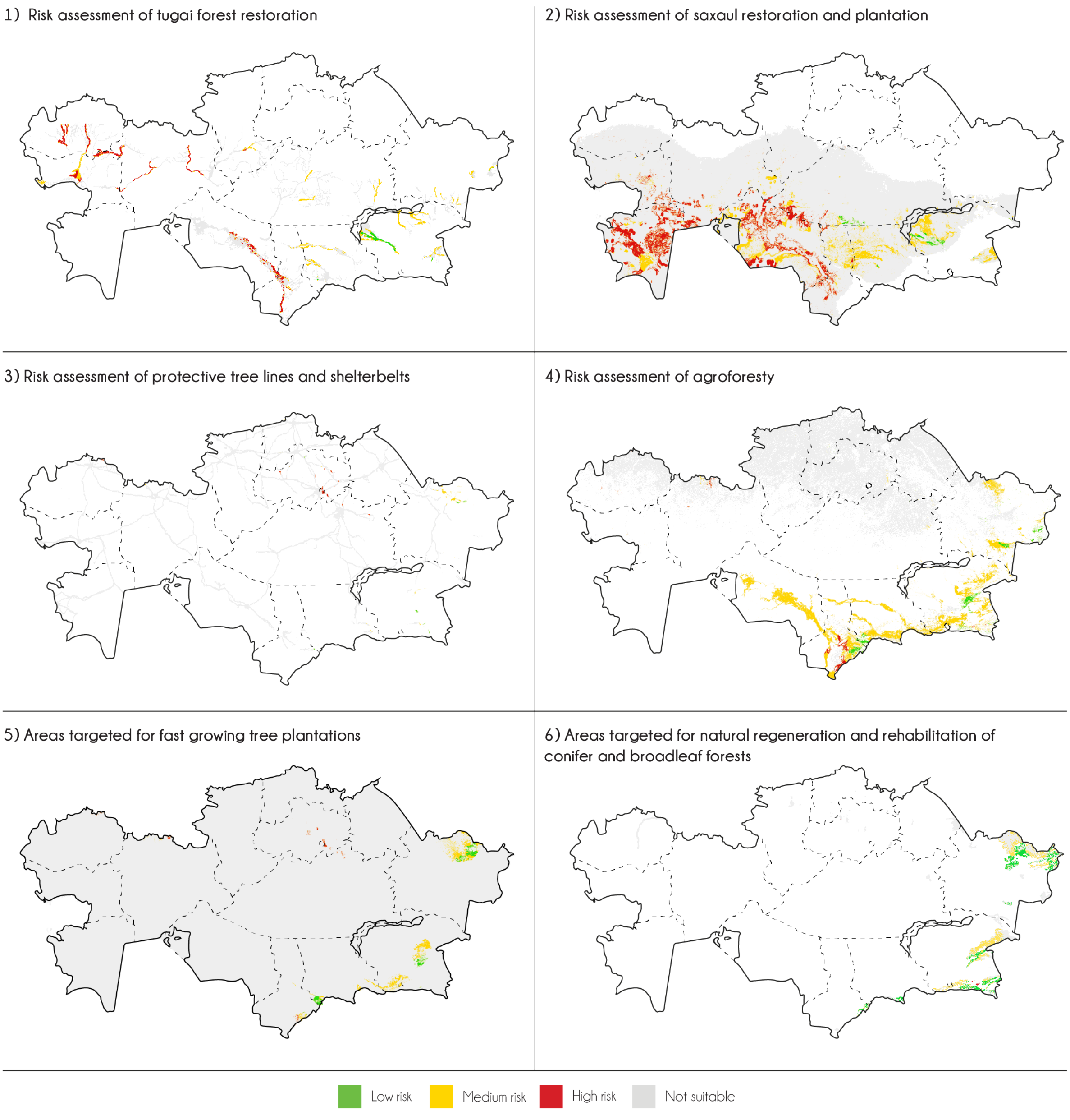


Figure 4.4: Risk assessment of targeted areas

The corresponding area of total suitable areas per FLR option, divided into low, medium and high risk, are presented in Table 4.1. Through the exclusion of unsuitable areas, it becomes apparent that water availability is the major influencing environmental condition that restricts the suitable areas. As water availability was not used as an assessment criteria to assess suitable areas for saxaul restoration, this FLR-option has the largest suitable areas for restoration. Sufficient water supply for the majority of the FLR options are only found in the mountains areas in form of precipitation and in the southern areas through irrigation systems. Due to high water stress in many irrigated areas, FLR options that requires additional irrigation, e.g. protective tree lines and fast growing tree plantations, was not considered suitable in these areas. The limitations that water availability poses on the suitable areas becomes especially apparent in the case of protective tree lines and shelterbelts. However, this is also influenced by the fact that this FLR option targets windy areas, mainly found on plain lands, that are also associated with low precipitation. Suitable areas for fast growing tree plantations were also delimited by accessibility to markets and protected areas, that were specific for this FLR option. Saxaul and agroforestry are the options with the largest suitable areas, and combined they accounts for more than 70% of the total suitable areas. However, the risks assessment shows that a large share of the areas identified as suitable for saxaul are associated with high risks.

Risk area (mill ha)	FLR option: Tugai 	Saxaul 	Shelterbelts 	Agroforestry 	Regeneration 	Fast growing 	Total (mill ha)
Low risk area	0.29	0.36	0.03	0.65	1.54	0.52	3.39
Share of total low risk area	9%	11%	1%	19%	45%	15%	
Medium risk area	1.67	6.96	0.15	8.37	1.84	1.67	20.66
Share of total medium risk area	8%	34%	1%	41%	9%	8%	
High risk area	1.45	7.52	0.08	0.38	0.02	0.10	9.55
Share of total high risk area	15%	79%	1%	4%	0%	1%	
Total suitable area	3.41	14.84	0.26	9.40	3.40	2.29	33.60
Share of total suitable area	10%	44%	1%	28%	10%	7%	

Table 4.1: Area results from risk assessment

The risk classifications are shaped by the distribution of the trends and projection presented in the previous chapter. Despite the limited potential identified as suitable for natural regeneration, it is the dominant FLR option of low risk areas. This is a consequence of having most of the suitable areas located in areas classified as low risk. With exception from the mountain areas that are already including the largest portion of today's forests, an area around the Ili river are associated with lower risks for both saxaul and tugai restoration. The southern parts of Qaraghandy are also associated with lower risks for saxaul restoration. The effects of the risk assessment become evident for saxaul, since most of the suitable areas for saxaul are located in high risk areas, which also results in a small share of low risk areas. Agroforestry is the only FLR option that was not assessed through projected water stress, due to the assumption that it is intended to improve water consumption and crop yields if applied in an appropriate way. This assumption generates a large portion of medium risk areas compared to the other FLR options.

4.4 Step 4: Evaluation of risks versus benefits

This chapter introduces the results of the mapping of areas that would benefit from restoration, and its comparison with the risks identified in Step 3, with the intention to identify opportunities for forest restoration.

4.4.1 Mapping of areas that would benefit from restoration

To map areas that would benefit from restoration, a set of factors indicating problematic conditions were mapped. These conditions were desertification, land degradation, salinization, salinization due to irrigation, landslides, flooding and wind erosion, which are visualized in Figure 4.5. Many of these problematic conditions are overlapping, especially in the southern regions along the river Syr-Darja. In the southern and western regions, salinization and desertification are often coupled or present each other's surrounding areas. Moreover, salinization due to irrigation is present in almost all irrigated areas mapped in Step 2, indicating reoccurring problematic irrigation practices throughout the country. Land degradation, however, seems not to be as well coupled with the other three indicators previously mentioned, and are also more present in the western regions. The difference in distribution of the different problematic conditions can serve as a reminder of the importance to consider local contextual factors when planning restoration efforts.

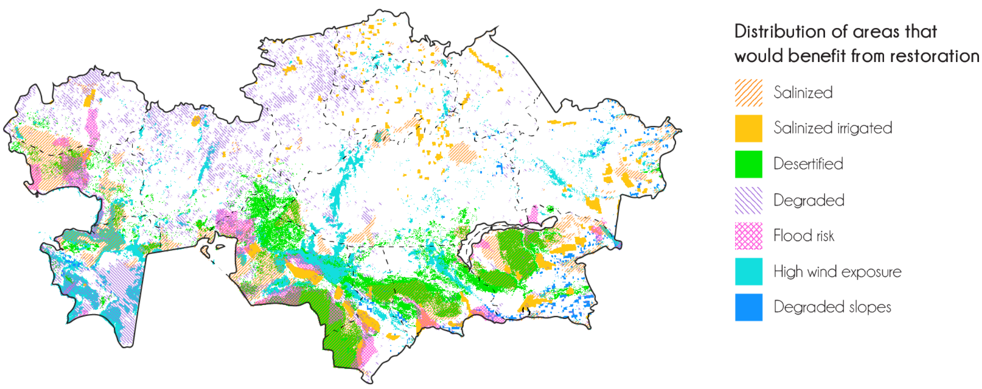


Figure 4.5: Distribution of areas that would benefit from restoration

4.4.2 Mapping opportunities

The results from the opportunity mapping are presented in Figure 4.6, including four different maps. The first, (i) Low risk areas of all FLR options, is a summary of all the resulting low risk areas from Step 3. The second map, (ii) Low risk opportunities for forest restoration, is a combination between the (i) Low risk areas and restoration needs presented in Figure 4.5. By extracting areas where these two maps overlap, a representation of areas with low risk and high need of forest restoration is generated with the intention to indicate restoration opportunities. The two remaining maps, (iii) and (iv), have the same logic, but was generated by using medium risks instead. The consolidation of Step 3 results, both for (i) low and (iii) medium risks, contains some restoration needs as it is based on the targeted areas identified in Step 1. Nevertheless, the intention of opportunities mapping, presented in (ii) and (iv), is to highlight where a specific risk is coupled with addressing high restoration needs. The area of low and medium opportunities per FLR option are summarized in Table 4.2.

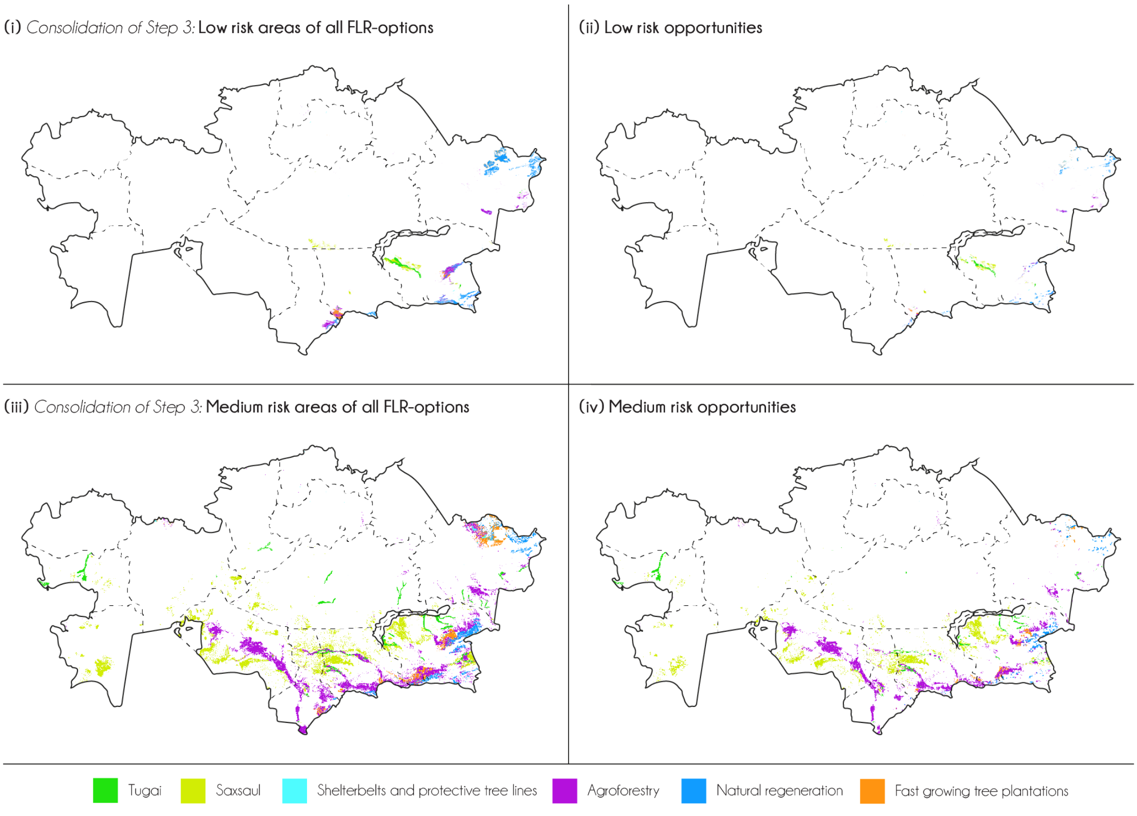


Figure 4.6: Summary of identified opportunity areas

The total area of low risk opportunities corresponds to 0.92 million hectares, and the resulting area per option is described in declining order as follows. Natural regeneration entails the largest area of low risk opportunity, 0.36 million hectares, due to beneficial environmental conditions in the mountain areas which are also likely to be classified with low risk through positive vegetation and forest trends and water stress projections. Although the areas are degraded to some extent, restoration attempt in these areas are assessed to have higher likelihood to sustain in the long-term perspective. Saxaul is the FLR option with the second largest low risk opportunity area, reaching 0.23 million hectares. The large area may be explained by the large area classified as suitable in Step 3, partly due to the exclusion of water availability of suitable environmental conditions. Nevertheless, this also means that medium and high risk areas are larger. Proportionally, low risk areas are small for the saxaul option in the risk assessment results. An area around the Ili river contains a large portion of the total opportunity areas of saxaul restoration. This area also includes the majority of the low risk opportunities for tugai restoration, being the next FLR option in declining order, in total 0.14 million hectares represented. The

0.12 million hectares representing low risk opportunities for Agroforestry are also clearly shaped by the beneficial conditions along mountain areas. The areas are restricted by the existing croplands areas, nevertheless, since future water projection was excluded from the risk assessment, the low risk areas are further restricted. Fast growing trees only reaches an area of 0.06 million hectares since many of the suitable areas are not overlapping with areas of needs. Lastly, protective tree lines and shelterbelts reaches less than 0.01 million hectares, explained by the already limited resulting areas from Step 3.

Opportunity (mill ha)	FLR option Tugai	Saxaul	Shelterbelts	Agroforestry	Regeneration	Fast growing	Total (mill ha)
Low risk opportunity area	0.14	0.23	<0.01	0.12	0.36	0.06	0.92
Share of total low risk opportunity area	15%	25%	1%	13%	39%	7%	
Medium risk area	0.87	4.27	0.02	4.75	0.72	0.53	11.16
Share of total medium risk opportunity area	8%	38%	0%	43%	6%	5%	
Total	1.01	4.50	0.02	4.87	1.08	0.59	12.08
Share of total	8%	37%	0%	40%	9%	5%	

Table 4.2: Resulting areas from opportunities mapping

Performing the same opportunity analysis of medium risk areas results in an area of 11.16 million hectares, which is considerably larger than 0.92 million hectares. When expanding the analysis to medium risk areas, the option containing the largest opportunities changes from natural regeneration to agroforestry. This shift is a result of the assumption behind the exclusion of current and projected water stress as an assessment criteria for agroforestry. Saxaul also represent a large share of both low and medium risk opportunities, but especially for medium risk opportunities. This is partly due to the large suitable areas of saxaul, which is a consequence of excluding water availability as an assessment criteria for this option.

5
Discussion

This study has evaluated options for forest restoration in Kazakhstan, assessing where different FLR-options may be suitable, associated with low risks and generate benefits by addressing problematic land degradation conditions. The results highlight the limitations that forest restoration has as a mean to combat land degradation, in line with concerns expressed by researchers in performed interviews. The relevance of this study was supported by a report released just prior to the publication of this study. As a consequence of the global trend of planting trees to address different environmental concerns, the report consolidated and assessed the effectiveness and success rates of forest restoration attempts, concluding the importance of context-dependency, including local climate and water availability [61]. In line with the results of the referred report, this study identified areas where forests can generate benefits continuously over long periods of time, using a step-wise exclusion of land was to determining targeted areas, suitable areas, risks and finally opportunities. The used assessment criteria and assumptions made during these steps have influenced the results.

The first step excludes areas based on reviewed national and international documentation, where the broad descriptions of areas targeted for forest restoration results in a limited area exclusion. The resulting large areas were considered a reasonable basis for the following assessments and to avoid the risk of inaccurate exclusion of potential areas. Based on the resulting environmental conditions from the second step, the third step excluded areas that are unsuitable for restoration. About 90% of the targeted areas are excluded in this step, mainly due to insufficient water supply. The limit of 400 mm/year of average precipitation were the assessment criteria resulting in the largest exclusion. Some excluded areas, for example along the northern border, includes some tree cover. Nevertheless, sufficient precipitation levels are especially important for seedling survival when planting trees, and to serve the purpose of identifying areas with high likelihood of successful restoration attempts, this limit was considered plausible. Moreover, choosing a limit for Kazakhstan provided by an experienced researcher within the field, Niels Thevs, who is frequently cited in UN documentation, was considered as the most viable option. An area sensitivity analysis was performed by altering the limit to 350 and 450 mm/year, resulting in 75% more and 30% less area respectively with sufficient precipitation for tree growth. The main difference for the lower limit of 350 mm/year is found in the north central areas, and using this limit, instead of 400 mm/year, would have generated larger areas suitable for fast growing tree plantations, agroforestry, natural regeneration and shelterbelts. Nevertheless, current water stress as well as negative trends in both land-cover and projected water stress would limit the impact a lower precipitation limit would have of both suitable areas and low risk areas. Lastly, the problematic conditions in these areas are limited, so the resulting low risk opportunity areas would not be greatly effected.

The suitability assessment is based on current conditions and the pre-identified FLR options, but if these conditions or options changes, so will the suitable areas. Existing irrigation systems are included in the assessment for fast growing tree plantation and shelterbelts, but potential expansion of current systems is not considered. Although possible system expansions would have increased suitable areas, many areas are also excluded based on current water stress that irrigated tree plantations could worsen. This exclusion was aligned with the purpose to identify areas where forest restoration can provide benefits. Lastly, fast growing tree plantations and shelterbelts were assumed to utilize unused irrigation systems in the north of Kazakhstan, where no irrigated agriculture is present, to avoid usage competition. The exact structure and availability of these systems to be utilized for the two FLR-options were not reviewed in this study.

The results of two FLR-options, saxaul and agroforestry, are affected by specific assumptions. Firstly, due to lack of data on groundwater levels from which saxaul derives its water, it was the only option not assessed based on existing water supply. Nevertheless, since saxaul is the most commonly used option to address land degradation in the most challenging climatic conditions, it was considered reasonable not to exclude these areas and capture this unique potential. This assumption, together with the largest targeted area, results in saxaul being the option with the largest suitable areas for restoration. This result corresponds with a previous study that identifies saxaul as the forest restoration option with the highest potential due to its low competition with other land uses [3]. Secondly, agroforestry was not assessed through current or projected water stress due to uncertainties in its effect of water consumption in Kazakhstan. As this FLR-option holds proven potential to reduce total water consumption [20], neglecting this potential was considered inadequate, especially in degraded areas that are in desperate need of water consumption improvements, such as along Syr Darya river. Also, agroforestry is the only FLR-option avoiding land use competition with agriculture and using current water stress would exclude many relevant areas. This assumption increases the areas suitable for agroforestry, and the effects on the following risk assessment and opportunities mapping are discussed later. A more detailed assessment of the total potential of agroforestry in Kazakhstan is therefore an area of future research.

The risk assessment concludes that only about 10% of all suitable areas is assessed to be associated with low risks for long-term lasting results of restoration efforts, excluding another 90%. These results are affected by the assumption that identified ongoing trends will proceed in the same direction, but if proactive measures are implemented to reverse negative trends, the results of the risk assessment will also change. Also, the identification of trends, used in the risk assessment, is based on a spatial aggregation where zonal statistics analysis was used. The size of zones affects the results, where larger zones are less sensitive to small changes not connected to actual trends, but increases the risk of losing local trends as a consequence of the aggregation. This was managed by individually determining the zone size for forests and vegetation index based on current distribution and response time of changes in the environment. Consequently, forests were divided into smaller zones both because of the limited distribution, but also the slower response time, which reduces the risks of inaccurately identifying short term changes as trends. With the opposite rationale, vegetation index was divided into larger zones.

Moreover, in the projected water stress data set, the worst case scenario was chosen to relate to the aim of highlighting risks, but also opportunities where forests can play a role in combating land degradation. In this step, natural regeneration was identified as the FLR option with the largest areas associated with low risks for restoration, which is reasonable as these areas are the natural ecosystems for forests. Saxaul is the FLR-option associated with the largest high risk areas, originating from high projected water stress and ongoing degradation in many of its suitable areas. The challenges present for restoration of saxaul has also been highlighted in national reports where, for example, the desert areas towards the border of Uzbekistan is described as no longer fit for saxaul vegetation due to ground water stress [7]. For agroforestry, the risk assessment results are affected by the exclusion of the assessment criteria projected water stress. Large areas with medium risks, and thereby less high and low risk areas, is a consequence of this assumption.

The last step includes a mapping of seven current problematic conditions connected to land degradation to identify areas that would benefit from forest restoration. Assurance of capturing large areas in need of restoration was achieved by including many different problematic conditions, but the small scale of the spatial overlapping to identify opportunities may fail to identify some opportunities. Moreover, the conditions potential change over time were not captured in this assessment, and therefore updated assessments are needed in the future. This step of identifying opportunities concludes that only about 1/4 of the low risk areas would generate benefits to combat land degradation, which is reasonable since low risk areas are often not strongly coupled with problematic conditions.

Forest contribution to combat land degradation, emphasized in both Governmental and UN documentation, was the main focus in this assessment. However, other benefits that forest restoration can generate, such as improved biodiversity by increasing habitat extent, connectivity and quality [12], carbon sequestration or development of a green economy, were not included and these additional reason for forest restoration would have generated larger opportunity areas. Even so, the opportunity areas would still have been concentrated in the mountain areas as a consequence of the low risk distributions, which is aligned with concerns expressed by several interview respondents although not yet supported by other studies. Moreover, the specific character and relative importance of each problematic condition were not considered in the assessment. Some issues, often associated with high risks and therefore excluded in the opportunities mapping, may be prioritized despite the high risks.

This strategic evaluation can be supported by the risk assessment and problematic conditions mapping, where known risks can then be mitigated through proactive actions. Areas with multiple problematic conditions may also be an indicator of areas in extra need of restoration, which was not weighted into the analysis. In these areas, moving into higher risk areas might be prioritized. To generate wider opportunity areas, and also mitigate risks of inaccurate exclusion by only using low risk areas, medium risk opportunities were identified. In this assessment, agroforestry is the option with the largest medium risk opportunities. This is a consequence of vast suitable areas with a large portion of medium risks, originating from the exclusion of projected water stress as an assessment criteria.

In order to achieve a broad overview of factors influencing forest growth and survival in a part of the world where field studies and data are limited and compromised by language barriers, geospatial data from different sources, years and in different formats were combined. The different formats included both global and local data sets, raster data with different resolutions and vector data. Although comparable data would have been preferable, including a wide range of factors were considered to better support the indented results. Some desirable data to support the assessment criteria, such as groundwater levels, were not found. The accuracy of the forest restoration potentials would be increased by integrating local socio-economic factors, such as land accessibility, land tenure and land productivity needs [13][26] [61]. Nevertheless, this study managed land use competition by excluding cropland in suitable areas for all FLR-options except agroforestry.

Data accuracy and plausibility were managed by comparing and combining data sources to minimize effects of differences, as well as validating data and results with researchers within the field through interviews. Representative data of land degradation, a crucial consideration for the study, is one example of where potentially conflicting data was encountered. More than 70% of the land in Kazakhstan is considered to be degraded to some extent [3][14][8], which is reflected in the data set of land degradation used in this study [40]. However, the analysis of change in vegetation cover during the last 20 years resulted in large areas with positive trends. The data differences were validated and discussed in interviews, where a recent rewilding of abandoned cropland and reduced grazing pressure were given as potential explanations. Subsequently, the two data sets were combined by using land degradation data [40] as a baseline for identifying areas that have been degraded historically, whereas the more recent changes in vegetation cover [46] were used to represent current trends. Moreover, in a country were irrigation systems are widely used to artificially stimulate vegetation growth, the use of geospatial data of vegetation cover was considered to potentially produce misleading results. To avoid this, the analysis was complemented with current and projected water stress.

Forest cover in Kazakhstan is limited, both due to prevailing climatic conditions and anthropogenic drivers of degradation. Using trees to tackle land degradation challenges in a areas where natural forests where never historically present may cause more damage than benefits by altering habitats that animals have adopted to [18][61]. Previous studies have identified abandoned cropland as opportunities for afforestation [26]. Nevertheless, in Kazakhstan, these areas are mainly found in the steppe areas of the north, not naturally including trees, and would rather benefit from rewilding [18]. In this study, these areas are excluded due to insufficient water supply, aligned with the native habitat without trees. As many areas that would mostly benefit from restoration also have unfavorable environmental conditions that complicates forest restoration, and were forests are not native, other means to combat land degradation might be more suitable, such as less water demanding vegetation or improved water use efficiency. For example, reducing industrial and agricultural water consumption in the west and south west or rewilding of steppes in the north may be a more appropriate ways to combat land degradation.

This national assessment of different options for forest restoration in Kazakhstan has generated multiple valuable results and considerations. The results should serve as a guidance of suitable areas, including risks and opportunities, rather than providing exact site specific recommendations. Therefore, complementary future research could cover more site specific assessments, including other measures to address land degradation.

6
Conclusion

This study has evaluated options for implementing the Kazakhstan forest restoration targets, with a unique focus on long term sustainability of the efforts by evaluating suitability, risks and opportunities. The scope of this study adds important aspects of forest restoration in Kazakhstan and concludes that large portions of targeted areas for forest restoration are either unsuitable or associated with high risks of unsuccessful FLR attempts. This is specifically apparent for protective tree lines and shelterbelts along rails, roads and settlements, an FLR option often mentioned as a priority in the documentation reviewed within this study. Hence, suitable areas for forest restoration in Kazakhstan are limited, both due to prevailing climatic constraints, but also direct and indirect anthropogenic influences.

The final resulting opportunity areas can serve as an indicator of where efforts are likely to be beneficial and sustainable in the long-term perspective. The risk assessment and mapping of areas that would benefit from restoration, partial results of the study, may also support trade-offs in decision making processes when planning national forest restoration. Moreover, the specific focus on water, a limited resource in Kazakhstan that is projected to change due to socio-economic and climatic factors, provides a new perspective on the subject. The largest opportunity of forest restoration is by natural regeneration, where political initiatives aiming at protecting areas around existing forests to recover will be crucial. With the exception of political implementation and competing interests of land use, protective measures of these areas can be considered as a relatively easy and effective way to increase forests cover, in comparison to tree plantations in high risk areas with unfavorable conditions.

The translation of the broad descriptions of targeted areas for forest restoration into geographical representations shows that most areas of Kazakhstan are subjects for restoration. Out of these targeted areas, 33.6 million hectares, or 12% of the total land area, were identified as suitable for at least one of the FLR options. Water availability was the most dominant factor to exclude unsuitable areas from the identified targeted areas. Saxaul and agroforestry are the options with the largest suitable areas for forest restoration, together accounting for more than 70% of the total 33.6 million hectares. Nevertheless, if trends in land cover and projected water stress are realized, many of these suitable areas could challenge forest growth and regeneration. The risk assessment, based on trends in vegetation cover and projected water stress, shows that out of 33.6 million hectares, only 3.4 million hectares are associated with low risk of forest restoration. The effects of the risk assessment differ between the FLR options. For example, saxaul accounts for the largest suitable area for restoration, but only the fourth largest area associated with low risks relative to the other FLR-options. The Altai and Tien Shan mountains are areas associated with low risks, resulting in natural regeneration being the FLR option with the highest potential to succeed in a long-term perspective. Parts of the areas around the Ili river in Almaty shows positive vegetation cover trends and water stress projections, resulting in low risk areas for restoration of saxaul and tugai.

This study also identifies areas that would benefit from forest restoration by mapping the problematic conditions, namely, desertification, salinization, land degradation, high wind exposure and land slide risks. This shows not only the vast areas in need of restoration, but also the distribution and concentration of the different problematic conditions. Opportunities for forest restoration were identified by locating areas with at least one problematic condition that were also associated with low risks, resulting in 0.92 million hectares in total. The challenges of forest restoration in Kazakhstan becomes evident by relating the 0.92 million hectares to the forest restoration target of 1.5 in the IUCN Bonn Challenge. This serves as an important message that, even though forests generate multiple benefits, forest restoration in Kazakhstan have limited potential. Expanding into larger areas are connected with higher risks, and the medium risks opportunities reaches 11.16 million additional hectares. Nevertheless, the limited low risk opportunities should not counteract the efforts of forest restoration in Kazakhstan. Awareness of limitations and risks, as well as focusing on opportunities, are of extra importance in a country like Kazakhstan with many conditions challenging forest growth. Natural regeneration and saxaul entails the largest low risk opportunity areas, 0.36 and 0.23 million hectares respectively, indicating suitable areas that would both benefit from forest restoration and where efforts are likely to sustain through threats posed by current land degradation trends and future water stress projections.

The urgency of reversing land degradation in Kazakhstan together with the resulting limited potential of forest restoration to combat these processes suggests that other measures are necessary. By carefully assessing where different measures to address land degradation are most beneficial, the benefits of each effort can be maximized. Although forests restoration in Kazakhstan is limited, it can play a crucial part in reducing land degradation in Kazakhstan by focusing on areas where forests can generate benefits continuously over long periods of time.

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